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PHER64 *Proceedings of Symposium . . .*

PROBLEMS IN WATER TREATMENT

CENTRAL PUBLIC HEALTH ENGINEERING RESEARCH INSTITUTE, NAGPUR-3

29th & 30th Oct. 1964

Problems In Water Treatment

CENTRAL PUBLIC HEALTH ENGINEERING
RESEARCH INSTITUTE, NAGPUR-3

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FOREWORD

The Symposium on Problems in Water Treatment was held by the Central Public Health Engineering Research Institute, Nagpur in collaboration with the Nagpur Centre of the Institution of Engineers (India) and the Public Health Engineering Division of the Institution of Engineers (India).

The Symposium was inaugurated by Air Vice Marshal O. P. Mehra, I.A.F. Maintenance Command, Nagpur on Oct. 29, 1964. Thirty Eight papers were presented and discussed in four sessions on Oct. 29 and 30, 1964. Over one hundred delegates representing State Govts. and Local Bodies, research workers and manufacturers of water treatment equipment, participated in the Symposium.

This volume contains the Proceedings of the Symposium. Session Chairmen and delegates have been listed in the end.

CPHERI thanks the co-operating agencies and the Delegates for making the Symposium a great success.

CENTRAL PUBLIC HEALTH ENGINEERING
RESEARCH INSTITUTE, NAGPUR

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Welcome Address

R. S. MEHTA
Director, CPHERI, Nagpur

Gentlemen,

Before we start the proceedings of the Symposium, I regret to announce the death of Mr. H. C. Dasappa, Union Minister for Industries and Supply. We got the news only this morning and we are quite shocked to hear that news. It would be in the fitness of things if we all stand up and observe silence for two minutes.

Thank you, Gentlemen.

Director's Welcome Address

Ladies and Gentlemen,

It gives me great pleasure to welcome you all here to this seminar. The interest that the people have shown far exceeds our expectations and you can well see that the result has been that the room which can accommodate about 150 people has been found to be very small. In one way it is a great pleasure to see that so many people have been coming forward to take interest in a subject which has up till now been a very specialised subject.

Now I have my great privilege and pleasure to welcome amongst us Air Vice-Marshal O. P. Mehra. He has been known to all the people in Nagpur and to the people in the country as a whole as in-charge of the Maintenance Command of the Air Force. It is the good fortune of Nagpur that the Air Vice Marshal is here and he and his band of engineers and technical people have given a new life both in the technical field as well as in the social field to this otherwise dull place, Nagpur. The army has also been very busy and the Defence people are doing lot of activities in and around Nagpur. I am therefore happy that Nagpur is now getting into being a more important place.

As we are going to discuss the problems of water treatment and as the Defence services have also been taking a very keen interest in this great problem in which all of us are very vitally interested, it is therefore in the fitness of things that this symposium be inaugurated by a person of an eminence of Air Vice Marshal O. P. Mehra.

Now, before I will tell him to inaugurate the symposium, I would like to say a few words about why this particular subject was kept for the symposium. There are very few people present here who have attended the first symposium on Water Works Operators which was held in 1953 in Delhi. This was sponsored by the Delhi Municipal Corporation, by the Joint Water and Sewage Board and the World Health Organization. This was an exteremely successful symposium and really laid the foundation for all the activities of the public health engineering which resulted into a full fledged Public Health Engineering Organization at the Centre, Central Public Health Engineering Research Institute here; and several other symposia, seminars and the Public Health Engineering Division of the Institution of Engineers (India). Today it is my privilege to welcome not only on behalf of the CPHERI but also on behalf of the Institution of Engineers (India), Nagpur who are also co-participants in this venture.

In the first three Five Year plans, as you are all probably aware, we have been able to do very little in this subject of giving protected water supplies to the country. There were several administrative and financial difficulties. The present organisations were not there. The whole subject of properly organising the divisions in the States for investigation and the execution of schemes and all these administrative questions were also there. It took very long time before the water supply situation could get into the strides and it is now accepted that, in the Fourth Five Year Plan, we are now properly organised to face this very vital and great problem of providing safe water supplies to the country. It is therefore all the more necessary that we should discuss this problem of water treatment along with the design, control and operation of the treatment plant.

The other problem that is facing us is about the maintenance and improvements for the existing water treatment plants. As you are all probably aware, the water treatment plants were started really by the army people in the army cantonments. They had comparatively small water treatment plants. On the civilian side, we had only slow sand filters in big towns like Delhi and Calcutta. All these types of plants really required very little operation and control. With the setting up of modern rapid filter plant, the question of the skilled operators and the control of the plant has come in and even today we are not in a happy position about the operation of the plants, though we have already got these costly plants. It is quite possible that with proper know-how and a few modifications, some of these plants on which we have spent quite a lot of money could be made to give us lot of pure water and could be made to run more efficiently so that just with little money we may be able to supply filtered and chlorinated water to a much bigger community. This is also one of the reasons why we thought this would be the most opportune time to invite people interested in this great problem.

The third reason was that our country has, as you all know, started putting up lot of industries. Now these industries naturally dispose off their wastes into the streams and into the rivers and ultimately all these industrial wastes in the raw water also flow into the inlets of the water treatement plant thereby causing a very serious and severe problem of treatment. This problem of the water pollution into the streams is not only present in our country. The problem is universal all over the world and in the last 20 years or so, the attention of the whole world has been focussed on this very important and very great challenging problem of the treatment of industrial waste water and other domestic sewage. Why I raised this point is that the complicated organic wastes, detergents, pesticides and fertilisers that are used on the plants ultimately find their way into the streams and that thereby create very complicated problems to our intakes of the water works. It is therefore necessary that we must have better and economical designs and better maintenance of the plant. In the world today, there are lot of new plants being designed and put up. In this country we have been satisfied with just about three or four designs and we are just putting up the same plants over and over again without actually going into the details of the quality of waters and the difficult problems that are facing us. It is therefore essential that we should know something about the new plants that are being put up in other parts of the world, the special types of coagulation tanks, coagulants and coagulant aids and all sorts of problems that are being faced and worked out by the other countries of the world.

In the water works, we should also have proper laboratory facilities, because the water that gets out of the plant should also be checked and controlled and the operators who should also be qualified and be competent to run these plants should also know what kind of water they are supplying in the public. Water work plant operation would also be a problem which would be discussed in detail.

This brings us to the question of the training and the refresher courses for the engineers and to the training courses for the operators who have not had the opportunity to go to the universities. Probably some of them may not know the English language and therefore they have to be properly trained by coaching them in Hindi or any regional language, if necessary. This problem of the training of the plant operators is another problem which this Institute, CPHERI, is also taking up along with the refresher courses. About this operators' course, I was just thinking that when we purchase a motor car of say Rs. 10,000 or Rs. 15,000 or when we give some work to an electrician, we always insist upon a licence. Here in this country when the water treatment plants are constructed at a cost of about 50 lakhs of rupees or even a crore of rupees, no one worries about the qualifications of the operators who are running the water treatment plants. It is therefore very necessary that we should also discuss the problem of licensing of water works operators. It is not that we are going to get rid of the operators who are working at present. The idea is that we should train them and see that they are able to perform the work for which they are supposed to be there and they should understand the responsibilities of the water treatment plant operators.

With this introduction, it is my great privilege to call upon Air Vice Marshal, O. P. Mehra to formally inaugurate the symposium and give us his good wishes.

Thank you.

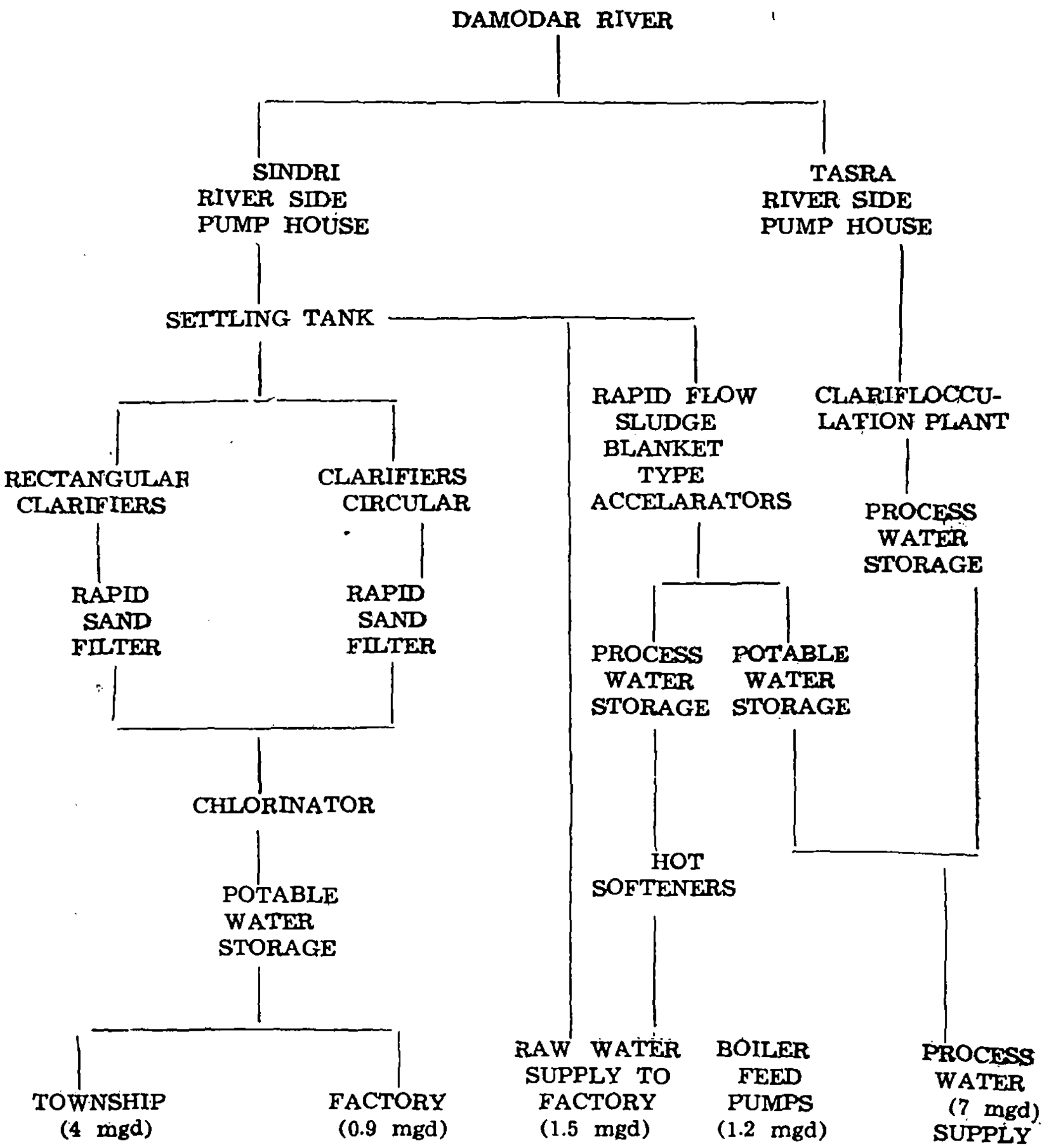

FIG. 1—FLOW DIAGRAM FOR SINDRI WATER SUPPLY & TREATMENT

water, one concentric type clarifloc-culator has been provided. The coagulant used is mainly filter alum with occasional use of sodium aluminate and, for partial softening as well as for pH correction, lime is used. In this process, the raw river water is mixed with the chemicals in a flash mixer and then fed into the flocculation chamber, a small amount of sludge is also recirculated. From the flocculation chamber, it passes into the settling basin and clear water is collected from the overflow channels. The flocculation period is about 40 min. and sedimentation period is about 2 hr. The capacity of this clariflocculator is about 5.5 mill gal/day.

In addition to this clariflocculator, there are three rapid flow sludge blanket type accelerators for the treatment of process water. Two accelerators were installed in the earlier stages of the Factory for the treatment of the entire quantity of water required for process purposes. A part of this water was also meant for further treatment for use in the boilers. It was observed that the actual capacity for treatment in these accelerators is much lower than that stipulated by the suppliers, particularly during the monsoon months when the turbidity is very high. As a result, one more accelerator was installed.

The function of rapid flow sludge blanket type accelerators is to reduce the hardness of the raw water and also to provide a stable clear water for process use. As the name implies, the water passes through a blanket of sludge formed in the process before entering the settling compartment. Raw water is fed into the reaction chamber built concentric to the accelerator along with lime and sodium aluminate or ferrous sulphate according to the nature of the water. The water passing out of the mixing chamber flows upward through a blanket of suspended sludge formed during the process in the lower part of the settling chamber. The blanket of sludge is maintained by the regulation of the chemical designs, water flow adjustment and sludge discharge. The clear water flowing out is taken to a storage chamber. A part of this is used for further treatment for use in the boilers. Another part is used for process purpose after correction of the pH by acid dosing. The designed capacity of each of these accelerators when installed was about 4 mill gal/day, but in actual operation a maximum of 2.5 mill gal/day was achieved. Since the total requirement of process water is at present mostly met from the clariflocculators, normally one or at most two accelerators are put into operation mainly for supplying water for boiler feed water treatment. Small amount of this water is also used to make up the deficit of the process water from clariflocculators.

In both the systems of treatment of process water, viz., clariflocculator and rapid flow accelerators, only turbidity is removed during monsoon period as the hardness is normally quite low. During the dry months, when the turbidity of raw water is very low, these are used as cold lime softeners. The analyses of the treated water from both the systems at different seasons are shown in Table II. A sufficient storage is provided for this treated process water in a

TABLE II—Analysis of Treated Waters

Point of Collection	Rapid Flow Accelerator Outlet		Clariflocculator outlet	
PERIOD	SUMMER	MONSOON	SUMMER	MONSOON
Total Hardness as $CaCO_3$	50-70	50-70	60-80	55-75
Alkalinity as $CaCO_3$				
Bicarbonate	5-10	Nil	Nil	50-70
Carbonate	50-65	30-40	40-60	Nil
Hydroxide	Nil	10-20	5-10	Nil
Total	55-75	40-60	45-70	50-70
Chloride, as Cl'	8-12	4-8	8-12	4-8
Sulphate as SO''_4	10-25	20-30	15-30	20-30
Silica as SiO_2	10-14	7-10	10-14	6-9
Total dissolved solids	110-145	105-145	125-185	110-150
Turbidity	6-15	7-20	6-15	10-20
*p*H	9.0.-10.0	10.0-10.5	8.8-9.5	7.5-8.0

Note: All values except *p*H are in mg/lit.

storage reservoir from where this water is supplied to different consuming units. In some of the consuming centres, some special treatments are given for the control of growth of algae, bacteria, etc., in the cooling towers and to neutralise the effects of chemical contaminations.

For Use in the Boillers : The Sindri Power House supplies the necessary power for running the Factory and also meets the huge demand of process steam, required in the process of manufacture of fertilizers. The boilers supplying the steam for the above purpose operate at 650 lb/sq less in and normally require 2.4 mill gal of boiler feed water per day. Since nearly 50 per cent of the steam is used for process purpose which is not returned to the boilers as condensate, the requirement of the boiler feed make-up water is about 1.2 mill gal/day. The treatment of water for boiler feed purpose was designed nearly 15 years back when the Factory was planned and is the old conventional hot lime-soda process. In this process, the clarified and partially cold softened water from the rapid flow accelerators is fed into top of the hot softener along with chemicals like lime, soda ash and magnesia. Low pressure steam fed into the softener heats up the incoming water and scrubs out the dissolved gases like oxygen, carbon dioxide, etc. The sludge settles at the bottom and the supernatant deaerated water is further filtered out in a battery of pressure filters before being fed to the boiler feed pumps. The condensate from the turbine condensers of the Power Plant are also deaerated with live steam and mixed this water at the inlet of the boiler feed pump. Suitable dosage of sodium sulphate and phosphate are made in order to maintain the correct level of sulphite and phosphate in the boiler water. The principle of this hot process softening is to reduce the hardness and silica content of water and to eliminate the dissolved oxygen. The requirement of steam for this process is met partially from the steam recovery system of the boiler blow-down. Typical analyses of the hot softened water, boiler feed water and the boiler water are shown in Table III.

There are three hot softeners integrated with a battery of filters, each having a treatment capacity of 250,000 lb/hr. Normally, two softeneres are in operation.

The general modes of treatment for potable or drinking water, process water and boiler feed water have been discussed above. During the operation of these processes a number of difficulties have been encountered at times and suitable measures to overcome these were evolved and adopted.

The raw water supply from the river was some times found to contain a large amount of coal and ash particles which created difficulties in the clarification and softening processes. Presence of alga in the river water particularly in the hot summer months, was responsible for the growth of alga in the settling tanks hindering the operation of the clarifiers and sand filters. This growth of alga was controlled with regulated and controlled doses of copper

Table III—Analysis of processed waters

Nature of Sample	Softener Outlet Water	Boiler Feed Water	Boiler Water
Total Hardness, as $CaCO_3$	15-20	7-10	...
Alkalinity as $CaCO_3$			
Bicarbonate	Nil	0- 5	Nil
Carbonate	35-45	25-35	130-250
Hydroxide	5-10	0- 5	170-250
Total	40-55	25-40	300-500
Chloride, As Cl	4-10	3- 6	40-70
Sulphate, as SO_4	10-25	6-15	250-350
Na_2SO	...	2- 4	25-45
Phosphate, as PO_4	...	...	25-250
Silica, as SiO_2	2-3	1- 2	15-25
Total dissolved solids	90-130	50-80	1000-1300
Dissolved oxygen	0.01-0.05	< 0.005	Nil
H	10.2-10.5	9.5-10.0	11.2-11.6

Note: All values except pH are in mg/lit.p

sulphate in the reservoir after thorough investigation of the nature and habitat of these species.

The cold softening operation was affected on certain occasions by the presence of organic contaminants like phosphates, anmonia, etc., in the raw water supply. Some of these were derived from the contamination of the raw water supply line by the factory effluents. These difficulties were overcome by realing the effluent lines and special treatment procedures wherever required.

The various treatments mentioned above are by no means the ideal procedure to be adopted as lot of modifications require to be done in order to obtain more efficient and economical treatment. Such modifications, starting from the supply of water from the river to the final treatment, are being studied thoroughly with particular reference to the nature of water available at different parts of India, where fertilizer factories are going to be installed, in the near future.

Acknowledgements

The authors are grateful to Dr. K. R. Chakraborty, General Manager, Planning & Development Division, F.C.I. Sindri, for his keen interest and encouragement during the investigation.

DISCUSSION

SHRI D. B. WILLETS (Calcutta): The value of 100 gal/capita/day was used by the author. Is this a measure of domestic consumption or industrial use ?

SHRI G. S. ROY : It is the domestic consumption.

DR. J. S. S. LAKSHMINARAYANA (Nagpur) : Do you have any algal problem in your water treatment plant ? If so, what measures do you employ to eradicate these ?

SHRI G. S. ROY : In our waterworks, we had faced algal problem only in the pre-monsoon summer months i.e. April-June. In the settling tank, there was algal growth mostly of filamentous type. The predominant species are **Oscillatoria, Spirogyra,** very little **Anabaena** and some diatoms. There was trouble in sand filters also. We used copper sulphate dosing 0.3-1-5 mg/lit. depending on the alkalinity of water. The algal trouble was eliminated.

DR. J. S. S. LAKSHMINARAYANA: Is there any connection between the practice of adding lime for pH adjustment and biological growths in the water treatment plant ?

SHRI G. S. ROY : In our industrial water treatement there was no particular algal trouble, as the pH in our treatment plant is not inducive for algal growth.

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Control of Water Treatment

S. J. ARCEIVALA
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Introduction

Having spent a good deal of money to build a first class water treatment plant, it behoves the engineering personnel to know the large number of factors that affect its efficiency of performance. A water treatment plant is as sensitive as any processing plant can be and will respond to the care and attention bestowed on it, rewarding the intelligent and careful operator with a quality product.

It has amused the author to meet operators who felt that their duty had been well done if their usual daily chores had been performed such as back-washing the filters, checking the alum dosage tanks, making sure that chlorination was in progress, keeping the pumps running, and so on. Many of these operators were satisfied, as long as their plant was running in the physical sense. Unfortunately, it was not understood that merely running a plant was not the same thing as running it well. If one asked some of these operators how they checked the filtrate turbidity, they promptly replied that the final turbidity was 'zero'; and if pressed further to say how they measured it, some dilapidated rod or some such thing was produced from the store-room! The fact that the instrument was not sensitive enough to read low turbidities had not occurred to them.

Similarly, the fact that alum was added was enough to some people; the ritual had been performed. Whether or not this gave good floc was of little consequence to anybody. Besides, some operators had not even heard of "floc-break-through," let alone knowing how to measure it. In one case, the operator boasted that his filters did not need back-washing earlier than every 5 to 6 days. He was not aware that for a variety of reasons his coagulation was extremely poor and that colloidal as well as flocculated turbidity was breaking through the filters.

Of course, it must be said in fairness to all, that there are some really good and sincere operators trying to do good job and one is heartened when one meets this rare species, but anyone will agree that we have a long way to go as yet. We have learnt how to build plants, but we have not yet learnt how to control their operation. In these days, when good operators are difficult to get, one wonders if a certain degree of automation may be beneficial in the water industry.

Baylis, the famous Engineer in charge of one of the World's best run plants states that "water that will

Inaugural Address

AIR VICE MARSHAL O. P. MEHRA

Mr. Mehta, ladies and gentlemen,

Before I would say something, I would like to complain. My complaint is that Mr. Mehta has told all that I wanted to say. I do not know how I am going to go through with this next 20 minutes of wording because lot of what I could have said has already been said. Notwithstanding that, I would like to say that I am conscious of the honour which you have bestowed on me in asking me to inaugurate today's symposium on "Problems in Water Treatment." Needless to say that I am happy and honoured to be with you. Being conscious of my own limitations, vis-a-vis this gathering of intellectuals, I was naturally reluctant to put in an appearance here. Good friends being what they are, Mr. Mehta refused to acknowledge or accept the fact that I was least qualified to address the cream of the country's public health engineers and research workers. I am indebted for the confidence which has been reposed in me.

I have deemed it necessary to say all this by way of introduction so that, should you, at the end of my attempt, feel dissatisfied, you know who else to blame for my unsuccessful attempt. Should, by any stroke of luck, any bouquets as opposed to brickbats or raw eggs be my lot, I would have no hesitation in placing them squarely in the lap of my friend, Mr. Mehta.

My approach to the problem of water has essentially to be the same as that of any citizen living in a country which boasts of knowledge in such fields as nuclear energy and lays claim to being on the threshold of revolutionary changes directed towards better living standards. As citizens, all of us are entitled to ask "What are the better living standards?" Surely, not a slightly fatter pay packet which stands fully neutralised before you collect the same; thanks to spiralling prices. I would like all my countrymen to enjoy the comforts of cleaner and better designed homes and towns, availability of the necessities of life at very reasonable prices and efficient community and public health services. I seek all these because they will, in turn, help to build a nation of healthy citizens comparable to the best anywhere in the world.

My reference to the word "health" or "healthy" as used just now, is in the broadest sense. It implies more than the absence of sickness in the individual, and indicates a state of harmonious functioning of the body and mind, in relation to his physical and social environment, so as to enable him to enjoy life to the fullest possible extent and to reach his maximum level of productive capacity. In every community there are three classes of persons, namely, those whose level of health is so low that they are victims of disease; others who, while they manifest no definite signs of sickness, are yet so devitalised that the possible range of their physical and mental achievements is considerably restricted and a 'third' class consisting of those who are blessed with an abundance of life and vigour. An assessment of the state of the public health in a country should, therefore, be based on the information relating to all these three classes of people.

Health is not necessarily the product of a monolithic organisation but is the resultant of a number of forces some directed specifically at improving mental and physical well-being, others widely removed from the scientific disciplines of preventive and curative medicine but nevertheless collateral and contributory to the main purpose. An ideal health service will, therefore, include not only environmental sanitation, personal health, community health, control of communicable diseases and vital research, but also social welfare and social security, insurance, labour standards, food production, recreation, family planning and many others.

Incidentally, the Constitution of the World Health Organisation defines "health" as "the State of complete physicial, mental, and social well being and not merely the absence of disease and infirmity" and goes on to say that "one of the fundamental rights of every human being, without distinction to race, religion, political belief, etc. is the enjoyment of the highest attainable standard of life."

There is no doubt that, for sometime now, we in this country have been alive to this vital need. As early as 1943, the Government appointed a Committee known as Bhore Committee, which submitted recommendations covering all aspects of "health". This has since been followed up by other measures including the appointment of "The Health Survey and Planning Committee" under the chairmanship of Dr. A. L. Mudaliar. The Mudaliar Committee, after two years (1959-61) of deliberations, submitted a comprehensive report. Quite a few of the recommendations contained in these two reports have already been implemented.

The Planning Commission is also seized of the problem. During the first three Five Year plans, Health Development schemes have been allocated fair sums of money. The figures for the first three plans are :—

Plan	**Total outlay of Plan**	**Health Development Schemes**	**Water Supply & Sanitation**
	(Crore Rupees)		
1st Plan	2,356	140	49
2nd Plan	4,500	225	76
3rd Plan	10,400	341.9	105.3

The Third Five Year Plan has its objectives in this order :—

(a) Improvement of environmental sanitation, especially rural and urban water supply.

(b) Control of communicable diseases.

(c) Provision of adequate institutional facilities to serve as basis for organising health services.

(d) Provision of facilities for the training of medical and health personnel.

(e) Public health services including maternity and child welfare, health education and nutrition.

(f) Family planning.

The above figures show that the outlay of health development schemes represents 5.9% in the first, 5% in the second and 3.4% in the third plan in relation to the total outlay on the successive plans. For a country like ours having huge area and large population, these amounts are not at all adequate. Statistics may lie, but when they reveal that the outlay on health development schemes has been given decreasing importance with each successive five year plan, one wants to know, "why so, in a welfare state ?"

Some of the major factors that are taken into consideration when tackling the health problems of any country are its population, food and nutrition of the people, housing, environmental hygiene, water supply and drainage and, above all, health education.

Population of this country has continued to increase at an alarming rate. It stood at approximately 440 millions at the time of the 1961 census. Owing to the improvements that have been effected in such fields as public health, the death rate is showing a lower trend. Whilst it is the logical thing for a Government to achieve it, the Government must also find an answer to the problems that are inherent in an explosive growth of population.

Of the 5,50,000 villages that exist in the country, there are approximately 3,80,000 which have a population of less than 500 each. The provision of comprehensive health services in rural areas in our country is, therefore, an extremely difficult problem. But, should a start be made by picking on selected villages, we may be able to tackle the problem over a period of time. This does not mean that we can afford to neglect places where more than 500 people live. We should spell out priorities and act upon them.

Food and Nutrition : We are all conscious of the efforts being made in this direction. Food continues to be our biggest problem. It may well be the main hurdle in the way of India attaining its proper stature in the world. The need of the hour, apart from being increased food production, is a change of eating habits.

Technological advances in the world have had a definite impact on us; as a consequence, we are in the midst of an industrial revolution. Industry needs very large quantities of water and, in turn, is responsible for creating problems of the disposal of industrial wastes. The problem of the public health engineers is to provide adequate quantities of safe water. When they succeed in doing so, they must simultaneously take care of the disposal of industrial and domestic wastes.

The industry has also attracted a large number of people to the urban areas thus making the existing facilities in towns most inadequate. There is no doubt that the public health services which are in existence have proved unequal to the requirements.

Health Education: No amount of money, no amount of schemes and no amount of effort will bear fruit unless the people are made aware of the benefits of these measures.

There is no doubt that our industry has to be stimulated to grow as fast as possible but we must make sure that it does not generate more evils than it eliminate. To quote Gandhiji's words, "Scientific truths and discoveries should cease to be mere instruments of greed. The supreme consideration is the man."

I am afraid, I have rambled far and wide successfully consuming the allotted time! I now return to the specific problem viz., "water". Water is an essential ingredient of living—leave alone good and healthy living. Unfortunately, most of our supply resources are polluted and unfit for drinking. Our efforts at making the same fit for drinking have not been so successful as to permit us to hold our head high with pride.

This statement stands amply proved when we look at the example of our capital city New Delhi—a place where we can ill afford to come up for ridicule. Every year, we hear of the drinking water supply at New Delhi being affected owing to the "wastes" that get fed into the river Jamuna near the Wazirabad Pumping Station. We obviously are slow in tackling the problems of a growing community.

I feel that the problems in this connection are provision and supply of safe and adequate quantities of water and disposal of wastes, and that these are the problems that should be handled and sorted out by the medical profession and our public health engineers jointly. Should the above statement be acceptable to all concerned, then, I seek to ask one question. Are we going on with this task in earnest and have we taken steps to ensure the much needed co-operation between the medical practitioners on the one hand and the public health engineers on the other? I would say we are not to the degree that is desirable. In this connection, I refer you to the composition of "The Health Survey and Planning Committee". The Committee consisted of Doctors and Members of Parliament but very few, if any, public health engineers. Perhaps, the intention was for both categories of people—the Doctors and the Members of Parliament—to deputise for most of you gentlemen, who claim to be specialists in the field of public health engineering!!

The magnitude of the problem has come to me, rather forcefully, after reading some of the facts enumerated under the title "Do you know" in the Brochure which has been issued in connection with this symposium by the Central Public Health Engineering Research Institute. Before I read a few abstracts, I must admit that I do not know. I only hope my audience is aware of these facts or else, the less said, the better!

The lack of safe drinking water resources is not only a problem for this country but the whole world. The magnitude of this problem has been amply borne out by some of the statistics which I have referred to a little while ago. I understand that, in India, at present, protected water supply even in the urban areas is made available adequately only to 34 per cent of the population and inadequately to an additional 26 per cent.

Having enumerated all these problems, I venture to say that the problems of water supply can not be treated in their isolation. If improved and better water supply has to make an impact on the general health of the country, then I submit that the problems of water supply should be treated along with allied problems like sanitation, town planning, disposal of human and industrial waste, nutrition, housing, communicable diseases, etc.

Once again, I repeat, whatever schemes we may conceive and implement, no beneficial results can accrue unless people, as a whole, are made conscious of this very vital problem and they begin to cooperate in this venture. It may be difficult to wean away older people from age old and well established habits and practices. You all know what I mean. Better and encouraging results would certainly be evident if a start was made at our schools, colleges and allied institutions to impart the necessary education.

The political situation along our borders has brought in its wake the need to take care of problems connected with water supply and sanitation all along our northern borders also. The conditions along these hills, as you are fully aware, are abnormal. The terrain is hostile and no facilities of any description are available to those who are required to make provision for some of the basic needs of the soldier. Ever since we started occupying positions in the mountainous terrain along our borders, our engineers in the defence services have endeavoured to provide these facilities with a great measure of success. In spite of the measure of success which they have achieved, they are conscious of the fact that still, they have a long way to go before they and others can be fully satisfied with the arrangements. I am pleased to note that a team of military engineers is taking part in your deliberations. They will thus get an opportunity of sharing and discussing their problems with those of you who may feel interested in yet another facet of your problems. I understand that the problems that concern the military engineers are of such magnitude that the organisers of this symposium have decided to set apart a special session for this purpose.

The Health Survey and Planning Committee 1959-61, in the concluding chapter of their report, have remarked as follows:

"It has been truly said that Health is Wealth and from this point of view, there can be no difference of opinion that, whatever may be the progress in other directions, the progress in the health of the population is a *sine qua non* for a peaceful existence and a genuine feeling of happiness. Every citizen should, within as short a period as possible, be provided with the minimum needs for the maintenance of health, namely, housing, pure water supply, efficient drainage, prevention of communicable diseases and a satisfactory method of health care."

The little that I have known about water and its problems has been instrumental in my personal consumption of water being reduced drastically. I sincerely hope that this feeling will not be universal or else you will have no more problems to tackle!

The problem of providing safe drinking water to one and all in India, is a formidable one. It needs energetic handling. There can be no two opinions about it. It is also indisputable that the economic resources of the country are relatively little. We would perforce have to tackle this gigantic problem in stages. The methods adopted by other countries may not necessarily yield results here, for obvious reasons. This is mainly because we have to contend with a legacy of the past. Any attempts to break away from the past in other than gradual stages with the active connivance of those for whom the good is intended. may result in failure. The very expensive and sophisticated schemes and equipment in vogue elsewhere in the world may not suit our pocket. So what do we do? Certainly, we cannot sit back and hope the problems will get solved by default. Unfortunately, water is not a problem which can be solved thus. We have to intensify research. Research aimed to achieve the goal within the financial resources of the country and with the use of indigenous materials.

Lord Rutherford, one of the most eminent scientists of the age, when confronted with a somewhat similar problem by British scientists, namely comparison of the financial and allied resources at the disposal of the scientists in America and Britain, is alleged to have remarked:—

"Americans have the money. We have none, hence we have to think". The lesson to our scientists, research workers and engineers, is obvious.

I sincerely hope that with the help of your current deliberations and with the active co-operation of research workers, scientists, engineers and doctors, the problems that confront the country, not only in respect of water but other allied public health problems would be satisfactorily solved in the shortest possible time with the use of indigenous materials and a financial outlay which the country can afford.

I thank the organisers and CPHERI and wish them success in their endeavours.

I am grateful to Mr. Mehta, the scientists of CPHERI and the Institution of Engineers (India) for having thought it fit to ask me to be here this morning. I have no doubt that this symposium will do good and I hope that with the passage of time your deliberations here will help to solve this problem of the country.

With these words, I have great pleasure in inaugurating this Symposium.

Director's Impressions on Air Vice Marshal O. P. Mehra's Speech

It was an extremely interesting speech by Air Vice Marshal O. P. Mehra. It was the survey of our activities on water supply that he has presented us today. Therein he traced the history of the protected water supply right from the Bhore Committee report to its status today. It was very outstanding.

His concluding remark will, however, highlight his speech. He has said that with our poor financial conditions our country can not supply protected water to the huge population with costly processes of water treatment. It is very necessary to think in terms of new methods of water treatment so that with the use of available resources with us and the indigenous materials, we can easily do this in a reasonable time. Therefore in the fitness of things, we have all met in this National Institute to discuss these problems.

I hope that all of you will join me to thank Air Vice Marshal O. P. Mehra who has inaugurated this Symposium.

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Proper Operation and Control of Water Treatment Plants

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In the first three Five Year Plans, we have not been able to achieve very much in the field of protected water supply and treatment of domestic wastes. In the Fourth Five Year Plan, however, a large provision has been made both for the water supplies and sewerage and sewage treatment plants. The existing plants in most of the towns are also gradually being overloaded and are not able to give the best results.

In olden days, when slow sand filtration was adopted, the operation of such a treatment plant was comparatively an easy matter. The operator had only to regulate certain valves and in cases of choking of the filters, the sand had to be taken out and washed. With the invention of the rapid sand filtration, there are a number of units which demand higher skill and care in operation. The rapid sand filtration consists of chemical dose, flash mixer, the flocculator, the clarifier, the filter bed and disinfection units and each item has its specific functions.

Industrial expansion in India has created problems of more serious water pollution. The streams and rivers carry wastes from the towns and from the industries and the surface waters may contain substances like phenols, oils and hydrocarbons which may form odour-causing complex compounds with chlorine. Organic nutrients increase algal growths and many complicated chemicals may affect the quality of water. Other non-industrial loads like detergents, pesticides and treated and untreated domestic sewage in the stream are very much on the increase. All these factors make it very necessary that the water treatment plants are operated by a skilled operator who can understand the working of the plant and can control it.

Unfortunately, the operation of the treatment plants in India is far from satisfactory and there is absence of skilled operation and control. The techniques required for simple chemical dosing and flocculation are not currently practised. The determination of coagulant aid dose with minor jar testing machines—if available at all—is rarely correct. Few operators seem to know about the effect of pH on the coagulant's efficiency; and, at present, not a single plant in India practises pH adjustment. Use of alternative coagulants —ferrous or ferric salts with wider pH range for effective coagulation is practically never made. Coagulant aids like activated silica or other indigenous substances are unknown in our country. Sometimes, the dose by the jar testing machine is correctly determined by the operator but he has no knowledge about the plant factor of the dose. Recently, we visited a plant with a capacity of about 20 mill gal/day. The operator had determined the alum dose to be 5 gr/gal by jar testing machine but in spite of that the plant did not give a satisfactory performance and our study showed that the plant factor was not taken into consideration at all. In this particular case, it was about 2. These factors do not vary from plant to plant but normally range from 1.2 to 1.8 with good mechanical flocculation and clarification and are higher for hopper bottomed type non-mechanical flocculated plants. There are other factors such as designs of inlets, overflow weirs, etc., which also affect these factors and every plant operator should know his own plant factor.

Similarly, the use of other coagulating aids such as lime to obtain heavy nucleus through low turbidity in summer season to remove colloids or ordinary clay or bentonite to seed the colloidal turbidity give easy removal of turbidity without disproportionate use of coagulants like lime etc. Thus, a combination of pH adjustment and proper chemical dose determination can save considerable amount of coagulant dose for chemical operation.

The second important function in the plant operation besides the chemicals, is the exact manipulation of the units—flocculation, sedimentation, filtration and disinfection. The sedimentation tanks presently installed in the country are of the following types:

(i) Clariflocculator unit with a flocculation chamber in the centre and peripheral clarifier;

(ii) The flocculation is done in a separate chamber with a circular clarifier with a tangential inlet;

(iii) The Dortment or hopper-bottom type tank has a sludge blanket; and

(iv) A regular tank with ridge and furrow arrangement.

The operation technique required for each unit depends on the exact design factor. The variability of speed and flexibility of detention period are rarely provided in any of these units. But a clever operator can sometimes manipulate this with the operation of two or three units to obtain the required detention time. The successful operation of these units also depends on the timely withdrawal of the sludge. Some hopper bottom tanks can give much better results with heavy sludge by maintaining a steady sludge blanket while the same unit with a lighter sludge may give a better performance with intermittent desludging. All these factors require a complete and thorough understanding of each unit to get the maximum benefit out of the plants. Recently, we saw two very well designed plants of 2 and 4 mill gal/day capacity. The plant operation was very poor and the quality of the effluent was even inferior to the influent. The operator in this particular case was not using coagulant at all and the sludge mechanism was also out of operation. In yet another plant of

4 mill gal/day capacity, the operator had nearly blocked the filter valve raising the water level in the sedimentation unit over the weirs and the outlet arrangement was totally submerged. In yet another city with a population of 7 lakhs and with an installed capacity of 10 mill gal/day, the operator used to leave the bottom hopper valve fully open, depriving the tank of the required sludge for forming the blanket. This has resulted in poor performance of the plant and about 15 per cent of the water was wasted. There are numerous such examples of well designed plants which should give very good quality of water and which are not functioning properly because the operator is not running the plant intelligently.

The most troublesome period in many of the sedimentation tank operations is during the summer months when the turbidity is low and the colloidal matters and algal growths are profuse. The skill of the operator is required to eliminate it by proper pre-chlorination and or copper sulphate application at the correct point. This technique, if suitably used, gives very effective results. In a city of 10 lakhs population treating the river water, they had a serious algal problem and the operator was using copper sulphate at a dose of about 2 mg/lit. in sedimentation tank at the inlet end and was unable to obtain the removal of algal trouble. But when the same dose was applied at the suction side of the raw water pump near the intake, the period of contact between the copper sulphate increases considerably and almost 75 per cent of the algae was killed before it reached the sedimentation tank. Similarly, the chlorination point can also be chosen by a single operator after studying the exact situation.

The next vital important unit in operation of the water treatment plant is filtration. Very few operators realise the significance of this unit and it can easily be said that this is the most neglected of all the units of operation. Very few filter beds can be said to be satisfactorily maintained though some of them may be delivering the required quantity of water. During the period of high turbidity or pollution, they feel the pinch of the inefficient operation as it is then that the filter refuses to give the requisite output. The basic necessity of good filter unit operation is the understanding of the backwashing cycle. Many times, the operators handle the valves in wrong sequence. They are sometimes not capable of judging whether the filter washing is being done to the required standard. Most of the troubles in the filter operation are due to the lack of proper backwashing. This may be due to the following reasons:

(i) Inadequate pressure available for the backwash water;

(ii) The capacity of the backwashing storage tanks may not be enough;

(iii) Insufficient size of the pipe and pipes and valves for the backwashed water supply;

(iv) Insufficient air both in pressure and quantity for backwashing purpose; and

(v) Inherent defects in the design of the filter.

Recently we saw a plant of about 2 mill gal/day capacity which was connected to the backwash tank by 4 in C.I. pipe. The Department had carried out the work of getting the pipe while the Firm that supplied the plant had finished off their line with an 8 in line. It was obvious that the plant would not get enough water for backwashing. In a number of plants that are overloaded due to the increased population, the overhead tanks for backwashing purpose are inadequate in capacity. In some cases, the colony near the water works has been given a pipe connection from this elevated tank with the result that the filters do not get enough water for backwash. In one plant recently visited by us, the compressor was coupled to a petrol engine and due to some starting trouble in the engine, the operator was not using the compressed air at all resulting in a very poor performance. Many operators do not seem to know the obvious defects of the sand beds such as mud balls, cracking of the bed, separation from the walls, the improper distribution of water at the initial opening of the valve for backwashing purposes and even simple observations on the grain of sand.

The rule of the backwash operation to continue it till the clear water appears is rarely observed. Instead, the bed is washed for 5 or 10 min irrespective of the results obtained. Many times, the turbid backwash water is allowed to stand 6-12 in deep over the bed and fresh water introduced resulting in immediate clogging of the bed and short runs.

In low turbidity season, the filter beds can give much better performance and for a little alum to raw water and filtering it directly instead of treating the water in the primary unit. Many operators have stopped using alum for this purpose for showing economy not realising the fact that the filters are not giving the satisfactory effluent.

The use of chlorination equipment is very important in water processing as on this depends the final safety of treated water. It is a useful tool in the hand of a clever operator. The point of chlorination if readily chosen can help to solve many problems with respect to odour and colour removals. The choice of prechlorination is sometimes critical, i.e., if there is pre-chlorination before sedimentation and flocculation and water is polluted by phenol, etc., the chances of odour increase. In such cases, the operator should apply chlorination after sedimentation. There are many sides of this question and detailed training should be given to the operator to be able to make a correct decision. The operator should also know the capacity of the chlorinator that he is using. Many plants in the country have chlorinators installed initially along with the plant. Since then the plant has undergone lot of expansion. The chlorinator, however, remains the same. The chlorinator has to be of such a capacity that it can be overloaded in times of emergency. Many operators have no clear idea about what the chlorine dose should be. The chlorine demand determination is not done in many treatment plants. Along with the operation of chlorination units, its maintenance is also equally important. Many chlorinators have their measurement tubes broken or valves jammed or even mixing towers are probably not supplied with adequate water and the chlorine escapes at the tops. This is a health hazard. We have found in many plants that chlorine cylinders are not available at all. The reason given in most of the cases is that there is the transport difficulty and the firms have not been able to supply them in time. If the operator knew that the cylinder is required by specific dates, this difficulty could be overcome in many cases. The weighing machine under the chlorine cylinders is of great help to the operator.

The routine maintenance of the equipment on water treatment plants is also mostly neglected. In any old plant, with a life of 10 years or more, the loss of head gauges, the flow indicators, the flow regulators, floats, etc., are usually out of order. Without these, the operator would never be in a position to evaluate the plant operation. Most of our water treatment plants lack the much-needed laboratory at the plant. In a few instances, a small laboratory building is in existence but the equipment is outmoded or is not working. The stock of chemicals is also usually exhausted, and for months on end no replenishments have been done. Every good sized plant should have a properly equipped laboratory with a laboratory technician. Unless a plant operator has a well equipped laboratory to guide him in the operation, he can never run his plant economically or efficiently.

We now come to the most important problem, the training of operators. In India, most of the plants are operated by persons who are not qualified and trained. Some of them do not know how to read and write. The solution of the problem is not in getting rid of those staff as that may not be possible. An intensive programme of the training of operators has to be taken up on a regional basis. All the operators should be given training courses and a certificate at the end of it. In future, the Municipalities should insist that the operators holding a licence or training should only be employed on treatment plants. As we are spending lot of money on water treatment plants and especially as the existing plants are to be overloaded for the next few years due to the shortage of supply, the training programme should be given the highest priority. The courses should be in English and other regional languages and the training received be followed up by giving the operators descriptive literature, of and on. They should also be given refresher courses every few years so that they are kept in touch with the latest techniques. The administrative set up in some of the municipalities is also responsible for the inefficient running of the water treatment plants. Necessary staff required to run the plant on three shifts is not given. Moreover, the Municipal Engineer may not be a man with public health engineering bias and may not give sufficient priority to the plant operation. Water supply can be a self—supporting department if it is properly run and it should always be appreciated by the staff that this is one of the most important utilities and on it depends the health of the community.

DISCUSSION

PROF. B. K. MAHAJAN (Jamnagar): In your paper, you have referred to the occurrence of hepatitis due to the presence of viruses. In this connection, I wish to know whether pre-chlorination and superchlorination are advisable to prevent such cases.

SHRI R. S. MEHTA: Hepatitis Virus is not yet isolated. Very recently Government of Maharashtra also referred to us some cases. As for my knowledge, the chances of occurrence of hepatitis can be avoided with proper and controlled high dose of residual chlorine of 0.5—0.6 mg/lit. at receiver's end. This much residual chlorine has shown some check over the occurrence of hepatitis.

SHRI J. M. DAVE: It is found that severe pre-chlorination can check occurrence of hepatitis. For example, in Okhla water works, it was observed that no cases occurred after pre-chlorination and conventional treatment followed by post chlorination was exercised strictly.

PROF. B. K. MAHAJAN: I think that pre-chlorination does not check occurrence of hepatitis.

PROF. ARCEIVALA (Bombay): Pre-chlorination will not be effective as Hudsons study reveals that 0.8 mg/lit. chlorine dose before any conventional treatment does not prevent jaundice but that, on the other hand, 0.2—0.4 mg/lit. of chlorine dose given after filtration prevents jaundice definitely.

SHRI S. N. TRIPATHI (Bareilly): Does the presence of Fe and Mn cause depletion of residual chlorine?

SHRI J. M. DAVE: The amount of Fe and Mn is determined and the water is treated with polyphosphate which stabilises Fe. This will avoid incrustation and there will be no depletion of residual chlorine.

SHRI M. I. GURUBAXANI (Tatanagar): It is pointed out that to determine optimum dose of coagulant, tests should be carried out in models along with correcting pH of water, if necessary. But I wish to add that during monsoon, the turbidity of river water varies to such an extent and so rapidly that the operator has no time to determine the dose of coagulant.

SHRI R. S. MEHTA: It is quite often that the turbidity varies suddenly when the river is in floods and regulation of alum dose and other adjustments of pH are difficult, as in the mean time, the turbidities change continuously. However, the trained and experienced operator knows the nature of the emergency and keeps the stock of alum and other chemicals ready at hand. If the dose can not be regulated correctly, he takes a larger factor of safety and adds more chemical by dumping it in conduits, etc. But, in a particular river in monsoon, the operator, after experience, can find out what dose he would need for 100, 500, 1000, 2000 & 4000 mg/lit. turbidities.

It is for this reason that trained operators are needed on plants. The settling tanks have usually sufficient margin to tide over the rapid fluctuations in turbidities for giving stabilised performance. I have, therefore, stated about staff requirement that good operators are needed in three shifts on all large plants, as this emergency repeats so many times every year.

SHRI D. A. NAIR (Ranchi): I suggest that for proper control of water works operation, only certified operators should be allowed to be in charge of water works. These operators should be given training and should receive certificates which will authorise them to operate treatment plants of various sizes and types. These water treatment plants should be classified as A, B, and C in conformity with their size, etc. and the operators certificate should indicate the category of the plant which he is competent to operate.

SHRI R. S. MEHTA: The suggestion is certainly good. It is absolutely essential to have trained operators, if plants are to be run correctly and economically. But unless the local bodies who own the plants take the decision, we can not do anything. We can only give courses for different categories of operators and recommend to the centre council of local state government to appoint only persons who have the necessary qualification and licence.

SHRI B. K. CHATTERJEE (Sindri): May I know whether CPHERI recommends to the Government something to the effect that the Government should frame rules and regulations regarding the appointment of qualified and trained public health engineers and operators for maintenance of the water treatment plant in the municipalities and industrial undertakings.

SHRI R. S. MEHTA: CPHERI has recommended to the government for licensing of the operators. But government has to convince the autonomous bodies with poor finances and political influences to accept this and this would take some time. When more and more operators are trained and plants are properly run, this must come into practice automatically.

SHRI P. R. MEHTA (Bhavnagar): If the CPHERI introduces a course of training of operators or a refresher course in its activities, the problems in water treatment can be easily handled.

SHRI R. S. MEHTA: The CPHERI has already started a training programme. A refresher course for engineers was held in September 1964 and several chemists and bacteriologists working on plants are receiving training off and on. However, a regular scheme for training of operators and for holding refresher course regularly has been placed before the Executive Council of the Institute and a decision would be taken shortly.

SHRI S. K. GAJENDRAGADKAR (Bombay): I agree with the speaker that the operators should be well trained and that the engineer-in-charge should be familiar with the knowhow of the working of the plant. It is also necessary to have a full fledged laboratory at every treatment plant and the necessary changes in dosing of different chemicals should be done as per the quality of the raw water. A record of yearly variation should be kept and this is necessary especially for bacterial quality.

SHRI Y. A. VEERAINDER (Bhilai): For better operation and performance of water treatment plant, NORMS should be laid out for design, provision of equipment and operation. Norms will minimise the variables and improve the operation.

SHRI R. S. MEHTA: Norms are being laid down by and by and are available in all foreign countries. Code of Practice is also prepared by the Ministry of Health but the question under the discussion is about operation and maintenance. Even if a plant is designed on standard practice and provided with proper equipment, unless it is properly maintained and operated it would not give the necessary results.

SHRI P. BHASKAR RAO (Nagpur): Is there machinery available which can be installed in the intake wells to remove the silt without the necessity of stopping the pumping operation?

SHRI R. S. MEHTA: Yes. Depending on the size of the plant, there are grab, chain and bucket mechanisms, grab and winch mechanism or submersible pumps for this purpose. The method to be adopted at any one place depends on so many considerations. In modern plants, stopping of intake well is definitely not required.

SHRI J. THOMAS (New Delhi): The author mentioned that Schistomes are practically completely removed by rapid sand filters. However, it is mentioned by Fair & Geyer that the cercariae of blood flukes are sufficiently motile to wriggle through the beds of rapid sand filters of normal depth.

SHRI J. M. DAVE: The blood flukes are of three types and they are *Schistosoma haematobium, S. Japanicumani* and *S. Mansoni.*

The first is present in Egypt and Middle East, second in Japan, China & Far East and the third in Western hemisphere. They are flukes belonging to pletihelminths group and are not great danger in India, though they are present in few areas. Their cercariae range from 0.35 mm to 0.50 mm in diameter and are normally removed by flocculation and filtration. Few rare instances have shown that highly motile cercariae can go through the filter beds.

SHRI L. F. LIMA (Poona): Different specialists of water treatment plant design have different methods of flocculation clarification and different figures of residual turbidity in the finished water. Two leading specialists' figures are given below.

	Specialist I	Specialist II
Maximum turbidity of raw water at inlet to the plant during worst conditions, mg/lit.	7000	7000
Flocculation	Flash mixing and flocculation	No flash mixture
Clarification	Clarifier	Clari-flocculator with hopper bottom
Detention period, hr	2½ — 3	2½ — 3
Turbidity of the effluent of the clarifier in clariflocculator, mg/lit.	10	20
Guaranteed filtrate turbidity, mg/lit.	0.5	5
Approximate cost of 10,000 gal/hr. capacity plant	Rs. 130,000	Rs. 95,000
Approximate cost of production, Rs. /1000 gal water	0.40	0.25

a) What should be the maximum permissible turbidity in the filtrate from the public health point of view? Is it 0.5 mg/lit. or 5 mg/lit.?

b) If it is 0.5 mg/lit., must specialist No. 2 use a flash mixer and a mechanical flocculator or go out of business?

c) If the answer is in the affirmative, is it inescapable that public undertakings invest nearly 1½ times the capital cost on specialist No. 1 than that required by specialist No. 2?

d) If the country is to introduce licensing to water treatment specialist, which would be the figure specified consistent with economy?

e) How far and to what extent can health of the community be sacrificed to effect economy in the quality of water?

SHRI J. M. DAVE: a) The standards of turbidity as per the international WHO standards is 5 mg/lit. and is less than 1 mg/lit. as per the standards of AWWA. The figure desirable from Public health view point is less than 1 mg/lit. as it eliminates many pathogens generally but it should depend on economy,

b) and c) It is desirable to have good flocculation and it can be with either type.

d) We do not propose licensing of water treatment plant manufacturers but operators to ensure proper training.

e) Health of community should not be sacrificed to effect economy generally but good water should not be rejected for best that is not available.

PROF. B. K. MAHAJAN: To kill **E. histolytica** cysts, virus of infectious hepatitis or Jaundice, ground water larvae or Cercariae, you need *superchorination and dechlorination.* Is there any cheap method and practical one to do that for large population or small population where filtered water supply is being made? If so, please state the stage and technique in general.

SHRI R. S. MEHTA: Regarding **E. histolytica**, the epidemics that broke out so far in the whole world were not caused by filtered water supply and they were because of some cross connection. Normally the cysts are removed in coagulated, settled and filtered water.

Regarding the removal of infectious hepatitis virus from the filtered water, it has been discussed already and in addition, I wish to quote that Norman A. Clerk has determined the viricidal efficiency of free chlorine in water. He chlorinated the distilled water contaminated with feces-borne infectious hepatitis virus with an initial chlorine dose of 3.25 mg/lit. for a contact time of 30 minutes. This chlorinated water with a free residual chlorine of 0.4 mg/lit. did not cause infectious hepatitis in any of the 12 volunteers during his studies. This virus is yet to be isolated. At present, this is the only method available to test its removal from water.

Since the cercariae perish after two days in water, storage is an effective method of treatment. They are not completely removed by coagulants and sand filtration, nor are they destroyed by chlorine in the doses usually employed in water works (up to 2 mg/lit. are necessary) There is evidence that cercariae are killed by the excess lime treatment of water. An interval of at least 48 hr should intervence, by *storage in closed reservoirs,* before the water reaches the consumer.

Small quantities of water can be rendered safe from cercariae by boiling or filtration through Stella or Meta filters. Water that is required for washing or bathing purpose *only can be effectively treated* by cresol (1 in 10,000).

sures. Sometimes there may even be negative pressures in the mains when pumping takes place. The present state of affairs is not likely to be remedied within the foreseeable future.

The high morbidity rate due to water-borne diseases is more on account of inadequate and intermittent water supply. The former compels people to use hazardous water. With continuous water supply, this high rate of morbidity is expected to be lowered.

At present, it is not necessary to construct the complicated modern treatment plants in this Country. They are mechanised to save labour and require skilled technical hands for operation and maintenance. Spare parts are not easily available and have to be imported. Foreign exchange is scarce and skilled operators for the job are woefully inadequate.

The funds available for the execution of water works are extremely limited in comparison to the amount necessary for solving the water supply problems properly. Greatest benefit to the greatest number has to be achieved with whatever means available. This is possible only by reducing the cost of treatment and by larger output of the treated water through filters. The increased rate may cause some deterioration in the quality but should not create any difficulty after proper disinfection with chlorine. Recent experience in Calcutta has shown that effective chlorination is possible even with the raw water from the river Hooghly. If necessary, provisions may be made in the overall plan to enable improvement in the quality at a future date. It is expected that reduction of the load per unit will lead to improvement in the quality of the effluent.

Attention should be directed more towards ensuring 24 hours supply of filtered water to each and every house and construction of cheaper, robust and, at the same time, reasonably efficient treatment plants.

The most important unit process in ensuring safe water supply is disinfection. Filtration comes next; it not only helps to maintain the efficiency of the disinfection process but also improves the physical quality of the water for the consumer. The other unit operations involved are for conditioning the raw water in order that the filter output can be increased; softening units when employed will obviously precede filters.

The treatment plant is a costly item in the water supply system. Innovations, which help in cutting down cost and avoid mechanisation as far as practicable but at the same time would ensure the delivery of water as per the standards, are most welcome. Even if some disinfection procedure, which remains unimpaired by turbid water, is found out, it is not reasonable to expect that the public will prefer to forego filtration for a consistently turbid water. Filters will be required to guard against pre-treatment failures. The cost of construction can be reduced by reducing the thickness of the filter bed; this is possible by taking advantages of the better quality of the effluent produced by pre-conditioning units. By adopting porous plate bottoms in supporting coarse sand and gravel layers, upward flow filters offer the possibility of utilizing the filtering capacity of the coarse layers at the bottom. Density stratified filter beds are another promising modification.

The construction of flocculation and sedimentation basins, together with filters within the same enclosure, will reduce the cost of construction and enable re-use of the back-wash water.

For conditioning units, it is expected that solid contact basins prior to filtration in small plants will reduce the cost of treatment.

For disinfection of water supply, no cheaper method than chlorination is in sight. Treatment with chlorine dioxide has been claimed to be more effective both for disinfection and oxidation purposes, although it leads to greater expense.

Taste and odour in water supply, which are not removed by conventional treatment methods, may be destroyed by ozonisation prior to chlorination. The possibilities of using potassium permanganate in this connection may be mentioned.

In recent times, great interest has been created by the detection of enteric viruses in water; these are being linked with various diseases and intensive investigations are being carried out. It has been claimed that with proper coagulation, the viruses can be reduced by 95 per cent or more and the rest inactivated by chlorination. The problem has, however, not been solved satisfactorily as yet: flaws still exist in the present protection barrier. The only redeeming feature is that viruses released to the environment may be less by five orders of magnitude than the bacterial pathogens. It may be reasonably expected that only when there is catastrophic pollution that a viral disease will invade a community through its water supply.

Algal growth in lakes used for sources of water supply and at the same time serving as recepients of waste waters is another problem deserving attention. Nitrogen and phosphorus present in waste waters are not removed in adequate amounts in the present treatment plants. Synthetic detergents add more phosphorus. The resulting enrichment of plankton food promotes algal blooms.

The other problems affecting water supply system are corrosiveness and tendency of the water to form incrustations on the surfaces in contact. Cathodic protection for pipe lines, chemical stabilization of water and the deposition of protective coatings from water itself have provided some solutions of the probltm. But new methods have to be found out for the final control of corrosion.

Modern treatment plants have solved quite a number of the problems, but as Professor Fair puts it: "To be boastful about sophistication of modern water treatment capabilities requires courage that can spring only from ignorance. For whenever man modifies his environments, he shifts the balance of the human ecology, which becomes more precarious as the people of the world increase in number and tax the capacity of the resources and environment. On occasions, interferences may end in disaster. The most important realisation should be that the sources of drinking water are among the most vital resources of modern man."

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Problems in Water Treatment at Bhilai

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Introduction

Natural water has become an important raw material as a result of modern technical developments. Standards of water quality both for domestic and industrial purposes are in a constant state of evolution. The industries are causing increasingly dangerous pollution of the water bodies. The wide range of pollutants and the desired requirements of water quality pose numerous problems. The rapid urbanization around the foci of natural resources has greatly contributed to water treatment problems. Widespread use of economic poisons such as pesticides and use of synthetic detergents add heavily to the pollution of receiving water bodies. Conventional methods of water treatment fail to respond to pollutants such as phenols, radioactive substances and other trade wastes. The present day water treatment begins in reality at the waste disposal, recovery or treatment works.

Among the problems that need prompt attention are pollution control, corrosion control, dependable and cheap method of disinfecting water supplies, treatment of algae-laden and organism infested water and that rich in minerals. Dearth of trained personnel to man the treatment works is equally an important problem.

Water Treatment Plant at Bhilai

The drinking and industrial water supply for Bhilai Steel Plant and its township is derived from a lake. At Bhilai, the problems in water treatment are considerably minimised due to the following features adopted in the design.

i) A well protected source of raw water;

ii) Pre-chlorination of raw water, whenever necessary;

iii) Functional layout of the water treatment plant;

iv) Use of alkathene pipe and fittings for passage of alum solution and chlorine dosage;

v) Use of air lift pump for agitating the alum solution to prevent stratification;

vi) Straight flow sedimentation tanks;

vii) Adoption of appropriate filtration media, and controlled operation of filters;

viii) Clear water underground reservoir with baffles permitting required chlorine contact period; and

ix) Provision of well equipped and properly staffed Control Laboratory attached to the plant.

The purification works provide for complete treatment with primary sedimentation in large storage reservoir, coagulation and settling, filtration and chlorination. The treatment plant was designed to treat 31,820 cu m of water per day for a provision of expansion to 45, 450 cu m/day without much alterations. At present, the plant out-put is 52, 320 cu m/day.

Raw Water Characteristics

The storage tank of 32 mill cu m capacity acts as a primary settling basin. In dry season, this tank is filled by a rain-fed irrigation reservoir located 80 km away, while in monsoons, it receives some water from the runoff of its 9.1 sq m of catchment area. No difficulty was experienced in pre-treatment of water for the first two years (1958-1960), when raw water showed fairly good turbidity particularly during the first filling and the monsoon periods. The characteristics have undergone remarkable change since then, as may be seen from Table I

Problem in Pre-Treatment

The low turbidity presented a problem in pre-treatment of water for the first time in 1961. The coagulation and floc formation occurred with difficulty resulting in poor settling. Secondly, the clarity of water and intensity of sunlight from November onwards encouraged algal growths. The effect of these phenomena was carry-over of floating flocs and lifting up of the settled sludge on the surface that passed on to the filters and very often clogged them. The cracking of filter beds became common. The probable reason for

Table I—Salient Characteristics of Raw Water

CHARACTERISTICS		CALENDER YEAR				
		1959	1960	1961	1962	1963
1. Turbidity (in unit)	Max.	400	260	30	8.5	3.6
	Min.	10	7.5	4.6	1.7	1.6
	Av.	20	10	6.5	4.0	2.8
2. *p*H Value	Max.	8.0	8.3	8.4	8.4	8.3
	Min.	7.3	7.5	7.7	7.9	7.8
	Av.	7.6	7.8	7.9	8.1	8.1
3. Chlorine demand mg/lit.	Max.	0.80	0.90	0.60	0.50	0.40
	Min.	0.50	0.50	0.50	0.40	0.30
	Av.	0.60	0.60	0.55	0.45	0.35
4. MPN-index (B. coli in 100 ml)	Max.	350	750	350	110	50
	Min.	160	140	110	50	16
	Av.	160	175	160	90	25

lifting of sludge is liberation of oxygen by the algal in presence of sunlight and it was this oxygen, which gave buoyancy to the settled sludge. This problem has since been overcome, to a great extent, by desludging the coagulation tanks at short intervals of 45 days.

The species of algae observed in various units of the plant were: i) *Ulothrix* (Dominant species); ii) *Spirogyra;* iii) *Pandorina;* iv) *Navicula;* v) *Ceratium;* vi) *Anabena;* vii) *Zygnema;* viii) *Oscillatoria;* and ix) *Eudorina.*

The difficulty in settling still persists to some extent. At present, the average turbidity of raw water is 2.8 units and the optimum dose of alum applied is 12.8 mg/lit, which, however, cannot be considered as economic. The coagulant used is commercial aluminium sulphate. The alum solution is dosed through constant head feed-box. The solution carrying pipe is of 1 in dia and is of alkathene material. Air lift arrangement keeps the solution agitated to maintain uniform density. The alum solution is mixed with water by means of flash mixer. The alum treated water passes straight to sedimentation tanks through multiple submerged opening. For a discharge of 45,450 cu m/day, the detention period in settling tank works out to be four hr, one hr in the flocculating zone and three hr in the settling zone. With the augmented supply of a little over 52,320 cu m/day, the detention time is reduced to 3.5 hr and the surface loading goes up to 25,515 lit./sq m. With the constantly reducing turbidity of raw water, carry-over of floc still continues.

Occurrence of Millipede Larvae

A difficulty is also experienced due to growth of a certain organism in the raw water, first noticed towards the end of 1961. On microscopical examination, the organism was found to possess two pairs of legs in each segment, except the first three segments in which only one pair was seen. The organism was identified as larva of millipede. The classification is as under:

i) Phylum .. *Arthropoda*
ii) Class .. *Myriapoda*
iii) Specimen .. Millipede (Larva)

A large number of these larvae were found embedded in strong calcareous sheath and later could be noticed even in the pores of the filter strainers. On examination of the affected strainers, similar hard calcareous sheaths were noticed. These deposits had partially cut off the pore area, resulting in uneven distribution of back-wash water and affecting the free flow of filtrate. Presumably, this was one of the factors causing pressure differential leading to shrinkage and cracking of the sand bed.

Obviously the growth of larvae occurred at the source itself but its exact cause is still not properly understood. The laboratory observations have revealed that these larvae are sensitive to sunlight, smooth surfaces and chlorine. The following control measures have since been adopted:

i) Periodical dredging of bottom sediments collecting in the raw water channel;

ii Pre-chlorination of raw water; and

iii) Provision of suitable screens to keep out the larvae from the raw water entering the chemical house.

Problems for Filtration

The influent to the filters has a turbidity of 1.3 to 1.8 units and chlorine demand round about 0.25 to 0.3 mg/lit., with practically no colour and odour. The filter boxes are 4 m×4 m in size each and are open to sky. The filters were designed to operate at the rate of 4,860 lit./sq m/hr. The under-drainage is of false bottom type with perforated china clay strainers. Two semicircular steel gutters of 600 mm dia, drain the high-rate back-wash water which spills in uniformly over the fine level edges. The invert of the receiving trough is kept 100 mm below the invert of the wash water troughs to allow easy drain off. The filter boxes are equipped with the standard accessories such as flow-raters, loss of head gauges, etc. The effluent pipe of 150 mm dia is provided with a test cock to permit occasional sampling of filtrate for analysis. The filter to waste connection is 75 mm in size. Filter media consists of 800 mm deep bed of analysed sand, having Effective Size of 0.45 to 0.55 mm and Uniformity Coefficient of 1.5 to 1.6, with 200 mm depth of graded gravel, in smooth and rounded form. Both sand and gravel are locally available. The clearance between the filter bed and the trough provides adequate space for sand expansion during back-wash.

Besides the problems arising in the course of pre-treatment and also due to growth of organisms, certain operating difficulties were experienced. The filters were observed to be getting air-bound after 6 to 8 hours run. This was eliminated by inserting a goose neck in the effluent pipe to provide water-seal against air entering the filter. As a further safeguard, a dwarf wall was constructed in the effluent collecting conduit to submerge the ends of filtrate delivery pipes.

To ensure longer filter runs, the algal growths are kept at their minimum by periodically scraping and cleaning the sides of the filter boxes and treating them with lime and copper sulphate.

The filters were operated at an average rate of 4,860 lit/sq m/hr when 31,820 cu m water was treated per day. Now that the demand has gone up a little over 52,320 cu m/day, the existing filters have got to be operated at higher rate which means 8,019 lit./sq m/hr. Since it is not practicable to expect a uniform discharge at this rate all the time, coarser sand (E.S., 0.60-0.65 mm and U.C. 1.3-1.4) has been used recently. This change enabled to obtain a discharge of about 9,720 lit./sq m/hr, without affecting the quality of the filtrate which, as usual, remains sparkling clear without any colour or odour and having very low chlorine demand. Visible organisms and suspended matters are totally absent. The quantity of wash water required for each filter is nearly 114 cu m which works out to about 2.5 per cent.

Quality of the water at different stages of treatment is given in Table II.

Table II—Quality of Water at Different Stages of Treatment

(Average figures given)

Test	WATER SAMPLE			
	Raw	Coagulated and settled	Filtered	Cholorinated
1. Turbidity (unit)	2.8	1.2	0.4	0.4
2. *p*H value	8.1	7.3	7.2	7.2
3. Total hardness, as $CaCO_3$ in mg/lit.	39	42	42	42
4. Total alkalinity, as $CaCO_3$ in mg/lit.	50	44	44	43.5
5. Chlorine demand in mg/lit. (30 min contact)	0.35	0.25	0.15	—
6. Oxygen consumed from acid permanganate, mg/lit.	1.25	0.85	0.55	0.44
7. M. P. N. index (B. coli/100 ml)	25	16	9	nil
8. Total count on nutrient agar plate at 37°C in 24 hours (per ml)	60	20	7	3

Industrial Water

The lake which serves as a source of drinking water supply also supplies the industrial water through another reservoir which is at a fairly lower level. The industrial reservoir is of the cooling and recirculating type with a baffle bund separating the supply outlet to the Steel Works and inlet for the return water. The temperature of the return water remains at average 4°C above that of the water supplied to the Plant. The reservoir is about 4 m deep and has an expanse of 2.1 sq km and a capacity of 8.4 mill cu m. The quantity of water circulating per hour through various shops and mills of the Plant is 41,000 cu m. This figure is likely to go up to 78,000 cu m for 2.5 million ton capacity plant, i.e., after expansion.

Temperature and depth conditions obtaining in the reservoir are ideally suited to aquatic growth. The enormous growth of marginal and emergent vegetations is posing a serious operation difficulty. The weeds dominating this water are *Elodea* and *Potamogeton*. Among the algae, *Chara* is the main species. The possibility of applying copper sulphate is ruled out as its presence, even in traces tends to hamper the industrial processes. The water entering the works is given a chlorine dose to prevent slime growths in the industrial structures. However, the control of weeds in the reservoir remains problematic for want of practicable methods. Attempt is being made to secure an appropriate mechanical dredger for weed removal and also to try some safe and economical weedicides for prevention of aquatic growths in the reservoir.

Conclusion

The paucity of trained personnel to run the plants and the laboratories proves to be a great handicap in the present day water supply and treatment industry. Every such industry will have its own problems depending on the characteristics of its raw water, the design of its plant and operating practices in vogue. Problems will go on changing in their character and intensity. Solutions may not necessarily come forth purely on local efforts. A team approach and free exchange of ideas will help to a great extent. It is therefore necessary to approach these problems in a proper perspective.

DISCUSSION

SHRI T. P. SHARMA (Bhopal): The real problem in water treatment at Bhilai is about the quality of raw water and the reduction of its turbidity. The maximum turbidiy of raw water was shown as 400 mg/lit. in 1959 and 3.6 mg/lit. in 1964 and this sudden drop in the amount of turbidity is unimaginable. Turbidities do vary during the seasons of a year but so much variation, nearly 100 times, in two years indicates some mistake in the observation. This low turbidity water is bound to create problem in further reduction of turbidity to 0.4 mg/lit. as claimed by the author unless some special precautions are taken. What is actually done has not been said by the author.

Again the coliform MPN is shown to vary from 350 in 1959 to 50 in 1964 in raw water. This is also not explained but it may be possible by better pollution control and management of the source of raw water.

The design of filters for a rate of 100 gal/sq ft/hr for this low turbidity water is not justified in the paper. This filter should have been easily tried for more load without changing the size of the filter media which is bound to affect the quality of effluent, although the same is denied.

The real problem is probably to justify the design of the plant in the light of the real quality of raw water which came to be known only after the plant was constructed and commissioned

SHRI C. B. KHARKAR: There are no mistakes in observations. Fortunately we have a most modern hydrological observation centre. I admit that we had not anticipated that the turbidity of raw water would go down so much over the years. However, the basic design of the plant should not bave been very much altered. Our problems are about the colloidal turbidity and algal growth due to extreme clarity of water.

Perhaps coagulant aids may prove helpful to us. The sudden reduction of turbidity and the coliform MPN in the raw water may be due to longer detention time in the reservoir.

As for higher loading on the filters, I have already pointed out that the filters are run at 8019 lit./sq m/hr.

SHRI D. A. NAIR (Ranchi): The author says that the raw water has a low turbidity now and that the turbidity got reduced from 400 mg/lit. to a single digit figure during a period of four years. This is evidently because the water in the impounding reservoir has been cleared of suspended solids due to settlement during these years.

In all waterworks, where the source of supply is an impounded reservoir, pre-settling will take place and hence the turbidity of raw water will be low. While designing the treatment plant in such cases, we should take into account the possible low turbidity and design the clarifier accordingly either by the use of coagulant aids or otherwise.

At Palghat in Kerala, the raw water is drawn from an impounded reservoir and we anticipated a low turbidity water. Therefore the conventional coagulation was not found to be effective and an accelerator clarifer was installed. This installation includes returning a definite amount of sludge to the clarifier to form the nuclei for forming the flocs. I feel that such a system should have been installed in Bhilai for the clarification of water.

SHRI C. B. KHARKAR: Thank you for your comments. We anticipated clear water and the requirement of pre-chlorination was expected by us. However, the growth of organisms is rather characteristic for each and every place. Your suggestion regarding coagulant aid is a sound one.

SHRI R. C. P. CHOWDHARY (Baroda): The speaker pointed out that the turbidity and **B. coli** content of raw water are on the decrease since 1959. He should explain why it is so. Is it due to the construction of a reservoir of a long holding time? If so, it should be stated when the reservoir was commissioned.

SHRI C. B. KHARKAR: The reservoir has a capacity of 32 mill cu m and was commissioned six years back. The reduction in turbidity and **B. coli** content is due to long detention time. Further, the reservoir has a small catchment area of its own of only 9.1 sq km and most of the water is received from large irrigation lakes through canal system. The irrigation lakes are upstream of this impoundage.

SHRI O. K. SHARMA (Patiala): Has the direct feeding of low turbidity water on the filter been tried? If so, what are the results?

SHRI C. B. KHARKAR: No please. Thank you for kind suggestion and we will take notice of it.

DR. M. G. GEORGE (Delhi): The raw water had an average turbidity of 2.8 mg/lit. in 1963. According to accepted practice, the raw water with such low turbidity needs only chlorination.

SHRI J. S. JAIN (Nagpur): I would like to know the turbidity of raw water and the reduction of turbidity achieved after complete treatment.

The filtration rate of 200 gal/sq ft/hr is very high and probably this may be the reason for poor effluent.

It is not clear what difficulties the Bhilai treatment plant is facing and what remedial measures have been taken.

SHRI C. B. KHARKAR: The turbidity of raw water is about 3.2 mg/lit. and that of finished water, after complete treatment, is 0.4—0.6 mg/lit. The effluent having a turbidity of 0.4 mg/lit. can not be considered to be poor. The high filtration rate has been adopted in three filters on experimental basis and the results obtained are satisfactory till now.

The idea was not to project our problems but to indicate that whatever problems were faced by us have been over come with utmost care.

Our vigilant staff is alive to the problem and suitable remedial measures are applied. These may be clear, if the questioner takes the trouble of going through the full text of our paper.

SHRI A. G. PANDIT (Poona): It was mentioned that cleaning of coagulation tank is effected by discharging water under gravity. This would mean that a substantial quantity of water may be wasted along with the sludge. I wish to ask whether mechanical cleaning of sludge will be more economical than wasting water for this purpose.

SHRI C. B. KHARKAR: Even in the case of mechanical cleaning and desludging, there is certain amount of water loss. Perhaps this loss may be less than that involved in our method. However, we save considerably on electricity required for the operation and maintenance of the mechanical cleaning devices. These devices require skilled operation, spare parts, etc. You might be aware that many of our mechanical equipments bring in troubles very soon because of general unskilled operation. On the whole, the relative economics may prove favourable to us. For a poor country like ours it is always better to minimise the capital investment and avoid mechanisms that need skilled operation.

SHRI K. R. BULUSU: When the turbidity of the raw water is so low why should a large quantity of alum be used for the pre-treatment of water? Can the quantity of alum be reduced?

SHRI C. B. KHARKAR: I do not think that we are using huge quantities of alum because a dose of 12.8 mg/lit. is given at three units of turbidity. The dose is an optimum one, though not economical.

SHRI O. K. SHARMA: What is the type of bottom provided for the settling tank? During the days of low turbidity, what is frequency of sludge removal? I do no think that it could be the settled algae that give out oxygen and that this oxygen lifts up the sludge from the bottom. It may be due to the part of the unremoved sludge that putrifies.

SHRI C. B. KHARKAR: Our settling tank has got three compartments and is of straight flow type. A compartment can be put out of service for desludging and still we can maintain the normal supply. Low turbidity is the problem present through out the year. Previously, we were cleaning the tank once in 8 months and on practical experience, we are now desludging once in 45 days. The sludge accumulation is very little and hence the possibility of the role of oxygen was mentioned. However, the main cause may be due to the decomposition at bottom of the tank.

DR. M. G. GEORGE: The speaker, has mentioned that the probable reason for lifting of sludge is the liberation of oxygen by the algae in presence of sunlight. This explanation is not justified, since with 45 days desludging interval, there is accumulation of sludge at bottom and this would prevent photosynthesis at the bottom. The depth being about 15-20 ft. would certainly prevent light penertation and photosynthesis. It is mostly a bottom zone of decomposition and there is no possibility of liberation of oxygen.

DR. S. AHMED (Sindri) : Have there been studies made to find the effect of liberation of oxygen from water due to temperature on bringing the settled sludge in suspension?

SHRI A. P. TIWARI : The liberation of oxygen has been indicated by us only as a possibility that photosynthesis may have resulted this. However, we feel now that, the main cause of sludge lifting may be due to the decomposition at bottom.

DR. J. S. S. LAKSHMINARAYANA (Nagpur): What are the weedicides used and the methods emplyed in their application? I would also like to know the common weeds that occur in the reservoir at Bhilai.

What is the chlorine dose employed for pre-chlorination for the eradication of millipedes?

SHRI C. B. KHARKAR: The trial of some herbicides is on hand only for the past 20 days and it is too early to say anything on this point. However, we have taken up Gramoxone herbicide supplied by the I.C.I. We have selected a small ditch near our catch water drain. The capacity is about 5000 lit. and weeds growing therein are **Elodea, Vallisnaria** and **Chara. Vallisnaria** has more growth. Incidentally, the same types occur in our industrial pond except for another additional weed namely **Potamageton.** Dies up to 15 mg/lit. have not shown any satisfactory result. A dose of 20 mg/lit. seems to destroy the **Elodea.** There has not been any appreciable depletion in the dissolved oxygen content of the water and no harm is experienced by the fishes in the ditch.

We apply chlorine dose of 0.5 mg/lit. only. It may be stated that it is the periodical dredging of the channel that helps us more than chlorination regarding the eradication of millipedes.

SHRI K. R. BULUSU: Are the millipede larvae water habited? Can they not be chironomus? How is the algae problem solved in your lake?

SHRI C. B. KHARKER: These organisms live in the aquatic environment as long as they are in larval stage. As the development proceeds further towards the adult stage, they cease to inhabitate the water. After having attained the adult stage, they are terrestrial.

We have not solved the algal problem and are unable to use copper sulphate. We are investigating the possibility of applying other chemicals which may not have adverse effect on the industrial installations. However the intial measures taken were removal of the vegetation from the tank bed and avoidance of shallow water. These measures are helpful in keeping down the algal population.

DR. M. G. GEORGE: The speaker reported the occurrence of millipede larvae in the raw water and in different units of the plant. From the description of legs in different segments, the organism falls in the sub-phylum **Myriapode.** But the members of **Myriapoda** are terrestrial. The possibility of the millipedes thriving in a purely aquatic environment is doubtful. It would be essential to verify the identification.

DR. S. AHMED (Sindri): Why can not copper sulphate be used as an algicide?

SHRI A. P. TIWARI : The industrial water supply also draws water from the same reservoir. In the Steel Plant the power generation unit has a boiler water plant that does not tolerate the presence of copper sulphate in water, since even traces of copper will affect the performance of the unit. Moreover, the algal growth has never produced any nuisance in our reservoir. Further, we feel that by using chlorine instead of copper sulphate bacterial load is considerably reduced and also the dose of post-chlorination is economised.

SHRI P. L. NANJUNDASWAMY (Bangalore): The turbidity is due to organic and inorganic matter. The food available in the form of organic matter for the algae is very much less in low turbidity water. The only other aid for its growth is sun light. To reduce the algal growth, I wish to suggest addition of algicides at the intake, pre-chlorination and avoiding sun-light on the raw water flowing through channels and clarifiers. To improve coagulation, coagulant aids and increased rate of mixing of chemicals can be tried.

SHRI C. B. KHARKER: Avoiding sun light on the surface of clarifiers is too expensive because we have to cover it. We can not also cover the entire lake. Small channels are covered.

We practise pre-chlorination according to seasonal demands and coagulation aids might improve the present situation.

SHRI O. K. SHARMA: It was said that pre-chlorination was done when necessary. What is the particular parameter that indicates the necessity of chlorination? At what stage of the treatment was this parameter observed?

SHRI A. P. TIWARI: Our raw water is fairly clear and hence encourages photosynthesis due to the presence of algae from December to June. During this period, pre-chlorination is done at the raw water pump house. We do not wait till the algae grow in large population. We do this as a precautionary measure.

SHRI S. K. GAJENDRAGADKAR (Bombay): What are the doses of pre-chlorination and post-chlorination? To what extent does algal growth in raw water pose problem in water filtration? How is this problem tackled?

SHRI A. P. TIWARI : The dose of pre-chlorination is 0.56—0.7 mg/lit. and that of post-chlorination is 0.55 mg/lit.

The algal growth has not gone to the extent of causing any nuisance. Whatever growth occurs is counteracted by pre-chlorination. Our filters are open to atmosphere and we have got a strict schedule for filter operation and maintenance. Growth of algae and formation of slime on the wall are removed once in a week by scraping and cleaning well. Besides the walls, metallic parts like troughs, spindles, etc. are painted periodically.

SHRI A. D. PATWARDHAN (Bombay): If pre-chlorination is done, is it possible that the use of coarse sand in the filters has caused high MPN index in water after filtration? If so, the solution to this problem may be to expand the filtration plant, to use finer sand in the new and existing units and to increase the pre-chlorination dose.

What are the chlorine doses before and after filtration?

SHRI C. B. KHARKER: The chlorine doses before and after filtration are 0.4 and 0.3 mg/lit. respectively. The chlorine dose at consumer's end is 0.2 mg/lit.

As for MPN index of the pre-chlorinated water after filtration, I feel that it is due to bacterial load borne by algal population at the effluent end of the settling tank, in effluent channels, in filter boxes etc. where pre-chlorination has little or no effect.

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Supply and Treatment of Water at Sindri Fertilizer Factory

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Introduction

A general outline of the supply of water and its treatment for various purposes at Sindri has been discussed in the present paper. Sindri Fertilizers being the largest fertilizer factory in India, the consumption of water and its treatment procedure broadly represent the general modes of treatments required by any other chemical or fertilizer factory of similar magnitude.

The production of the different fertilizers at Sindri is as follows:

1) Ammonium Sulphate	...	1,000 tons per day
2) (Double Salt) (Ammonium Sulphate-Nitrate)	...	400 ,, ,, ,,
3) Urea	...	70 ,, ,, ,,

The major raw materials consumed in the process are:

1) Coal	...	2,000 tons per day
2) Gypsum	...	2,000 ,, ,, ,,

The principal by-products and waste products which require to be disposed of are:

1) Cinders and ash (carried outside for disposal)	...	600 tons per day
2) Chalk (sent to A.C.C. for manufacture of cement)	...	1,400 ,, ,, ,,

The above figures of production of different fertilizers, consumption of the raw materials and the magnitude of the waste products clearly indicate the vastness of the factory operations and consequent consumption of utilities of which water is the principal item. The total requirement of water for supplying the needs of the Factory as well as the Township is of the order of 15 mill gal/day. The entire quantity of the water is drawn from the Damodar river flowing by the side of Sindri.

From the time of planning of the Factory up to the present stage, the conditions of water supply and the consumption potential has undergone many changes due to modifications and expansion of the Factory and altered conditions of the river. In the initial stages, the Damodar was free flowing and the supply of surface water was not dependable throughout the year. Hence, arrangements were made for tapping water from below the river bed by constructing an infiltration gallery. A reserve emergency storage of water was also maintained by putting a barrage across Gowai Nala, a small tributary, meeting Damodar up-stream of Sindri. In later years, due to the construction of Panchet Dam, the water level of the Damodar at Sindri has been maintained and the usefulness of the Gowai barrage and the infiltration gallery practically disappeared. During this period, the consumption of water has also increased from 12 to 15 mill gal/day. Since the inception of this Factory, quite a large number of difficult problems had to be faced in various stages of supply and treatment of water at Sindri. Some of these difficulties were created by the changed condition of the river due to the construction of the Panchet Dam and some by the changed operating conditions due to expansion and modification of the Factory.

The supply of raw water to the Factory Township and the various treatment procedures normally being practised at Sindri are discussed below.

Raw Water Supply

Raw water to the extent of 15 mill gal/day is pumped from the Damodar by two pump-houses, one situated at Sindri river side about 2 miles down-stream of the Factory, and the other at Tasra about 1 1/2 miles up-stream of the former. From Sindri river side pump-house, water is pumped to a settling tank having a capacity of 90 mill gal. The river water gets about 10 days retention time in the sedimentation basin where coarse suspended particles are separated from water by plain sedimentation. The settling tank also serves the purposes of evening out the raw water fluctuations and as an emergency storage. The Tasra pump-house supplies raw water directly to the Factory for treatment.

Like all natural surface waters, this raw water also shows seasonal fluctuations in quality, as is seen from Table I. The raw water is treated for the purpose of supplying the needs of the Factory as well as the requirement of the Township. The supply of raw water and the different treatement procedures adopted for this are shown in **Fig. 1.** The total supply of potable water for the Township and the Factory constitute a large proportion of the raw water being of the order of 5 mill gal/day. The disposal system of ash, transportation of chalk, etc., in the Factory require smaller quantity of untreated raw water. The make-up water of the cooling towers and other processes require largest proportion of water in the form of process water amounting to 7 mill gal/day. The make-up water for the boilers, although not constituting a very large quantity, requires a special treatment.

Table I—Seasonal Fluctuation in Raw Water Quality

SEASON	SUMMER (April — June)	MONSOON (July — Sept.)
Hardness as $CaCO_3$		
Calcium	55 — 70	25 — 40
Magnesium	45 — 60	15 — 20
Total	100 — 130	40 — 60
Alkalinity as $CACO_3$		
Bicarbonate	95 — 125	45 — 60
Carbonate	Nil	Nil
Hydroxide	Nil	Nil
Total	95 — 125	45 — 60
Chloride as Cl'	10 — 12	4 — 8
Sulphate, as SO"	10 — 25	8 — 12
Silica, as SiO_2	10 — 15	7 — 12
Total dissolved solids	160 — 210	80 — 120
Turbidity	10 — 100	700 — 2,000
CO_2	1.5 — 2.5	3.0 — 4.5
Dissolved Oxygen	4.5 — 5.5	5.5 — 6.5
*p*H	7.5 — 8.2	7.0 — 7.5

Note: All values except *p*H are in mg/lit.

Treatment of Water

For Drinking : potable water at Sindri is supplied at the rate of 100 gal/capita/day, the total quantity being about 5 mill gal/day. The treatment plant consists of a battery of rectangular sedimentation tanks, continuous clarifiers, rapid gravity sand filters and chlorinators. The potable water treatment plant was constructed in two phases, each of 3 mill gal/day. The rectangular sedimentation tank of the older installation has been improved upon by putting up more scientific continuous clarifiers. For the clarification of the water, filter alum is used as a coagulant, the doses varying from 10 to 50 mg/lit., according to the nature of the raw water.

For Process Use : The requirement of water to make up the loss of water in the cooling towers and process use and also leakages, wastes etc., in the operating plants amounts to about 7 mill gal/day. As the water is required as a make-up for the cooling towers which supply cold conditioned water to the various heat exchanger systems of different plants, treatment of this water is of utmost importance. The broad treatment procedure is indicated in Fig. 1. The raw water available from the river normally requires no treatment other than clarification during the monsoon period. In other seasons, when the hardness increased, a nominal treatment by lime along with clarification suffices. For the clarification of the raw

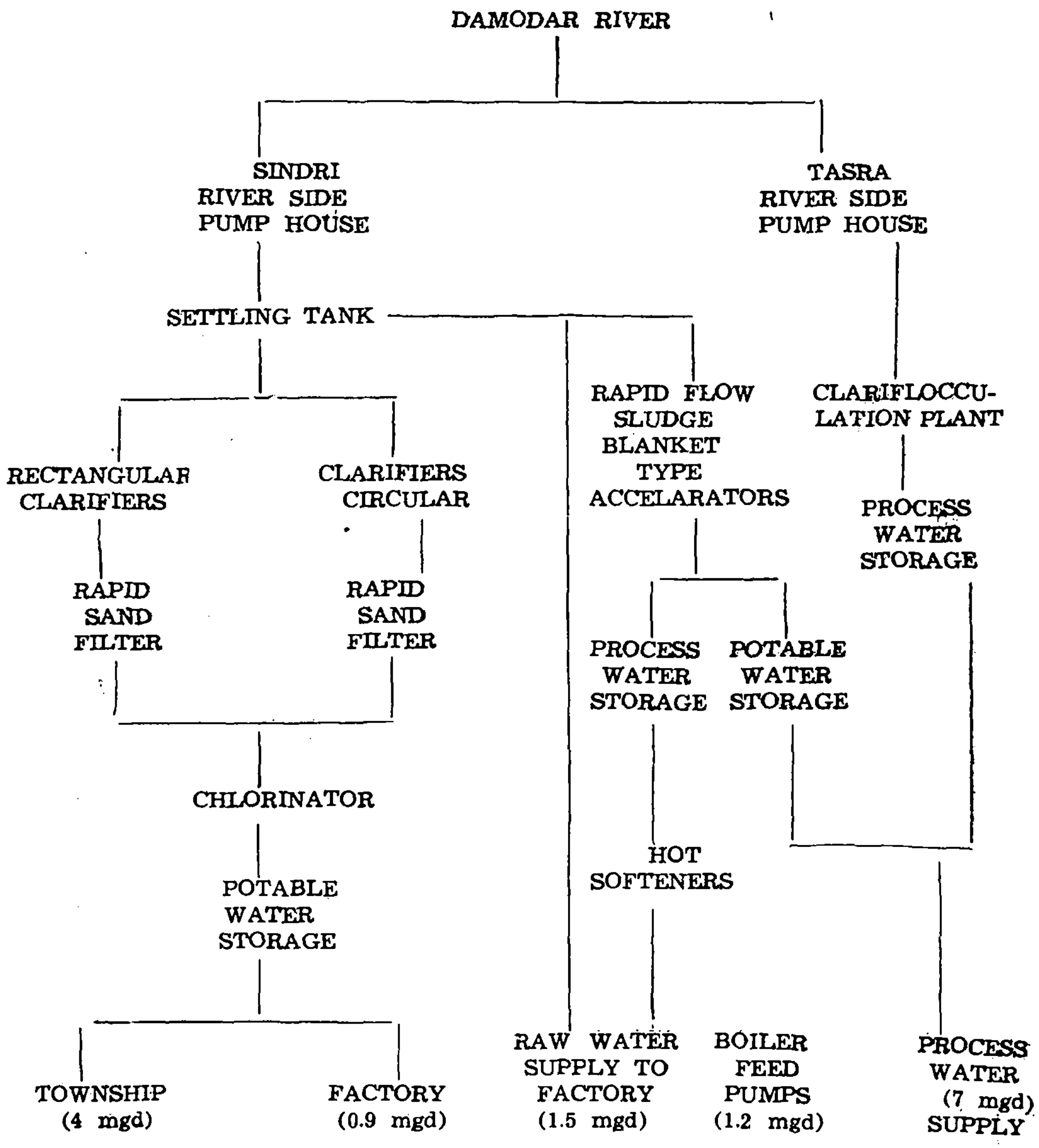

FIG. 1—FLOW DIAGRAM FOR SINDRI WATER SUPPLY & TREATMENT

water, one concentric type clariflocculator has been provided. The coagulant used is mainly filter alum with occasional use of sodium aluminate and, for partial softening as well as for pH correction, lime is used. In this process, the raw river water is mixed with the chemicals in a flash mixer and then fed into the flocculation chamber, a small amount of sludge is also recirculated. From the flocculation chamber, it passes into the settling basin and clear water is collected from the overflow channels. The flocculation period is about 40 min. and sedimentation period is about 2 hr. The capacity of this clariflocculator is about 5.5 mill gal/day.

In addition to this clariflocculator, there are three rapid flow sludge blanket type accelerators for the treatment of process water. Two accelerators were installed in the earlier stages of the Factory for the treatment of the entire quantity of water required for process purposes. A part of this water was also meant for further treatment for use in the boilers. It was observed that the actual capacity for treatment in these accelerators is much lower than that stipulated by the suppliers, particularly during the monsoon months when the turbidity is very high. As a result, one more accelerator was installed.

The function of rapid flow sludge blanket type accelerators is to reduce the hardness of the raw water and also to provide a stable clear water for process use. As the name implies, the water passes through a blanket of sludge formed in the process before entering the settling compartment. Raw water is fed into the reaction chamber built concentric to the accelerator along with lime and sodium aluminate or ferrous sulphate according to the nature of the water. The water passing out of the mixing chamber flows upward through a blanket of suspended sludge formed during the process in the lower part of the settling chamber. The blanket of sludge is maintained by the regulation of the chemical designs, water flow adjustment and sludge discharge. The clear water flowing out is taken to a storage chamber. A part of this is used for further treatment for use in the boilers. Another part is used for process purpose after correction of the pH by acid dosing. The designed capacity of each of these accelerators when installed was about 4 mill gal/day, but in actual operation a maximum of 2.5 mill gal/day was achieved. Since the total requirement of process water is at present mostly met from the clariflocculators, normally one or at most two accelerators are put into operation mainly for supplying water for boiler feed water treatment. Small amount of this water is also used to make up the deficit of the process water from clariflocculators.

In both the systems of treatment of process water, viz., clariflocculator and rapid flow accelerators, only turbidity is removed during monsoon period as the hardness is normally quite low. During the dry months, when the turbidity of raw water is very low, these are used as cold lime softeners. The analyses of the treated water from both the systems at different seasons are shown in Table II. A sufficient storage is provided for this treated process water in a

TABLE II—Analysis of Treated Waters

Point of Collection	Rapid Flow Accelerator Outlet		Clariflocculator outlet	
PERIOD	SUMMER	MONSOON	SUMMER	MONSOON
Total Hardness as $CaCO_3$	50-70	50-70	60-80	55-75
Alkalinity as $CaCO_3$				
Bicarbonate	5-10	Nil	Nil	50-70
Carbonate	50-65	30-40	40-60	Nil
Hydroxide	Nil	10-20	5-10	Nil
Total	55-75	40-60	45-70	50-70
Chloride, as Cl'	8-12	4-8	8-12	4-8
Sulphate as SO''_4	10-25	20-30	15-30	20-30
Silica as SiO_2	10-14	7-10	10-14	6-9
Total dissolved solids	110-145	105-145	125-185	110-150
Turbidity	6-15	7-20	6-15	10-20
*p*H	9.0.-10.0	10.0-10.5	8.8-9.5	7.5-8.0

Note: All values except *p*H are in mg/lit.

storage reservoir from where this water is supplied to different consuming units. In some of the consuming centres, some special treatments are given for the control of growth of algae, bacteria, etc., in the cooling towers and to neutralise the effects of chemical contaminations.

For Use in the Boillers : The Sindri Power House supplies the necessary power for running the Factory and also meets the huge demand of process steam, required in the process of manufacture of fertilizers. The boilers supplying the steam for the above purpose operate at 650 lb/sq less in and normally require 2.4 mill gal of boiler feed water per day. Since nearly 50 per cent of the steam is used for process purpose which is not returned to the boilers as condensate, the requirement of the boiler feed make-up water is about 1.2 mill gal/day. The treatment of water for boiler feed purpose was designed nearly 15 years back when the Factory was planned and is the old conventional hot lime-soda process. In this process, the clarified and partially cold softened water from the rapid flow accelerators is fed into top of the hot softener along with chemicals like lime, soda ash and magnesia. Low pressure steam fed into the softener heats up the incoming water and scrubs out the dissolved gases like oxygen, carbon dioxide, etc. The sludge settles at the bottom and the supernatant deaerated water is further filtered out in a battery of pressure filters before being fed to the boiler feed pumps. The condensate from the turbine condensers of the Power Plant are also deaerated with live steam and mixed this water at the inlet of the boiler feed pump. Suitable dosage of sodium sulphate and phosphate are made in order to maintain the correct level of sulphite and phosphate in the boiler water. The principle of this hot process softening is to reduce the hardness and silica content of water and to eliminate the dissolved oxygen. The requirement of steam for this process is met partially from the steam recovery system of the boiler blow-down. Typical analyses of the hot softened water, boiler feed water and the boiler water are shown in Table III.

There are three hot softeners integrated with a battery of filters, each having a treatment capacity of 250,000 lb/hr. Normally, two softeneres are in operation.

The general modes of treatment for potable or drinking water, process water and boiler feed water have been discussed above. During the operation of these processes a number of difficulties have been encountered at times and suitable measures to overcome these were evolved and adopted.

The raw water supply from the river was some times found to contain a large amount of coal and ash particles which created difficulties in the clarification and softening processes. Presence of alga in the river water particularly in the hot summer months, was responsible for the growth of alga in the settling tanks hindering the operation of the clarifiers and sand filters. This growth of alga was controlled with regulated and controlled doses of copper

Table III—Analysis of processed waters

Nature of Sample	Softener Outlet Water	Boiler Feed Water	Boiler Water
Total Hardness, as $CaCO_3$	15-20	7-10	...
Alkalinity as $CaCO_3$			
Bicarbonate	Nil	0- 5	Nil
Carbonate	35-45	25-35	130-250
Hydroxide	5-10	0- 5	170-250
Total	40-55	25-40	300-500
Chloride, As Cl	4-10	3- 6	40-70
Sulphate, as SO_4	10-25	6-15	250-350
Na_2SO	...	2- 4	25-45
Phosphate, as PO_4	...	...	25-250
Silica, as SiO_2	2-3	1- 2	15-25
Total dissolved solids	90-130	50-80	1000-1300
Dissolved oxygen	0.01-0.05	< 0.005	Nil
H	10.2-10.5	9.5-10.0	11.2-11.6

Note: All values except pH are in mg/lit.p

sulphate in the reservoir after thorough investigation of the nature and habitat of these species.

The cold softening operation was affected on certain occasions by the presence of organic contaminants like phosphates, anmonia, etc., in the raw water supply. Some of these were derived from the contamination of the raw water supply line by the factory effluents. These difficulties were overcome by realing the effluent lines and special treatment procedures wherever required.

The various treatments mentioned above are by no means the ideal procedure to be adopted as lot of modifications require to be done in order to obtain more efficient and economical treatment. Such modifications, starting from the supply of water from the river to the final treatment, are being studied thoroughly with particular reference to the nature of water available at different parts of India, where fertilizer factories are going to be installed, in the near future.

Acknowledgements

The authors are grateful to Dr. K. R. Chakraborty, General Manager, Planning & Development Division, F.C.I. Sindri, for his keen interest and encouragement during the investigation.

DISCUSSION

SHRI D. B. WILLETS (Calcutta): The value of 100 gal/capita/day was used by the author. Is this a measure of domestic consumption or industrial use?

SHRI G. S. ROY: It is the domestic consumption.

DR. J. S. S. LAKSHMINARAYANA (Nagpur): Do you have any algal problem in your water treatment plant? If so, what measures do you employ to eradicate these?

SHRI G. S. ROY: In our waterworks, we had faced algal problem only in the pre-monsoon summer months i.e. April-June. In the settling tank, there was algal growth mostly of filamentous type. The predominant species are **Oscillatoria, Spirogyra**, very little **Anabaena** and some diatoms. There was trouble in sand filters also. We used copper sulphate dosing 0.3-1-5 mg/lit. depending on the alkalinity of water. The algal trouble was eliminated.

DR. J. S. S. LAKSHMINARAYANA: Is there any connection between the practice of adding lime for pH adjustment and biological growths in the water treatment plant?

SHRI G. S. ROY: In our industrial water treatement there was no particular algal trouble, as the pH in our treatment plant is not inducive for algal growth.

Proc. Symp. Problems in Water Treatment
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Control of Water Treatment

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Introduction

Having spent a good deal of money to build a first class water treatment plant, it behoves the engineering personnel to know the large number of factors that affect its efficiency of performance. A water treatment plant is as sensitive as any processing plant can be and will respond to the care and attention bestowed on it, rewarding the intelligent and careful operator with a quality product.

It has amused the author to meet operators who felt that their duty had been well done if their usual daily chores had been performed such as back-washing the filters, checking the alum dosage tanks, making sure that chlorination was in progress, keeping the pumps running, and so on. Many of these operators were satisfied, as long as their plant was running in the physical sense. Unfortunately, it was not understood that merely running a plant was not the same thing as running it well. If one asked some of these operators how they checked the filtrate turbidity, they promptly replied that the final turbidity was 'zero'; and if pressed further to say how they measured it, some dilapidated rod or some such thing was produced from the store-room! The fact that the instrument was not sensitive enough to read low turbidities had not occurred to them

Similarly, the fact that alum was added was enough to some people; the ritual had been performed. Whether or not this gave good floc was of little consequence to anybody. Besides, some operators had not even heard of "floc-breakthrough," let alone knowing how to measure it. In one case, the operator boasted that his filters did not need back-washing earlier than every 5 to 6 days. He was not aware that for a variety of reasons his coagulation was extremely poor and that colloidal as well as flocculated turbidity was breaking through the filters.

Of course, it must be said in fairness to all, that there are some really good and sincere operators trying to do good job and one is heartened when one meets this rare species, but anyone will agree that we have a long way to go as yet. We have learnt how to build plants, but we have not yet learnt how to control their operation. In these days, when good operators are difficult to get, one wonders if a certain degree of automation may be beneficial in the water industry.

Baylis, the famous Engineer in charge of one of the World's best run plants states that "water that will just pass the water Standards should not be considered even a rough indication of good filtration plant operation"[1]. Several authorities have suggested that much greater refinement of filter performance is needed, particularly in regard to turbidity of the filtered water which, it is suggested, should average more than 0.2 units for various reasons enumerated by the author in another Paper[2].

Pre-treatment of Waters

It can be seen in quite a few of our existing water treatment plants that the treatment of water prior to filtration has degenerated into something like a ritual of merely adding some alum and passing the water through a set of tanks. This is not intelligent operation. The fact that a jar test is occasionally performed, does not mean that everything possible has been done.

There are so many, many factors which affect the performance that one must take an overall view. The chart gives an idea of the various factors involved. In case of poor performance, it would help the engineer in the diagnosis of the "illness" so as to help him find the correct remedy.

An aspect which is not very clearly appreciated by all is that, for a given quality of water, the alum dose required depends on how efficient the mixing, flocculation and sedimentation units are. Often the permissible effluent turbidity in settled water going to the filters is specified. But the question is, at what cost is this result going to be achieved? An efficient set-up will consume less alum than a relatively inefficient set-up to give the same final clarity. Unwise saving in Capital cost can be more than offset by substantially increased running costs in chemicals, power, etc. These are 'hidden' costs which do not show up easily when considering alternative proposals for new plants.

The fact that enough attention is not being given to all aspects of the problem of pre-treatment can be judged from the fact that in India alum only is used, without any attention being given to the use of iron salts and hardly exhibiting even an academic interest in the use of coagulant aids. Activated sillica, for instance, has been used in the West since 1935, but not even in one plant in this Country. Same is the case with other chemicals, with dry-feeding, with different types of flocculation devices, with two-storied tanks, and many other innovations waiting to be tried out.

When tenders are invited, the equipment suppliers can hardly be expected to suggest new alternatives and innovations without being demanded. The tenderer finds it advisable to keep conventional because that tender which is the lowest and conventional will be most likely to be chosen in favour of that which is low by virtue of a new or untried (untried in India) device. Generally, plants are not designed but tenders are invited thinking that all's well since the specifications tie down the tenderer. This stultifies progress rather than encouraging it.

As some one has said: "Just as a good Doctor can not practice by merely prescribing patent medicines, so also a good public health engineer can not practice by merely studying the catalogues of equipment manufacturing companies and abdicating all his thinking powers to them."

Nature of Turbidity and its Measurement

It is generally not differentiated that the turbidity in a filter effluent can be of two types:

i) Colloidal turbidity; and

ii) Flocculated turbidity.

Each type has its own causes of occurrence and the remedy for each type is also different. It would, therefore, be of great advantage to an intelligent operator to know what type of turbidity, if any, he is getting in his filtrate and then apply the remedy accordingly.

Colloidal Turbidity : This is caused by very finely divided silt, clay or other inorganic or organic substances, iron and manganese compounds, micro-organisms, etc. Such turbidity can occur in the filter effluent if flocculation is insufficient so that unfloculated matter passes through the sedimentation and filtration units.

The presence of this kind of colloidal matter has the effect of diminishing the penetration of light by scattering and absorbing it rather than allowing it to be transmitted in straight lines.

For turbidities less than 5 units, measurement of *scattered* light rather than *transmitted* light is preferred. The Baylis and St. Louis Turbidimeters and some commercially available photoelectric instruments such as the Hellige turbidimeter work on this principle. They can detect as low as 0.1 to 0.05 units of turbidity.

When recording turbidities less than 5 units, one has to be careful not only in the technique but also in the choice of the instrument. Each instrument has its range of accuracy and if low values of turbidity are beyond this range, the operator will always record "zero" turbidity when in reality it may be anything up to a few units. For instance, the well-known Jackson Candle Turbidimeter has a lower limit of turbidity measurement of 25 units and some other instruments can never be used with waters of less than 50 to 100 units.

The next question is 'how often should turbidity be measured ?' The answer lies in the knowledge that as a filter gets progressively dirtier, the materials accumulated in it penetrate deeper and deeper until a "break-through" occurs. Break-through is almost always accompanied by sharp deterioration in the quality of the filtrate. Badly maintained filters may exhibit a "break-through" very soon after back-washing. The unfortunate part is that no one knows *when exactly the break through will occur.* Occasional testing of turbidity is, therefore, not the answer. To be really effective, filtrate turbidity should be recorded continuously on a continuous-recording instrument. Such instruments are not difficult to make. They can be easily made in India, if only the demand for them is created.

Floccmlated Turbidity : This type of turbidity in filter effluent is due to weakly-bound floc. It is very high in water content and, therefore, does not impede transmission of light in the usual turbidimetric determinations. Such turbidity can, however, be seen by **reflected** light as in the Baylis Floc detector, or in a clear well illuminated by side lighting, or by the Baylis type cotton plug filter.

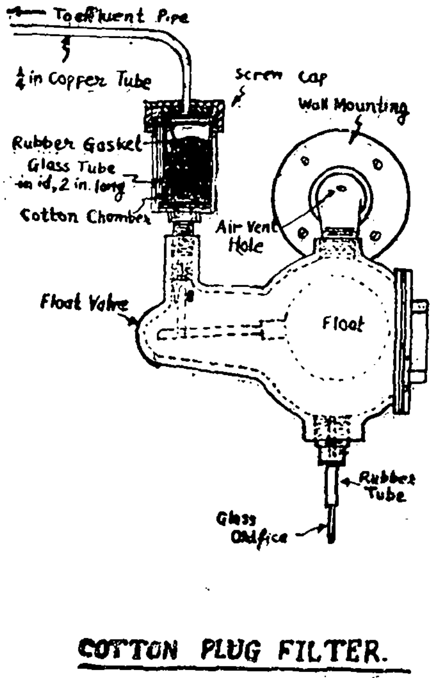

Fig. 1— Cotton plug filter

The cotton plug filter is considered to be very sensitive. (See Fig. 1) The method is based on the effectiveness of absorbent cotton in filtering out any coagulated material. The cotton plug filter is attached to the sand filter and kept running continuously at a flow rate of approximately 100 ml per minute. Material is allowed to accumulate in the cotton plug until visual observation shows that there is enough to be weighed after burning the cotton to ash in a muffle furnace. Sometimes in the case of very well run filters, a few days may be required to accumulate enough materials. Cotton plug filters can be accurate to a floc volume of 0.1.

Coagulated material or floc passing out of a sand filter would otherwise be difficult to detect in the usual type of optical turbidimeters.

High-rate Filtration

It will thus be seen that without proper instrumentation, one could hardly blame the operator for not controlling the operation of the plant as intelligently as one would like. After all, since the filter plants are designed for conventional rates of filtration (80 to 100 gal/hr/sq ft), there is no reason for not getting anything but the most excellent effluents. Unless one insists on the best, neither the operators, nor the equipment manufacturers will give better value for money spent.

One hears a lot of talk these days about high-rate filtration. But, it must be remembered that, in high-rate filtration, the danger of early floc break-through is increased, and how is one going to control such plants unless simultaneously the most sensitive continuous recording devices are installed? Back-washing of high-rate filters, or for that matter, any type of fiilter, should be done **before** floc break-through occurs, and not necessarily when a certain value of loss of head is reached. The latter method is only a 'rule of thumb' method. The more one increases the filtration rate, the more sensitive filters become and then rules of thumb are not enough. Merely increasing the filtration rate without taking the attendant precautions can be very much fraught with danger.

Conclusion

The proper operation of a modern water treatment plant needs control of several different factors, each having a definite effect on the chemicals consumed and the final filtrate quality. A plant can be really well-run only if it has (a) an intelligent operator, (b) adequate instrumentation, and (c) an inherently good design. Current practice in India is not conducive to encouragement of variety and innovation in design, with the result that emphasis has been on conventionality and standardisation.

A chart has been appended which summarises the effect of various factors of design and operation on final quality, and performance. It is hoped it will be found useful by all concerned.

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DISCUSSION

SHRI S. N. TRIPATHI (Bareilly): Bareilly Waterworks is designed as zonal system with deep tube well as source of water supply. Chlorination is done in the rising mains under pressure and the supply is distributed from overhead balancing tanks. Raw water is quite clear, potable and bacteriologically pure. pH is between 7—7.5 and carbon dioxide is present in water. Chlorides are within the permissible limits. The combined iron and manganese content varies from 0.1 to 0.5 mg/lit., when samples were taken at different times. The solution tower of the chlorination plant gets clogged with dark brown precipitate. Walls of the overhead tanks are also coated with dark brown material. Dark brown precipitate settles down in the mains and when the lines are washed, dark brownish water discharges from the scour outlets. The water meters also get jammed because of this deposit quite often. Even a high dose of 1 mg/lit. chlorine often does not provide any residual chlorine at the farther ends. About 0.1 to 0.5 mg/lit. of chlorine is consumed at the pumping station itself and a sample which may have 0.5 mg/lit. of chlorine at the time of sampling may not have been left with any residual chlorine after about 24 hours.

What method of iron and manganese removal will be advisable and economical for this problem ? Very little space is available at the existing pumping station and because of this fact, aeration coupled with lime treatment, sedimentation and filtration is not possible to adopt. Normally 40,000 to 65,000 gal/hr of water is to be treated at each station.

PROF. S. J. ARCEIVALA : This is very interesing question about iron and manganese trouble in Bareilly water supply. Although raw water is clear and transparent, dark brown precipitates are found in storage tower, supply lines, etc. This is due to the fact that iron and manganese tend to remain in the soluble form (Fe^{++} and Mn^{++}) underground in the absence of oxygen. As the water is pumped up and needs air or oxygen, the soluble forms get oxidised and become insoluble (Fe^{+++} and Mn^{+++}) thus giving the precipitates. Dark brown stains reported seem to indicate manganese trouble. Manganese is slower to precipitate and more difficult to treat than iron. Chlorine residuals will not persist in such waters, as reported, because chlorine is also an oxidising agent and slowly goes on converting the soluble Fe and Mn to insoluble forms as explained above. Bearing in mind that space is restricted, the following alternatives may be considered.

i) Use a sequestering chemical like Sodium Hexametaphosphate to prevent the precipitation of Fe and Mn while the water passes through the distribution system. It could be dosed as the water is pumped up to the tower (i.e. before any natural exposure to air takes place). As a rough guide, the dose may be taken as twice the content of Fe and Mn for calculating the economic aspect of this alternative.

ii) Increase the chlorine dose to oxidise all Fe and Mn. Apparently the present dose has been set more from the point of view of normal disinfection rather than oxidation of Fe^{++} and Mn^{++}. Manganese is oxidised by free residual chlorine but the reaction rate is slow unless pH exceeds 8.5 to 10.0. Chlorine dose has to be about 1.25 mg/lit. for each mg/lit. of Fe and Mn. Oxidation is aided sometimes by the use of 0.2 mg/lit. of copper sulphate, the copper acting as a catalytic agent. It is good that in this plant, chlorination is done before the water goes to the tower. This gives contact time.

iii) Perhaps the best solution will be to try feeding some potassium permanganate which is of late much favoured for oxidising Mn^{++} and Fe^{++} in water, in the form of a 2% solution to the chlorinated water falling into the tower. Dose required will be 1 mg/lit. for each mg/lit. of iron and 2 mg/lit. for each mg/lit. of manganese. Reaction is quick, taking only 5 to 10 minutes. Please note that for both (ii) and (iii) above, pre-aeration will help to reduce the dose. If pre-aeration is contemplated, let it be of the perforated tray type because of the presence of Mn. It will be best to try all the above suggestions on a laboratory scale to find which will be the most effective and economical solution. Let me know if I can be of any further help.

DR. N. U. RAO (Nagpur) : You have stated that zeta potential is the charge on the colloidal particles which keeps them in suspension.

I request you to clarify. How can a potential be a charge ? I am under the impression that a potential is a difference in charges ? How can the zeta potential be neutralised ?

PROF. S. J. ARCEIVALA : No doubt a potential is a difference between two charges. Zeta potential is actually a function of the charge difference between the particle and the body of the solution, at the surface which separates the immobile part from the diffuse part. Its ordinates are so chosen, by definition, that zeta potential is a simultaneous measure of the charge and of its extent from the colloid surface to the point of electroneutrality (zero charge). That is why the difference of charge between the particle and the body of the solution becomes numerically equal to the charge on the particle.

The distance over which this zeta potential extends (namely the ionic atmosphere of the diffuse layer surrounding each particle) expands or contracts as the salt content of a solution is decreased or increased. Increasing the ion concentration, (by alum, etc.) causes a contraction of the diffuse part of the double layer surrounding the colloid. As more ions are added, the zeta potential reduces until a point is reached when Van der Waal's attractive forces are greater than the repulsive forces of the potential. Coagulation then takes place.

DR. W. M. DESHPANDE (Nagpur): Will the knowledge of zeta potential ever lead as to find out the optimum dose of coagulant? If not, why should we rely upon zeta potential instead of the jar testing experiments ?

PROF. S. J. ARCEIVALA: The jar test is no doubt useful because it is a visual observation of the optimum dose under given conditions. The Chart in the paper also states that the optimum dose is to be determined by the jar test.

Zeta potential determinations have a value at present in research work—a far more precise tool than the jar test to study the mechanism of coagulation. All the same, there are one or two plants in USA where zeta potential determinations are done to fix the alum dose for a highly coloured water, and, perhaps some day, it will be used in more plants. But for regular usage the jar test is not likely to be displaced for a long time to come.

SHRI J. S. JAIN (Nagpur): The author mentioned a firm in Bombay which deals with polyelectrolytes as coagulant aid. Kindly let me know the name of that firm.

I would like to know the cost of bentonites as compared to that of lime-stone in its use as coagulant. Is the price of bentonite in India favourable to use bentonite here ?

Is there any plant in India where zeta potential is being controlled in water treatment ?

PROF. S. J. ARCEIVALA: The name of the firm is **Indian Gum Industries Ltd.**, 32, Nicol Road, Bombay-1.

Bentonites are available in India. Relative economy compared to limestone will depend on dosage required for the given type of water.

There are no plants in India where zeta potential is being determined in daily operational work. How can plants do it when a well staffed research Institute like CPHERI has not yet done it ? The jar test is good enough for plant operation.

SHRI K. R. BULUSU (Delhi): You have mentioned about the jar tests. You have observed a striking difference in the residual turbidity in the settled effluent when alum was added at the surface and bottom. For example, the raw water turbidity was in the range of 500—2500 mg/lit.

When the same alum dose was added both at top and bottom of the water in the jar, the turbidities in the settled effluent were 9 and 70 mg/lit. respectively.

I shall be glad to know the position of addition of alum in your jar test and whether this aspect was considered in arriving at the factor.

PROF. S. J. ARCEIVALA: I have been very much interested to read about the difference in the efficacy of alum when added to the top surface and to the bottom. After discussing with you, we have also been trying out in Bombay and are experiencing the same striking difference. We have no explanation for this yet.

SHRI K. R. BULUSU : It has been mentioned that for removing iron from water, it is necessary to raise the pH to 9.6 or above. As you are aware that iron is kept in solution in sub-soil water in Fe + + state by excessive quantities of carbonic acid and if this is removed by suitable aeration, iron would be precipated and can be removed either by sedimentation or filtration or both. If so, why is it necessary to raise the pH to 9.6 or above ?

It was also mentioned that the variation in the quantity of alum required was due to the clay particles from black cotton soil by virtue of their ion-exchange capacity. I may add in this connection that the ion-exchange capacity of the particles will be already satisfied by the mono, di-, and tri valent cations in the water in which the clay particles are in suspension. Will it be possible for the Al + + + to get exchanged on the particle when the exchange capacity is exhausted ?

PROF. S. J. ARCEIVALA : Plain aeration can bring down CO_2 concentration to 3 to 5 mg/lit. and not less. Plain aeration does not generally succeed in lowering the concentration of iron in the case of waters containing iron bound with organic matter.

Ferrous bicarbonate alone usually may be precipitated upon aeration without lime treatement when the removal of CO_2 by aeration raises the pH to about 7.0 or more. If, however, iron is combined with organic matter in soluble, stable compounds, lime treatment, following aeration, may be needed to produce a pH of 8.5 or more to encourage precipitation.

The ion-exchange capacity of clay particles definitely has an effect on alum dose. This has been amply demonstrated by the work of Black, Langelier & Ludwig, Stumm, etc. A clay particle that has already adsorbed other cations from the water could have a preference for alum (Al + + +) when alum is added. Further, some colloids in water can also behave like poleylectrolytes with plenty of ionisable sites.

SHRI A. G. BHOLE (Nagpur) : When should lime be added while using $FeSO_4$ as a coagulant ? What are the advantages ?

PROF. S. J. ARCEIVALA : Lime has to be used in conjunction with Ferrous sulphate since the latter is not effective until the pH of water is well above 9.5. No lime would be needed if the water had a naturally high pH. Fe + + salts are quite soluble below *p*H 9.5.

SHRI O. P. GUPTA (Rourkela) : Ferrous sulphate is used as the coagulant in the industrial water treatment plant of about 30 mill gal/day capacity at Rourkela Steel Plant. Ferrous sulphate used is a by-product of the steel-plant. The clarification expected out of the clariflocculator is from an average turbidity of 2,500 mg/lit. to less than 50 mg/ lit. It has been observed that the floc formed in the afternoon is comparatively lighter than that in morning and the evening. The sunshine is the brightest in the noon. This reduction in the toughness of the floc during noon has resulted in the penetration of the floc through the rapid sand filter media.

May I know the reason for this and a remedy for the same? Can this be set all right by increasing or reducing the dose of ferrous sulphate?

PROF. S. J. ARCEIVALA: For ferrous sulphate to be effective, the pH of the water must be correctly controlled. It is not clear from the the question whether lime is added to the water along with ferrous sulphate. Correct dosage of lime will give better coagulation as well as a floc which will be heavier than at present. One would like to have more details about water quality and tank design to be able to pinpoint the cause.

SHRI T. S. BHAKUNI (Nagpur): Can you enlighten me on the problem of removing taste and odour economically from water as they pose a big problem particularly during rainy season?

PROF. S. J. ARCEIVALA: There is no single remedy which acts as a panacea for all taste and odour ills. The right remedy will depend on the real cause of taste or odour. Without knowing the details of your problem, nor the source of water supply, it is not possible to offer any solution.

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Problems in Water Treatment

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Introduction

Treatment of water is one of the important functions executed in all waterworks. In this, different operations are carried out for making the raw water obtained from various sources fit for the uses to which it is to be put up, e.g. domestic, industrial, fire fighting, etc. The common operations involved and the impurities removed in municipal water treatment plants are given in Table I.

Table I

S. No.	Operation	Impurities removed
1.	Aeration	a) Dissolved gases like CO_2, H_2S, etc. b) Dissolved minerals like Fe, Mg, Mn, etc. c) Dissolved organic matter causing bad tastes and odours.
2.	Sedimentation	
	i) Plain	Larger and heavier suspended solids.
	ii) Aided with coagulation	Smaller and lighter suspended solids.
3.	Filtration	Fine suspended and colloidal matter and some living organisms including bacteria.
4.	Disinfection	Killing of living pathogenic organisms, e.g., protozoa, bacteria, viruses, etc.
5.	Chemical precipitation	Dissolved minerals, other organic materials, salts causing hardness, Fe, Mn, Fluorides, etc.
6.	Special processes	Tastes and odours by using activated carbon, aeration, etc.

The actual operations to be carried out, their sequence, and the results to be accomplished depend upon the quality of raw water to be treated and the standards of purification to be attained. They are jointly looked after by the waterworks engineer, chemist, and the biologist. The problems they have to face are many and varied, and they can be broadly classified into two categories:

(i) Those arising from the peculiar quality of the raw water to be treated or the changes in the same; and

(ii) Operational difficulties and breakdowns.

These will be discussed along with some of the solution tried successfully.

Quality of Raw Water

Preliminary : Before designing a water treatement plant, the quality of the raw water and its likely variations are always studied in detail. The managing and operating authorities must therefore know the provisions included in the design in order to utilise them most fruitfully. Many times, unforeseen changes occur suddenly in the quality of raw water. These should be detected through the results of the day-to-day examination of water conducted in the waterworks laboratory. Routine year round inspection and sanitary surveys of the catchment area also prove very useful in understanding the significance and the causes of the different impurities detected by laboratory analysis. If these causes could be removed by taking preventive measures, the pollution load on the plant will be reduced, and many of the problems arising due to them will disappear.

Turbidity : Turbidities due to silt and inorganic suspended matter are normally high in rivers and in surface streams, and increase still further in the rainy seasons. The turbidity load on clarifiers from such sources is therefore high and it impairs their efficiency. Deep presettling tanks with detention period of 2-3 hr will be useful in removing the gross turbidity and in reducing the load on the more sensitive flocculation-clarification system. Such tanks need not have mechanical scrapers and can be cleaned during periods of low demand or at such intervals depending upon the designed allowance for sludge accumulation. The cleaning can be manual or under hydrostatic pressure of water. If the turbidities are low throughout the year, pre-settling will not be necessary.

At some places, it is observed that although turbidity is not very high, its day-to-day fluctuations are quite significant, e.g., water supply to Erode town in Madras State shows turbidity vadying from 4 to 7,000 mg/lit.[1] A continuous watch will have to be then kept on the turbidity, and the dose of coagulatnts to be added will have to be worked out by the jar test. The chemical dosing equipment is to be then suitably set to inject the required dose.

At some places like Bombay, the sources of supply are impounded reservoirs with guarded catchments. Since the water remains stored here for a long time, it becomes quite clear (turbidity being usually less than 10 to 15 mg/lit.) and no treatment except chlorination is therefore given. However, in the rainy season, the turbidity of these waters increases considerably, say about 25 to 50 mg/lit. and even higher. This not only spoils the appearance but also gives physical protection to the pathogens in water against the action of chlorine. The chlorine dose will have to be then increased suitably (say by 50 to even 100 per cent) to meet with the situation. The chlorination equipment should be capable of administering this increased dose. Arrangements may also be made to inject additional quantities of chlorine in the distribution system through service reservoirs and other points.

The problem of high turbidity and other suspended matter in water can be reduced considerably by suitable designing of the intakes. The intakes should have a number of ports fitted with penstocks to draw adequate quantity of water from near the surface at any time of the year. Normally, this water is found to be more clear and pure and is drawn by opening the proper port depending upon the level of water in the source. An interesting example in this respect can be obtained from annals of Bombay's water supply. The water from lake Vaitarna was commonly being supplied to the City by first bringing it into lake Tansa where it could settle and get clarified. The intake tower of the Vaitarna has got only big size entrance port at its bottom above the full supply level of the Tansa, and there are no arrangements for drawing surface waters. In May 1961, an attempt was made to bring water from the Vaitarna directly into the city distribution system through an independent pipe line; but it brought along so much of dirt, mud and larvae that the programme was required to be discontinued. Thus, now arrangements are being planned to construct additional ports at different levels in the intake tower of lake Vaitarna for tapping the water from the near surface.

In some lakes, inversion of water layers takes place due to the seasonal variations in the temperatures. This causes foul bottom layers to rise up and to change the purity pattern in the lake. By taking samples of water at different depths and analysing the quality, it will be possible to decide upon the port to be opened for taking in the water. This will naturally reduce the burden of impurities to be removed at the treatment plant.

Organic Matter : In some lakes and reservoirs which are not well stabilised, algal blooms of different types appear in different seasons. They are usually killed and removed at the sources by using chemicals like copper sulphate, because such waters are commonly treated by plain chlorination and the organic matter apart from consuming the chlorine also gives physical protection to the pathogenic organisms to be killed. Biological means like the fish **Gambusia** who feed on algae are also used to control the problem at the source. Thus at Tulsi and Vihar lakes which supply water to Bombay City and are infested with algae, both these methods are being followed. About 180 kg of copper sulphate are sprayed over these lakes at a time and 500 to 1000 fish are introduced in alternate years. Fortunately, the algal densities are lesser than 200 to 250 counts per ml, and not many thousands as observed in many of the lakes, e.g., Lake Michigan, U.S.A. The worst period is from end of March to beginning of June. The dose commonly given is from 0.2 to 0.4 mg/lit.

The troubles due to algae and other organic matter in the impounded reservoirs get accentuated when there is no overflow; because during overflows, such impurities floating near the surface get flushed out over the spill-ways. This observations was made at Vihar lake, Bombay which did not overflow for a long period between 1935 to 1945. The programme of drawing water from this lake was then so modified that it overflowed at least once in a year. The algae and organic matter troubles got then automatically reduced.

A patented process evolved by *M/s. Glenfield and Kennedy* of England, called the micro-straining in which raw water is passed through fine mesh screens of special design, having an apperature size of 23 35μ is also found to be very useful in removing the algae by 80 to 90 per cent. The unit is commonly loaded at 750 gal/hr/sq ft of the wetted area with a head loss of 6 in. Wash water consumption is also less than 1 per cent of the water strained.

This process is very well suited to treating algae-laden waters, from impounded reservoirs, which have disinfection by chlorine as the only treatment. Experiments conducted at Powai by the Bombay Municipal Corporation on a 1 mill gal/day capacity pilot microstrainer plant gave good results. The removal of algae ranged from 79 to 89 per cent of the initial. However, the straining fabric used to get choked up by slime growths within a fortnight. Cleaning by chemicals is troublesome and may affect the fabric material. The best way is to prevent the slime growth by using ultraviolet rays continuously cast over the strainer as it is being used.

The trouble due to algae and other organic matter in raw water is also observed in the summer months at places, drawing water from alluvial rivers in plains, like Delhi, Agra, Kanpur, etc. In this season, the turbidity in the river waters is low but the organic matter and plankton are high in numbers, causing frequent clogging of the filters so that they need washing at intervals of even 8-10 hr. This reduces the filter performance and increases the wash water requirement considerably, i.e., by 50 to 100 per cent above normal. The remedy lies in pre-chlorination with high doses of chlorine and more careful coagulation and settling.

At some places, the river water or the water from canals is first taken in large storage reservoirs having a storage capacity of 15 to 20 days. These storage reservoirs prove useful in settling out the turbidity and in clarifying the water. It also gives an uninterrupted supply at the time of closing down of the canals for repairs and maintenance. However, it is observed that, at times, large amounts of algae and other plankton grow in them and cause tastes and odours and choking troubles in filters. In such cases, it would be better to keep the raw water in these reservoirs stagnant and pump the water directly from the river or canal to the purification plant. The algae in the storage reservoirs can then be killed by means of copper sulphate treatment. Alternatively to prevent stagnation, 10 to 20 per cent of the supply can be drawn from the raw water reservoir, while the major portion may be taken from the river or the canal.

At many places, the pH value of raw water changes in different seasons and the dose of coagulants or disinfectants to be added requires adjustment. Such changes might be due to discharge of industrial wastes from seasonal industries into waters upstream of the source. In rainy season, the surface run-off brings along with it washings from the catchment which add acidity or alkalinity of the organic or inorganic type. This requires to be neutralised by means of chemical treatment. Thus all the chemical dosing equipment should work over a wide range, and the dosing pipelines be of adequate sizes.

Problems in Operation

A number of difficulties are met with due to operational troubles or design limitations. Lack of proper maintenance, repairs and replacement of old worn-out or damaged parts is often the cause of serious troubles resulting in shutting down of one or more units. Careful planning, foresight, and experience is required in handling the situation. The results of water treatment are continuously being watched by thousands of the users who are conscious of their civic rights and the responsibilities of the water works department in this respect.

Over-loading : Overloading is a very common trouble observed in many waterworks, because the plants have been built long back and have not been expanded to cope up with increased demand due to lack of funds or red-tapism or even discord among the local bodies who administer them. This naturally reduces the efficiency of the plant and the quality of treated water suffers. Under the circumstances, careful use of coagulants and auxiliary chemicals should be made to obtain the best possible clarification in the settling tanks so that the filters will not be damaged and also give satisfactory results. The capital cost of chlorination equipment being not very high, additional units can be installed to inject sufficient quantity to be on the safer side. However, these are only temporary measures to tide over the difficulty for short periods and the lasting solution lies in quick augumentation of the plant.

Every plant should have devices for measuring and recording the flow of water that is being treated. Estimating the flow on the basis of pump capacities is not a good practice for knowing the hydraulic load on the plant. These devices should be checked at regular intervals and at least once a year.

Some times, cases of qualitative overloading are observed due to pollution of the sources upstream of the intake by the discharge of sewage or industrial effluents which was not there when the water treatment plant was installed. These may be tackled on lines similar to those explained above. Water pollution abated for obtaining relief.

Proper Maintenance and Repairs : Proper maintenance and repairs are most essential for successful operation of any plant including a water treatment plant. Unfortunately, this is not the case at many places. The causes are many and varied but the effect is the same, i.e., damage to the plant and deterioration in the quality of treated water, which may even endanger the health of the public. The situation can be avoided by :

(i) Propely planning and executing the programme of routine upkeep and maintenance;

(ii) Providing adequate standbyes so that maintenance or repairs can be carried out without overloading the remaining portion of the plant.

(iii) Posting qualified competant and sufficient number of operational and supervisory staff to look after the plant;

(iv) Keeping adequate supply of spare parts for the machinery piping and valves;

(v) Providing stand-by operating staff; and

(vi) Making the design as simple and easy to work with due consideration to the difficulties in operation and maintenance and the training and experience of the operating and supervisory staff who run the plant.

In spite of all these precautions, many problems can arise at treatment plants. Some of these are discussed below.

Leakages : Many old plants leak very badly through either cracks in civil works or in pipe points valves, fittings, etc. Leaks not only cause loss of precious water that is brought from the source but also erode and weaken the civil construction and soil underneath endangering the structural safety of the plant. At Tulisi Filtration Plant of the Bombay Municipal Corporation (which was built some 40 years ago), it was observed that more than 20 per cent of the water taken in was being lost in leakages. Grouting of the Civil works with neat cement grout and inspection and remaking of the faulty joint must be taken in hand immediately. Arrangements must be made to measure the incoming and outgoing flows to know if the leakages are reduced or not.

Sedimentation Tanks : With all the care in the design and operation, it is observed that the designed detention period is not realised in practice, reducing considerably the efficiency of the tanks. The ratio of flowing through period to the theoretical detention period rarely exceeds 0.40. This is on account of: (i) disturbance due to wind, (ii) density currents due to temperature and turbidity load differences in the incoming water in the tank, (iii) uneven setting of the outlet weir, and (iv) disturbances due to movement of scrapers. Baffles will of course be useful if properly designed, as otherwise, more harm, than good, will result by reducing the cross sectional area of flow and increasing the horizontal velocity of flow giving a scouring effect on the settled sludge. Desludging of the settled sediment also creates problems. If it be made continuous, more water is lost; while if it be made intermittent, more space is lost in holding the accumulated sludge. The decision lies in the desigbiers directives and the experience of the plant operator.

Problems in Coagulation Sedimentation

Some waters have a very low turbidity and do not coagulate well. Increasing the dose of coagulants does not help. The situation can be saved only by adding coagulant aids like Fuller's earth which weigh down and give contact surfaces for further adsorption. In many waters, auxilliary chemicals are required to correct the pH; otherwise costlier coagulants get wasted. Thus at Rourkela, the required alum dose was reduced from 8 to 4 gr/gal by raising the pH from 6.5 to 8.5 using lime [2].

Alum salts are easier to handle and store. They are non-hygroscopic and commercial alum can contain about 18.5 per cent of effective salts, but the floc formed is not very suitable and it is extremely fragile. The chemical solutions are acidic and attack practically all metals. Special corrosion resistant materials are to be employed in its use. Care is also required in getting instantaneous floc formation and its conveyance along with shortest route to the flocculation and sedimentation basins.

Ferrous salts are cheaper and can be successfully employed for preparation of industrial waters, especially so when available as by-products from the steel mills. Typical installations employing ferrous salts are industrial water treatment plants at Rourkela. Although ferrous salts give fairly stable and heavier floc which settles rapidly, many difficulties are encountered such as: (i) after precipitation of iron in the distribution system; (ii) fairly large amounts of lime doses preceding their application; and (iii) ferrous salt solutions are acidic and corrosive to metals and present difficulties in handling and storage.

Effects of Algae : For good flocculation with alum, the *p*H required is between 5.6 to 7. Due to algal photosynthesis, CO_2 from soluble bicarbonates is removed causing them to precipitate out as insoluble carbonate. pH gets raised but the alkalinity is reduced. Coagulation is thereby affected. Coagulation may also get affected if some algae carry the same type of charge as that of the chemical floc. The photosynthetic activity and the release of gases will also buoy up the floc laden with algal masses. Thus there are difficulties in floc formation, settling and even after settlement there are chances of reflotation. Use of coagulant aids like silica for weighing down, or iron salts or lime (with alum) would be better. The algae can be removed by means of pre-chlorination using a dose of 2 mg/lit. of chlorine which may be added to the flocculated water while it enters the settling tanks or even before that.

Problem in Filtration

The more common problems met with in filter operation are mud-ball formation, air binding, formation of mounds and craters on the sand surface, cracks in the sand, and coating of sand grains. The causes and remedies for these are discussed in the following paras.

Mud-balls are formed by the gradual building of the material not completely removed in back-washing of the filters. They tend to accumulate at or near the surface of the sand initially and are usually small. If they are not removed, the compressive force of filtration causes the mud-balls to clump together and form large masses which then sink during washing through the expanded sand bed to the surface of the gravel.

Many times, mud-balls are formed due to overloading of the filters on account of poor pre-treatment. Even if wash-water rates are adequate, and filters are washed enough, mud-balls may get formed when there is no surface wash. The problem of mud-balls can be tackled by proper pre-treatment, adequate washing and use of surface wash, or vigourous work with a long handled rake during back-washing.

At intervals of an year or more, some debris which do not wash off in the normal back-washing process, accumulate on top of some sand filters. It is desirable to remove the debris from the sand surface by means of shovels. Sometimes, a column of mud may be found extending all the way from the sand surface to the gravel. In such a case, the whole of the sand should be taken out, washed and put back or be replaced by entirely new sand.

Air binding : This trouble is commonly observed in algaeladen waters or where negative heads are utilised in the working of the plant. This seriously affects the filter efficiency and capacity, thus reducing the filter performance. This can be prevented by removal of algae by proper pre-treatment and by keeping the filter beds clean at surface. An air-bound filter can be rectified by placing it first out of service and then allowing the water to fall below the level of sand, thus assisting the air to escape. Then the filter may be washed as usual. However, if the wash water is applied to an air-bound filter, it will cause the water to rush up through the gravel and this may result in some of the gravel being carried up into the sand bed and spoiling its gradation.

Mounds and craters are formed if the gravel layer or the under-drainage system gets damaged. Naturally, the remedy lies in removing such damage.

Cracks in the Sand Bed: These occur due to either pressure differentials in the body of the filter or due to shrinkage of dirty sand. Resistance to flow being least along the walls of a filter, the head loss adjacent to the walls is less and the pressure at any depth is greater than in the body of the filter. Water short-circuits through the resulting shrinkage cracks and fills them with caking suspended matter. Pressure differentials are also created by inequalities of flow over the filter area and may also open shrinkage cracks in the body of the bed. It is usually observed that the orifices in the under-drainage system near the wall do not receive their own share of wash water owing to greater head losses towards end points so that sidewall cracks do not get properly washed and they develop into clogged areas during the next filter operation. Such troubles can be avoided by keeping the loss of head below six feet of water and by proper designing of the underdrainage system. Thus in better designs, a false bottom is provided to the filter tanks and the wash water is dispersed in three stages from the point of admittance to the final orifices. These stages are: (i) Primary distribution as in case of a manifold and lateral system with the only difference of the head loss at the exit; (ii) Equalisation of pressure differences in the space between the primary distribution structure and the false bottom above; (iii) Secondary distribution structure at the false bottom with low head loss. Wagner, Leopold and Camp have evolved special designs for filter underdrains on these principles.

Where heavy lime treatment is practised for softening of water, it has been observed that calcium carbonate crystals get formed in the filter beds and coat the sand grains. They adhere fast and do not get removed in washing. As this coating increases, the filter design is impaired and the efficiency in removal of turbidity is affected. This can be prevented by carbonation of the water before passing it through the filter. This gas is generated by burning coke gas or oil. Caustic soda and sulphuric acid treatment can also improve the matters. Compounds of manganese can also give similar coating, which impairs the efficiency of filtration, and which can be removed by using sulphur dioxide.

Slow Sand Filters: Although these are not so commonly employed in newly installed plants, they continue to work at many of the old plants. Their rate of filtration is low but they are highly efficient in removing bacteria and other living organisms. At some places, these filters pose peculiar problems; for example at Madras. Here, the water, obtained from a distant source called the Red Hills Reservoir, contains impurities bearing sulphur compounds. It was observed that when this water was put on filters, sulphur reducing bacteria residing in the filter beds reduced these compounds with the production of H_2S. The gas not only affected the aesthetic quality of water due to its intense foul odour but also induced growth in the storage reservoirs and distribution system and rendered the filtered water difficult to chlorinate (One mg/lit. H_2S requires 8 mg/lit. of chlorine for chloro-oxidation). The quantity of H_2S recorded in the filtered water ranged from 0.5 to 4.4 mg/lit. on different days. Experiments carried out from 1955-58 on this water showed that the H_2S trouble can be removed and the filter performance can be improved by 72 per cent by using break-point chlorination prior to filtration[3].

Chemical Treatment

This is given to remove from water undesirable chemical impurities like the hardness, iron and manganese, fluorides, acidity, alkalinity, etc. It is carried out either by means of chemical precipitation followed by sedimentation and filtration or by means of ion-exchange process. In chemical treatment, it is very essential to know all the impurities in water, otherwise in trying to remove one, the other might be increased. Thus the effect of any treatment on different constituents will have to be seen simultaneously. For example, while removing colour by means of alum at low pH, the water may be made corrosive. The pH should be therefore raised by pre-treatment again taking care to see that it does not go too high or else the colouring matter may redissolve and appear in the effluent. Similarly, while removing iron and manganese by aeration, one should be careful to examine the other qualities of water also. Thus if water contains bicarbonate hardness, calcium carbonate will get precipitated and may cement the filter media. H. W. Coulson has given a very interesting account of his own experience in this respect. In a plant designed by him in England for removal of Fe, CO_2 and Mn from a deep mine water, the filter sand got completely choked and cemented by an effect mentioned above so that it required pneuematic chisel to break it[4].

Softening : This is a very important process commonly carried out in treating industrial waters. Lime-Soda process is the cheapest method when the treatment is to be on a large scale. If the total Mg hardness is more and must be removed, excess lime treatment followed by addition of soda would be better. The dense floc of $Mg(OH)_2$ will also help in coagulation and settlement. If all Mg is not to be removed split treatment would be better. In this, a portion of water is overtreated and then mixed with untreated portion. Such a modification gives both economy and higher efficiency. Excess lime treatment poses the following problems.

i) Excess lime if allowed to go on to the filters is likely to deposit on sand bed and will necessitate periodical changing of sand from filter beds.

ii) In practice, all insoluble $CaCO_3$ can not be precipitated and when taken to the filters, may clog the media and shorten their runs.

iii) Disturbing the chemical stability of water and thus affecting the distribution mains and household fixtures.

The problem of suspended $CaCO_3$ can be tackled by the addition of sodium hexametaphosphate (0.25 to 1 mg/lit.) before the water goes to the filtration plant. If added before the filters, a second dose may be required to assure stabilization. Its effect decreases with time and higher temperatures. Its actions are as yet not well understood and it is not a substitude for recarbonation. Its application is therefore considered as a threshold treatment.

While stabilizing softened waters, Langelier's Index becomes a useful tool. The common practice is to keep it near about + 0.5. In utilising the chemical balance process to build up a protective coating in water mains, care must be taken to see that this building up process over a long length of time does not clog the pipes.

The other major problem associated with the operation and maintenance of a lime softening plant is the disposal of large volumes of sludges. In a big plant, it might be economically feasible to recover lime by calcining the lime sludge especially when the cost of hydrated or quicklime is high. The common difficulties met with in this process are the presence of magnesium sludge and other dirt in the sludge mixture. Excessive dirt can be avoided by first stage sedimentation where most of the silica and other inert matter gets removed. The sludge from the second stage sedimentation will be recarbonated to convert $Mg(OH)_2$ to soluble $MgCO_3$ form.

Iron and Manganese : Fe and Mn compounds are found in waters in the mining areas of their ores. Their removal is essential more from aesthetic and economical view point rather than for health purposes. There are different methods for their removal, and the proper one can be selected by conducting a thorough study of the raw water constituents. The commonest method is that of aeration, settling and filtration. Settling may be avoided only if the quantity of iron to be removed is less and there is no danger of early choking of the filters. Double pumping of well waters can be avoided by employing pressure filters with oxidizing type of media which are activated by means of chlorine or potassium permanganate. If the pH is low or the iron is bound with organic acids, such treatment is not possible. Lime will, in such cases, have to be added after aeration, followed by settling and filtration.

Problems in Disinfection

Now-a-days, disinfection is carried out almost exclusively by means of chlorination; so that the problems in chlorination become the problems of disinfection. Chlorination is usually carried out by dissolving gaseous chlorine in a small quantity of water in a mixing tower and then feeding or injecting the same in the bulk of the water to be treated. The problems in chlorination arise due to its corrosiveness, poisonous nature, and tastes and odours it may impart to the water to be treated.

Corrosiveness : Chlorine is extremely corrosive to all metals in the presence of moisture and, being hygroscopic, it readily absorbs atmospheric moisture. Thus chlorine leakage causes corrosion of its own dosing equipment and other apparatus nearby. Chlorination equipment can be protected by using sealing plugs with lead washer which prevent entry of atmospheric moisture. Deposits of corrosion can be removed by cleaning with carbon tetrachloride at intervals to prevent complete choking.

Even then, sometimes, gas supply lines are found to have been completely choked. This is very dangerous as large volumes of water will then pass unchlorinated. Such chokes can be flushed out with very hot water. The pipe lines be then thoroughly dried, cleaned with CCl and then put into commission.

Since chlorine is a corrosive gas, it should be housed in the same room where pumps, recorders and such other equipment are installed.

To have a check upon the chlorinator and the amount of chlorine passed, the supply cylinders should be kept on weighing platforms. Any volumetric calibration made by the manufacturers in Europe or in U.S.A. at 15.5°C (60°F) temperature will not be of use at 26.6°C (80°F) prevalent in India. The gas pressure shown on the gauges is sometimes erroneous and a serious accident can take place if the operator is misled into believing that the cylinder is empty when it is still containing some chlorine.

Troubles due to icing, reliquefaction and formation of chlorine hydrate are commonly seen when the temperature falls below 10°C (50°F). This may happen if the gas is drawn at an excessively high rate. In places where temperatures fall below 10°C, cylinders and chlorinators should be kept in separate rooms which can be warmed by heating. The doors and windows of this room should open outwards. Chlorine being heavier than air, vents should be provided at floor level of the room for driving chlorine out.

Chlorine is a poisonous and irritating gas and exposure to concentrations of 40 to 60 mg/lit. for more than half an hour is dangerous. Therefore operators should be provided with the oxygen breathing apparatus type respirators and eye goggles. First-aid apparatus should be kept ready and the workmen trained in its use.

Chlorine leaks from near its outlet can be stopped by tightening the outlet screw. Throwing water over the leaks will not be of any use because it will corrode the metal parts. Instead, the pressure of gas in the cylinder may be reduced by cooling the cylinder with a jacket of dry ice and then absorbing the escaping chlorine into a slurry made with 1 kg lime in 1 lit. About 0.6 kg of chlorine can be absorbed in 1 kg of lime.

Tastes and Odours

Many sources of water contain large amounts of algae, plankton. Other organic matter is usually removed of pre-chlorination and settling so that the filters can have longer runs. However, chlorination leads to bad tastes and odours due to the formation of malodourous intermediate compounds of chlorine with organic matter. It is better to give a high dose of chlorine so that the taste causing substances will get fully oxidized. The resulting taste and odours of chlorine proper can be removed after filtration by dechlorinating with sodium bisulphite.

Break-down at waterworks are not very common. One or two units in a process may go out of order, but the plant as a whole continues to work, because the design always provides some stand-bys. If however, there is power failure, the entire plant may have to stop, and hence, it is advisable to take power from two sources. Internal combustion engines should also be kept ready to go into action at the time of such emergencies.

Summary

The problems in water treatment are many and varied, and depend upon the quality of raw water to be treated and the processes and equipment used. There can not be any standard solution for solving them. Good knowledge of the quality of water and the effluents from different processes must be obtained by day-to-day laboratory examination. It will indicate the appropriate line of action. Regular maintenance and upkeep of the plant and equipment will minimise the numbers and gravities of the problems. Difficulties will always come but they should be tackled right away, before they get aggravated into problems.

One should always be optimistic because no problem is unsurmountable. Experience, judgement, and foresight on the part of the waterworks superintendent can set right any situation and prevent the occurance of many.

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DISCUSSION

SHRI D. A. NAIR (Ranchi) : The speaker mentioned microstrainers to screen out organic turbidity. But this will have very little application in India since microstrainers have to be imported. Some other equipment may be developed from indigenous sources to meet this contingency.

SHRI S. R. KSHIRSAGAR : I agree that the micro-strainers have to be imported these days and that is one of their draw-backs, but they are most suitable for removing turbidity due to algae and plankton from lakes and reservoirs. They have got a number of advantages like low head loss, less space required, simple automatic operation and less power consumption. Thus they should be given a fair trial.

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Investigations on the Water Treatment Plant at Hyderabad

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Introduction

Hyderabad, the capital of Andhra Pradesh, has a population of nearly 1.3 million. There are four lakes—Osman Sagar, Himayat Sagar, Mir Alam Tank and Hussain Sagar of which the first two form the source of drinking water supply to the city (Fig. 1). The flow diagrams and the salient features of the two treatment plants are presented in Fig. 2 and Table I respectively.

The Problem

The main problem with Hyderabad Water Supply is the residual turbidity in water which ranges between 10-15 APHA units as against the limit of 5 units[1]. In view of the correlation between residual turbidity and the incidence of viral infection, such as jaundice, the present day trend is to restrict the residual turbidity to much lower limits than the prescribed limit[2], and hence,

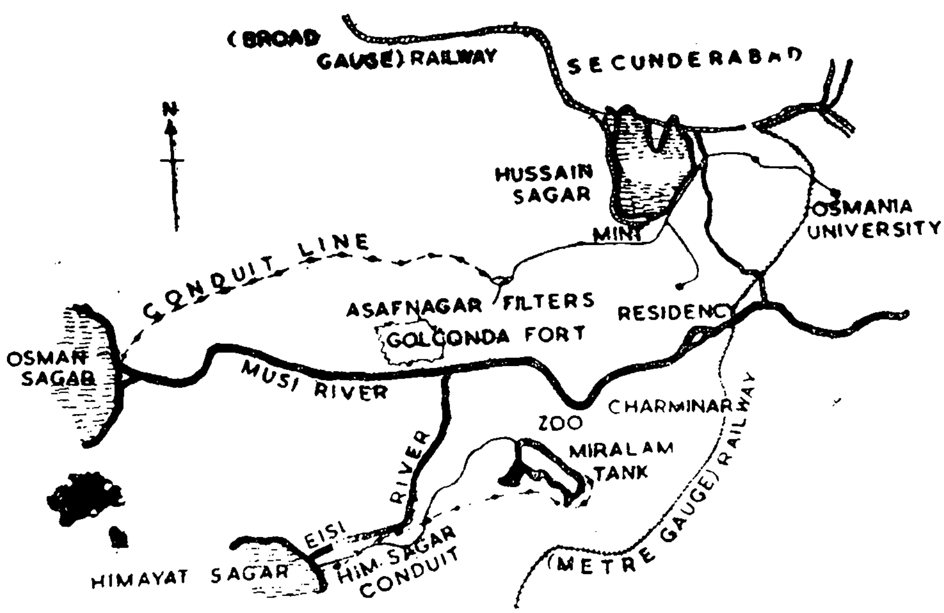


Fig. 1 — Location of lakes around Hy derabad

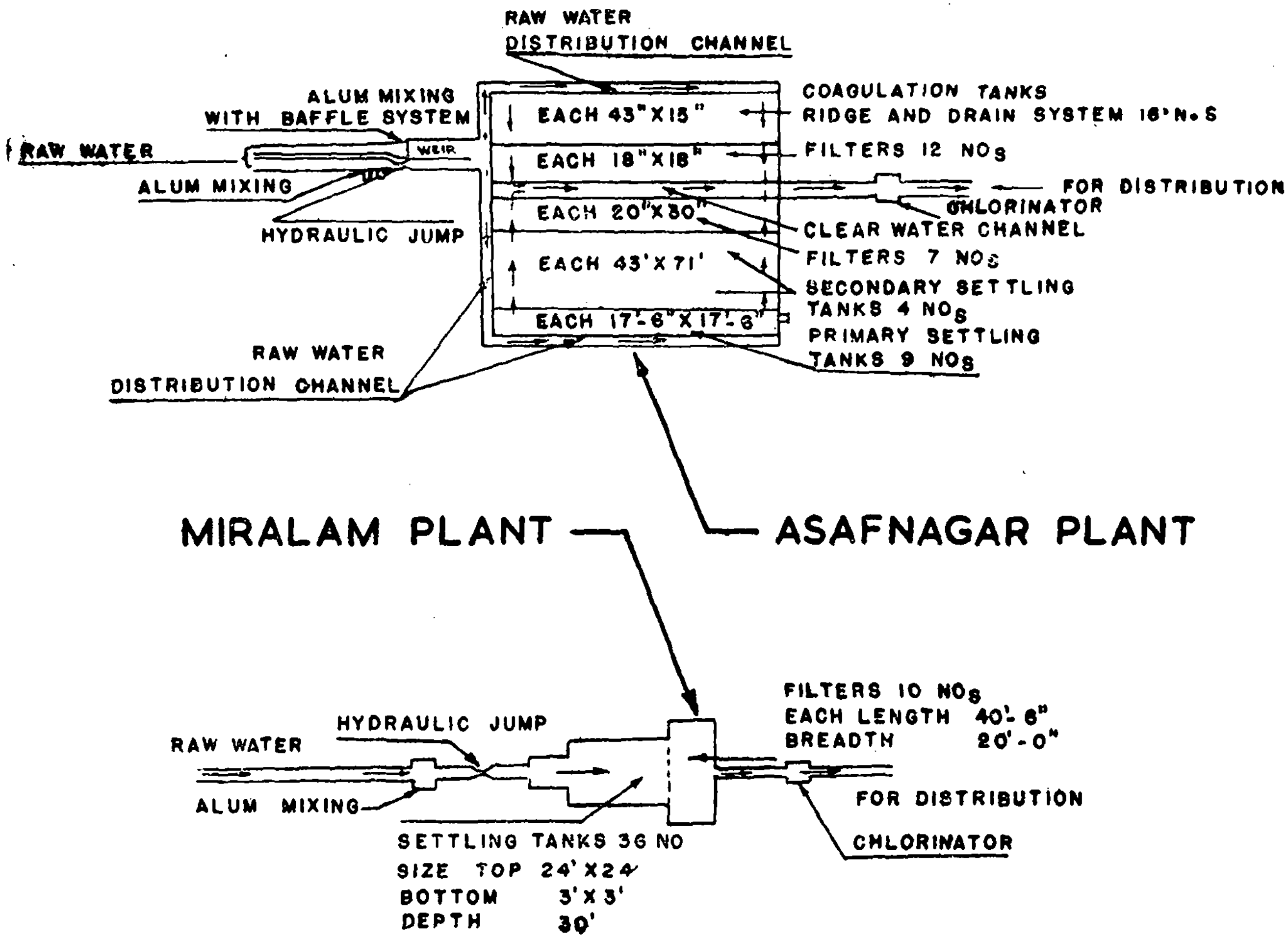


Fig. 2—Flow diagrams of water treatment plants

Table I—Salient features of the Water treatment plants

(Rate of Water Supply, 40 gal/capita/day)

Particulars	Asafnagar	Mir Alam
Year of installation	1922	1937
Source of Raw Water	Osman Sagar	Himayat Sagar
Type of plant	Patterson & Candy RGF	Candy RGF
Capacity	9 mill lit. (20 mgd.)	9 mill lit. (20 mgd.)
Rate of filtration	437 lit./sq m/hr (90 gal/sq ft/hr)	485 lit./sq m/hr (90 gal/sq ft/hr)

this problem requires immediate investigation. In this connection, it may be pointed out, that with the complete treatment as is being practised in Hyderabad, it should be possible to get residual turbidity, much lower than the prescribed limit, since with partial treatment such as proper coagulation alone, the prescribed standards are being achieved in some of the water treatment plants elsewhere.

There is yet another problem with the Hyderabad Water Supply, viz., the occurrence of molluscan shells in the inlet conduits and the settling tanks. Though this problem is not so serious at the moment, this needs careful investigation as the results of these investigations will be of immense use, if the problem becomes suddenly serious here or elsewhere. There appears to be very little work done so far on the control of these shells.

The Method of Approach

From the problems presented above, it can be seen that these need detailed investigations, on all aspects of water treatement and to facilitate these investigations, the studies have been divided into the following three parts:

i) Study of the variations in the characteristics of raw water in different seasons.

ii) Determination of the proper treatment to be given, so as to produce better quality of finished water.

iii) Investigation of the deficiencies in the existing treatment plants.

Based on the data collected above, it will then be possible to suggest the necessary modifications in the treatment plants as well as in the method of treatment so as to obtain the finished waters which meet the standard requirements.

The studies reported herein contain the progress of results of the investigations conducted so far.

Seasonal variations in raw water characteristics

Raw water samples were collected from the two sources once a week and analysed in the laboratory to study their physical, chemical, microscopical and bacteriological characteristics, according to Standard Methods. This work was commenced in January 1964.

The physico-chemical characteristics are presented in Table II. The total solid contents is well within the allowable limits, i.e., 228 mg/lit. as against 500 mg/lit. and about 50 per cent of this is inorganic matter. The turbidity due to this inorganic matter can be best removed from the water by coagulation, as the waters are having an ideal pH range for this purpose. The turbidity is, however, very low and hence it may require special treatment with alum or coagulant aids. The water is sufficiently alkaline for complete reaction with alum which is the most common coagulant used. The watershed is relatively free from pollution as can be seen from the low oxygen consumed value. In this connection, it may be pointed out that though 50 per cent of the total solids are organic in naure yet the oxygen consumed value is low. This may be due to the fact that the organic matter present is comparatively stable.

The microscopic analyses indicate that odour producing organisms such

Table II—Physico-chemical analyses of the raw waters

(collected during January to July 1964)

Item	Osman Sagar		Himayat Sagar	
	Geometric Mean	Standard Deviation	Geometric Mean	Standard Deviation
Temp., C	25.6	8.2	25.6	8.2
Solids:				
Total	228	145.8	298	206.0
Suspended	38	29.8	25	17.3
Chlorides	28	26.0	36	21.0
Total alkalinity	440	196	514	258
Turbidity	50	15.0	50	14.0
Oxygen absorbed	2.6	2.0	3.7	3.4
*p*H	8.5	0.97	8.4	1.4

(Note: All values except pH and temp. are in mg/lit.)

Table III—Bacteriological analysis of raw water

	Osman Sagar		Himayat Sagar	
	Geometric mean	Range	Geometric mean	Range
Plate Count, 37°C	20	5-100	15	5-30
MPN/100 ml	229	16-2400	115	2-350
Faecal Strept./100 ml	11	4-93	14	4-93

as **Synura** were not present during the course of the study. However, only once (between the period March and June) that too in a very negligible quantity, **Tabellaria**, which is responsible for odours, was detected in Osman Sagar. Filter clogging algae such as **Melosira**, **Cyclotella** and pollution indicating algae such as **Chlorella** and **Euglena** were also detected in these lakes. No quantitative estimates could be made due to the non-availability of plankton-net. However, by counting with Haemocytometer, it was found that the concentration of these organisms is of very low order, to be of any significance in the water treatment processes.

The results of the bacteriological examination are presented in Table III.

These results indicate that the watershed is relatively free from pollution.

From the above discussion, the following conclusions may be drawn:

i) The watershed of these lakes was relatively free from pollution;

ii) Odour producing algae were not present during the course of the study. However, other types of organisms such as filter clogging algae and pollution indicating algae were present in such a low concentration as to be of no real significance in water treatment processes;

iii) The pH of the water was most suitable for coagulation of clay turbidity, as the case with these waters. Because of the low turbidity, the waters may require special treatment with alum or with coagulant aids. The alkalinity of these waters was sufficient for complete reaction with alum.

Determination of the Proper Treatment

For this purpose, jar tests have been employed. It is realised, that the results obtained by this method may not be exactly similar to that of full scale plant because of the various factors of hydraulic similitude, physical factors controlling subsidence, time and speed of mixing, etc. However, in the absence of the more acceptable method for this purpose, the above tests have been conducted.

The equipment consists of a manually operated machine consisting of 6 vertical shafts with common drive and fitted with 'H' shape blades of 1 cm width.

As soon as the coagulant was added to the sample of water in the jars, the contents were mixed quickly for three minutes and then slowly at 5 rpm for 20 minutes for good flocculation, and then allowed to settle for 30 minutes. The results of the tests were judged by the size and settling characteristics of the floc and residual turbidities. Low turbidities were measured with Hellige's Turbidimeter.

The following three series of experiments were conducted :

i) In the Hyderabad Water Treatment Plant, the average dose of alum that is applied to the water for coagulation is 1 gr/gal and a residual turbidity of 30 units is obtained after sedimentation. The aim of this series of experiments was to find out whether better result could be achieved with the same dosage by controlling the pH. The theory behind these experiments is that if the pH of the water is adjusted near the isoelectric point of the alum, best coagulation is obtained.

In order to do this, the alum dose of 1 gr/gal was maintained in all the experiments and the residual turbidities, obtained with pH of the water varying from 8.7 to 7.5, were determined.

From Table IV, it can be seen that at pH 6, the effluent had a residual turbidity of 5 units. From this it may be inferred that if the pH is controlled, it is possible to obtain best results with the usual dose.

ii) In this series, experiments were conducted to find out whether it was possible to obtain the same efficiency by merely increasing the alum dose without adjusting the pH. The results are tabulated in Table V.

From this, it can be seen that it was possible to obtain the same efficiency with a dose of 3 gr/gal of alum, which is 3 times the usual dose.

iii) Experiments in these series were planned to find out whether it was possible to decrease the alum dose and still get the same efficiency with coagulant aids, such as activated silica.

First, the minimum dose of the coagulant aid was determined and found to be 4 mg/lit. Then keeping this as constant, experiments were conducted with varying doses of alum.

Table IV—Results of the jar tests conducted at different pH values

(Alum Dose, 1 gr/gal;
Raw water turbidity, 40 units)

	Jar No.				
Item	control	1	2	3	4
pH	8.7	6.0	6.5	7.0	7.5
Residual Turbidity, Units	40	5.0	20	35	35

Table V—Results of the jar tests conducted with different alum doses

(Raw water Turbidity, 40 units)

	Jar No				
Item	Control	1	2	3	4
Alum dose, gr/gal	Nil	1.0	2.0	3.0	4.0
Residual Turbidity	No change	35.0	35.0	5.0	5.0
Final pH	8.7	8.4	8.0	7.8	7.5

From Table VI, it can be seen that the same efficiency as in the previous two cases has been obtained with 2 gr/gal of alum in combination with 4 mg/lit. of activated silica.

From the above, it can be seen that all the three methods gave identical results, but from actual utility point of view method no. i appears to be difficult as it involves adjustment of pH, both before and after treatment. Out of the remaining two methods, both are practicable, but method no. iii appears to be cheaper. It may offer a possible solution for the improvement of the coagulation of the raw waters of these treatment plants.

Investigations of the Deficiencies of the Various Treatment Units

Mir Alam Treatment Plant :

Though the rated capacity of this treatment plant is 18 mill gal/day, it can handle peak loads up to 21 mill gal/day. The treatment plant is provided with a hydraulic jump, 36 hopper bottom settling tanks of size 7.3 m x 7.3 m x 9.1 m each, and 10 filter beds of size 6.09 m x 13.1 m each as shown in Fig. 2. Investigation of the draw-backs of the various treatment units is in progress and the studies so far conducted are discussed below.

Hydraulic Jump (Alum-mixing device) : The alum solution is dispersed into the raw water by means of hydraulic jump. As the method is not so efficient, the present trend is to use flash-mixing. In this connection, the observation of Camp[8] is worth quoting. "The value of violent initial mix has not been conclusively demonstrated for water treatment but Rudolfs has shown a decided improvement in clarification of sewage by chemical coagulation

Table VI—Results of the jar test conducted with fixed dose of activated silica and variable alum dose

(Raw water turbidity, 40 units; activated silica, 4 mg/lit.)

Item	Jar No.				
	Control	1	2	3	4
Alum dose, gr/gal	Nil	0.5	1.0	1.5	2.0
Residual Turbidity	No change	32	24	15	5.0
Final pH	8.7	8.5	8.3	8.1	7.9

Table VII—Design data of sedimentation tanks

Item	Rated Flow	Peak Flow
1. Detention time	166 minutes	142 minutes
2. Overflow Rate	43,378 lit./day/sq m	50,600 lit./day/sq m
	(868 gal/day/sq ft.)	(1012 gal/day/sq ft.)

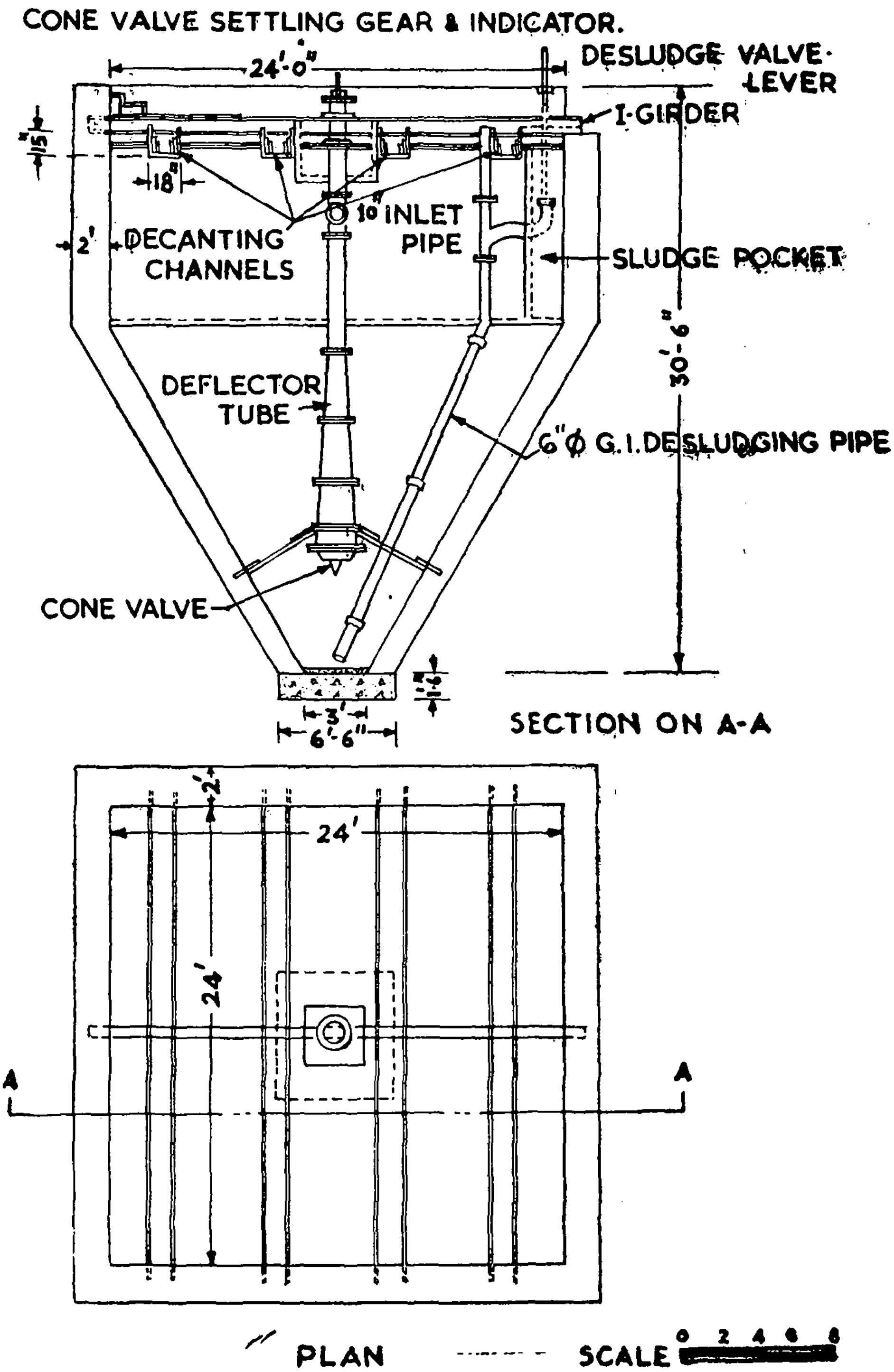


Fig. 3 — Sedimentation tank (Old) at Mir Alam treatment plant

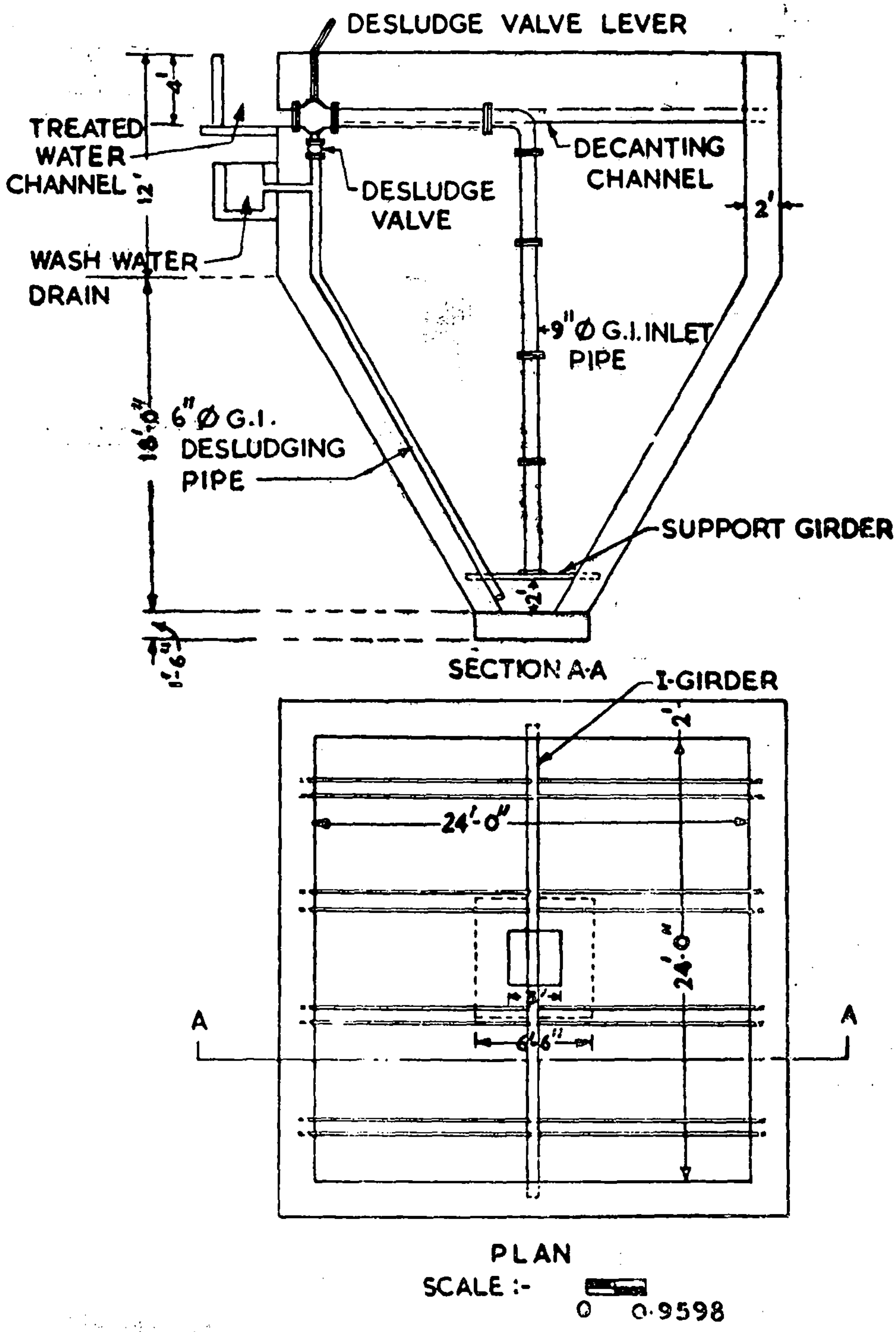


Fig. 4 — Sedimentation tank (New) at Mir Alam treatment plant

when flash-mixing precedes flocculation."

Sedimentation Tanks : Of the various treatment units, the worst offenders appear to be the sedimentation tanks. This can be seen from the fact that while the raw water turbidity is 50 units, the residual turbidity after sedimentation is 30 units or sometimes more. On the other hand, the properly designed and operated unit should be able to produce water of 5 units residual turbidity. One of the probable reasons for the unsatisfactory performance may be due to the absence of mechanical flocculators. The other probable causes are discussed below

The first step in an investigation of this type is to examine whether the usual design perameters conform to the standard practice. Hence these have been calculated and presented in Table VII.

From the above, it appears that the design conforms to the standard practice. But the most common type of failure in these types of tanks is due to short-circuiting. Hence the extent to which the short-circuiting is occuring in these tanks has been investigated by dispersion curve technique. The tracer employed for these studies was sodium chloride as it is found to be very useful for such studies

Out of the 36 sedimentation tanks, two representative tanks which have different inlet arrangements were selected for conducting the test. Figs. 3 & 4 show the details of the sedimentation tanks.

Dispersion curves for the outer channels of the sedimentation tank in Fig. 3 is shown in Fig. 5, and the dispersion curves for the inner channels of the same sedimentation tank is shown in Fig. 6. From these curves, the probable detention time has been calculated and found to be 69 minutes for the inner collecting channels and 60 minutes for the outer collecting channels.

Similar dispersion curves of the outer channel for the sedimentation tank (Fig. 4) have been drawn (Fig. 7) and for this the probable detention period was found to be 69 minutes.

To find out the temperature difference in bottom and top layers, samples at the top and bottom were collected with the help of a Water Sampler, manufactured by Soil-Test Company. It is noticed that the difference in temperature is about 0.5°C, in the top and bottom layer of water.

From the above results, it may be concluded that one of the important causes of failure of these tanks is due to short-circuiting as the actual detention period is about an hour, while the theoretical detention period is about 3 hours.

These results clearly demonstrate the importance of proper inlet and outlet arrangements. For the same type of sedimentation tank, the inlet of Tank in Fig. 4 is giving better performance than the inlet of the tank in Fig. 3. Similarly the inner outlet troughs are giving better results than the outer outlet troughs. In view of this, it may be possible to improve the performance of these tanks by providing better inlet and outlet arrangements. This problem is being tackled with the help of the model, being designed in this Laboratory.

Fig. 5—Dispersion curves of sedimentation tank

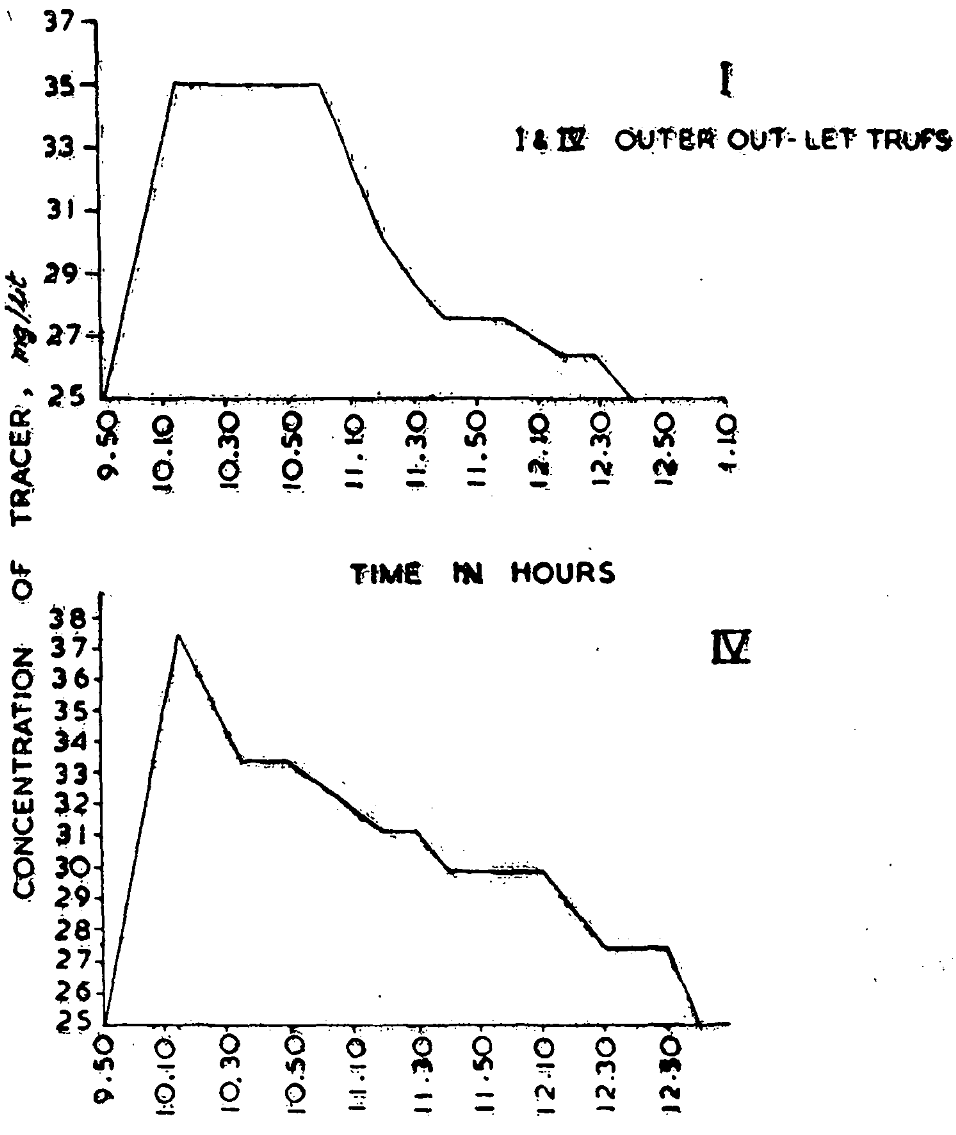
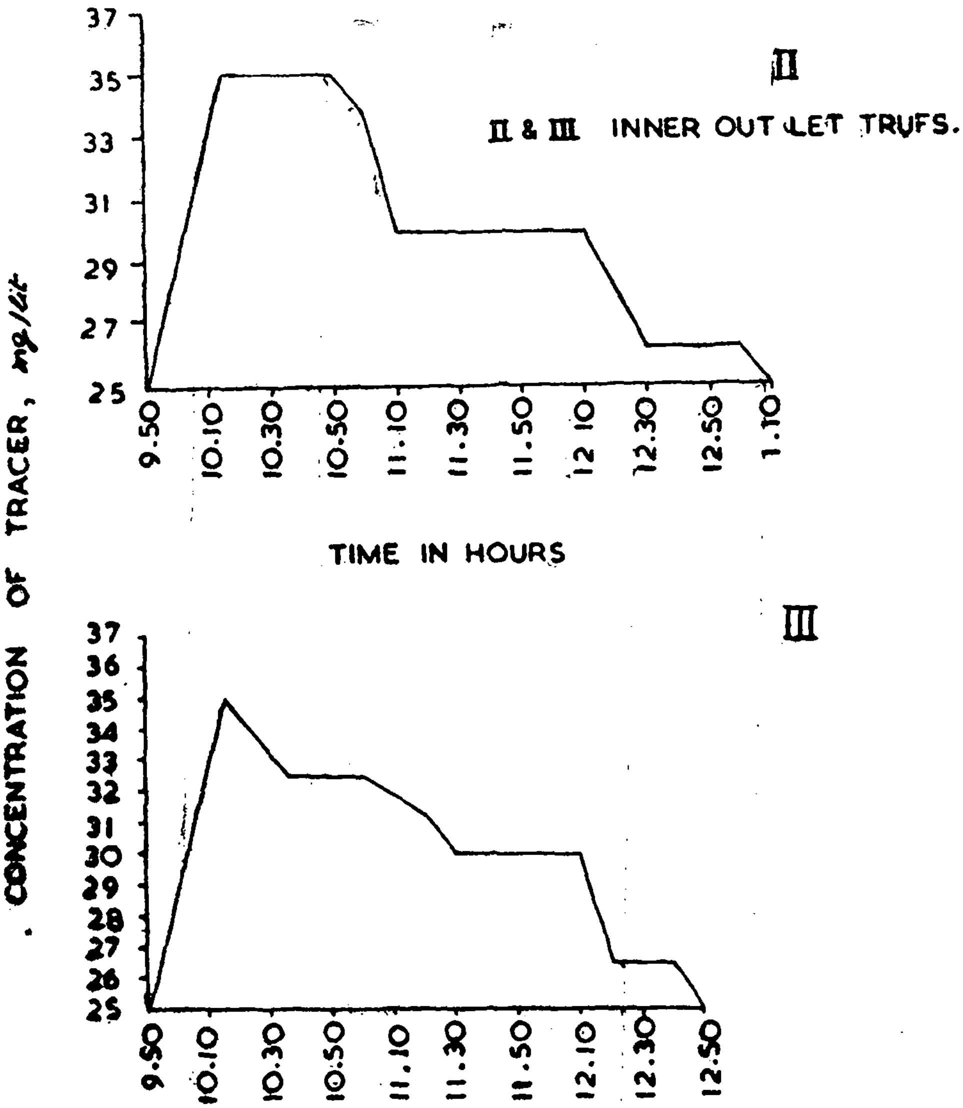


Fig. 6—Dispersion curves of sedimentation tank



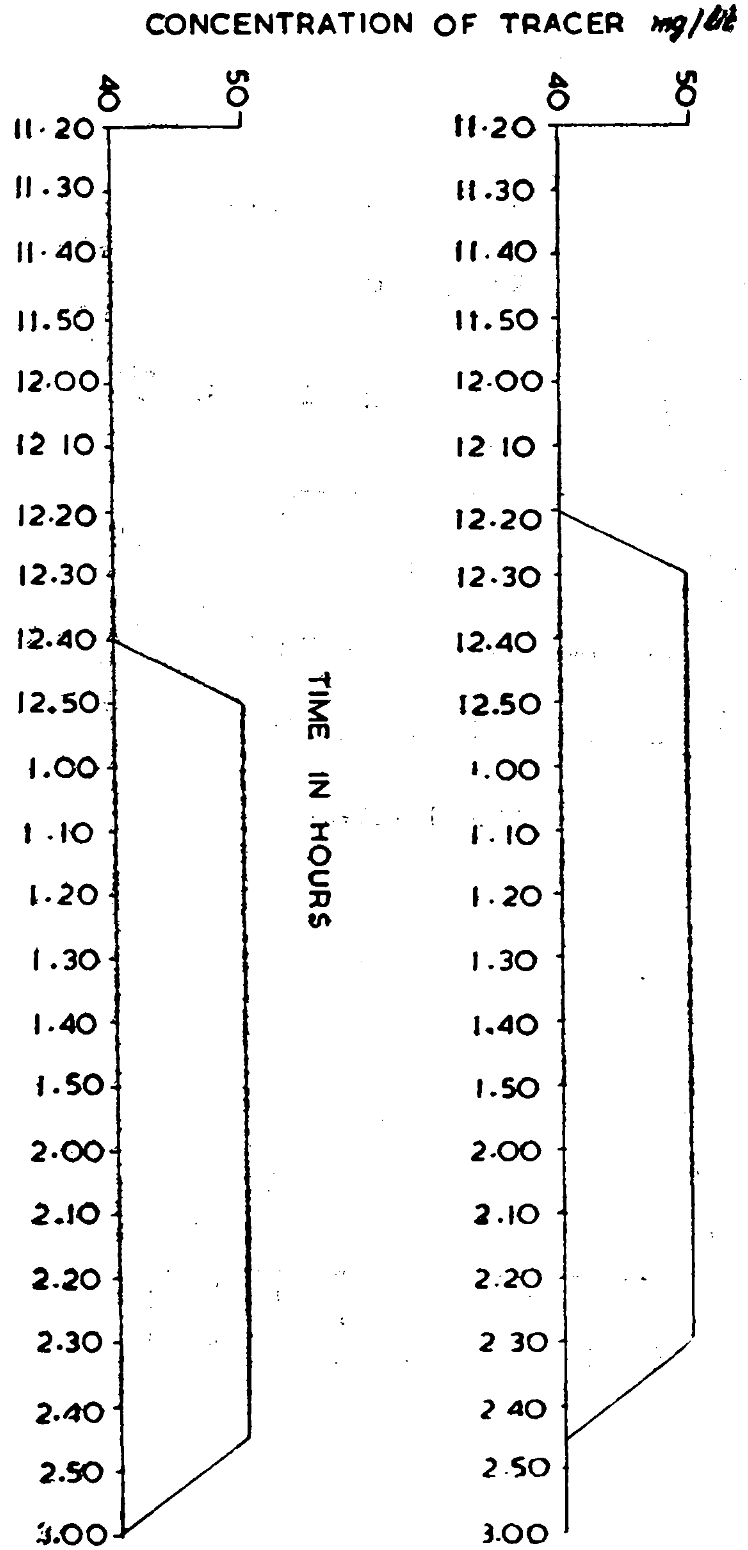


Fig. 7—Dispersion curves of sedimentation tank

The temperature difference of 0.5°C will be higher in summer. This temperature difference is likely to set up density currents which also contribute to the short-circuiting. This aspect is also under investigation.

Acknowledgement

The studies mentioned in this paper were made possible through the help of Shri Naram Krishna Rao, Executive Engineer, P.W.D., Hyderabad Water Works and his colleagues, who gave all the necessary facilities during the course of these investigations.

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DISCUSSION

SHRI N. KRISHNARAO (Hyderabad): I would like to ask Dr. Seth whether he has also observed the actual detention period and correlated it with the flow-through period which he had observed with the help of sodium chloride. If so, what would be the efficiency of the displacement ?

DR. G. K. SETH: Yes. The efficiency from the point of view of detention period is 55 per cent.

SHRI N. KRISHNARAO: Does the growth of molluscs in the sedimentation tank have any relation to the detention period as based upon its life cycle ?

DR. G. K. SETH: During the studies, we observed the molluscs get attached to the inlet pipe, resulting in reduced diameter. This reduction in diameter depends on the periodicity of cleaning. Our observations have shown that the diameter of the inlet pipe under the same condition affects the detention time. This point will be clarified only after conducting the model studies.

SHRI N. KRISHNARAO: I wish to know whether the question of formation of the required sludge blanket has been studied as it is important to such type of tanks.

DR. G. K. SETH: This aspect is being investigated.

SHRI S. R. AGARWAL (Kanpur): At what stage was the activated silica added, and may I know in what form it was added ?

DR. G. K. SETH: Activated silica was added ahead of the addition of alum, generally 2-3 min., and it was dispensed in the form of suspension in water.

SHRI A. R. KANGA (Bombay): I would like to know whether the investigations have considered the fundamental issue of suitability of the vertical flow flocculation cum clarification units at Hyderabad for the treatment of low turbidity water. It has been my experience that when light floc is formed it usually travels in vertical flow units of this type on to the filters, creating fresh problem.

DR. G. K. SETH: The studies reported in our paper are of preliminary nature. The question raised by Shri Kanga is very pertinent.

Studies are in progress to investigate this aspect.

SHRI J. M. DAVE (Nagpur): These tanks are of sludge blanket type. Did the authors during operation, operate them at the correct sludge blanket depths?

DR. G. K. SETH: I understand that these tanks were not designed on the sludge blanket principle. However, investigations elsewhere have indicated that these types of tanks can be operated successfully with the sludge blanket.

This aspect is being investigated with the help of model studies.

SHRI S. K. GAJENDRAGADKAR (Bombay): What is the method used for determining the efficiency of the tanks? If it is determined by detention period, was the mean time taken or the model value? I suggested that model time should be preferred to the mean. What is the upflow velocity of the particles?

DR. G. K. SETH: As the main function of the settling tanks is to remove the turbidity, this was adopted as a yard-stick. If the settling particles are discrete, the overflow rate is the criterion for the design. But in this case, the particles are of flocculent nature, hence in addition to overflow rate, the detention period is equally important for the design of the settling tank.

For determining the detention period, the present practice is to use either the mean or model time. In this particular case, the mean time was selected by us. However, to get over the difficulty, we are going in for dimensionless curve technique, which takes both these aspects into consideration.

The upflow velocity of the particles is being determined.

SHRI J. S. JAIN (Nagpur): I would like to know if the authors found any difficulty with filtration unit. What is the load on filter beds being used?

DR. G. K. SETH: So far our studies are confined to the pre-treatment units. After completion, we shall take up the filtration units.

SHRI A. D. PATWARDHAN (Bombay): The slide showed an increasing diameter of the inlet pipe with increase in depth. What is the diameter of the pipe where the raw water enters the settling tank? At what height does the inlet pipe end above the bottom?

DR. G. K. SETH: In one case, the diameter is 2 ft and in the other case it is 9 inches.

The clearance between the inlet pipe and the bottom of the tanks is about 6½ feet.

SHRI M. I. GURUBAXANI (Jamshedpur): The speaker has described three methods of reducing turbidity from 40 to 5 mg/lit., i.e. 1 gr/gal alum & acid, 2 gr/gal of alum & activated silica and 3 gr/gal of aluminium. He recommends that his work with actived silica is the most suitable. I would like to know the capital cost and the running cost of these three methods and I feel that the choice of the method should also depend on the economic running cost of the plant.

DR. G. K. SETH: I am in complete agreement with Dr. Gurubaxani's observation. This aspect is being studied, as already indicated in the text of our paper.

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Water Treatment In India

Past, Present and Future

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The author's association with water treatment plants in India started from the year 1924. The first plant installed was for the G.I.P. Railway Colony (Now Central Railway Colony) at Bhusaval. The suppliers of this plant could not fulfil the guarantee given regarding the dose of the coagulant. They were, therefore, liable to pay a penalty equal to the capitalised cost of the excess expenditure on the coagulant, but, as a special case, it was waived by the Railway administration. Other two filtration plants put up subsequently by the G.I.P. Railway were at Kalyan and Dhond. The G.I.P. Railway also installed a plant at Puntamba. This plant was mainly a water softening plant. The author has since been conntcted with the design of new water treatment plants and study of existing plants in the country as well as abroad. He has, in this Paper, traced the development of the techniques of water treatment in the last forty years.

The object of treating water is to make it potable and safe so as to prevent spread of water-borne diseases. It has to be made acceptable to the consumer by removing tastes and odours, and also satisfy his aesthetic sense

Raw water contains impurities in the form of suspended solids (turbidity and sediment), dissolved solids, dissolved gases, colour and organic matter. It also contains micro-organisms. Raw water has, some times, bad tastes and odours. All these impurities and micro-organisms have to be removed to make the final product of water treatment conform to certain accepted standards for drinking water laid down by the local authority. The standards are dependent upon the use of the treated water and the cost involved.

It is only recently that standards for drinking water have been laid down by the Indian Council for Medical Research. Before that, standards followed in British Water Works Practice were in use. The Indian Standards Institution has also come out with certain standards.

The Union Ministry of Health have very recently produced a Manual and Code of Practice laying down Drinking Water Standards as well as standards for the design of the component parts of the water treatment plants. It is presumed that this Manual will be used in future in the design of the water treatment plants in the country. This Manual is not the last word and will have to be revised from time to time as new techniques for the treatment of water are developed. Revision of the manual, every five years, may be necessary.

The modern concept of a good water supply system, to supply safe water at the consumer's tap, is (i) Selection of the best available sources of supply; (ii) treating the raw water in modern rapid sand filter plant with pre-and post-chlorination, adequate coagulation, flocculation, settling; and (iii) a well maintained distribution system capable of supplying water equitably and at adequate pressure to the different parts of the town or city. If the water is hard, it must also be softened to bring down the hardness within permissible limits. The supply has also to be round the clock and not intermittent.

The system should also provide for super-chlorination and dechlorination for being brought into operation in emergencies. The sources of supply must be protected from pollution by sewage and trade effluents as the quality of raw water at the source affects the degree of treatment required at the water treatment plant. Secondary treatment of sewage by biological processes like biological filters and activated sludge removes 85 to 90 per cent of the organic matter which can be readily oxidised by biological organisms. In primary and secondary treatment of sewage, physical removal of approximately 90 per cent of the heavier or suspended solids takes place. These processes do not remove inorganic, dissolved chemicals and many of the more resistant organic chemicals which are not readily degradable by micro-organisms. Attempts are being made to improve the efficiency of sewage treatment processes to reduce the load of the resistant chemicals, on sources of supply.

Further, the art of water treatment, as practised at the present moment, is not adequate to prevent transmission of diseases caused by viruses, amoebae and nematodes. The present water treatment plant is no doubt approaching perfection in eliminating the transmission of bacterial diseases through water. A good deal of research investigational work is in progress to find out how agents other than bacteria present in water, like viruses, could be inactivated.

Before the advent of rapid sand filters in India slow sand filters were in use. They were preceded by sedimentation tanks providing a detention period of 4 to 7 days, depending upon the characteristics of the raw water. The sedimentation tanks allowed suspended clay matter contained in surface water to settle at the bottom of the tanks. The suspended clay matter was maximum when the river was in spate. Where the raw water was obtained from an impounding reservoir and not from a flowing river, the sedimentation tanks were not provided. The amount of suspended clay or turbidity contained in raw water was in many cases as high as 3,000 mg/lit. Turbidity is the relative measure of the suspension of colloidal clay particles, which have become dispersed into the water by erosive action of run-off waters on solids.

These sedimentation tanks could not economically remove colloidal suspension of clay particles as it is quite stable, posseses negative charges and can be settled out preferably only by chemical treatment. It was a costly job to remove the sludge from the sedimentation tanks as the accumulation of silt was very heavy and had to be removed by manual labour.

The sedimented or settled water was then put on the slow sand filters. The rate of filtration was about 2 gal/sq ft/hr, while the depth of filtering material was about 4 ft. The slow sand filters worked on the constant rate principle. When the designed loss of head, generally 7 ft, was reached, the filters were thrown out of use for washing and cleaning. The washing of sand was another big job. For this purpose, sand washing machinery was evolved and, at some plants, this machinery was used. Major portion of the silt contained in water can not be removed by sedimentation alone and the slow sand filter has to take care of it in the filtering process.

The exact action of the slow sand filter in removing the turbidity from the settled water is still not known. Some of the factors responsible for cleaning action are: (i) Sedimentation in the filter bed; (ii) absorption due to opposite electric charge; (iii) adhesion due to Brownian movement and conversion of stream lines between sand grains; (iv) coagulation within the filter bed; (v) biological agencies; and (vi) colloidal mesh structure on filtering media.

The slow sand filter is unsuited to treat waters containing large quantities of organic matter. When they were first introduced in the Country, the sources of supply were not polluted with sewage and trade wastes, as they are today due to increase in population and fast urbanisation.

The slow sand filters require large areas of land, because the rate of filtration is very low. Their maintenance and operation costs are not insignificant.

For these reasons, slow sand filters fell into the back-ground and their place has been taken by rapid sand filters for the past forty years. It must be said to the credit of slov sand filters that they worked efficiently and produced a good filtrate when the waters treated by them did not contain large quantities of organic matter. Even today, they can be used in water treatment plants serving small communities, if the cost of land required for their location is reasonable.

Madras City is one of the many places where slow sand filters were installed to treat water from a lake. They were giving a lot of trouble. Veeraraghavan, O. T. Raghavan and Ganapati have pointed out their erratic performance and types of treatment undertaken to eliminate the production of H_2S and other growths in the supply mains requiring frequent renewal and cleaning.

In Kaval towns of U.P., slow sand filters were installed for purifying river waters, preceded by pre-sedimentation basins (units). The pre-sedimentation units were intended to relieve the filter influent of unusual load of silt. In these plants, heavy algal growths causing shorter runs, involving frequent scraping and formation of buoyant algal mats are reported. Earnest steps are necessary to find out ways and means to correct these defeets.

In Delhi, similar units of slow sand filters have been replaced by rapid sand filters and pre-sedimentation tanks supplemented by coagulation tanks and channels. In expanding the water treatment facilities to meet the growing needs of the increasing population, pre-sedimentation tanks have been done away with, and all the components, of a modern water treatment plant have been included in the new designs.

In a rapid sand filter, the rate of filtration is very high, as much as 80 to 300 gal/sq ft/hr. The removal of turbidity, to a large extent, is accomplished by treating the raw water by chemical dosing, flocculation and settlement before its entry on to the filter. The process of cleaning and removal of turbidity by this filter is different from that of slow sand filter. In the rapid sand filter, the colloidal mesh structure has less chance to develop and less opportunity exists for lodging of the jelly-like substance in openings between sand grains to form a frame work as this filter is frequently disturbed by back-washing for cleaning purposes when the designed loss of head is reached. The velocity through its bed is too high to produce effective sedimentation in the bed. A porous layer is deposited on the top of the sand bed, but this layer is believed to be composed of mostly heavy flocculated material, collected on the surface of the sand bed, either by settling, straining or adhering action or by the combined effect of all these factors. The filtration phenomena is so complex that none of the above factors can be said to be responsible for the filtering action.

As pointed out before, the pretreatment given to the raw water in the case of a rapid sand filter consists of chemical dosing flocculation and sedimentation. Some river waters are given a dose of chlorine before they are pre-treated to get rid of the algal and plankton trouble and to lengthen the filer runs.

Turbidity of water in the pre-treatment process is taken care of by using a coagulant. The coagulant used earlier was alum and it still continues to be used in the existing plants in the Country. In the early period, the solution of alum was made in a mixing tank and the mixed water was introduced into the inlet channel of the coagulation tank. To ensure thorough mixing of the coagulant chemical with raw water, horizontal and vertical baffles were provided in the inlet channel. The coagulation tank was rectangular in shape and was provided with baffles to prevent short-circuiting. Sludge drains were provided on the floor of the tank to remove the sludge manually by opening a valve or valves, provided on the outlets of sludge drains, at frequent intervals. The tanks provided a detention period of 4 to 8 hr. Detention time is the length of time for a segment to flow from one end of the tank to the other. Detention is calculated by dividing the volume of the tank by the rate of flow through it. It is in essence the function of the overflow rate.

The object of using the coagulant is to neutralize repelling charges on colloidal particles of turbidity and produce jelly-like spongy masses called "Floc." This floc has an enormous surface area per unit of volume that entraps or adsorbs particles of turbidity, organic matter and bacteria. Coagulation is induced both by chemical and mechanical action. The latter plays part in gathering in or adsorption of suspended solids.

When it was found that baffles in the inlet channel of the coagulation tank did not succeed in securing thorough and uniform mixing of the coagulant with raw water, flocculation was introduced as a component of the water treatment plant. It has come to stay and is included in all the modern plants. Flocculation consists of mechanical entrapment of the agglomerated particles by adsorption on to the floc formed with coagulant chemicals and also by molecular bridging of the individual molecules of the coagulant. Flocculation causes considerable increase in size and density of coagulated particles, resulting in a faster rate of settling of the floc particles.

The chemical characteristics of raw water influence floc formation and coagulation. Coagulation and floc formation are also influenced by the pH value of water and the degree of mixing. Investigations have shown that temperature does not affect appreciably the rate of floc formation though optimum pH value changes with temperature.

Paddles are used for flocculation. Time of flocculation must be so adjusted as to make particles large enough to settle effectively. Flocculation is generally accomplished by initial rapid mixing to provide contact between the coagulant and the particles of turbidity to neutralise repelling charges and by gentle and slow mixing. Paddles are of two types—vertical and horizontal—on fixed shafts and walking shafts. The peripheral velocity of the outer most paddle does not exceed 3 ft/sec. The mean velocity of the average paddle ranges between 1 to 1.5 ft/sec. The time of flocculation varies between 20 to 40 min. There appears to exist a close relation between the dose of the coagulant, power requirement and settling characteristics of the floc produced. With the knowledge of the interdependibility of these factors, it should be possible to evolve an overall economical design for the water treatment plant as a whole. The present practice of providing power of 3 to 5 h.p. per million gallon of raw water treated per hour, irrespective of the dose requirement or settling characteristics of the floc does not lend to economy.

South African Studies on Flocculation : Basic studies were carried. out by the National Institute for Water Research, South Africa, in 1962, on flocculation by means of comparative photographs obtained by using a phase contrast microscope on precipitates of aluminium hydroxide and ferric hydroxide in membrane filtered river water. As contrasted with the floc produced by these reagents in non-filtered water, the studies indicate that the same binding force exists between the colloids and the precipitates. Comparative tests with calcium chloride and calcium hydroxide revealed that the chloride fails to neutralize the zeta-potential or to coagulate the colloids whereas the hydroxide performed both functions successfully.

Zetameter helps to determine zeta-potential in a relatively short time. The addition of coagulants narrows the range of the curve and coagulation occurs at relatively high negative zeta potentials. A high dosage of coagulant was necessary to reduce the charge to zero or to change it to positive. It has also been found that the charge did not remain constant but became increasingly negative with time.

Flash Mixing: In earlier plants, the solution of the coagulant with raw water was made manually. The dry alum was mixed with water to make a solution. To get a thorough, intense and uniform mix of raw water with the coagulant, high speed impellers have since been introduced. They have a capacity greater than that of the flow through the plant. This device is known as "flash mixing." The other purpose of flash mixing is to keep the consumption of the coagulant to the necessary optimum level required for satisfactory treatment.

The rate of settling of the floc is now-a-days accelerated in the foreign water treatment plants, by using "Coagulation aids" which are available in the market. Coagulation aids, by themselves, are not coagulants. But they assist in the coagulation process. They act as binders or bridges by mechanically entrapping or sticking floc particles together creating thereby, larger and heavier flocs which help to speed up the settling process. The coagulation aids are bentonitic clays, non-ionic organic polymers and activated silica. Organic polyelectroytes are employed both as coagulants and coagulation aids.

In addition to alum (aluminium sulphate), sodium aluminate, ferric and ferrous sulphate, and various organic polyelectrolytes are used as coagulants in foreign countries. Some experiments carried out by CPHERI on the use of **Nirmali** seeds as a coagulant are reported. Practical and economic methods of their application on a large scale have yet to be explored.

There is no reason why iron salts should not be used as coagulants in this Country. They are now being produced by Hindustan Steel Ltd., and are sold at an economic price of Rs. 166 per tonne. It is likely that their use in water treatment may prove economical and satisfactory; because, the dose of iron salts, required for coagulation, is comparatively much less than that of alum. It is, however, necessary, before they are used, to carry out investigations to stabilize these salts against the humid conditions prevailing at the waterworks plant. Ferric floc has been developed in the U.S.A. to withstand much humid conditions. Further, certain waters have selective perference to iron salts and they respond favourably with a small dose. Besides, flocs formed with iron salts being heavier, overflow rates of the clarifiers can be increased without impairing the quality of the flocculated and clarified waters. It is also likely that the use of iron salts may require less depth of the filtering media or may permit higher rate of filtration.

It is also desirable to use liquid alum instead of dry alum which is in use today. In large plants, liquid alum will help in reducing the cost of the coagulant and the mechanical equipment used for making the solution. Liquid alum is manufactured in the first place and it is then evaporated to dry alum for the convenience of the waterworks engineer.

The dose of the coagulant depends upon the characteristics of the raw water. The correct dose for optimum floc formation is arrived at by carrying out 'Jar Tests.' The dose varies from 5 to 6 gr/gal in the monsoon period, when the turbidity of the raw water is very high, to about 1 to 0.5 gr/gal in the dry weather. Where water from an impounding reservoir is to be treated, no coagulant may be necessary during the dry months when the turbidity is low. The low turbidity can be taken care of, by the settling tank and the filter. Owing to the peculiar characteristics of the raw water at Madras, a high dose of 100 mg/lit. has to be given on occasions

Some type of alkaline reagent is required to be added to some waters to raise their alkalinity to a point, sufficiently high to ensure effective coagulation. Lime is used for this purpose. It is also used in some plants to raise alkalinity and for inhibiting corrosion.

Rectangular settling tanks were common in the early period. Their place has been taken by circular tanks called clarifiers. In rectangular tanks, the method of baffling and withdrawal of sludge were similar to those in use in coagulation tanks. Circular tanks are provided with mechanical scrapers for continuous removal of sludge deposited on the floor of the tank. By continuous scraping, the chances for the sludge to get septic are arrested. The detention period continues to range between 2 to 4 hr.

The design of the clarifier is governed by several factors such as prevention of short-circuiting, turbulence, density current, and inlet and outlet conditions. The area required for clarification is related to the volumetric flow rate. The vertical liquid rise rate at any level should be less than the solids subsidence rate at that level. The inlet to the clarifier must achieve distribution of incoming flow throughout the cross-sectional area of the clarifier. Inlet velocities are kept as low as possible. They are generally less than 5 ft/min. The inlet should also ensure adequate horizontal and vertical distribution of the incoming flow. To achieve this objective, perforated or slotted baffle is introduced in the clarifier. The baffle is so designed that the head loss across the baffle is of the higher magnitude than the maximum kinetic energy of the flow upstream.

The circular clarifier is provided with a central feed and a central sludge draw-off. The effluent is withdrawn along the entire periphery of the basin. Dorrco clariflocculator, accelerator and centrifloc and Bamac clarifier fall under this category.

The area provided for settlement is such that the optimum over-flow rate of 4 to 6 ft/hr is not exceeded. The weir rate does not exceed 30,000 gallons per day per lineal foot of the periphery.

Between 1935-54, tangential flow clarifiers with one or more inlets and partial peripheral weir were installed in the Country at few places. Their popularity ceased there-after, probably because, better types of clarifiers have since been developed.

Sludge Blanket Type Sedimentation Tanks

Accelerators of the upward flow sludge blanket type, functioning both as flocculators and sedimentation tanks have been installed in the last decade. In this type of tank, an inverted cone is placed centrally and is separated from the clarifier zone by an intermittent ring placed at the top. Raw water is introduced into the inverted cone with the required chemical dose. An impeller is provided, which in addition to the mixing of raw water and chemical, churns out the mixture into the clarifier zone through the intermittent ring. As the water enters the clarifier, it rises towards the exit and sweeps through a suspended blanket of previously formed sludge. This helps to complete the process of flocculation and grade up the particles of floc so that a clear clarified water zone is created above the suspended blanket. A part of the sedimented sludge is recycled by the impeller and some portion of the sludge bleeds out through sludge pockets. This type of clarifier requires no mechanism for scraping the sludge and, for this reason, the bottom of the clarifier is made flat.

These clarifiers are so far dealing with impounded water either by presedimentation tanks or impounding reservoirs. It is yet to be known whether they would be able to treat waters directly drawn from rivers under high flood conditions, without any provision for pre-sedimentation.

No change has taken place in the design of these filters during the past forty years. Filter beds consisting of graded sand 24 to 30 in deep with effective size from 0.4 to 0.7 mm and uniformity co-efficient 1.3 to 1.8 supported by a layer of gravel are still in use.

Suggestions have been made, in some quarters, to reduce the depth of sand and also to use coarser sand. For a number of years, the rate of filtration was not allowed to exceed 80 gal/sq ft/hr, and only recently has it been increased to 120 gal/sq ft/hr. There is room for further increasing the rate of filtration, provided more attention is paid in processing the raw water, before it is admitted on the top of the filtering media.

Air and Water Back Wash

The filters continue to be washed with air and wash water. To ensure uniform distribution of air and water for obtaining a good wash, filters are provided with different types of filter bottoms. For efficient back-wash, sufficient number of outlets of adequate size are provided at the bottom of the filter. The outlets take the form of orifices in the pipe laterals, slots, openings in false bottom plates, interstices in built-up bottoms or other water spreading system. Whatever system is adopted, it should provide controlled sand expansion and proper friction between sand grains and minimise the mixing of filter supporting media with the sand, a condition that can cause uneven distribution of air and back-wash water.

Filter Bottoms

In the early period, filter bottom was of the manifold type. It consisted of perforated CI or WI laterals of dia 2-3 in, and holes of 5/16-1/4 in dia staggered at 3-6 in centres. This system continues to be adopted even in new plants. In some recent plants, nozzles have been used. Thought is being given to use wheeler bottom, porous plates and other bottoms, similar to those used in the U.S.A.

Porous plates eliminate the graded filter media support. The average dia of pores in porous under-drain plates is more than twice the average dia of interstices in 0.5 mm filter media. Porous plates are not recommended for the filters in conjunction with water softening plants. Where filters have to remove precipitated iron or manganese hydroxide, adequate treatment is a must, if porous plates are to be used. In previous designs, channels and plain plates with pier support were in use. The present trend is to use long bolt support. This provides unobstructed space below plates for uniform wash water distribution.

Surface Jet Wash

Some experiments were carried out in Bombay to test the efficiency of surface jet wash. In American water works practice, air-scour for filter washing is not looked upon with favour. The system of surface jet wash is preferred. Fixed jets or sweeping jets are used for the purpose. It is claimed that sweeping jet wash saves wash water to the extent of about 30 per cent but it is not efficient to deal with filter corners.

Rate of Air-Scour

The air-scour rate is 2 to 3 cu ft/min/sq ft of the filter bed at a pressure of 8 to 10 lb/sq in. This is practically the same as for back-wash water. Filtered water is used for back-washing by storing it in an elevated tank about 20 to 25 ft above the full supply level of the filter bed. Where possible, a direct connection is taken from the adjoining supply main, having adequate pressure, for the same purpose.

Amount of Wash Water

The amount of wash water varies from plant to plant. The maximum quantity reported is about 8 per cent of the filtered water. In good practice, it should not exceed 2 per cent. This figure is always exceeded and increased up to 4 per cent.

Frequency of Washing

Filters should be washed when the need is indicated by the loss of head. *In existing plants*, the frequency of washing is reported to vary from 10 to 48 hr. The practice of washing the filters every 24 hours irrespective of the loss of head, is being followed in most of the plants. Greatest care must be taken in saving filtered water used for washing.

Frequent washings add to the waste of filtered water. Better method for fixing the frequency of washing must be found out. Washing of the filters should not be done as per convenience of the operator. There seems to be a close relation between filter washing and the performance of the water treatment unit as a whole, in all its steps of chemical dosing, flocculation, and settling. Studies of the different water treatment plants at Delhi, on the basis of the designed head loss, revealed varying performance potential of the different treatment units preceeding the filters.

It would be worth while to study the performance of the existing water treatment plants to arrive at a rational method for fixing the frequency of filter washing.

Future Filter Design

From the studies so far made abroad on the working of the rapid sand filters, it appears that an ideal filter bed would consist of a relatively coarse top layer, which will remove most of the turbidity without introducing excessive head loss and a relatively fine bottom portion which can also effectively remove the turbidity which passes to it. It is also believed, that a properly sized filter bed made of anthracite or another similar material and sand would give a better performance than the conventional graded sand bed. In some experiments carried out in the U.S.A., the best combination was found to be 8 in of 30-40 mesh sand 22 in of 6-18 mesh anthracite. It is claimed, that with this combination, filter water turbidity could be kept less than 0.01 mg/lit. for all raw water conditions at a filtration rate of 6 U.S. gal/min/sq ft, or even more.

Variable Filtration Rate Filter

Taking advantage of the knowledge that when a clean filter is placed into service, the filter usually produces effluent of a relatively high quality at the earlier part of the filter run, and the effluent starts degrading towards the latter part of the run, a filter working on variable filtration rates is being evolved. As per present practice, the filtration rate is controlled at a constant rate through the entire run. This means, that in the conventional filter, the water is filtered through the bed at a continually increasing velocity as the bed becomes gradually clogged. Pilot plant study made in the U.S.A. on a variable rate filtration unit has shown that its run was 22 per cent longer than that of the constant rate unit and the removal of suspended matter by the pilot unit was better than the constant rate filter.

Upward Flow Filters

Upward flow filters have been used in U.S.S.R. and Singapore. The "Contact Clarifier" used in U.S.S.R. is a combination clarifier and filter. It is similar to a rapid sand filter but the water in the "Central Clarifier" is filtered upwards. The raw water, without any pre-treatment, is injected with coagulants just ahead of the filter inlet. The filter effluent is collected by a trough at the top of the filter bed.

The Singapore upward flow filters are of 33 mill gal/day capacity. The upward flow filters were built after studying the performance of this type of filter on a 2000 gal/day capacity pilot plant. In the 33 mill gal/day plant, water enters at the bottom and filtered water is taken off at the top. There are no troughs. The filtrate flows away through perforated absestos pipes and the wash water is carried away through large valve out-lets below these pipes. Glass marbles are placed in the first layer above under-drain slots in concrete, and above is about 4 inches layer of gravel. The filter itself is 15 in of sand which is graded to pass 1/8 in and is retained on 1/10 in mesh. Filters operate at 210 gal/sq ft/hr. The average run is over 50 hr with a maximum of 150 hr. Wash water together with air is supplied at 12 gal/min/sq ft, duration of washing being 10 to 15 min. Wash water seldom exceeds 3 per cent of the filtered water.

The following advantages are claimed for the upward flow filter; (i) No filter rate control is required; (ii) filters can not run dry when in use; (iii) filters can not become air bound or generate a negative head; (iv) the underdrain system performs a proper funcion in that water passes through the coarse element first and through the fine medium last; (v) the filtrate can be observed in gravity type upflow filters as it flows upward through the medium to the clear well or reservoir, and changes in appearance can be easily noted; (vi) some of the suspended matter will tend to settle out in the underside of the filter preventing clogging of the sand; (vii) the different layers of various types and sizes of medium can be maintained more easily in proper position in filter; (viii) good, even distribution is provided through out the medium; (ix) there tends to be a greater penetration of floc using the whole of the medium so that all of the filter bed is made to work; (x) if a break-through occurs, it can be readily observed and the filter taken out of action; and (xi) owing to its low loss of head, which need not exceeded 15 in, the clear water tank can be located at a higher elevation, thus saving head.

Modification in Filter Design under Study

Robert A. Taft Sanitary Engineering Centre (USA) is studying several modifications in water filtration for over two years. The modifications taken for studies include such ideas as high rate filtration, with coarse, high weight media on top of sand; control of floc strength and its passage with polyelectrolytes in the filter effluent; the use of filters for flocculation of low alum doses as well as for removal of turbidity and the use of granular activated carbon in filter beds. The pilot plants have been of various sizes to determine the passage of coliform bacteria, powdered activated carbon, viruses and gross turbidity through the filters. The results of studies on turbulent water from the Little Miami River were: (i) a double layered bed of coarse media made up of 18 in of coal (effective size, 1.05 mm) on top of 6 in of sand was able to remove as much or more turbidity, coliform bacteria, poliovirus or powdered activated carbon as a bed of coal or sand alone; (ii) with proper coagulation ahead of the filter, a rate of 360 US gal/sq ft/hr was as effective in removing all test particles at a rate of 120 US gal/sq ft/hr; (iii) Adequate floc strength was more important in achieving clarity than a certain settleability, when coarse media and high filtration rates were used. This strength was frequently obtained only by addition of 5 to 20 mg/lit. of activated silica as a coagulant aid, or 0.05 to 0.2 mg/lit. of a synthetic polyelectrolyte as a filter aid; (iv) when water was relatively clear (less than 25 turbidity units), the flocculation and sedimentation steps of conventional treatment design could be omitted if coarse media was placed on the top of the sand; (v) for this particular river water, the inclusion of flocculation and limited sedimentation permited longer filter runs and better water during winter and flood conditions; (vi) poliovirus in clear water was found to be more readily removed by beds of fresh, clean granular activated carbon than by sand.

Some experiments were carried out in Bombay by the Bombay Municipal Corporation on mixed beds and up-flow filters of varying sizes. The results confirmed more or less the advantages claimed for both. It is recommended that experiments on a large scale at two or three places should be carried out independently for future confirmation.

Filter Performance

Performance of a filter is measured by the quantity of water (in million gallons) passed through it, per one foot increase in loss of head. It has been reported by Baylis that filters operated at a constant rate of 2 gal/min had an average performance of 0.71 mill gal over a period of 6 years at Chicago. His experience of filters working at a rate of 4 gal/min. showed an average performance of 1.02 mill gal for the same period representing an incrase in performance of 44 per cent over that at the 2 gal/min rate. The reason for greater performance may be due to the fact that loss of head often increases at an accelerated rate. If this loss is 0.5 ft/hr in the first part of the filter run, it may be as much as 0.6 ft or more per hour when the head loss is near 8 ft. In the high rate filter, initial loss of head is higher but when the loss of head reaches 8 feet, it is not as great as that produced by a low filtration rate.

Disinfection

The only objective for the disinfection of water is the prevention of transmission of disease through the agency of water. Consequently, the accepted criterion of the sanitary quality of water has been the presence or absence of the coliform group of bacteria. It does not apply to the presence of other enteric pathogens. The viruses are more resistant to disinfection with chlorine than are coliforms. The doses of chlorine used in present waterworks practice can not inactivate them without excessively long contact periods. A study of the effect of chlorine on enteric viruses has shown that inactivation of enteric viruses in water at *p*H 7 and temperature, 25°C, requires a minimum free residual chlorine concentration of 0.3 mg/lit. for contact periods of at least 30 min; at higher pH levels or lower temperatures, more intensive chlorination is necessary. The minimum time and dose required to inactivate hepatitis virus have not yet been finally determined. Some investigations have shown that this virus was inactivated with a dose of 15 mg/lit. in thirty minutes contact time. Poliomyelitis virus as per investigations, requires 5 mg/lit. of chlorine residual for inactivation. Very recent investigations have shown that at water temperature, O°C and pH 8.5 and free chlorine contact time, 7 minutes, the residual required is of the following order:

Organisms	:	Minimum free chlorine residual, mg/lit.
Viruses	:	5.0
Bacteria	:	0.6
Cysts	:	Filtration necessary

For water in the range of 8.5 to 7 *p*H and for temperature from 0°-32°C (32-90°F), the residual based on the presently available data is 5 mg/lit. of free chlorine for the destruction of pathogenic vegetative bacteria and viruses. Water chlorinated with such a high dose has to be filtered through a pre-coat carbon filter containing media fine enough to remove amoebic cysts for dechlorination to make it fit for human consumption.

It is recommended by some that until more adequate measures are available for judging the total disease transmitting potential of a water, super-chlorination should be practised.

At the present time, there are no tests to detect the presence of viruses and other organisms in treated water, The commonly employed methods used for the evaluation of the safety of the water such as the coliform MPN are not adequate guides where these organisms are involved. It is necessary to develop techniques for the detection and enumeration of such organisms which can be used by ordinary water works laboratory.

Uric Acid as Pollution Index : A new method for determining pollution of water by measuring its uric acid content has recently been evolved. Uric acid, discharged in the urine of men and excrement of birds, serves as a measure of pollution. The test is specific for pollution of public health significance. This method determines the degree of pollutant and provides results in about an hour, without extensive laboratory procedure. The test method is a modification of the spectrophotometric method commonly used for the determination of uric acid in chemical specimens.

Desirability of Specifying Design Standards

Till recently, while inviting tenders for the water treatment plants, no design standards were specified. The companies made their own designs which were accepted. The companies had a sort of monopoly and theirs was the final voice in the plant design. It was not then possible to compare the tenders received for water treatment on one common basis. Cost or experience was mostly the guiding factor in the acceptance of the tender. There are many public health engineers in the country who leave the design part of a water treatment plant to the specialist firms. They only give information regarding the quality of water to be treated and specify the desired quality of the filtered water. It is necessary, while calling tenders for a water treatment plant to specify the performance of each of its components. For instance, the turbidity of the flocculated and settled water before its application on the filter bed is not specified and there are instances where the turbidity of such settled water is as high as 30 mg/lit. before its application on the filter bed.

It is not yet realised that pre-treatment of water before its application on the filter bed should receive utmost attention. If the pre-treatment is perfect, the part played by the filter itself in upgrading the water quality is insignificant. It should be borne in mind, that the most expensive component of a water treatment plant is filter and its accessories. For this reason, more study on the filter is called for to make its value more commensurate with its cost. Liberal allowances should be made for plant capacity, while inviting tenders, for overloading. The present provision of 20 to 25 per cent for overloading of the filter units is not considered adequate. It should be increased to 100 per cent. The mixing and settling tanks should have considerable excess capacity. The hydraulics of the over-all plant should provide for 100 per cent over-load. The question of automation should also be considered. Modern trend in foreign countries is to use automation on a large scale. It may, however, take a few years before complete automation forms a part of the treatment plant.

The recovery of the coagulant alum from the sludge should be given due attention. If the turbidity of the water to be treated is within a low range, as in the case of water obtained from impounding reservoirs, the recovery of alum would be substantial without much extra cost, if the plant has to treat large quantities of water. This should find place in the call for tenders.

Similarly, the re-use of water used for filter washing requires equal attention. In large plants, the quantity of wash water is substantial and if it could be used over again, it would help to prevent wastage of water. If the wash water is treated in sand filter and returned to the raw water for being passed on through the treatment plant, the water admitted into the treatment plant in this manner is not likely to affect the quality of the filtrate, and it will also save the wastage.

Micro-strainers

Bombay has carried out some experiments on micro-strainers for the removal of algae from Vihar Lake Water. The experimental work has demonstrated that the micro-stainer is effective in removing algae but not turbidity.

Micro-strainers are giving satisfactory results in many parts of the world. There are three standard grades of micro-straining fabrics. Mark O, the finest, has about 160,000 apertures per sq in, the aperture size being approximately 20 microns. This finest grade is being used in some plants for the clarification of potable water as the sole filtration process. It is also used for polishing filtered water.

Mark I fabric has apertures of some 35 microns and about 80,000 apertures per sq in. This fabric is used for primary filtration as well as polishing of sewage treatment plant effluents.

Both the Mark O and Mark I fabrics are much finer than a rapid sand filter bed.

Mark II fabric has apertures of approximately 60 microns and about 58,000 per sq in. It is used for treating industrial raw and process waters.

The type of micro-straining plant required in any particular case depends upon the suspended solids in the water. It also depends upon the degree of elimination of such solids required in particular applications. **M/s Glenfield and Kennedy** are the patentees of micro-strainers. Micro-strainers take the form of self-cleaning rotary drum filters. They are manufactured from non-corrosive metals. High speed automatic washing is incorporated in their design. They are installed in a reinforced concrete tank and operate in open gravity flow conditions. The sizes of the drums vary from 2½ to 10 ft dia and 2 to 10 ft width. Standard size drum is 7½ ft dia and 5 ft wide.

The introduction of micro-strainers prior to filtration helps in reducing the load on filter beds and thereby reducing the frequency of cleaning and reducing the quanity of wash water. It is worthwhile to give the micro-strainers a trial in suitable situations.

Research Problems

Research problems in the treatment of water are without end. Since they reflect both new needs for information and new problems of water pollution. Improved control methods for coagulant dosage are needed. Conductometric methods may be found useful for this purpose as all turbidity is removed at dosages of alum less than those at which the break in the conductivity curve occurs. The break-point is said to be governed by the alkalinity of the water and not by the alum dosage, optimum for colloidal removal.

How to design a filter scientifically and to operate the same effectively with maximum economy is still to be learnt. Today, the trend is towards change from the 'art' of water filter design to the "science" of water filter design. Research should concentrate in finding: (i) How a given particle is removed on a filter; (ii) what factors affect its design and operation and how these factors affect the economy of operation.

Research is also needed to find, how water should be tested. New and improved methods of water analysis are called for. Methods of the cultivation and classification of iron bacteria are overdue. Methods of determination of nitrates and organic pollution should receive attention. Methods for detecting the presence of viruses in water are a top priority item.

Investigational work is necessary to gather correct data as to the extent of influence of water quality, management of filtration facilities, sand characteristics and hydraulic conditions of the filter itself on the rates of filtration.

Another problem that should not be lost sight of is the generation of H_2S in the sand bed when treating waters deficient in dissolved oxygen and containing large amount of organic matter.

Fluoridation

Fluoridation of water may have to be used in water treament plant in the country sooner or later. Our present problem is defluoridation. Concentration of research on finding out economical and simple methods for defluoridation is essential.

For the fluoridation of water, fluorspar can be used in two ways: (i) The mineral can be dissolved in alum solution and fed as a liquid into the water; or (ii) it can provide the principal raw material in the manufacture of various fluoride containing compounds which can be fed directly, either liquid or solids. The primary compound manufactured from fluorspar is hydrofluoric acid from which are produced most fluoride containing salts including sodium fluoride. The process of dissolving the fluorspar at the water plant is reported to be the most economical of all fluoridation processes.

Radio-active Contamination

No work has so far been done on the contamination of drinking water supply by nuclear radiation, the presence of which may be harmful through the process of ionization. Alpha and beta particles and the gamma rays are most important in water works practice. The accidental or careless discharge of radio-isotopes to a water supply will always be a potential hazard to health. Radio-active contaminations of surface waters as a result of weapons testing or nuclear war is a possibility. Natural background radioactivity exists everywhere in the environment and must be considered in any radiation control programme. Maximum permissible concentrations (MPC) concept should be carefully studied by every water works engineer.

Spectrophotometric Analysis

Spectrophotometric analysis is being used abroad to determine the water purification efficiency. Experiments with this instrument carried out on Leningrad water demonstrated that, in some respects, the effects of various treatments like coagulation, settlement & filtration are additive. In other words, the area, between the raw water spectrum and spectrum following each unit process of treatment can be added for a succession of processes.

It is claimed that the spectrophotometric method offers opportunities for the rapid determination of the purification efficiency of various steps in the water treatment process and can identify break-downs in the treatment.

The Treatment Plant of the Future

According to M/s Sorsica and Lindsey, the future water treatment plant laboratory will be equipped with an automatic analyser where samples of both raw and finished water will be continuously analysed and the results of analysis with the flow data will be fed into a computer mechanism. The computer, in turn, will adjust the dose of the coagulant (lime or other chemicals) as well as the proper dose of chlorine for disinfection to produce water of the pre-determined quality, in regard to residual turbidity removal or hardness and tastes and odours. In the case of hard waters, a portion of water will be passed through a demineralizer, operating along electro-osmotic principles and recombined with a second portion which has been merely clarified to secure a pre-determined final product containing just the right amounts of chemicals desired in solution.

Chemicals in liquid form will be used in large plants. The solution of chemicals will be pumped to a point of application eliminating the need for chemical houses.

Filters will be back-washed automatically, on the basis of maximum loss of head and the washing period will be governed by the turbidity in the waste water. Rate of back-washing be controlled by sand size and expansion.

Safeguards will be provided all along the treatment path to detect and prevent errors in operation.

Operating controls will be centralised in chemical laboratory where a complete instantaneous picture of operation will be recorded on a continuous strip chart. Operator's duties will consist of checking calibration of various devices, renewing standard reagents in analysing equipment, ordering chemical supplies, preparing statistical reports and supervising maintenance.

The operator of the future will be a process supervisor, who will be a trained engineer with a complete back-ground in sanitary engineering plus knowledge of electronics and automatic operation.

The electron microscope will continually scan the final effluent and with a television feed-back will control disinfection or sound an alarm to the community if the disinfection process fails.

Automatic recorders may be installed in impounding reservoirs to note the changes in the quality of the water from season to season. This will help the operator in adjusting the dose of the coagulant to suit the changing characteristic of the raw water.

Conclusion

In conclusion, it may be stated that yet, a good deal regarding the economical design of water treatment plants to suit different types of water has to be learnt. Their operation and maintenance, which is to-day of a rather poor quality has also to be improved. A good deal depends upon the operator of the plant. If he is not vigilant and careful, the quality of water supplied to the consumer may not be as desired resulting in the impairment of public health. Operation of the plants is therefore as important as their design. All energies and resources must be concentrated in changing the 'Art' of water treatment into a perfect 'Science'.

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There is No New Method in Teaching How to Treat Water

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Problems in water treatment have endured for years. Problems in water treatment have aparently been solved, only to reappear subsequently for re-solution. Problems in water treatment arise and will continue to arise to demand solution, and to fill water works literature with accounts of their solution. Problems in water treatment demanding attention are not all in the water treatment plant, in the office, or in the laboratory. Some problems arise and remain in the classroom, in the method of teaching how to solve the problem. Any one with sufficient patience and understanding to consider this has been and continues to be a student, and possibly a teacher, of problems and of methods of water treatment. Each is experienced in learning and with definite ideas on how to transmit knowledge.

A new method of teaching how to solve problems in water treatment may result from a restudy of old methods of treatment. No one can teach without knowledge, for teaching is the transmission of knowledge. The teacher is at least tolerated, if not actually welcomed on a basis of equality and comradship, in most engineering and scientific organizations. A discussion of teaching methods in the solution of problem in water treatment is, therefore, in order.

A change in procedure in water treatment may be looked upon as progress since change is some times considered to indicate progress. Unfortunately, the change may be without direction. It may be forward or it may be backward. The change may be progression or it may be retrogression. Some educational methods are changing but the change is not universal. For example, significant changes are occuring in methods of teaching reading, language and mathematics. Knowledge of political geography and of current events is changing so rapidly that even the specialist can not keep pace with it; much less the teacher who must study and learn as he teaches.

Knowledge of reading and of language are being taught by new methods which avoid the necessity for memorising alphabets and words, for mastering grammar, for parsing sentences, or for conjugating verbs. It is even claimed that a vocabulary can be acquired, pronunciation conquered, and fluency attained rapidly, pleasantly, and effortlessly by new methods of teaching. It is claimed that similar progress can be made in the teaching of mathematics through logical reasoning without, for example, memorising multiplication tables or studying methods of long division

However, the art of reading and the science of mathematics are changing less rapidly than knowledge of political geography, of current events, or methods of water treatment. The teacher of the changing methods of water treatment may, therefore, justifiably change his methods of teaching less rapidly than the teacher of such relatively static subjects as reading, language or mathematics. Changes in methods of teaching about water treatment may, therefore, be less spectacular than methods of teaching more fundamental knowledge.

It is common to feel that a research project, to be satisfactorily concluded, must report a positive conbribution to knowledge. The project must produce a new and satisfactory method of water treatment, or a new method of imparting knowledge. To report that an existing method can not be improved or that an idea will not work attracts little or no attention. A technical editor might be reluctant to accept for publication an article entitled "A method for Softening Water that Won't Work" or "Potable Water Can't be Reclaimed from Sewage." This article will conclude: "There is no spectacularly new or easy method of teaching or of learning how to treat water," Such a conclusion is worth-while as it may prevent loss of time and effort, and avoid disappointment, in a fruitless search for a short-cut method of teaching in our field.

The teaching of methods of water treatment is generally confined to students who have attained basic knowledge in such science as mathematics, physics, chemistry, water bacteriology, hydraulics of water supply, mathematics as applied in water supply problems, and technical language and writing. Until recently, the student in a college of engineering has been trained as a specialist. For example, after four years of under-graduate study, he has become a bachelor of science in public health engineering, or in sanitary engineering, or in electrical engineering, or in mechanical engineering, or what else have you? The trend in education today is to provide the same curriculum for the first four years for all students in the same college. All engineers are taught the same subjects. Scientists are taught the same subjects as other scientists. All liberal students are equally polished. During the fifth year of academic subjects, specialists are developed. For example, the public health engineer, who is to solve problems in water treatment, is taught methods of solving problems in water treatment. Such teaching methods are based on the premise that the student's broader education and wider knowledge of basic sciences will lead to the development of new and better methods of water treatment. When knowledge of new, or different, methods of water treatment is acquired, the knowledge will be transmitted to others by such traditional methods as directly listening, looking, and doing. There are no newer ways to teach methods of water treatment.

An understanding of the meaning of the search for a new method of water treatment may be gained through a look at attempts to solve one of our oldest problems in water treatment such as, for example, purification by sedimentation. The problem of how to improve the quality of water by sedimentation has been at the fore-front in water treatment, since the first Chinaman put 'salt' into a bucket of water to clarify it. Few subjects lend themselves more enticingly to mathematical analysis or to chemical procedure than the removal of suspended particles from water by sedimentation. Successful methods have been attained by mathematical studies and by chemical tests. Even new structures have resulted from trial and error methods. Sedimentation basins have been designed and operated successfully to satisfy all assumed conditions. In all formulae, procedures, or methods unknown, a factor of safety, or an allowance must be made for a factor of safety, or an allowance must be made for uncertainties.

For example, in a study of sedimentation, Fair and Geyer, in "Water Supply and Waste Water Disposal" state that in sedimentation basin

$$h = h_o \; v_s \; l/h_o = v_s \; A/Q$$

where h is the vertical distance that a settling particle drops while flowing a horizontal distance l_0 in the sedimentation basin, and other nomenclature is given by the authors. The conditions to which the formula is applicable are carefully delimited. For example, the flow is quiescent, the particles are discrete, the continuous phase is a liquid, and the temperature is constant. If these and other conditions exist, and none others interfere, the particle will behave as the formula indicates. However, no widely applicable method of water treatment by sedimentation can be based solely on this basic and simplified formula, because conditions in sedimentation basins vary widely. Another well-known authority in water-treatment, Camp (as quoted by C. V. Davis in "Handbook of Applied Hydraulics," p, 962) in Trans. ASCE, 1946, p 895 states:

"The following simplifying assumptions are made to develop the theory for the ideal rectangular basin:

1. The direction of flow is horizontal, and the velocity is the same in all parts of the settling zone. Hence, each particle of water is assumed to remain in the settling zone for a period equal to the retention period.

2. The concentration of suspended particles of each size is the same at all points in the vertical plane perpendicular to the direction of flow at the inlet of the setting zone.

3. All suspended particles maintain their shape, size and individuality during settling and settle without interference. Hence each particle is assumed to settle at constand velocity for a given temperature.

4. A particle is removed when it strikes the bottom of the settling zone.

The restrictions and limitations are many. No acceptable formula of general application has been developed without unknown or uncertain constants, coefficients, or other limitations."

It can be accepted and concluded, therefore, that there is no new and universally adopted method of treating water by sedimentation. Hence there can be no new method of teaching how to settle water by sedimentation. What we do not know we can not teach. Such a conclusion is not altogether discouraging because the student, the practitioner, the researcher, and the teacher can anticipate continuing problems requiring solution in the field of water treatment. There is no new, short-cut method in the teaching of how to treat water. Knowledge must be transmitted by showing, telling, and doing, as it has been transmitted in the past.

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Water—What It Matters For A Plater

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Introduction

"It little matters, actually how we eulogise water. Just so long as a single city must do without because chromium plating waste was dumped thoughtlessly into its supply; just so long as entire areas are reduced to shortage; just so long as industry's costs rise because of poor water, just so long we do commit flagrant abuse against ourselves" *

It is really a fallacy to note that, though water is used universally for electroplating and metal finishing processes such as anodising, little care has been given to the treatment of water to make it suitable for plating and to the savings effected thereby. Proper use of rinse waters and well planned engineering in plating industry for reuse of the waters used up in rinsing tanks and heat exchanger units has been shown (1) to reduce the total consumption of water to nearly half the amount used before such steps were taken. Particularly when our Country is heading towards industrialisation on all fronts, it is apparent that water will become more expensive unless and until an economic method of desalting sea water is accomplished. Even though it is obvious that location of an electroplating plant, for which water is especially important, should be at a site (2) where water supply is: (i) abundant for a long time to come; (ii) available at sufficient flow rates and pressures to meet all demands; (iii) water is soft with less of dissolved solids and organic contaminants; it has not been possible to execute the same for various other reasons such as availability of electric power, the importance of the plating unit in the major industry, etc. Naturally a responsible electro-plater should strive his utmost to (i) find economic use for water; (ii) avoid wastage; and (iii) study the plant operations and find methods for reusing water after treatment. Apart from these facts, he has to be conscious of the control of effluent water before it is allowed into sewerage or near-by water course. There is no specification available in literature for water used in electroplating in-

* Bug. Clyde Kelly in **Plating**, August, 1955.

dustry but an experienced plater will easily understand how untreated water can act as a source of perennial trouble such as causing 'water spots' and stains on finished products, entrapping of dissolved solids in anodic sealed coatings and hence reducing their resistance to corrosion, increasing plating troubles, in adversely affecting the performance of cleaning solution, in forming scales in cooling and/or heating pipes, etc. In this connection, it is interesting to record that a continuous source of trouble in an acid zinc plating bath was finally traced to be due to organic contamination in the raw water used for making up evaporation losses (3).

Need for Water Treatment

Evidently before one decides on a method of treatment of water for his purpose, he must know the impurities present in the available water supply, the effect of these impurities on his contemplated work and the degree of purification needed. The source of raw water supply for the plating industry may be from the municipalities where the industry is located or from privately owned wells and springs. The impurities generally are dissolved mineral solids, organic contaminants, dissolved gases, turbidity and micro-organisms. The harmful effect of these impurities for the particular plating work depends on the nature and amount of these impurities present and the tolerance of these impurities for a particular plating or anodising operation. A hard water has to be demineralised if it is to be used for rinsing and cleaning purposes, whereas it will be enough to exchange cations in the raw water with sodium if it is to be used for plating bath make up, provided the plating bath has wide tolerances for anions present in water. To illustrate this (4), let it be assumed that water from a raw water supply for a plating shop dealing in chromium, copper, cadmium and zinc (from cyanide baths) and tin (from stannate) is having a hardness 82 mg/lit. expressed as $CaCO_3$; silicon, 6 mg/lit.; dissolved total solids, 182 mg/lit.; chloride, 10 mg/lit.; sulphate, 100 mg/lit.; and pH, 6.2. This water is only slightly hard and can be used for general purposes and the total solid contents may be satisfactory for plating baths make up. But for cleaning and rinsing purposes, it may leave behind water spots and water stains in the finished product; and, in sealing anodic coatings, it may be detrimental, reducing the corrosion resistance of the coating. It has been shown (5) that, where anodic sealing rinses are carried out with deionised water, the resistance to salt spray test is as high as 2,000 hr. Hence this water has to be demineralised for use in rinse line and sealing line in order to improve the quality of the finished work and to have a better control. It is apparent now that a complete analysis of the water supply and a thorough understanding of its harmful effects on the products are quite important.

Probable Impurities in Water Supplies

The nature and amount of the impurities will vary from source to source and, at times, from season to season. The common impurities that may be present in any raw water are generally calcium, magnesium, sodium, potassium, iron, manganese and lead as cations; chloride, sulphate, nitrate, bicarbonate, silica, fluoride as anions; and dissolved gases like carbon dioxide, oxygen, occasionally hydrogen sulphide and sulphur dioxide (6). Turbidity and organic contaninations are also normally present in many of the raw water supplies particularly in surface waters or lakes. These waters are generally loosely classed as very soft, soft, moderately hard, hard, very hard and extremely hard which, even though giving some qualitative idea of comparison, is unsatisfactory as the tolerances for hardness may vary for different industrial uses or even for different processes in the same industry as shown earlier. Water which may be considered harmless for a particular plating process may be highly detrimental for another plating process, since many plating processes are highly sensitive even to trace impurities. This leads a plater to equip himself with a complete knowledge of the trace impurities in a particular plating process.

Effect of Impurities in Plating

Although literature on the deleterious effects of the impurities in a plating bath is abundant, there is no clear specification as to the tolerance of the impurities in a particular plating process. Even when specifications are available, sometimes there is no agreement on the limits by different investigators (7-9). A brief discussion of these effects will not be out of place as it would help the plater to have a proper choice of water treatment for his purpose in view and to have a better control.

Plain cyanide baths are fairly tolerant to many of the impurities present in raw water, provided it is soft or moderately hard, but bright cyanide baths are highly sensitive to some of the impurities. Turbidity and too much of silicon in raw water is harmful in any bath as it leads to pitted or porous deposits reducing the resistance of the coat to corrosion. Organic contaminants particularly in high speed cyanide copper or bright cyanide plating baths, produce pitting and non-adhesion of subsequent coat (10).

Copper Cyanide Bath : In copper cyanide baths, calcium or magnesium in water have a tendency to precipitate out and hence lead to porous deposit (9). Iron beyond the range of 500 mg/lit. precipitates out as ferrocyanide giving a coarse deposit with a poor anode efficiency (7, 11). Further, removal of iron from this bath is rather difficult (5) and hence it is advisable to keep it within these limits. Hexavalent chromium, in even a few mg/lit. concentration, is very harmful (7), however, its presence in water is rather very remote. Lead, in traces, causes a non-uniform deposit (10) and the subsequent nickel coat will peel off because of poor adhesion of copper to basis metal. Silica, if present, produces a spotty dull deposit of copper and impairs plating efficiency. Organic compounds, particularly sulphur compounds, are the main causes for streaky, pitted or burnt deposits (11-12).

Fluoborate Acid Copper : In fluoborate copper, presence of sodium or potassium beyond a limit lowers the brightness of the deposit (13). The presence of potassium, sodium, iron or manganese lowers the limiting current density for plating, and traces of chloride (11) are harmful and better kept within 50 mg/lit. in copper refining.

Cadmium Cyanide : In cadmium cyanide plating baths, iron greater than 4,000 mg/lit. causes a hazy deposit as it may precipitate out as ferrocyanide (7); in amounts greater than 3,000 mg/lit. produces stains and reduces throwing power of the bath. Silver, lead, tin, thallium, antimony and arsenic are most harmful metallic impurities in cadmium cyanide bath. Carbonate is allowed to build up to a maximum limit of 50 gm/lit. Beyond this limit, it reduces the plating current density range. Organic contaminants lower the resistance to corrosion as formation of pitted, porous deposit is favoured (11).

Silver Cyanide : In silver cyanide plating solution, the presence of chloride in amounts greater than 25 mg/lit. markedly affects the corrosion resistance (16). Iron beyond 300 mg/lit. produces stained, discoloured deposit (9). Organic impurities produce a streaky, dark deposit (7).

Zinc Cyanide Plating Baths: : In plain zinc cyanide baths, no deleterious effects are caused by the presence of lead, cadmium, tin, copper or iron, the limit of tolerance being fairly high (10). But in bright zinc plating, lead, in concentration greater than 5 mg/lit., dulls the brightness of the plate (10). Iron, 10 mg/lit. leads to rough deposit and lowers the current efficiency (17). Copper, in amounts greater than 80 mg/lit. causes dullness of the deposit (7) and, in amounts greater than 300 mg/lit. darkening of the deposit is observed. Calcium, magnesium and manganese cause nodular and treed deposits in acid $ZnSO_4$ baths. Chromium and molybdenum in traces (5 mg/lit.) produce blistering in high current density areas (10). Organic contaminants favour porous deposits and poor adhension and hence cause trouble in subsequent steps.

Acid Zinc Sulphate Baths : Copper, in amounts greater than 0.0032 oz/gal, is stated to cause needle like growths and spongy dark coating at low current density areas and is deposited preferentially in higher concentrations (21). Iron, in concentration exceeding .008 oz/gal., reduces the cathode efficiency (21).

Chromium Plating Baths : It is well known that ferrous iron, zinc and copper build up in concentration in a chromic acid bath. When iron exceeds 400 mg/lit., it reduces the already poor throwing power and increases the cell resistance resulting in increased power consumption (18-20). Chromium (trivalent), copper, zinc and other metallic impurities have deterimental effects on plating (19). Sodium and magnesium, it is reported, reduce the throwing power of chromium plating baths when present beyond certain limits (18). The presence of chloride and nitrate narrows the bright plating range (7); whereas sulphate, since it alters the optimum ratio of CrO_3: SO_4, has all the deleterious effects associated with the change in ratios and makes control of the bath difficult (11, 18). Organic impurities are easily oxidised by chromic acid and therefore increase the trivalent chromium concentration which has the effect of reducing the throwing power and conductivity of the electrolyte (7, 21).

Nickel Plating Baths : Nickel plating baths, particularly the modern bright nickel baths are very sensitive even to traces of impurities and the literature is also abundant on this subject.

Calcium (24) or magnesium (9, 22, 23, 25) when they form a precipitate, lead to pitted deposits and hence poor resistance to corrosion. The limit accepted is about 300 mg/lit. Magnesium, if present in solution, favours the formation of soft bright deposits (9, 25, 26). As the presence of sodium or potassium or NH_4 leads to hard brittle deposits (7-9) their presence is considered undesirable. The tolerance limit for iron in a bright nickel bath has been quoted from 20 to 100 mg/lit. by different authors (7-9). It has been found that embrittling, peeling and flaking of nickel can not occur within the pH range 3 to 6 if the specified pH of the bath is carefully controlled, but a very unfavourable effect occurs at low pH, 2-3, baths even with traces of iron. The main effect of iron in the bath is to cause stressed deposits leading to peeling (10, 26). In high pH baths, it may form precipitates in the cathode film leading to pitted or streaky deposits. It is better to remove iron from the make up water. Bright nickel baths are very sensitive to traces (7 mg/lit.) of copper (8, 23, 28). In a plain Watts bath, the tolerance is fairly high. The effect of copper is to decrease ductility and to cause dark deposits at low current density areas (26). Manganese, even in traces, produces rough deposits (23). Aluminium in amounts greater than 50 mg/lit., leads to darkening of the deposit (25, 29). Certain anions like nitrates, phosphates (30) silicates (7) and carbonates (17) also affect the physical characteristics of the nickel deposits. Nitrate has adverse effect on anode current efficiency, also tends to give cracked deposits and to reduce the throwing power. Carbonates, in high pH bath, have a tendency to precipitate out basic salts of nickel and iron, etc., in the cathode film which are included into the deposit (29). Hence the deposit has a tendency to crack and to have poor resistance to corrosion. Silica precipitates out leading to pitting (7). Similarly fluoride, when calcium is also present, precipitates out as calcium fluoride which naturally leads to rough deposits (9). Some metals like cadmium and zinc (10 mg/lit.) are used as secondary brighteners (27, 31), but when their concentrations exceed the limits or, when they are without the first class of brighteners, produce cracking and peeling at high current densities and darkening of deposit at low current densities. Lead even in amounts greater than 2 mg/lit. leads to brittle deposits after annealing and hardness of the deposit is decreased (30). Trivalent or hexavalent chromium (27) (20 mg/lit.) have harmful influence on cathode efficiency, hardness and corrosion resistance of the nickel deposit (39). Any organic contaminant is harmful in bright nickel baths and is to be definitely kept out.

Cleaning And Rinsing : Cleaning baths generally contain carbonates, silicates and phosphates. A hard water, when used for making up such baths, will give a precipitate, and cleaning efficiency is reduced, causing troubles in subsequent plating (32). Further use of hard water for cleaning make up leads to wastage of chemicals. It is therefore, always a good practice to use waters of zero hardness for cleaning bath make up.

The rinse water should always be zero hardness water in the first rinse otherwise the calcium, magnesium, iron and manganese may form a precipitate on the surface with the anions carried over and will cause trouble in plating. The second rinse should be with the demineralised water (33).

Anodising Aluminium : Demineralised water is the best for anodising aluminium (34, 35) and also for sealing anodic coatings (5, 34) as already stated. In a recent article on the influence of sealing water impurities on anodised surfaces of aluminium, Richard (36) has found that: (i) copper and iron, 200 mg/lit. and silicates, 100 mg°lit. considerably increase the conductance of the oxide film which indicates poor sealing; (ii) phosphate and silicate, 5 mg/lit. and iron, copper, calcium, magnesium, fluoride and hypochlorite, 50-200 mg/lit. favour penetration of ink into sealed anodic coatings; and (iii) chemical resistance of the oxide film is reduced by sealing in water containing copper, 10 mg/lit.; silicates, 10 mg/lit; phosphate, 5 mg/lit; and fluoride, 30 mg/lit. It is the authors' experience that even traces of chloride have very deleterious effect in 'forming' aluminium capacitor foils and utmost precautions have to be taken to keep the chloride ions within 5 mg/lit.

The dangers of using hard water in heating or cooling coils are well known. The scale forming and enhancing of corrosion rate are more serious troubles in these cases.

From the preceding paragraphs, it is apparent that for most purposes, deionised water is the best to be used and in some cases the second best being zero hardness water. Thus for any plating industrialist, water treatment is essential although particularly, at present this aspect is neglected. It is not enough to go in for fine chemicals and plating salts but it is equally important to pay great attention to water that is being used.

Methods Of Water Treatment And Choice For Electroplating

Industrial water conditioning processes can be classed broadly as: (i) Ion-exchange processes; (ii) Lime-soda processes; and (iii) Physical methods which may be further classified as:— (a) Sodium cation exchange process; (b) Hydrogen cation exchange; (c) Demineralisation or Deionisation; (d) Cold lime soda process; (e) Hot lime soda process; (f) Coagulation, Sedimentation and Settling; (g) Aeration; (h) Deaeration; and (i) Distillation.

A number of factors have to be considered for a proper selection of the process or a combination of the processes. As far as an electroplating chemist is concerned, he has to consider the following essential factors, the purity desired for the end use and the most efficient process or a combination of the processes which will give this desired purity and of course the cost of such treatments.

The purity of the water required for electroplating and metal finishing has already been dealt with. To achieve this end, the ion-exchange processes stand out foremost (38) combined with activated charcoal treatment and/or deaeration (3). The ion-exchange processes have the definite advantages over the other processes in this particular application (39, 40) such as uniformly higher quality water of zero hardness (or completely deionised) with an equipment which is simple, elegant and has a size adaptable to any desired load. Regeneration of resins is easy and cheap with the added advantage of reclaiming metals or metal salts from the rinse waters. The water which is thus obtained is purer than raw water and can be reused and in the long run it pays for the equipment and works on profit. But organic contaminants can not be eliminated by these processes (3, 41); and hence, if it is desired to remove these contaminants, this process is preceded by activated charcoal treatment. In order to get the maximum benefit out of an ion-exchange treatment in plating industry, the industry should be provided with: (i) save rinse tanks; (ii) counter flow rinsing; and (iii) separate drains for chromic acid rinses, cyanide rinses and the rest.

Water Conditioning By Ion-Exchange And Charcoal Bed

The basic principle of the ion-exchange process is quite simple and essentially a two step process.

M^+ + H or Na ion exchanger ... H^+ or Na^+ + M^+ ion exchanger (spent resin)

A^- + anion exchanger ... OH^- + A^- ion exchanger (spent resin)

and during regenerations

M^+ spent resin + H_2SO_4 or NaCl ... H^+ or Na^+ ion exchanger +M^+ SO_4 or M^+ Cl

A^- spent resin+ NaOH ... anion exchange + Na^+ A^-

The ion exchange processes selected for water conditioning in the plating industry may be any one of the following systems principally determined by the installation cost and the end use. The four systems are (42):

(i) Two bed systems (a) Cation—weak base anion; (b) Cation-weak base anion— aeration; (c) Cation—strong base anion; and (d) Cation—aeration—strong base anion.

(ii) Mixed bed system.

(iii) Cation exchange—aeration—mixed bed system; and

(iv) Four bed system.

In the zeolitic process (sodium cation exchanger), the reaction during conditioning is

$$\left.\begin{matrix} \\ Ca \\ Mg \end{matrix}\right| \begin{matrix} (HCO_3)_2 \\ So_4 \\ Cl_2 \end{matrix} + Na_2z \rightarrow \begin{matrix} Ca \\ Mg \end{matrix} \left| Z + Na_2 \right| \begin{matrix} (HCO_3)^2 \\ So_4 \\ Cl_2 \end{matrix}$$

and during regeneration

$$\left.\begin{matrix} Ca \\ Mg \end{matrix}\right| Z + 2\ NaCl - 2\ Na_2\ Z + \begin{matrix} Ca \\ Mg \end{matrix} \left| Cl_2 \right.$$

The efficiency in removing hardness goes down as the initial hardness of water increases and the hardness of the effluent water is 3, 20 and 40 for an initial hardness of 514, 1028 and 2056 respectively.

The hydrogen cation exchangers are of organic type and are more effective than the zeolites, but the approximate operating cost is nearly twice that of zeolite process.

In the anion exchangers, the reactions are $R_3N + HB - R_3N\ HB$ during exchange and $2R_3N\ HB + Na_2CO_3 - 2\ R_3N + 2\ NaB + H_20 + CO_2$ during regeneration. Of the two types of anion exchangers, the former can not remove weakly basic anions such as bicarbonates or silicates. The strong base anion exchanger is efficient in removing these weak acids almost completely but the operating costs of a strong base anion exchanger is nearly three times that of the weak base anion exchanger for same amount of anion removed.

For an efficient and economic operation, the different exchange processes are combined in different ways. Factors affecting the costs of the various ion-exchange systems are: (i) Cost of regenerant chemicals; (ii) Water for regeneration; (iii) Resin amortization; (iv) Equipment amortization; and (v) Power and labour.

In the two bed system, the cation--weak base anion exchanger is the most economical and will be sufficient if the presence of silica and dissolved carbon dioxide is not objectionable in the end use or if the raw water contains these impurities within tolerance limits. If carbon dioxide is to be removed, a step of aeration follows the above system in which the effluent water from the ion exchangers passes through a forced draft decarbonator. The cation — strong base anion exchanger removes silica as well but the *p*H of the effluent water is slightly on the alkaline side. The cation strong base anion exchanger system is the best system if highest purity is expected from the ion-exchange treatment. The choice of mixed bed system and the combination system is justified if very low (1.1 to 1.0 mg/lit) dissolved total solids is the permitted limit in the treated water in spite of the added cost. If the bicarbonate alkalinity or dissolved carbon dioxide is in excess of 25 per cent of total anions, cation-aeration mixed bed system is the most economical, as the first step reduces the load on the mixed bed system and increases its efficiency. Where the raw water has a relatively high dissolved total solids exceeding 300 mg/lit., the four bed system is the best choice.

Hence as already stated, it has to be emphasised that the choice depends on the nature of raw water available and the degree of purity required. For most purposes in the plating industry, the mixed bed system of deionising strikes a mean between the operating costs and degree of purity desired and is most generally used.

The ion-exchange processes can not remove the organic contaminants in raw water and it is well established that the presence of these organic contaminants proves a source of continuous trouble in most of the modern electroplating and anodising baths. If the raw water or the rinse water for reuse is given an activated carbon treatment (3) before entering the ion exchangers, it not only removes the organic impurities but also protects the resin from weakening in their ion absorptive capacity due to poisoning of the resin by these organic contaminants.

The activated charcoal treatment is quite familiar for an electroplater as he uses it for purification of electroplating baths. The same type of treatment is given for raw water before deionisation or the rinse water effluents; normally 10 parts of activated carbon granules of mesh size 12 to 20 are required for 1 part of organic contaminants to be removed.

Economic Use Of Water

Economic and prudent use of water can be achieved if an electroplater trains himself to observe the following rules:

(i) Prevent leaks, spray losses, etc.;

(ii) Recover the spent water for recirculation; and

(iii) Treat the wastes for salvage after all other possibilities have been exhausted.

The first rule can be followed by giving proper engineering design and careful handling. Since rinse tank takes the major share of the plating industry, careful design of the rinse tanks such as use of counter flow rinse, application of fog or spray rinses at the exit of plating tank, adaption of still water save rinse immediately after the plating tank and a clean house keeping are main factors to be thought of in advance before installing the industry. The possibility of cooling waters or steam condensates from heating system should not be overlooked wherever it is acceptable. These steps not only avoid wastage of water but in the long run also reduce the operating cost.

Deionised water is used for rinses. If a save rinse is used, the rinse water after save rinse is much purer than raw water and contains only the salts from the cleaning or the plating tanks. By using multiple counter current rinsing (40, 58) the load on the resins and for treating the final rinse waters will be minimized. If separate drains are used for the rinse waters from each tank, the recovery of the metals or the metal salts is possible. In many instances, it has been proved that the invested capital on water treatment equipments has been repaid in a short time (46).

Thus if nickel recovery is contemplated by ion-exchange process using ion exchanger and sulphuric acid regeneration for recovery of nickel sulphate, it has been calculated that the cost of the equipment will be recovered in less than 5 months. If the effluent from ion exchanger is then fed through a weak base anion exchanger (which is quite sufficient since the rinse waters do not contain silica, etc. and contain less amount of dissolved total solids), the water coming out of the anion exchanger can be reused for making up the drag out and/or evaporation losses in the plating bath or for rinsing purposes.

Similarly in chromic acid recovery plant, the paid up capital for the water treatment equipment can be realised in less than 3 years.

This plant recovers (i) the costly chromic acid which hitherto has been sent to plating waste treatment plant for destruction of hexavalent Cr to prevent pollution of the water in the area; (ii) the spent chromic acid plating bath, as it is now possible to treat chromic acid bath without dilution prior to treatment; and (iii) the spent water is revivified and at the same time discharge of hexavalent Cr in the effluent from the industry is kept within the limit specified (47, 59).

For cyanide plating baths such as zinc, brass, copper, etc., ion-exchange method has not reached the stage of commercial installations yet, because the treatment of plating solutions is not feasible economically. However, waste metal recovery from rinse waters from zinc, copper and other cyanide baths and reuse of water in making up drag-out and evaporation losses in the cyanide baths have been practised economically (47,59).

It has been shown that evaporation method for recovery of wastes from zinc cyanide baths and reuse of the condensate water in the closed cycle has resulted in a nett gain of $ 607 per 24 hr run, whereas the cost of operation of conventional destruction method (33) runs to $ 74-35.

Ion Exchange Processes For Recovery Of Plating Salts

Because of increased knowledge of salvaging plating salts by ion-exchange processes and the resultant savings in the metals and the metal salts together with the improved economy in water consumption and efficient abatement of water pollution, the trend towards recovery of waste products from rinse waters by ion-exchange techniques is becoming widespread. Thus cadmium, (54), copper, (47, 61) nickel, (48, 57) chromic acid from plating (49, 57) and anodising baths, (50) noble metals like silver (51) and gold (52) have been economically recovered from rinse water and the effluent water is re-used. The ion-exchange treatment for recovery of water and the metal salts has an increasing demand in the metal finishing industry because of the following advantages (38, 53).

(i) The operating expenses for producing demineralised water are reduced, since processing of rinse water in lieu of raw water processing is easy and cheap;

(ii) The operating labour for operating a batch destruction plant on a once thorough rinse system will be heavily reduced if ion exchange equipment is used;

(iii) The regenerant effluents from the ion-exchange equip-

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Problem of Brackish Water in Vidarbha

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Since early times, man has been intrigued with the possibilities of simple and economical processes for conversion of saline waters for satisfying ever-growing needs for water for personal, industrial and agricultural purposes.

Three-fourth of the earth's surface is covered with saline water, and the problem has been, its conversion in a form convenient and suitable for the use of man, at an economical cost.

Over a long period of time, this problem has received sporadic attention but not very satisfactory answers from both the view points of quality and cost of water have been developed. The growing demands for more and more acceptable water, rapidly exhausting the natural sources, and man's activity into regions not supplied with natural sources, creating a need for development of water supplies, have now combined to require intensive development of saline water conversion processes.

Many countries like U.S.A., Australia, Holland, Japan, France, Germany, U.K., Israel, Italy and South Africa have been actively engaged on this important problem and the methods generally studied and employed are:

(i) Distillation by Thermal Compression;

(ii) Solar distillation;

(iii) Electrodialysis, Membrane & Osmosis processes;

(iv) Freezing;

(v) Ion-Exchange; and

(iv) Chemical treatment.

The position in this respect in India is quite alarming. Even in the interior there are regions where the ground water available is so rich in salts that this is unfit for any utility. The low rainfall and non-availability of surface-waters make the situation still worse even to the extent that at some regions, no well, yielding fresh, potable and even tolerable water for drinking is noticed for miles together and people are left with no other alternative except to satisfy themselves with salines, especially in summer when the few available surface water resources have also dried away. Such brackish water tracts stretch for hundreds of miles and there are a dozen such tracts in Maharashtra, Rajasthan, Punjab, Andhra Pradesh, Madhya Pradesh, etc.

Brackish waters predominantly contain salts of calcium, magnesium, sodium and potassium in the dissolved state in the form of chlorides and sulphates, etc., and these interfere with the quality of drinking water.

The various methods to demineralize such waters have already been listed and the applicability of a particular method is dependent upon the conditions of a specific case.

Thus the problem of sweet water supply to the inhabitants in brackish water tracts is an urgent and important one and conversion of these brackish waters into waters fit for human consumption becomes of paramount importance.

Before any such scheme is taken up, it is necessary and important to have a clear picture of the extent of brackishness in various saline tracts for the purposes of evaluation of the most suitable economical method for their treatment. With this aim in view, the brackish water belt, covering the districts of Amraoti, Akola and Buldhana in Maharashtra State was selected for the preliminary studies.

A survey covering wells in 450 villages in Amraoti, Elichpur, Daryapur, Akot, Akola, Multizapur, Balapur, Malkapur, and Khamgaon talukas of these three districts was taken up. Samples from about 1400 wells in 370 villages were collected and analysed chemically.

The items estimated are:

(i) Colour;

(ii) Odour;

(iii) *p*H;

(iv) Total dissolved solids;

(v) Alkalinity as $CaCO_3$

a) Phenolphthalin,

b) Methyl Orange;

(vi) Hardness as $CaCO_3$

a) Temporary,

b) Permanent;

(vii) CaO;

(viii) MgO;

(ix) Chlorides; and

(x) Sulphates.

The survey brings out the following important points:

(i) The whole region is covered by underground salt deposits. The subterranean water picks up the soluble salts from the deposits during its passage and the wells yield only this brackish water, resulting in dearth of fresh water. The concentration of the salts dissolved depends upon concentrations of salt deposits, time of contact, distance traversed, temperature, surface pressure, porosity of soil, etc.

(ii) The salts dissolved in water are chloride, sulphate, and carbonate of sodium; and chloride, sulphate and bicarbonate of calcium and magnesium. The sodium salts are present in high concentration in form of chlorides.

These dissolved salts can be conveniently expressed in terms of their ionic loads, i.e., cations and anions, particularly when dealing with water with high dissolved solids. Removal of brackishness can be achieved only by reducing these two parameters, i.e., cations and anions loads generally expressed in terms of calcium carbonate simultaneously.

The following Table gives the maximum values of ionic loads observed in well waters in various talukas in terms of $CaCO_3$.

Taluka	Cation load	Anion load
Amraoti	17315	16005
Daryapur	11724	11044
Elichpur	7531	6831
Akot	9390	2554
Akola	11953	11793
Murtizapur	10419	9639
Balapur	5173	4653
Malkapur	2707	2247
Khamgaon	3980	3422

Note: Maximum recorded values in mg/lit.

The optimum limits adjudged for economical demineralisation normally are 1,000 and 800 mg/lit. respectively.

It has been our endeavour to reduce the ionic loads to within the permissible range by setting up small demineralisation plants in the villages. A calculated portion of the water quantity required for a community will be demineralised and this demineralised water will be blended with the raw water so as to keep the total dissolved solids within 250 mg/lit. The cost of demineralising water being directly proportional to the dissolved solids content, the raw water should not have more than a particular concentration of dissolved salts so as to keep the process economical and within the reach of villagers.

The important points to be considered when selecting a water source are:—

(i) Water Quality: Should be within the permissible limits

(ii) Water Quantity: The source should yield sufficient water to meet the demands of the community throughout the year.

(iii) Accessibility of source: Source should be conveniently approachable by vehicle during all seasons and should not be much in the interior so that no difficulty for transportation of materials and regenerants is presented.

(iv) Cost: As far as possible, the community should be able to contribute a portion of the cost.

Keeping in view the results of survey, considerations listed above and the suggestion and recommendation of Divisional Development Council, Nagpur, three places (i) Khartalegaon, (ii) Kutasa and (iii) Apatapa were selected for preliminary pilot plant studies.

A comprehensive survey was then undertaken of the various wells and bores in these villages, results of which are given in the Table following.

Khartalegaon

(Population: 2,700)

Well S. No.	hardness $CaCO_2$	Total alkalinity	Chlorides	Sulphates $CaCO_3$
1.	5660	650	7800	
2.	5000	540	4800	
3.	6850	410	5000	
4.	1800	540	1000	
5.	1600	280	1900	
6.	800	430	1700	210
7.	4300	530	3100	
8.	2000	530	3200	300
9.	500	670	450	200
10.	190	550	550	
11.	160	455	80	
12.	5600	530	4400	
		Kutasa		
		(Population: 4000)		
1.	3900	410	3700	300
2.	190	340	110	Traces (Sweet water stream)
3.	4900	430	4400	700
4.	4400	350	4100	600
5.	1100	220	2800	150
		Apatapa		
1.	900	550	2200	350
2.	400	350	600	250
3.	1300	100	4300	250
4.	400	350	1900	250
5.	200	250	75	Traces (Sweet water stream)

Note: All values: in mg/lit.

On the basis of this survey, it has been proposed to set up the 1st pilot plant in the village Khartalegaon at well No. 6, as the conditions and pre-requisites necessary for such a scheme are comparatively much better fulfilled at this place.

DISCUSSION

PROF. M. V. BOPARDIKAR (Nagpur): This problem should be solved economically whether it relates to individual wells or to a community water supply from wells yielding brackish water. The choice of the desalting depends on the amount of the salt content in water. For brackish water with a salt content up to 1,000 mg/lit., demineralisation by ion-exchange method, is economical. If the salt content is more than 2,000 mg/lit, the electrodialysis method is economical.

In India, there is no electrodialysis plant. During my visit to Phoenix and Buckeye, I was shown big electrodialysis plant which supplies water at the rate of 650,000 gal/day. The raw water contains about 2,500 mg/lit. of dissolved salts and the salt content, after treatment, gets reduced to 500 mg/lit. This is the largest electrodialysis plant in the whole world.

The Ionics Incorporated have constructed plants on similar lines in the world.

But the main question is to study the economics of the methods of desalting and compare it with that of the conventional method of bringing sweet water from distances of about 30-50 miles. As a case study, the State Public Health Engineering Department of the Maharashtra State estimated that it would cost about Rs. 3/- crores to supply 3 mgd. to a cluster of 400 villages, if sweet water should be brought from a distance of 30 to 40 miles from River Poorna.

Against this estimate, the present survey work was taken up with a view to work out the comparative cost of desalting the brackish water and supplying the processed water to the cluster of villages in the brackish water track. The study is not complete and we are making progress.

PROF. C. H. KHADILKAR (Baroda) : The method suggested for desalting by Prof. Bopardikar is very costly and not practicable.

PROF. M. V. BOPARDIKAR: These processes of desalting are to be adopted only when there is no other source of water in the particular area in question except the availability of brackish water and when the cost of bringing quality water from further places to this area in question is more than that of desalting process.

SHRI M. SUSIKARAN (Katpadi): I would like to know whether all possibilities of getting ground water of good quality have been explored.

PROF. M. V. BOPARDIKAR: The area under our study contains only brackish water and the degree of brackishness is high due to the salt content of about 1,000— 3,000 mg/lit. Water of good quality can be obtained only from places of considerable distance of about 30 — 40 miles.

SHRI D. B. WILLETS (Calcutta): Demineralisation by electrodialysis is costly. If the population to be served is not big, then solar distillation may be found suitable. This method has been tried successfully in foreign countries.

SHRI R. S. MEHTA (Nagpur): This is really a good suggestion by Shri Willets. This Institute has taken up the experiment of solar distillation and the method will be quite suitable during summer and can be adopted for small population.

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Preliminary Observations on Agra Water Works

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During the last several years, the water quality in Agra had deteriorated considerably in summer. The public had complained about taste and odour and frequent occurence of certain worms in tap water. A preliminary investigation, to assess the quality of raw water and the problems encountered in its purification, was carried out in the last week of June and is discussed in this paper.

Water Purification Facilities

Agra Water Works was started in 1880 with the installation of 7 mill gal/day slow sand filters. The capacity of purification units was increased gradually to 25 mill gal/day by the addition of several rapid sand filters of different types. The layout of the units and their capacities are shown in Fig. 1. Every summer, temporary earthen channel is constructed in river Yamuna to divert its flow towards the intake well.

The old sedimentation tanks, with a detention of about 24 hr and depth of nearly 5 m, have no regular desludging arrangement. The tanks are emptied once a year or two and cleaned manually. There is no provision for alum feed, but in summer, the water works staff was adding alum slabs in the inlet channel. Hopper bottom sedimentation tanks and Paterson rapid sand filters are provided with alum feed and flocculators with horizontal baffles. The Geo-Miller plant is provided with alum feed device and mechanical flocculators.

A composite sample of 60 cm core of Chambal sand from slow sand filters showed effective size and uniformity coefficient of 0.3 mm and 2.28 respectively. Gas chloronomes of 150 kg/day total capacity (equivalent to 2.1 mg/lit. chlorine dose in summer) are installed on different units for disinfection. A pipe with several openings is fixed near intake well to add $CuSO_4$ solution to raw water for plankton control.

Methods

The physico-chemical and bacteriological analysis of water samples was done according to the Standard Methods. All chemical tests except for sulphates, nitrates. and hardness were performed at site within 24 hours of sample collection. Because of the limitations of time and equipment during this field investigation, Tidy's test (oxygen consumed by permanganate) at 37 °C was conducted for determination of organic matter.

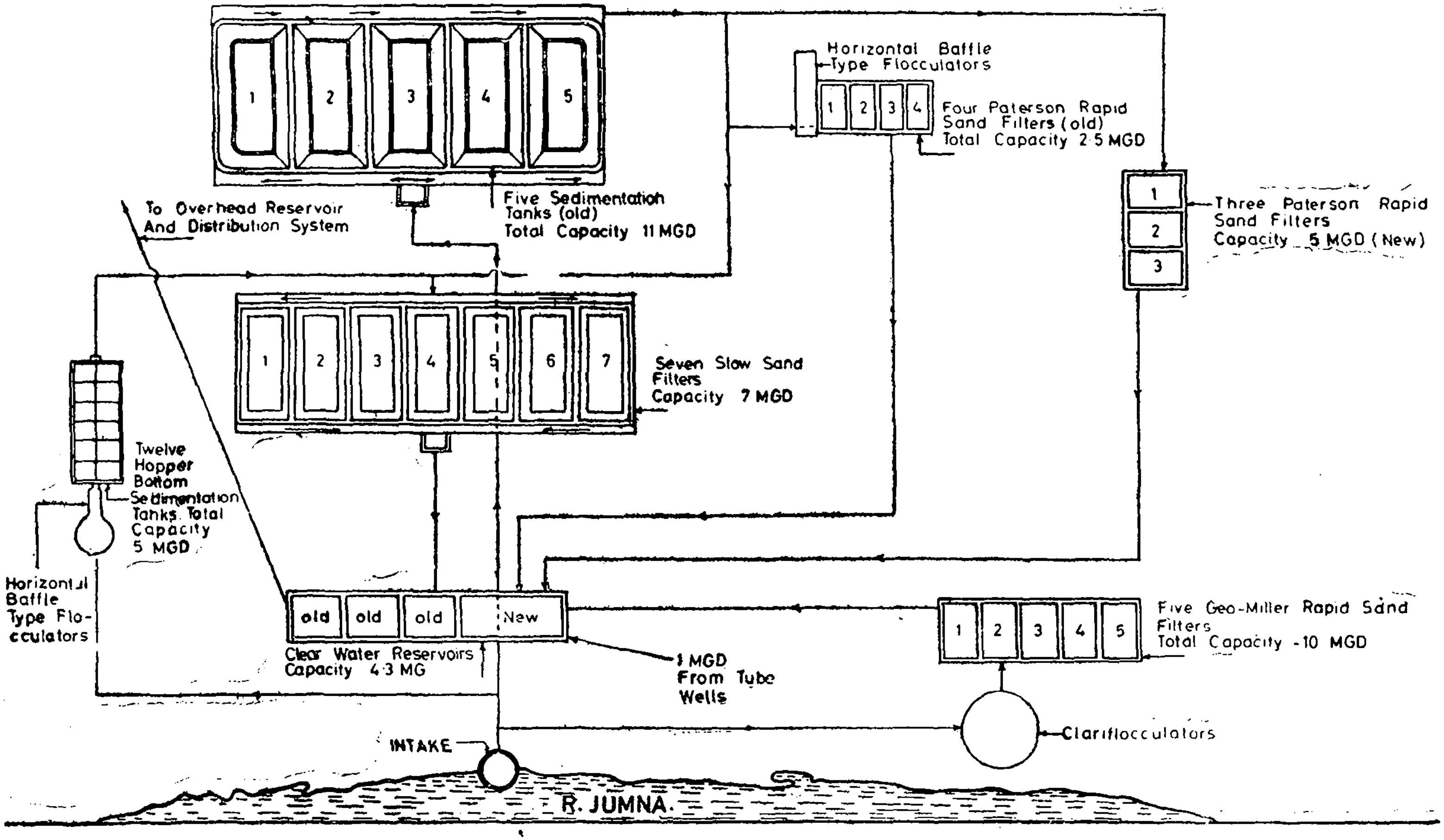

Fig. 1—Flow diagram of water purification units at Agra

Quantitative plankton estimation of water samples from the river was carried out by the inverted Microscope. Organisms present in the effluent of various filters and in tap water were concentrated by filtering one litre of sample through membrane filters of 0.45 μ pore size. Enumeration was done by the Drop Method and the number of organisms per litre was calculated. Ekman dredge was used for collecting the mud samples. Enormous amount of sand and debris coming at the intake impaired the algal count by Inverted Microscope. The algal count of raw water, therefore, is likely to be more than reported values. This would also explain certain anomalies in the data.

Bacteriological analysis was done by MF technique using enrichment and endo-basal media for coliforms and M-enterococcus agar for enterococci.

Observations And Discussions

Raw Water Source: Last summer, the minimum flow passing over Wazirabad reservoir was about 25 mill gal/day and in Yamuna near Agra intake, nearly 60 mill gal/day, about one third of which was pumped for Agra water supply.

In the 480 km river stretch between Agra and Delhi, sullage water from Brindaban, Mathura and several villages is discharged into the the river. A pumping station is provided at Mathura for lifting sullage to farms but its capacity is not sufficient and a part of sullage flows into the river. The cattle from the towns and villages on the banks of river stay in the river for the better part of summer and contribute organic matter. Some of the domestic and the industrial wastes from Delhi, Faridabad and Ballabhgarh might also be flowing into the river.

Water samples were collected from Wazirabad reservoir, overflow of Okhla weir, Hassanpur, Mathura and Agra, to study the change in physical, chemical and biological characteristics in the river between Delhi and Agra.

The results are presented in Tables I and II. The location of sampling stations and the relative characteristics of water are shown in Fig. 2. A gradual increase in chlorides and sulphates indicates industrial and domestic pollution of the stream though it may not necessarily mean the presence of organic matter. However, a gradual increase in Tidy's value from 1.02 to 4.54 mg/lit. shows the increase in oxidizable organic matter. The settled organic solids in slow moving stream may be suddenly buoyed up by the gases formed during anaerobic decomposition and thus cause an additional load on the purification units.

Plankton population at Okhla may be low due to the dilution from Hindon cut but it increased considerably at other stations. Another significant feature was the difference in the composition of the plankton population at different stations. At Wazirabad and Okhla, Myxophceae was not represented; while from Hassanpur onwards, there was increase in Myxophyceae indicating increased organic pollution in the river. A forty-fold increase in chlorides between Wazirabad and Agra accompanied by a seven-fold increase in sulphates and forty-fold

Table I—Physical and chemical characteristics of Yamuna water between Delhi and Agra

Sampling Station	BOD	Tidy's value	Chlorides as Cl	Sulphates as SO_4	Ammonia as NH_3	Nitrates as NO_3	Total Hardness as $CaCO_3$	Total Alkalinity as $CaCO_3$	pH
Wazirabad Reservoir	NA	1.02	6	21	Traces	Traces	105	81	8.20
Overflow from Okhla Weir	NA	1.62	12	16	„	„	113	90	8.05
Hassanpur	NA	2.88	48	45	„	Nil	117	106	8.55
Mathura	NA	2.57	152	101	„	Traces	244	191	8.35
Agra Intake	14	4.54	242	154	„	„	289	175	8.60

All values except pH are in mg/lit. NA—Values Not Available

Table II—Biological characteristics of Yamuna water between Delhi and Agra

Sampling Station	Coliform No per 100 ml	Enterococci No per 100 ml	Plankton Population/Litre							
			Chlorophyceae	Euglenophyceae	Bacillariophyceae	Myxophyceae	Unidenfied algae	Rotifera	Crustacean larvae	Total
Wazirabad Reservoir	49	Nil	1000	...	236000	...	...	3000	...	240000
Overflow From Okhla Weir	330	49	1000	...	49000	...	...	1000	...	51000
Hassanpur	110	50	234000	...	660000	492000	...	6000	6000	1398000
Mathura	NA	NA	75000	...	1395000	1185000	...	...	...	2555000
Agra Intake	1800	700	100000	15000	1035000	7200000	1290000	15000	...	9645000

NA—Values Not Available

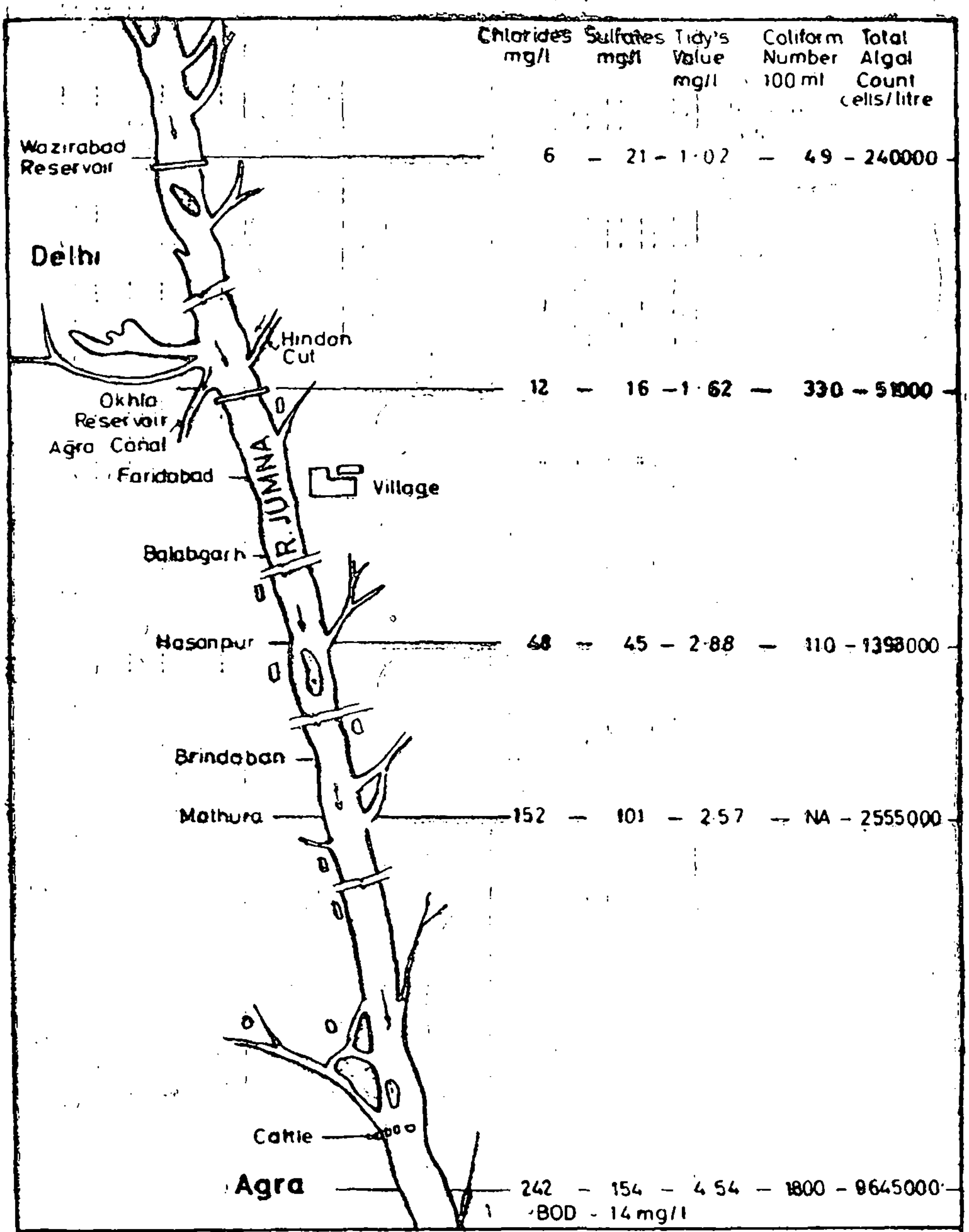

Figure 2 - Change In Quality Of Jumna Water Between Delhi & Agra

increase in coliform and algal counts is interesting.

Tables I and II show that the water quality at Agra intake was very poor. The BOD of raw water at Agra was 14 mg/lit. as against 6 mg/lit. maximum limit recommended in International Standards.

These observations establish that the upstream communities are responsible for polluting the water available at Agra. The extent of pollution caused by each community, the self-purification capacity of the stream, and the limit to which the organic matter can be discharged can be assessed only after carrying out a detailed stream survey in summer, at least between Brindaban and Agra, a stretch of about 150 km.

Water Purification Units

The physical and chemical characteristics of water from different stages of water purification are shown in Table III and biological characteristics in Tables IV and V. These observations are discussed below process-wise.

Flocculation And Sedimentation

The effectiveness of a coagulant and its proper dose in removal of turbidity and organic matter was studied by running jar tests on raw water. Two series of tests were conducted: the first with alum alone using 0 to 70 mg/lit. of alumina ferric and the second with 0 to 50 mg/lit. of alumina ferric with 20 mg/lit. of sulphuric acid. In each test the flocculation and settling periods were fixed at ten minutes each. The results are plotted in Fig. 3. With an increase in alum dose, there is a decrease in residual turbidity. It shows that the optimum dose was 40 mg/lit. and it reduced the turbidity from 27 to 13 mg/lit. and Tidy's value from 5.46 to 0.30 mg/lit. The floc size and its settling characteristics at this dose were good. Addition of 20 mg/lit. sulphuric acid lowered the pH from 8.70 to 7.20 but it showed no improvement over alum alone either in the reduction of turbidity or organic content of settled water.

About 70 mg/lit. alum added in the inlet channel of old sedimentation tanks without proper feed and flocculation, yielded poor floc which did not remove fine colloidal organic and inorganic impurities present in raw water. The change in sulphate concentration between raw water and effluents from sedimentation tanks and filters (Table III) gives the amount of sulphate contributed by alum. The difference in these values in different units shows that alum was unequally distributed. In these tanks, the turbidity was reduced from 27 to 19 mg/lit. and the Tidy's value from 3.87 to 2.50 mg/lit. The jar tests had indicated that 70 mg/lit. alum dose with proper flocculation should reduce the turbiditv and Tidy's valuse to 6.5 and 0.46 mg/lit. respectively.

The old sedimentation tanks have no arrangement for regular desludging and the settled organic matter undergoes anaerobic decomposition. About a metre deep black sludge was observed during desludging, and it showed Tidy's value of 200 mg/lit. The rising of gas bubbles, due to anaerobic decomposition of settled matter, was noticed in all the tanks. These bubbles contribute hydrogen sulphide to the water. The necessary chemicals were not available at the site to deter-

Table III—Physical and chemical characteristics of water at different stages of purification

Sample	*p*H	Turbidity	Chlorides as Cl	Sulphates as SO_4	Ammonia as NH_3	Nitrates as NO_3	Total Hardness as $CaCO_3$	Total Alkalinity as $CaCO_3$	Tidy's value	Dissolved Oxygen
Raw Water	8.60	27	242	154	Traces	Traces	289	176	4.54	5.97
Effluent From New Sedimentation Tanks	NA	19	NA	164	„	„	304	NA	2.50	NA
Effluent From New Patterson R.S. Filters	8.13	18	242	168	„	„	289	171	3.35	1.02
Effluent From Geo-Miller R.S. Filters	7.90	24	242	170	„	„	293	178	3.68	2.04
Effluent From Slow Sand Filters	7.80	21	242	180	„	Nil	295	163	3.44	0.51
From Clear Water Reservoir	NA	15	NA	164	„	Traces	307	NA	1.70	NA

NA—Value Not Available
All values except pH are in mg/lit.

Table V—Biological characteristics of water at different stages of purification

Sample	Zoo-plankton Organisms/Litre					
	Copepoda	Crustacean Larvae	Oligochaeta	Nematoda	Rotifera	Total
Raw Water	...	...	...	...	15000	15000
Effluent From New Patterson R.S. Filter	3	...	...	3	153	159
Effluent From Geo-Millers R.S. Filters	...	12	12	...	444	468
Effluent From Slow Sand Filters	...	...	...	...	...	...
Tap Water	3	...	3	...	51	57

Table IV—Biological characteristics of water at different stages of puri fication

Sample	No/100 ml		Phytoplankton Cells/Litre					
	Coliform	Enter-occocci	Chloro-phyceae	Eugleno-phyceae	Bacillario-phyceae	Myxo-phyceae	Unidenti-fied	Total
Raw Water	1800	700	100000	15000	1035000	7200000	1290000	9630000
Effluent From New Paterson R.S. Filters	120	240	1287000	72000	162000	5085000	342000	6948000
Effluent From Geo-Miller R.S.Filters	1440	70	2780000	120000	1380000	7020000	1480000	12780000
Effluent From Slow Sand Filters	4500	60	1008000	54000	252000	6192000	486000	7992000
Tap Water	2	2	351500	...	646250	5965000	...	692750

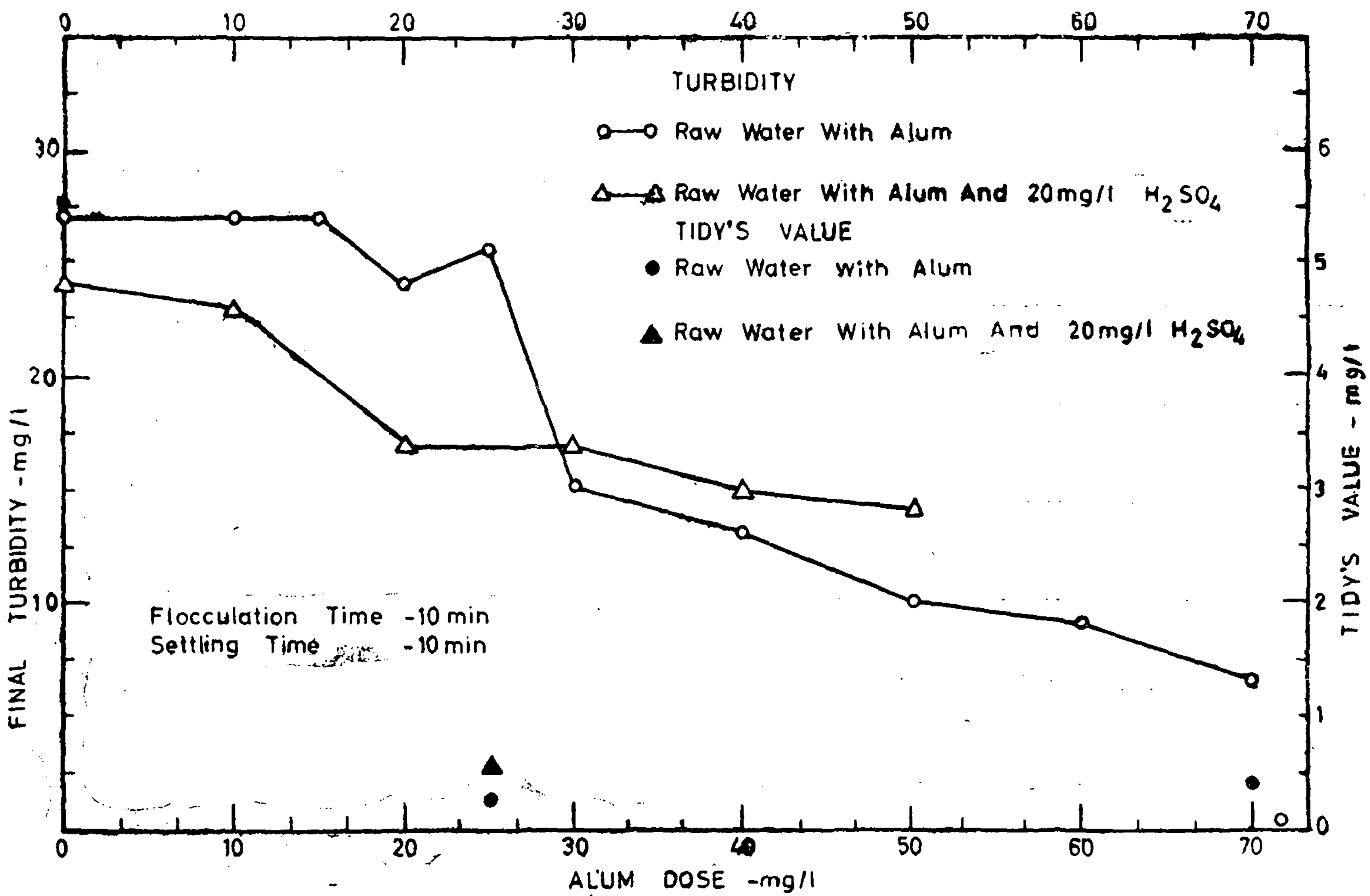

Fig. 3—Effect of alum dose on turbidity and Tidy's value

mine H_2S but it is expected to be fairly high. Mechanical flocculation of raw water entering old sedimentation tanks and continuous desludging through perforated pipes will improve the performance. Till these arrangements are made, these tanks should be desludged more frequently. Gradually, these sedimentation tanks can be converted to clariflocculators.

The old Paterson units and hopper bottom sedimentation tanks are provided with horizontal baffle type flocculators. Alum was added in hopper bottom tanks but not in old Paterson units as it had already been added in old sedimentation tanks. The efficiency of these flocculators compared to the mechanical system should be studied and these can be changed if necessary. The hopper bottom sedimentation tanks must be connected directly to New Paterson filters.

Geo-Miller clariflocculator is provided with mechanical flocculating and scraping mechanism. This mechanism was not functioning although alum was being fed. The increase in sulphate concentration by 20 mg/lit. in filtered water as compared to raw water is equivalent to the addition of 46 mg/lit. of alumina ferric. Even with this alum dose, the reduction in turbidity and Tidy's value during clariflocculation was from 27 to 24 mg/lit. and from 3.87 to 3.68 mg/lit. respectively. This poor performance was due to the absence of proper flocculation. Though the clariflocculator was desludged once a day, the sludge was thick and black, emitting foul smell. A continuous desludging of clariflocculator and hopper bottom sedimentation tanks is considered better.

Filtration

Each slow sand filter put out of operation once a week and a top half inch layer was scraped off. The rapid sand filters were backwashed every 24 hours or less if the head loss exceeded 5 feet. This removed many organisms from sand beds, but still a considerable number might be retained and grow in underdrains. The organic matter in clarified water would support this growth.

It is necessary to oxidise the organic matter to prevent the growth of organisms. A part of the organic and inorganic matter in effluent from old sedimentation tanks can be removed by aeration with diffused air in outlet channel. The remaining organic matter has to be oxidised by chlorination as discussed latter.

The turbidity of filtered water from the new Paterson units was 18 against 27 mg/lit. in raw water. This was accompanied by a low removal of organic matter from 3.87 to 3.35 mg/lit. and high depletion in dissolved oxygen from 5.97 to 1.02 mg/lit. Similarly the Geo-Miller and slow sand filters showed high turbidity, high organic content and low dissolved oxygen in their effluents. The poor performance of rapid sand filters was mainly due to lack of proper pre-treatment and that of slow sand filters due to weekly scraping of Schmutzdecke, a top layer which is primarily responsible for improving the water quality. Extension of operational period might improve the efficiency.

The reduction in coliform and enterococcus counts in the effluents from Geo-Miller, New Paterson and slow sand filters are given in Table IV. Except for the effluent from slow sand filters, which showed an increase in the coliforms, the effluents from other units showed a considerable reduction. Since only one sample was examined from each source, the increase in the coliform count in the effluent from slow filters can not be explained.

Table IV shows that the algae present in the effluents from the filters and the final water were very high. The raw water showed a large number of bdelloid rotifers and a high percentage of these was removed at the filters. Chironomus larvae were not observered in any of the samples analysed. In the effluent from the slow sand filter, there was no zooplankton. Effluent from Paterson and Geo-Miller filters showed the presence of **Cyclops** and **Pristina longiseta.** These organisms and a variety of rotifers were recorded in the final water. Most of the zooplankton were found to be dead.

The mud samples collected at the intake showed only a few ostracod shells. Since the channel bed was new, the analysis of the mud was not representative. A precise account of the organisms contributed by the raw water could not be obtained. However, the very large number of planktonic forms present in the effluent from the filter leads to the conclusion that most of the organisms originate from the raw water.

Chlorination

The organic matter remaining after treatment should be oxidised by chlorination. This practice will have the additional advantage of providing free chlorine. The chlorine demand was determined by iodometric titration after ninety minutes contact time. Two typical results are given in Fig. 4 and 5. Because of the absence of ammonia and nitrite in water, the typical peaks for chloramines with breakpoint were absent. But, in each case, an initial chlorine demand was observed indicating the direct oxidation of certain inorganic and organic matter without giving any residual chlorine. In certain cases, even after the initial demand was met, the residual chlorine did not match the chlorine added for some more concentration indicating a slower oxidation of certain other organic matter. After chlorine demand was satisfied fully, the curve followed approximately a 45 ° relation.

The values for initial demand and total demand for water at different stages of purification are given below:

	Chlorine Demand, mg/lit. Initial	Total
Raw Water	3.6	10.0
Effluent From Old Sedimentation Tanks	1.7	6.4
" Geo-Miller Clariflocculators	2.5	6.9
" New Paterson R. S. Filters	1.6	5.2
" Geo-Miller R. S. Filters	3.5	3.5
" Slow Sand Filters	2.7	2.7

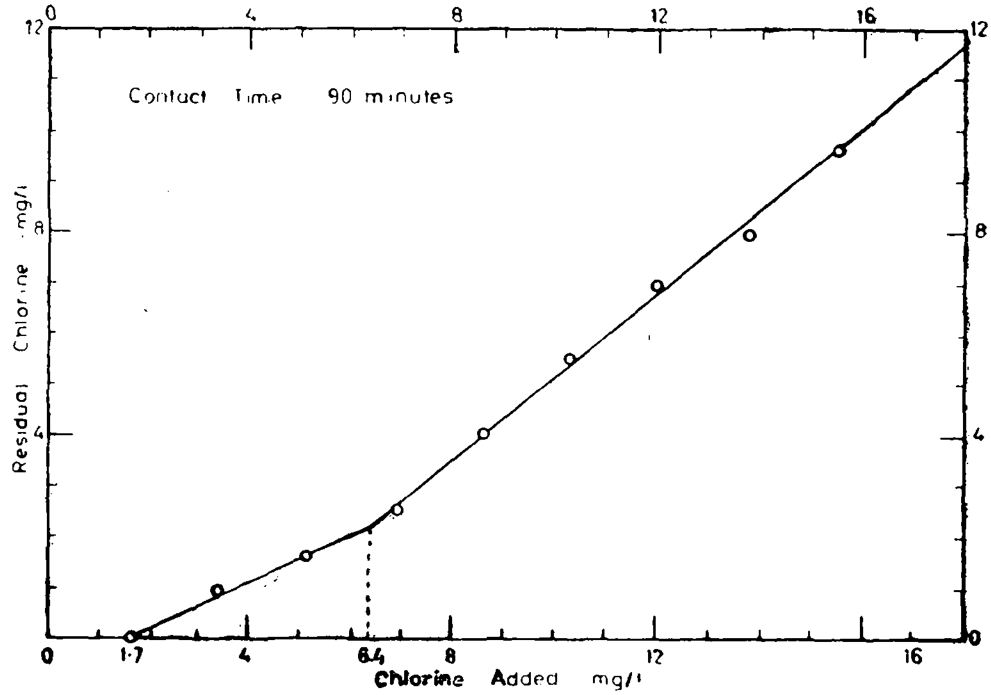

Fig. 4—Chlorine demand of effluent from old sedimentation tanks

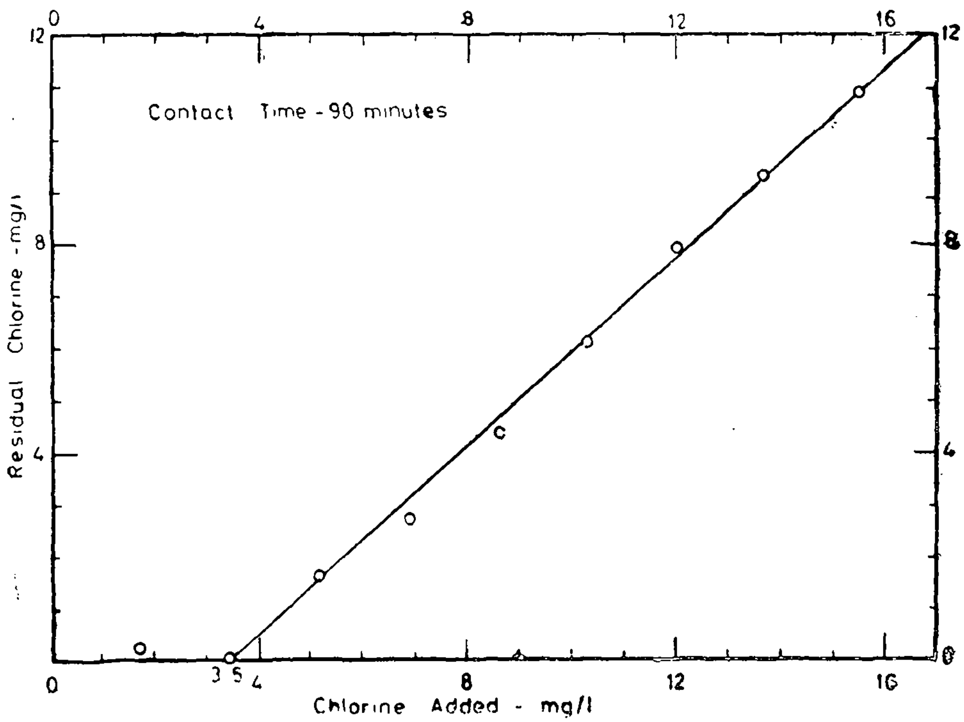

Fig. 5—Chlorine demand of filtered water from Geomiller Filters

The chlorine demand decreased as water passed through different stages of purification. In rapid sand filters, the chlorine should, therefore, be added to the effluent from filters, since the organic matter collected in filter beds would be backwashed regularly. However, in slow sand filters the chlorine should be added to the influent to the filters so that the organic matter is oxidised to avoid anacrobic decomposition resulting in taste and odour. This practice should be followed till an arrangement for flocculation of water entering old sedimentation tanks is made. In each case, a free residual chlorine should be maintained. The chlorine demand will be reduced after the arrangements are made for flocculation and aeration. Chlorination before clarification is not needed.

Copper sulphate, 0.5 mg/lit.; was added to raw water to control algae and Chironomus larvae. The observations showed that this dose was not sufficient to kill these organisms. Short term experiments on the effectiveness of $CuSO_4$ and chlorine showed that 2500 mg/lit. $CuSO_4$ or 17 mg/lit. Chlorine was required to kill Chironomus larvae within six hours. The correct dose of copper sulphate required to kill algae has to be determined by carrying out experimental studies.

Each filter should be purged with 20 mg/lit. chlorine solution for 6 hr followed by drying for 48 hr at least once a fortnight to remove any organic matter or organisms that collect in the beds. While putting one bed out of operation, the other beds can be overloaded proportionately.

Clear Water Storage

The filtered water from various units and 1 mill gal/day water from tube wells is stored in clear water reservoirs. The new reservoir of 2.3 mill gal capacity is provided with scour outlet but the old three reservoirs of 2.0 mill gal capacity have no such arrangement. The enormous number of organisms alongwith large quantities of organic matter that were not removed at various stages of water purification, had gradually accumulated in the storage reservoir. An analysis of bottom sludge is shown below:

		Organisms/cu ft
NEMATODA	—	8064
OLIGOCHAETA—Pristina longiseta Ehrenberg	—	49536
OSTRACODA—Shells only	—	403200
ACARI	—	16128
DIPTERA—Chironomus larvae	—	26496
Chironomus pupal cases	—	13824
MOLLUSCA—Gastropods	—	8064
	Total :	525312

Tidy's value of Sludge—97 mg/lit

The Oligochaete, **Pristina longiseta,** ostracod shells, Chironomus larva and the pupal cases were present in very large numbers. Tidy's value of 97 mg/lit. as against 1.7 mg/lit. of supernatant indicates the heavy concentration of organic matter at the bottom. The chlorine added to the water in summer was insufficient to oxidise the entire organic matter and kill organisms and it is no surprise that coliform and enterococcus organisms were present in tap water.

A residual chlorine of 1.0 mg/lit. or more in reservoirs and at least 0.5 mg/lit. in distribution system should be maintained. **This is most important for disinfection of water supplied to the public.**

A bell mouth suction of pumps flush horizontally to the tank bottom. Whatever organic matter and organisms are collected at bottom get pumped into the distribution system. A regular flushing and drying of the reservoir and raising suction level of pipes will improve the quality.

Conclusions

Based upon the preliminary investigations carried out in summer, the following conclusions are drawn:

1. In summer, the Yamuna water at Agra was highly polluted by domestic and industrial wastes from various communities and by cattle wading in the river upstream of Agra. These conditions were accentuated by a low flow in river.

2. Jar tests conducted on raw water with 40 mg/lit. alum dose and with flocculation and settling periods of ten minutes each showed a considerable reduction in organic matter and turbidity. Acidification with sulphuric acid showed no improvement. The existing arrangement for alum feed and flocculation in Agra Water Works are poor and, even with 50-70 mg/lit. alum dose, there was no improvement in water quality.

3. The settled sludge in old sedimentation tanks had high organic matter which undergoes anaerobic decomposition. This can impart taste and odour to the water.

4. There was a little removal of turbidity and organic matter but a high depletion in dissolved oxygen in rapid sand filters. This was due to poor pre-treatment. The filtered water showed the presence of **Cyclops, Pristina longiseta,** rotifers and enormous number of algae.

5. Effluent from slow sand filter showed a high turbidity and organic matter and a high depletion in dissolved oxygen. This was due to weekly scraping of top layer which primarily improves the water quality. Algal population in filtered water was high but no zooplankton were observed.

6. The organic matter in the water can be oxidised by chlorination. The chlorine demand of raw water was very high, but it gradually decreased as the water passed through different stages of purification. A dose of 2.1 mg/lit. that was added in the plant was all consumed by the organic matter and no chlorine was available for disinfection.

7. There was a large accumulation of sludge in clear water reservoirs. This sludge contained enormous number of the Oligochaete, **Pristina**

longiseta, ostracod shells, Chironomus larvae, pupal cases and a large amount of organic matter. The old storage reservoirs have no scouring arrangements and provide an excellant breeding place. Some of these organisms and organic matter can get pumped into the distribution system.

8. 0.5 mg/lit. copper sulphate added to raw water did not kill algae and Chironomus larvae. It was observed that 2500 mg/lit. copper sulphate or 17 mg/lit. chlorine would kill Chironomus larvae in six hours.

9. The public complaints about taste, odour and worms are attributed to the presence of high algal population, Chironomus larvae, **Pristina longiseta** and zooplankton organisms, coliforms and enterococci and organic matter and the absence of DO in final water.

Acknowledgement

The authors are indebted to Shri S. V. Agrawala, Superintendent of Agra Water Works, for his sustained interest and unfailing co-operation in the investigation. Thanks are also due to the staff of Agra Water Works for their assistance.

DISCUSSION

SHRI K. G. VEERARAGHAVAN (Madras) : It is a very interesting account about the Agra Water supply. I wish to know what the difficulty was in cleaning the clear water reservoir.

DR. J. K. BEWTRA : The engineer who designed the tank provied the scour valves at the bottom. But there was no arrangement to operate these scour valves and the tank was 20 ft. deep. Therefore, it was only possible to clean the tank by scouring manually.

SHRI G. S. BHATTACHARYA (Sindri) : From your analysis of the raw water of River Yamuna, it is evident that the water is polluted by organic wastes mainly coming from sewage. Your figures for chlorides and sulphates show this. But I wonder how you fail to get ammoniacal nitrogen and nitrite nitrogen in this water.

DR. J. K. BEWTRA : The high algal population in raw water was responsible for the absence of nitrite and ammoniacal nitrogen. This nitrogen was assimilated by algae in cell material.

SHRI G. S. BHATTACHARYA : What is the phosphate content of this raw water ? This much of sewage pollution would definitely add some phosphate in water which would affect the water conditioning in later stages.

DR. J. K. BEWTRA : Phosphate concentration in raw water was not tested because these tests could not be carried out at site.

Phophates are also assimilated by algae and their concentration should not have increased considerably.

SHRI G . S. BHATTACHARYA : Your data on count shows that algal population is excessive in raw water. What is the predominant algal species in the raw water of Yamuna ?

DR. J. K. BEWTRA : The predominant algal species from Wazirabad till Mathura was **Fragilaria.** From Hassanpur onwards, members of **Myxophyceae** appeared and Merismopedia became the most dominant algae at Agra intake.

SHRI O. K. SHARMA (Patiala): The turbidity of the effluent from the slow sand filter is 21 mg/lit. and that of the water sample from clear water reservoir is 15 mg/lit. This difference may kindly be explained because in the absence of any further treatment it could not decrease.

DR. J. K. BEWTRA: The final water reaching the clear water reservoir is not only from the slow sand filters but is a composite of the effluent water from slow sand filters and various types of rapid sand filters.

SHRI O. K. SHARMA: It does not sound all right that it could be due to dilution because the effluent from rapid sand filter itself was 15 mg/lit. There may be something wrong with observation.

DR. J. K. BEWTRA: A high turbidity in filter effluents, even with a high dose of alum, indicates that a part of the floc is passing through the filter beds. The floc along with some suspended matter settles down in clear water reservoir and thus a decrease in turbidity was observed. It is mentioned in the paper that the old clear water tanks had sludge deposit and this sludge was due to turbidity removal in clear water tank. Turbidity was tested with Hellige Turbidimeter. It is the easiest test in public health engineering and there is no possibility of making a mistake in these observations.

SHRI J. M. DAVE (Nagpur): The chironomids are observed to lay their eggs in the clear water reservoir. Did you try to prevent this? Have you done any investigation on their growth?

DR. J. K. BEWTRA: We did not attempt to prevent the chironomids from laying eggs in the reservoir. The water works is operated by the municipal corporation and we have no control over it.

The possibility of chironomids multiplying in the reservoir has been discussed in detail in the paper.

SHRI G. S. ROY (Sindri): As there is no nitrogen either as ammonia or as oxides of nitrogen, it seems from your observations that all the nitrogen has been taken up by the excessive algal growth. If this is so, there should not be high BOD in the raw water as reported by you.

DR. J. K. BEWTRA: The raw water contained only traces of ammonia and nitrates. The algal population of raw water was very high and it had assimilated the nitrogen present in raw water into cell material. While running BOD test, this cellular nitrogen becomes available to the bacteria during aerobic decomposition of organic matter. Therefore, the raw water had shown high BOD values.

Kumari R. MITRA: From your observation, it appears that Chironomus larvae are not found either in the effluent of rapid sand filter or in that of slow sand filter but their presence is mentioned in the distribution system and at the consumer's end. What is then the source of their infection?

DR. J. K. BEWTRA: It is true that, during our investigations, the effluent from rapid and slow sand filters did not show the presence of chironomus larvae. The possibility of the younger stages passing through the filters can not be ruled out. In any case, the benthos of the clear water reservoir had a number of ventilators and these may be the places through which the fly got access to the reservoir. These larvae entered the distribution system from the clear water reservoir.

SHRI K. GOVINDAN NAIR (Trivandrum) : There can not be any cyclops in the filter effluent because they can not pass through either slow sand filter or rapid sand filter. Certainly these must have been found in clear water reservoir that has been said to be in insanitary conditions.

It is high time that the clear water reservoir is emptied, cleaned and disinfected. Necessary provision should be made for scouring purposes.

DR. J. K. BEWTRA : It is incorrect to say that cyclops can not pass through slow and rapid sand filters. We have enough data to believe that they pass through these filters in Agra Water Works. Also this has been observed occasionally at Chandrawal Water Works, Delhi. When the number of these organisms in the filter bed is high, some will certainly pass through the filter bed. We have also sufficient data to prove that not only cyclops but certain dipteran larvae, nematodes and rotifers pass through rapid sand filters. Similar observations have appeared in recent years from abroad also.

Undoubtedly, the old clear water reservoirs require frequent cleaning and operating authorities have been suggested accordingly.

Proc. Symp. Problems in Water Treatment,
Oct. 29-30, 1964 (CPHERI, Nagpur) (1965).

Fluoride in Waters and its Removal

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Central Public Health Engineering Research Institute, Nagpur

Introduction

It is now well established that fluoride concentration up to 1 mg/lit. in drinking water is essential for healthy teeth and for prevention of dental caries in children. On the other hand, ingestion of excessive amounts of fluoride causes mottling of tooth enamel, entails defective calcification of teeth and bones, and causes various enzymatic disorders in human body. In Western countries, optimum limit of fluoride concentration has been fixed at 1.0 mg/lit. tentatively (1). Although later recommendations of U.S. Public Health Services suggest for a review of the optimum limit which varies with the ambient temperature (2) (Table I), the optimum fluoride concentration might vary from 0.1 to 1.2 mg/lit. for temperate to cold climate. Moreover, the effects due to excessive fluoride ingestion may depend on dietary habits (3); people taking sufficient quantities of vitamin C in their diet are more resistant to such effects. In India, no systematic work has been done so far to fix the optimal fluoride concentration for human or cattle. The limit has been assumed to be 1 mg/lit. as per the International Standards irrespective of climatic conditions.

Table—I

Mean Maximum Temp °F		Recommended optimum fluoride concentration mg/lit.
50.0 to 53.7	...	1.2
53.8 to 58.3	...	1.1
58.44 to 63.8	...	1.0
63.9 to 70.6	...	0.9
70.7 to 79.2	...	0.8
79.3 to 90.5	...	0.7

* Ref. No. 2

In India, fluorides have been reported in excessive concentration from different parts of Madras State (3 & 4); Kerala (5); Andhra Pradesh (6); Punjab (7 & 8); and Bihar (9 & 10).

In connection with fluorides in drinking waters and their effects on human and cattle consumers, the following main problems are worthy to be studied in details.

I. Finding optimum concentration of fluoride for Indian conditions;

II. Biochemical studies of effects of fluoride ingestion on human and cattle physiology ;

III. To carry out a systematic survey of different well waters through out the country ;

IV. To make up the fluoride concentration in waters deficient in fluoride or to reduce it wherever necessary ; and

V. To develop a cheap and simple material for reducing the fluoride concentration in drinking waters to optimum level.

Each of above problems is a project in itself and should be dealt with independently. Work is being carried on at this Institute on developing a simple and cheap technique for defluoridation of drinking water.

Defluoridation of Water

Although the problem of fluoride removal has been given serious thought for the last thirty years, ever since the discovery of effects of water-borne fluorides on man and cattle, and several materials have been developed for defluoridation, there is as yet no water supply scheme which has any working unit, using any of these materials. These materials include: (i) processed bone, (ii) natural or synthetic tri-calcium phosphate or hydroxy-apatite, (iii) activated alumina, (iv) lime, (v) activated carbons and (vi) ion-exchangers.

Processed Bone : Bone contains calcium phosphate and has a great affinity for fluoride. The bone is degreased, dried and powdered to mesh size 40 to 60. The powder can be used as a contact bed for filtration of fluoride-bearing water. The material removes 56.3 gm of fluoride per cu ft. (11, 12). The exhausted bed is regenerated with sodium hydroxide solution.

Bone is also processed by burning it in exposed air and pulverising the charcoal. The powered charcoal shows fluoride absorption of 29.2 gm for every cu ft. of material (13).

Another material prepared from bone known as bone apatite has also been used for defluoridation (14). It has been tried on pilot plant scale in Britton, South Dakota (15), but not with much success.

(ii) *Tri-calcium Phosphate :* Tri-calcium phosphates, natural or prepared synthetically by reacting milk of lime and phosphoric acid, have been used for defluoridation. The regeneration of exhausted bed is done with 1 per cent sodium hydroxide solution, followed by a mild acid wash. The reported capacity of such material is 19.5 gm /cu ft.

Another material (13, 17) named as "Fluorex" is a mixture of tri-calcium phosphate and hydroxy-apatite; it is regenerated with 1.5 per cent sodium hydroxide and subsequently by a passage of carbon dioxide. Its capacity has been found as high as 16.8 gm/cu ft. This material was tried in pilot plants at Climax, Colo., U.S.A. in 1937 and Scobba, Miss., in 1940 but without any success and the plants were abandoned.

(iii) *Activated Alumina :* Aluminium oxide was used as early as 1934 as a defluoridating substance (18) which was regenerated with sodium hydroxide and dilute hydrochloric acid. Subsequently, further studies (19) showed that the substance can also be regenerated with aluminium sulphate solution and gives a high capacity (130 gm/cu ft). The material has been tried on pilot plant scale at Bartlet, Texas. In this case, regenerants used were sodium hydroxide and hydrochloric acid. The plant worked successfully. Later, Savinelli and Black tried regeneration with 1 per cent solution of aluminium sulphate (filter alum) and found the capacity to have improved.

(iv) *Lime :* It has been observed that while giving lime treatment to waters containing magnesium salts in sufficient quantity, fluorides are absorbed on magnesium hydroxide flocs and it results in fluoride removal (19). Empirically, the amount of fluoride removed is equal to 0.07 F. Mg, where F represents mg of fluoride initially present and Mg the mg of magnesium disappearing in the form of flocs. In this case, the water must be treated to a caustic alkalinity of 30 mg/lit. and a *p*H of 10.5 or above and as such, recarbonation is necessary (12).

(v) *Activated Carbons :* Activated carbons prepared for the purpose give fluoride removal at reduced *p*H, 2 to 3, and can be regenerated with treatment of weak acids and alkaline solutions.

(vi) *Ion-exchange Resins :* The fluorides are also removed along with other anions while treated with strong base anion-exchange resins, but since the proportionate quantity of fluoride as compared to other anions is very small and the resins not being selective to fluoride only, the capacity of such resins works out quite low (20). Some inorganic ion-exchangers, e.g., complex metal-chloride silicate, formed from barium or ferric chloride with silicic acid, also exchange fluoride for chloride.

An organic anion-exchange resin made from diaminobenzene or phenol and formaldehyde has been found quite selective for fluoride removal (21). But it has not been tried in detailed studies.

Cation-exchange resins impregnated with alum solution have also been found to act as excellent defluoridating substances (22, 23). As regards use of anion-exchange resins, the process is tedious and cost involving. Use of alum-soaked cation-exchangers shows promise, but such substances have not been used so far.

Defluoridation Studies in India

Various materials have been developed on similar lines as detailed above and studied in Indian Institute of Science, Bangalore; King Institute, Guindy, Madras; and under different schemes sponsored by the Indian Council of Medical Research (12, 22, 24). The materials can be grouped as follows: (1) Phosphate compounds; (ii) Aluminium compounds; (iii) Ion-exchange resins; and (iv) Active-carbons.

Phosphate Compounds : Among these, super-phosphate, a product of fertilizer industry; processed bone-meal and bone-charcoal; synthetic tri-calcium phosphate; and hydroxy-apatite have been used. Super-phosphate requires boiling of water which will not be practical. Bone product shall have sentimental objection in this Country. Since it also creates taste and odour problems, it is not considered.

Synthetic tri-calcium phosphate and hydroxy-apatite require phosphoric acid, which is imported, and these can not be hence suitable.

Processed rock-phosphates containing phosphatic nodules have been found to have affinity for fluoride removal but the same has not been studied in detail.

Aluminium Compounds : Various aluminium compounds have been used for defluoridation, viz., aluminium sulphate, sodium aluminate, aluminium phosphate, calcium aluminate, aluminium silicate, etc., and all these, except filter alum (aluminium sulphate), were found to be not useful or practically adaptable. The capacity of filter alum to reduce fluoride is effected by the presence of other anions.

Ion-Exchangers : Similar ion-exchangers as described earlier have been prepared and tried on laboratory scale. Amongst different ion-exchangers, a condensation product of phenol and formaldehyde which was found to be quite selective to fluoride ions and a cation exchanger prepared from **Avaram** bark, are worth mentioning. But these products are also of only academic interest.

Activated Carbons : Various types of activated carbons were tried for defluoridation out of which aluminium based paddy-husk carbon prepared by Venkatramanan is most effective. In this case, paddy husk is digested with 10 per cent KOH and then soaked overnight with aluminium sulphate solution (2 per cent). The material acts as an efficient defluoridating substance at *p*H 6.0 to 8.5 After exhaustion, the material is regenerated by soaking it in aluminium sulphate solution for 12-14 hr. It has been tried in a pilot plant installed at Guntakal Railway Colony (1955-61), but the results of the studies have not been published so far. According to laboratory scale studies, the capacity of the materials works out to be about 320 mg/kg of carbon. Subsequently, Venkatramanan, in one of the Indian Council of Medical Research meetings in Calcutta, suggested that capacity can be improved by alternate treatment of the carbon by acid and alkali. But no further studies have been undertaken using this material.

Some more active carbons were prepared from different wastes, e.g., cotton waste, coffee waste, coconut waste, etc. and tried for defluoridation. All these materials are of academic interest.

A review of all the materials developed by different workers for defluoridation shows that most of the methods involve acids and alkali either during pre-treatment or regeneration steps and are not suitable for easy handling. The phosphate compounds and ion-exchange materials are not practical for large scale use.

The only materials of much interest are activated alumina and porous cation-exchangers impregnated with filter alum solution. Paddy husk carbon, developed by Venkatramanan, has a comparatively lower capacity than other porous materials and in absence of pilot plant studies, can not be considered for large scale units.

Work Done in CPHERI, Nagpur

Defluoridating substances were prepared by carbonising saw-dust in limited supply of air (saw-dust was taken because of its greater and ready availability than substances like paddy husk, etc.) All organic matter in saw-dust is burnt away, it is quenched in 2 per cent aluminium sulphate solution. This material has been studied in detail in the laboratory. It works efficiently at *p*H 6 to 8.5 and has a capacity 390 to 450 mg/kg of the material (25). It has been used in successive cycles after regeneration and does not exhibit much deterioration in its fluoride removing capacity. Other anions present in water affect the capacity to some extent. The material possesses good hydraulic properties but is likely to undergo attritional losses when used for a long time. This material has been studied in batch scale and also in continuous flow columnar studies, and shows consistent results (26). However, on account of non-availability of naturally occurring fluoride-bearing water, it has not been tried with such waters.

Recently, another material has been prepared by sulphonation of saw-dust (27). The saw-dust is reacted with concentrated sulphuric acid and treated with 1 per cent solution of sodium carbonate and then soaked with 1 per cent solution of aluminium sulphate. The material can be regenerated as in case of other carbon with a passage of 0.5-1.0 per cent filter alum solution and reused. The material is being studied in detail as regards its optimum conditions for preparation and its use for defluoridation. Preliminary studies show that the capacity varies from 1200-1700 mg/kg of the material which is quite high as compared to previous carbon. Studies on preparation and use of activated alumina from bauxite ore are also planned. After laboratory studies, these materials need a field trial for verification of different operational features in a plant scale. As such it would be desirable to have full scale operational studies using these materials.

Demestic Defluoridator : A domestic defluoridation unit which consists of three tin vessels kept one over the other has been designed and fabricated. The central vessel contains the activated carbon prepared in this Laboratory. Presuming the capacity of carbon to be about 400 mg/kg, it can treat water (containing 3-5 mg/lit.) sufficient for drinking and cooking purposes for a family of 5 members.

Pilot Plant Studies : Pilot Plant studies will be undertaken after sulphonated saw-dust is explored completely.

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DISCUSSION

SHRI S. SUBBARAO (Singur): The author has mentioned that saw-dust is more readily available than paddy husk. I disagree on this point and wish to say that paddy husk is more readily available.

What is the cost of the domestic defluoridator that is suggested?

SHRI T. S. BHAKUNI: Comparatively, the paddy husk is put to use for more purposes than the saw-dust. Therefore I feel that the saw-dust is available more easily and in greater quantity for our purpose than the paddy husk.

Regarding the cost of this equipment, the capital cost is Rs. 45/- per unit. The recurring cost, for regeneration of carbon, is about 40 paise for 1,000 gal of water.

SHRI K. G. VEERARAGHAVAN (Madras): In Madras, we have done some work in this connection and have yet to put up a plant on community basis. I wish to mention that these treatment units should be demonstrated to the people and popularised.

Though in 1939, severe form of skeletal fluorosis was markedly seen in Kanigiri taluks of Guntur district, such one does not seem to be prevalent now in the areas in the far South where drinking water has as high a fluoride content as 4-6 mg/lit.

A complete reapraisal of the problem is desirable.

SHRI O. K. SHARMA (Patiala): Does the solution of alum for regeneration have to be made from fluoride-free water? What is the volume of water used for regeneration? Do we have to use fluoride-free water for washing and rinsing the bed?

SHRI T. S. BHAKUNI: The regeneration solution has to be prepared in fluoride-free water and the volume of this water is approximately 4 times the volume of the defluoridation bed.

Rinsing of the regenerated bed can be done with fluoride-bearing water without any difficulty and there may be very little loss of the bed capacity owing to the fluoride content in the wash water. The rinse water volume as experimented is about 5-8 per cent of the total treated water.

SHRI J. S. JAIN (Nagpur): I would like to know the cost of the water obtained after defluoridation. Has the CPHERI developed a satisfactory unit which can be used in rural areas?

SHRI T. S. BHAKUNI: The recurring cost as estimated on domestic defluoridator is approximately 40 paise for 1000 gal of water, assuming the cost of filter alum as Rs. 250/- per ton.

The unit developed in CPHERI has not yet been tried on naturally occuring fluoride-bearing water but we hope that this would prove to be a satisfactory unit for defluoridation.

SHRI C. D. SARKAR (Sindri): What is the raw material used for preparing activated carbon that can reduce the high fluoride content of water to optimum level? What is the maxumum concentration of fluoride that you have tried in your experiment?

SHRI T. S. BHAKUNI: The raw material used was saw-dust. The maximum concentration of fluoride was 6 mg/lit.

SHRI C. D. SARKAR: Is there any method of regeneration for the exhausted active carbon samples? How many times can we use the same active carbon in this process? What is the bulk density of the active carbon tried by you?

SHRI T. S. BHAKUNI: The regeneration can be done by using 0.5 - 1.0 per cent filter alum solution. The carbon can be used for several cycles after regeneration. Active carbon No. I, used by me, was of bulk density of 463 kg/cu m. For the other sample, the bulk density is being determined.

SHRI K. P. GOVINDAN NAIR (Trivandrum): The sulphonated saw-dust carbon is said to contain sulphonic acid groups. What is the exchange capacity and the optimum concentration of Al salts required to load the column of saw-dust? Was the Al ion eluted out from the column when the raw water to be treated contained other cations? Did you take into consideration the interference of Al while estimating fluoride, in case Al was eluted out?

SHRI T. S. BHAKUNI: It has rightly been stated that the sulphonated saw-dust carbon acts as a cation exchanger. Since we are interested in its defluoridating effect, we did not carry out any studies regarding its base exchange capacity.

We use 1 per cent alum solution to load the column of saw-dust carbon. During defluoridation, aluminium is not necessarily eluted out. Still whatever aluminium is leached as an impurity during exhaustion cycle is taken into consideration while estimating fluoride by any one of the colorimetric methods. The results are occasionally verified by distillation also.

SHRI S. K. GAJENDRAGADKAR (Bombay) : How does this method compare with those of alkali impregnated paddy husk, and activated magnesia ? What is the cost of the process ?

SHRI T. S. BHAKUNI : The capacity of alkali impregnated paddy husk carbon is 390 mg/kg whereas those of saw-dust are 430 mg/kg and 1500 - 1800 mg/kg respectively. Regarding activated magnesia, I have no data to compare. For the salt carbon defluoridator, the initial cost is about Rs. 45/- and the recurring cost is about 40 paise for 1000 gal of water.

SHRI S. R. AGARWAL (Kanpur): Have you tried sodium sulphonates in place of sodium salt of lignin sulphate ?

SHRI T. S. BHAKUNI : I do not think that these substances shall have any defluoridating property.

DR. A. K. ANWIKAR (Nagpur) : I wish to point out that the chemical process for defluoridating is costly. As an alternate method to this, I am suggesting that dams should be constructed across the village streams. The effect of this will be to raise the ground water level and dilute the fluoride concentration of water in the wells to an extent of 1 mg/lit. At this concentration, the water does not cause any harm to man or animal. Dilution will continue as years pass on. Therefore this method seems to be most economical.

SHRI T. S. BHAKUNI : I have no comments.

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Defluorination of Drinking Water by Active Magnesia

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Introduction

Fluorides in drinking water have been shown to be the cause of mottled enamel on teeth. The standard fixed for the concentration of fluoride in drinking water is 1 to 1.5 mg/lit. (1). In some European countries, fluoride is added to drinking water supply to bring the concentration to 1 to 1.5 mg./lit., as this concentration is found to be helpful in strengthening the teeth. In India, the condition is reverse. Fluoride in excessive quantity has been detected in many parts like Andhra Pradesh, Maharashtra, Punjab, Rajasthan, Saurashtra, etc. (2). The fluoride contents of some of the wells in Saurashtra are shown in Table I. (Reproduced from a Chart exhibited by the Public Health Laboratory, Baroda at the Exhibition during the Open Session of the Indian National Congress at Bhavnagar, 1961).

Several methods including ion exchange methods have been suggested from time to time for removal of fluoride from drinking water. One of the easier methods is the adsorption by activated compounds. Active magnesia is suitable, both from the point of view of cost and efficiency. Venkateswarlu and Narayana Rao (3) studied the use of magnesium oxide for the removal of fluoride and reported that when fluoride containing water is treated with MgO (2 g/lit.) at 40°C with stirring, the fluoride content is reduced so as to be within the prescribed limits. The present work was carried out using magnesia obtained by calcining mineral magnesite.

Material

The raw magnesite (MgO, 47.51; CO_2 49.40; R_2O_3 0.104; and acid insolubles, 2.88 per cent) was broken into small lumps and calcined at different temperatures for 2 hr. The decomposed product was analysed chemically. The activity of the product was measured in terms of iodine number. It was observed that iodine number is maximum for the product obtained by calcining the magnesite at 800°C (Table II). The measurement of the particle size by sedimentation method showed that 80 per cent of the particles were within the range of 2 to 20 μ.

Method

The stock solution containing a known amount of fluoride was prepared by dissolving required quantity of sodium fluoride. A measured

Table I—Fluoride Contents of water of Bhavnagar District (Gujarat State)

Name of Village	Nature of water	Sodium Fluoride mg/lit.	Fluoride mg/lit.
1. KALYANPUR	Well Water	17.8	8.056
	Tank Water	3.4	1.538
2. HARIPUR	Well Water near farm yard	15.6	7.058
	Well water near pond	12.2	5.52
3. SAJANTIMBA	Drinking water well	15.6	7.058
	Pond water	13.1	6.019
4. ECLERA	Well Water	14.8	6.697
	Drinking water well	11.4	4.71
5. KHARA	Well Water near farm yard	14.8	6.697
	Well water of pond	0.44	0.199
6. ASHODAR	Small well water	13.0	6.019
	Well near school	11.2	5.057
	Tank water	10.4	4.71
7. DHANGALA	Water near well	15.2	6.876
	Drinking water well	4.8	2.172
8. EGLORALA	Well Water	10.4	4.71
	Tank Water	...	...
9. GUNDARAN	Well near school	4.8	2.172
	Well outside village	3.0	1.30
10. HATHIGADH	Well water of Bhagwan	4.0	1.81
	Tank Water	0.1	0.045

Table II—Active magnesia from magnesite

	(Time of calcination, 2 hr.)			
Temperature, °C	700	800	900	980
Iodine Number	31.56	99.29	63.10	64.40
MgO, %	57.48	94.06	94.75	95.04

amount of the solution was treated with burnt magnesite. At definite time intervals, an aliquot of the sample was withdrawn, filtered, suitably diluted and fluoride content estimated colorimetrically using zirconium alizarine sulphate method (4). The colour was compared with the standard disc in the B.D.H. Nessleriser.

Results

It can be seen from Table II that the activity of magnesium oxide obtained at 800°C in terms of iodine number is higher than that obtained at 900°C. The removal of fluoride from water treated with these products (2g/lit. MgO) estimated at intervals and shown in Fig. 1 also indicates that the product calcined at 800°C is more efficient than the one calcined at 900°C.

Varying quantities of MgO prepared at 800°C were used in the treatment of water (1 lit.). The mixture was stirred for 5 to 10 minutes mechanically and fluoride contents, estimated at intervals. From the results shown in Fig. 2, it is found that the optimum concentration of MgO is 2g/lit. for water containing 20 mg/lit. of fluoride. In a scale up experiment, 200 lit. of water containing 20 mg/lit. of fluoride were treated with 400 g of active magnesia, stirred for two hr and the fluoride contents estimated at intervals. It can be seen from the results shown in Fig. 3, that there is a sudden drop in the fluoride content from 20 to 2 mg/lit. in the first two hours, after which the removal of fluoride is slow. However within four to six hours, the fluoride content in water is within the safe limits.

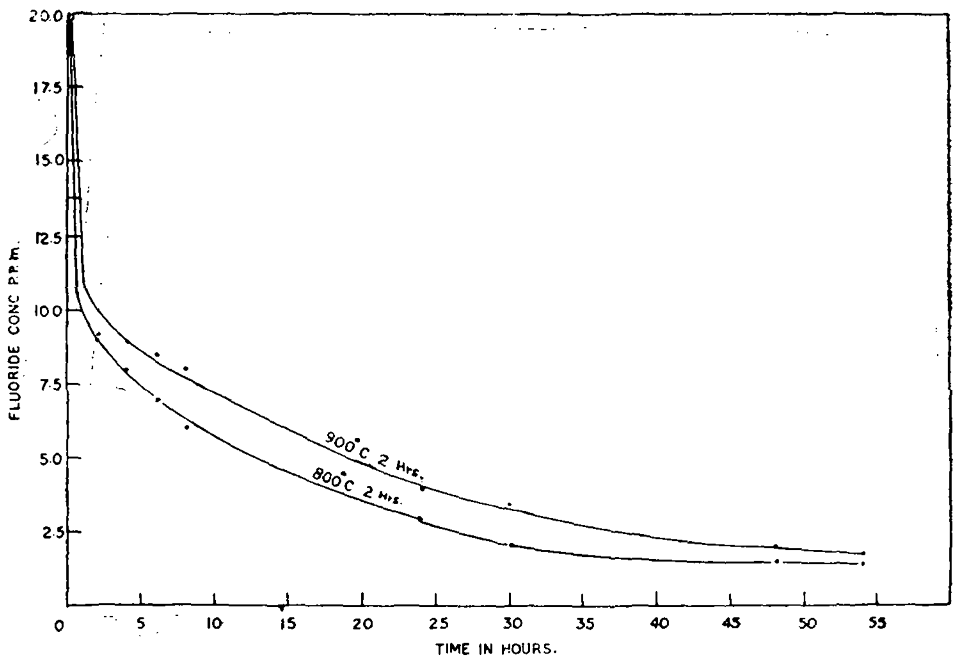
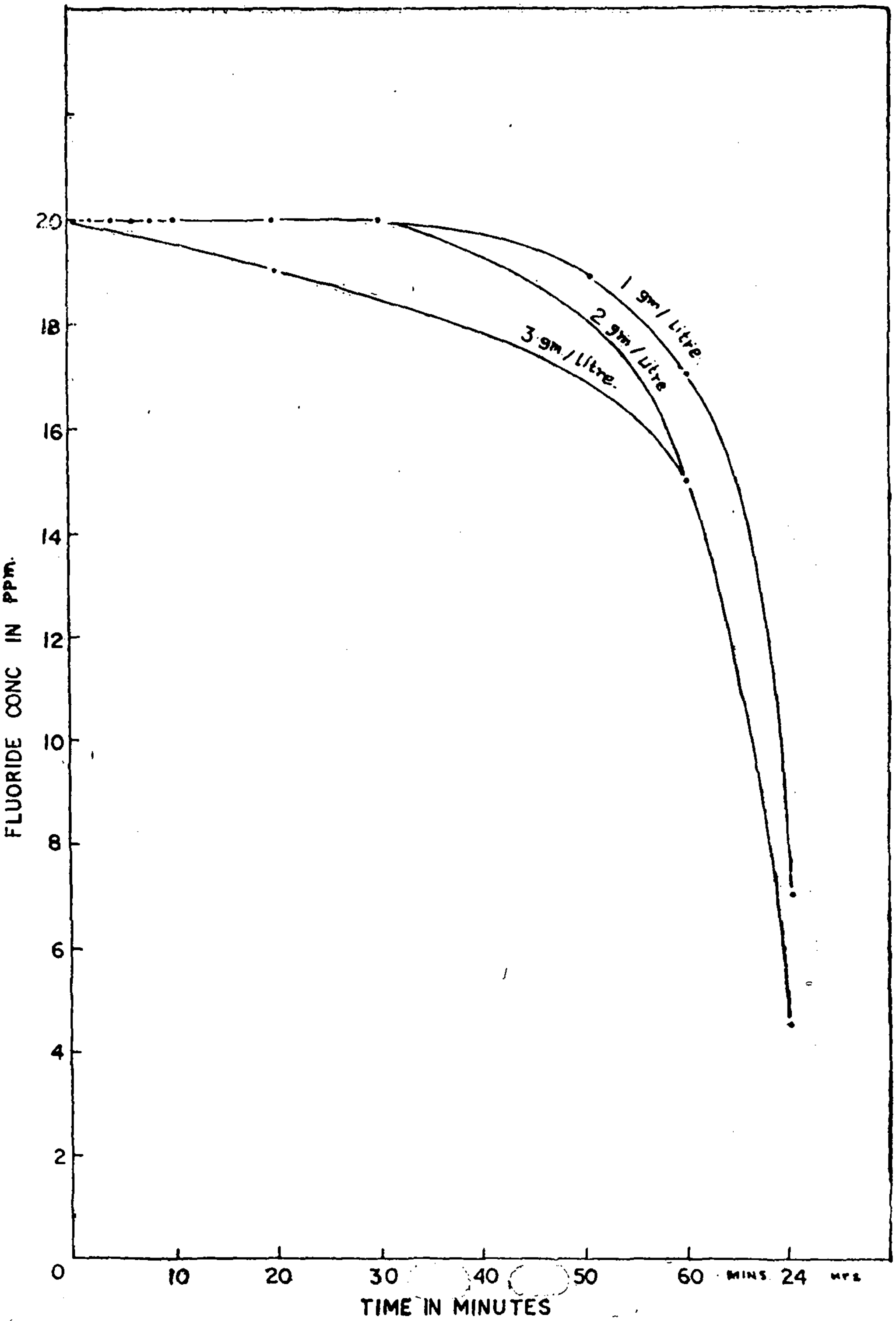


Fig. 1 — Effect of temperature of calcination of magnesite on the removal of fluoride

Fig. 2 — **Effect of the concentration of magnesium oxide on the removal of fluoride**



An additional advantage in using active magnesia for defluorination is that because of its higher bulk density, magnesium oxide settles down at the bottom of the container with the result that defluorinated water can be syphoned out easily.

The authors express their grateful thanks to Dr. D. S. Datar for his valuable suggestions in writing this paper.

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DISCUSSION

SHRI O. K. SHARMA (Patiala): Is activated magnesia being manufactured by CS & MCRI?

SHRI P. R. MEHTA: No please. The Institute being a research laboratory, does not manufacture activated magnesia. You can procure it from outside agencies.

SHRI G. S. BHATTACHARYYA (Sindri): As you have studied the optimum conditions of roasting temperature of magnesite, I wish to ask whether you have studied the effect of pH on defluoridation of water by activated MgO.

I am interested to know the particle size analysis of MgO sample that you have used in your defluoridation experiments.

SHRI P. R. MEHTA: The active magnesia when reacting with water

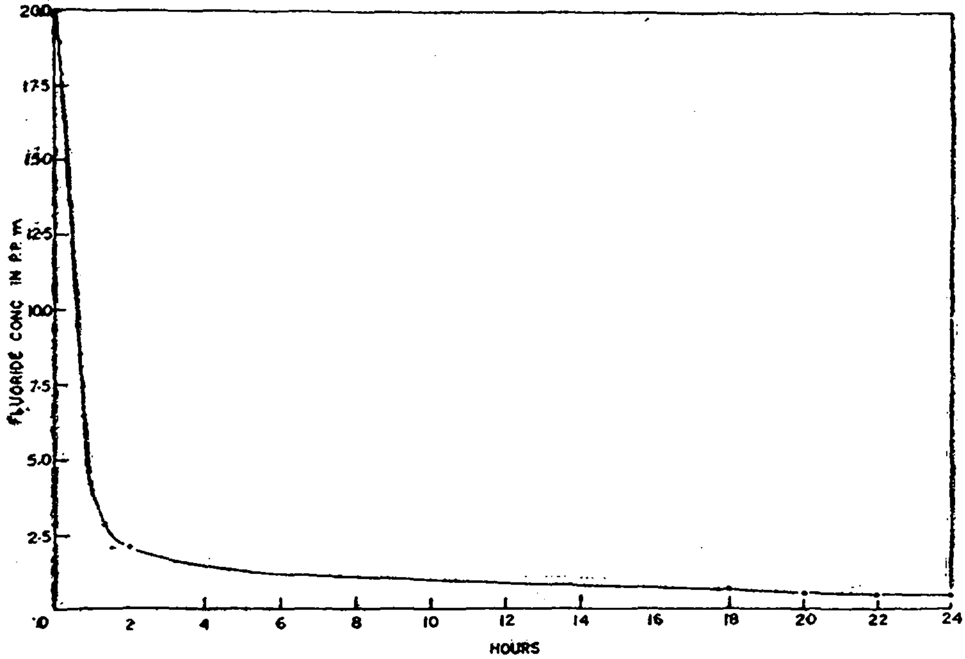

Fig. 3 — Decrease in fluoride concentration with time when treated with 2 g/l MgO and stirred for one & half hour

is expected to have the following reaction.

$$MgO + H_2O \rightarrow Mg(OH)_2$$

The hydroxide so formed has a fixed solubility in water and this itself fixes an alkalinity of about 9 *p*H as determined by Universal *p*H paper. Thus, in this case, it was not necessary to study the variation in *p*H.

As for the particle size analysis, it is obtained for the calcinated magnesite (800°C for 2 hr) as follows.

	20 and above	4.39%
between	20 and 10	28%
,,	10 and 5	34%
,,	5 and 2	18.8%
,,	2 and 1	7.2%
,,	1 and below	7.6%

SHRI K. G. VEERARAGHAVAN (Madras): What would be the cost of water treated by this method of defluoridation?

SHRI P. R. MEHTA: Depending on the salt content, the cost is about one rupee for 1,000 gallons.

SHRI S. K. GAJENDRAGADKAR (Bombay): Can the activated magnesia be regenerated after defluoridation and can the same magnesia be reused?

SHRI P. R. MEHTA: Only a few experiments have been done in this connection. The results of the efficiency of the process are yet to be finalised.

SHRI K. R. BULUSU (Delhi): You have mentioned the limits of fluoride as 1-1.5 mg/lit. The normal air temperature in most parts of our country is over 80°F. At this temperature or above it, the permissible limits are 0.6, 0.7 and 0.8 mg/lit. in the order of lower, optimum and upper limits respectively.

SHRI P. R. MEHTA: The standard fixed for the concentration of fluoride in drinking water is 1-1.5 mg/lit. You may kindly refer to the International Standards for Drinking Water by W.H.O. For our country, if there is any standard specification laid down according to the variation of temperature or any meteorological factors, please cite the references that you came across.

SHRI M. B. JAIN (Jodhpur): There are villages in Rajasthan where dental caries as well as mottling of teeth are found prevalent among fifty per cent of the population. Will Shri P. R. Mehta and Shri T. S. Bhakuni suggest the optimum range of fluorides which causes both. Or is it due to some heredity effect in addition to fluoride content?

SHRI T. S. BHAKUNI and SHRI P. R. MEHTA: The standard fixed for the concentration of fluoride in drinking water is 1-1.5 mg/lit. as per International Standards for Drinking Water by W.H.O. Now it is being felt that this limit of fluoride concentration should be somewhere between 0.6-1 mg/lit. The excessive amount of fluoride in drinking water is responsible for those ill effects.

As far as the question of heredity is concerned, you are requested to refer to the medical authorities who have actually studied these factors perfectly.

SHRI G. S. ROY (Sindri): I wish to know the bulk density of active magnesia and the percentage of $MgCO_3$ in magnesite.

Is your experiment in the laboratory bench scale stage of research or have you already gone for a pilot plant operation? What is the rate of flow?

SHRI P. R. MEHTA: The bulk density of the active magnesia sample used was 41.14 lb/cu ft. The raw magnesite analysis was as follows: MgO, 47.51; CO_2 49.4; and R_2O_3 0.104; and insolubles, 2.88 per cent.

The work on the laboratory scale is over. Pilot plant work is yet to start. The question of rate of flow does not arise because the water to be treated is collected in a tank, stirred and allowed to settle. The defluorinated water can be syphoned.

SHRI V. D. DESHPANDE : (Nagpur) What type of reaction do you expect between magnesia and fluorides since magnesia is an insoluble substance in water?

SHRI P. R. MEHTA: On calcining the magnesite, the magnesia obtained is active in nature and it is expected to be an adsorption reaction.

Shri A. P. Mehta, the Session Chairman exphasised the point that the laboratory studies should be put into field work and requested that Shri P. R. Mehta should put his studies on defluoridation into actual use in the field.

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Study Of The Ahmednagar Water Supply

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Introduction

The historical city of Ahmednagar has a population of about 1,00,000. There are three sources of water storage.

1) Pimpalgaon reservoir—14,40,000 gal/day
2) Savedi percolation well—80,000 gal/day
3) Wadgaon percolation well—1,20,000 gal/day

The total water supply is 1.65 mill gal/day. Pimpalgaon reservoir, about 11 km from the city, is rain-fed and to some extent supplemented by the Dongargan Nalla water. From this reservoir, water is fed to the Water Treatment Plant which is about 200 m from this reservoir. Especially during summer, the water in the reservoir had an unpleasant odour and muddy appearance with greenish shade. Raw water is led to the treatment plant through a C.I. pipe of 18 in dia. The treatment plant consists of an aeration fountain, two flocculators in series, one clarifier, two filters and a clear water well (Fig. 1). The treatment plant has a capacity of 2.0 mill gal/day. Filtered water is then pumped to the service reservoir situated in the city. This service reservoir also receives untreated well waters from Savedi and Wadgaon percolation wells. This mixed water is supplied to the population, after disinfection. At the Pimpalgaon Waterworks part of the filtered water is stored in an open dug well, near the treatment plant, where another water is mixed and this mixed water is also pumped through the same pipe line carrying filtered water to the service reservoir.

Samples from various stages of water treatment were collected and analysed chemically, bacteriologically and biologically. The results of analyses are given in Tables I & II. Some of the observations based on these results are:

Table I—Quantitative analysis of planktons

(Source of sample: Pimpalgaon Water Works, Ahmednagar)

PHYTO-PLANKTONS	no/100 ml
Navicula	1950
Coelastrum	240
Pediastrum	180
Fragillaria	330
Melosira	3780
Total count	6,480/100 ml
ZOO-PLANKTONS	
Amoeba	180
Entosyphon ovta	270
Colpoda	210
Total count	6,60/100 ml

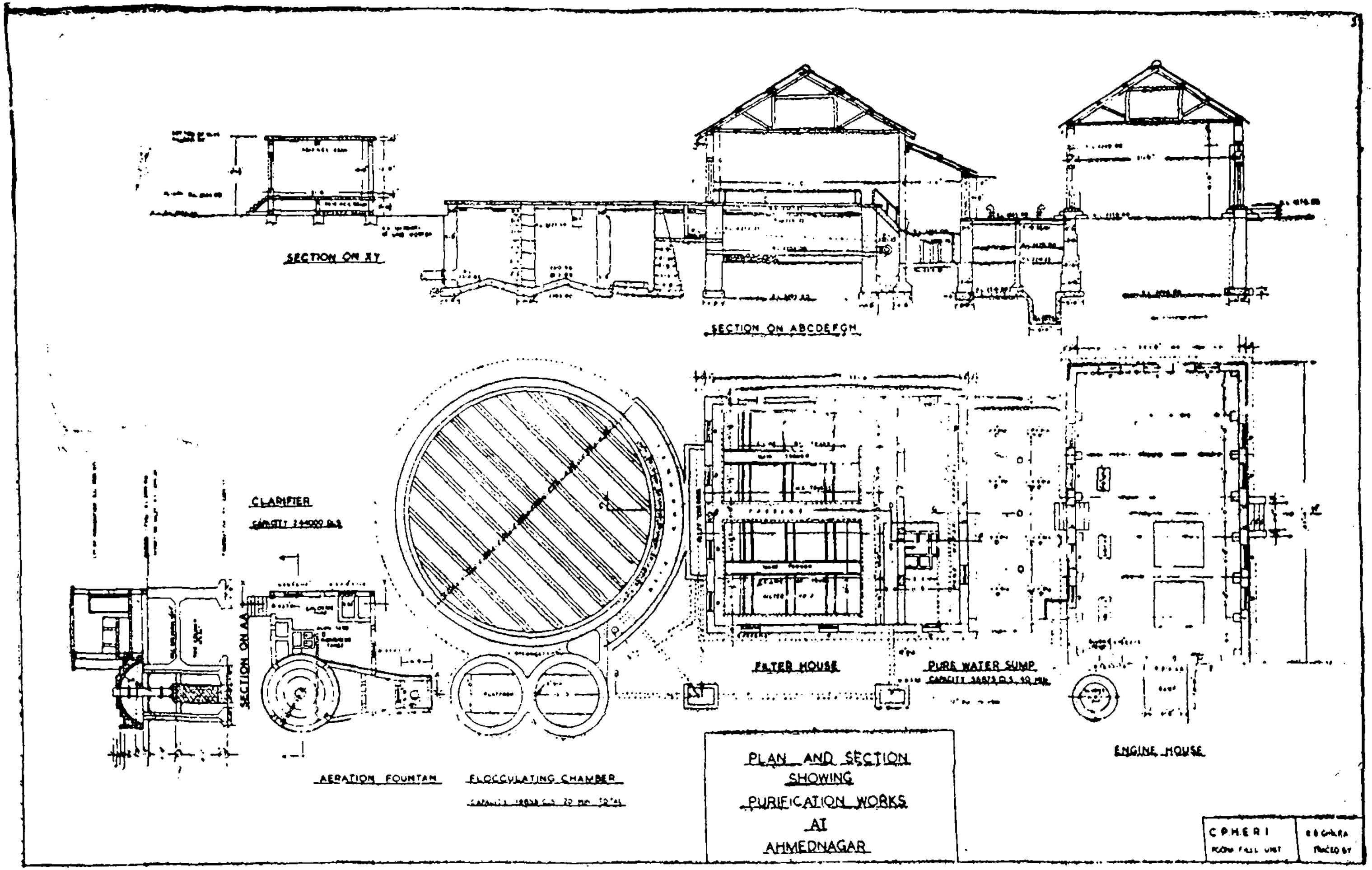
SECTION ON XY
SECTION ON ABCDEFGH
CLARIFIER
SECTION ON AA
AERATION FOUNTAN
FLOCCULATING CHAMBER
FILTER HOUSE
PURE WATER SUMP
ENGINE HOUSE
PLAN AND SECTION
SHOWING
PURIFICATION WORKS
AT
AHMEDNAGAR
C.P.H.E.R.I.

Fig. 1

(i) The dissolved oxygen increased from 4.5 mg/lit. (at the inlet of the aeration fountain) to 6.0 mg/lit. (at the outlet of the aeration fountain) but this did not help in odour removal which still persisted.

(ii) The raw water turbidity was 97.0 mg/lit. with faint greenish colour and vegetative odour while the filtered water turbidity was 44.0 mg/lit. with muddy appearance but no odour, for the samples collected on 30-5-62.

(iii) BOD of raw and treated waters was 11.0 and 8.5 mg/lit. respectively for the samples collected on 30-5-62.

(iv) Three samples from the distribution system showed high bacteral count, higher values of sulphates, total solids, hardness, etc.

(v) Bacteriological analysis of raw water at the Pimpalgaon Waterworks showed high count of the algal sp. of **Navicula** and **Melosira**.

From the above observations, it is clearly indicated that the entire process of water purification is not working satisfactorily. This might be due to improper and sometimes inadequate treatment or modifications if any, necessary in the units of the water treatment plant. Following is an attempt made to study each unit of the water treament plant as well as service reservoir. Details of each unit are shown in Fig. 2.

(I) *Aeration Fountain :* It is a cascade type. Though there was an increase in D.O., odour sometimes persisted even after aeration. Aeration probably may be insufficient. Turbidity in the reservoir on one occasion was 97.0 mg/lit. which dropped down to 77.5 mg/lit. at the inlet to the aeration fountain which means settlement of particles takes place in the pipe line.

(II) *Flocculator :* The flocculator consists of two circular tanks in series, each is 3.96 m (13 ft) and 4.88 m (16 ft) deep. Each tank has a set of flocculator blades, moved by an electric motor with suitable reduction gear and level wheels. The detention period as calculated from the above dimensions is nearly 20 minutes (at designed rate of 2 mill gal/day). The flocculators are emptied once a year by opening a drain valve. At the time of the first visit, the blades of the flocculator were not moving, as there was much accumulation of sludge at the bottom (about 6 ft). The following are some of the modifications suggested:

(a) Separate scour valves are required to be provided for each well. The existing scour pipe is only 0.15 m (6 in) in diameter. This should be increased to 0.30 m (12 in) which will be able to suck more sludge accumulated at the bottom of each well.

(b) The existing flocculator floor slopes away from the centre towards the periphery as shown in (Fig. 2). This may prevent the effective scouring of the flocculator which should be provided with a flat bottom, or slope towards the centre, bringing the scour valve opening near the centre.

(c) In the drawing, three openings in the partition wall between the two wells are shown. The inlet to the first flocculator is at the bottom and is directly in front of the lowest of the three openings. This may cause a direct flow of raw water with floc formation and the flow of accumulat-

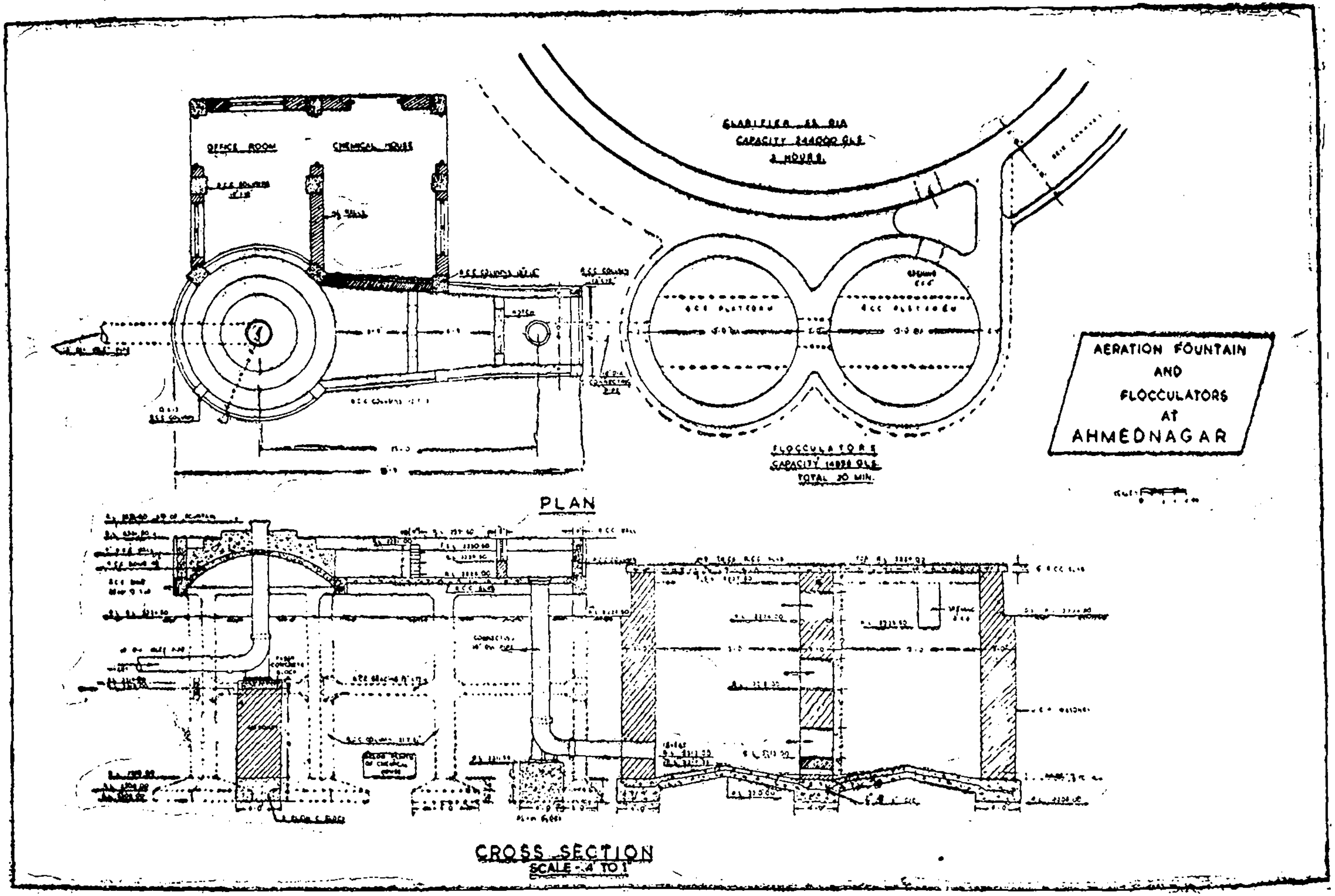
OFFICE ROOM
CHEMICAL HOUSE
FLOCCULATORS
AERATION FOUNTAIN
AND
FLOCCULATORS
AT
AHMEDNAGAR
PLAN
CROSS SECTION

Fig. 2

ed sludge near the inlet into the second well. This is undesirable. The bottom opening to the common wall of the two wells should be closed. To avoid floc settlement in the chambers, paddles should be kept continuously moving.

(d) The flocculator paddles in the two wells are moving at the same speed. Since the two wells are connected in series, floc in the first well is likely to break when it enters the second well. The speed of the paddle in the second well should therefore be suitably reduced. This reduction in speed will help in maintaining the floc in a suitable condition to settle down easily in the second chamber.

(e) Generally, the detention period for flocculator varies from 30 to 60 min. (1). This treatment plant when run at its designed capacity (2 mill gal/day), the flocculation time as worked out comes to 19 min. It seems that this period is inadequate.

(f) There is a chamber in between the flocculator and the clarifier. There is every possibility of the floc from the incoming flocculated water getting settled in this chamber. This may cause odour due to putrefaction of the settled sludge as there is no provision for scouring this chamber.

(III) *Clarifier :* Chemically treated water from the flocculator enters the clarifier at the bottom in the tangential direction. The clarifier is 17.76 m (55 ft) in dia and is 4.88 m (16 ft) deep. The detention period worked out to 3 hr for a designed flow of 2 mill gal/day. The weir length is 8.68 m (28½ ft) giving a loading of 3,94,200 lit/hr/m or 2920 gal/hr/ft. Generally, clarifiers are provided with hopper bottom. This clarifier has got ridges and furrows for the collection of the sedimented sludge. The scour pipe opens at the periphery of the clarifier and discharges the settled sludge into a scour chamber. This present arrangement is obviously not sufficient for the efficient removal of the settled sludge. If a hopper bottom is provided with the scour pipe opening near the centre, the efficiency in this respect could be attained easily.

(IV) *Rapid Sand Gravity Filter :* (Paterson design): Generally Paterson filters are designed for 80 gal/sq ft/hr. Here, each filter is loaded with 63.3 gal/sq ft/hr (at the designed rate of 2 mill gal/day). The filters are thus underloaded. In spite of such a low loading, the filtered effluent had 44.0 mg/lit. turbidity. It clearly shows that the filters are not working properly. The filter beds are washed every 24 hours by passing compressed air for 3 min, and wash water for 6 min. The wash water is collected in troughs and discharged on the land. The wash water tank is 3.04 m× 3.04m×1.82 m (10 ft× 10 ft×6 ft) and holds 33,750 lit. (7,500 gal) of water. For washing one filter bed, about 10,000 gal of water are required. This works out to 2 per cent of the quantity filtered between runs. The head of wash water over the filter sand is only 4.57 m (15 ft). Compressed air flows at a pressure of about 25 lb/sq in. The capacity of the compressed air reservoir is inadequate. The pressure, therefore, falls off rapidly as washing continues. The following might be the reasons: (a) Inefficient pre-treatment (i) from the turbidity readings of the effluents from flocculator as well as clarifier, it is seen that there is improper pre-treatment. It is desirable to have a turbidity less than 20.0 mg/lit. in the influent to the filter. The clarity is not achieved in the influent water which has a turbidity of 44.0 mg/lit. (ii) A sticky mass is observed on the walls of the filter at the time of washing.

(b) Improper washing of the filter (i) Air supply is inadequate because the compressors are not able to maintain the requisite air pressure even for five minutes. (ii) Back-wash water: Generally wash water used is filtered water stored at the elevated reservoir. But here the filtrate turbidity is 44.0 mg/lit. The overhead wash water tank should necessarily be 9.14—10.67 m (30—35 ft) above the top of the sand bed. In this case, the height is only 7.62 m (25 ft). This reduced head fails to wash the filter bed properly because sufficient pressure is not attained and required expansion of sand bed is not achieved to clean the inter-space of the sand grains.

(V) *Service Reservoir and Distribution System :* The filtrate from the Pimpalgaon Waterworks and the water from the dug well are pumped and collected at the service reservoir situated about 11 km away. This reservoir also receives untreated waters from Savedi and Wadgaon percolation wells. Chlorination by bleaching powder is carried out at one spot near the inlet pipe of the water from Pimpalgaon. Chlorination is done as long as waters from the three sources continue to add in the reservoir. When this ceases, chlorination is stopped. The supply from the reservoir to the city is intermittent. In the service reservoir, there are three inlets at different places: (i) Filtrate from Pimpalgaon Waterworks; (ii) Untreated well water from Savedi; and (iii) Untreated well water from Wadgaon. Disinfection with bleaching powder, carried out at (i) only, will be more advantageous and effective if all the three inlets are at one point, so that the whole quantity of water stored in the reservoir will be evenly treated. All the sides of the reservoir walls have windows, provided near the top, which are meant for ventilation. But when there is an overflow in the reservoir, the water emerges out of these windows and spreads outside the reservoir. This wastage could be stopped by closing these windows completely and the provision of the ventilators should be made at the top of the reservoir. Intelligent management of distribution storage requires information as to the level of the water in the reservoir. Where this can not be observed directly, gauges, floats or electrically operated indicators and recorders must be installed to meet the particular requirements of the system.

The reasons of getting high bacterial count in the distribution system might be due to:

(i) Old distribution system pipes which may have cracks due to old age, or joints may have opened out due to settlement;

(ii) Sampling point may be too far away from the chlorination point so as to show no available chlorine; and

(iii) Intermittant distribution system.

General Remarks

It is a general practice that the filtrate should not be exposed to atmosphere because there is always a possibility of the algal growth. Growth of algae depends on exposure to sunlight, clarity of the water, stagnation of water, etc. The most important preventive measure is the exclusion of sunlight. Collecting tanks for spring and well waters and service reservoirs for pure and purified water, should always be efficiently covered. Some restriction of growth in large reservoirs is possible by avoiding shallow areas and maintaining circulation of water.

Possible source of causing odour is the growth of algae in the Pimpalgaon reservoir. The mode of its removal is either by aeration and/or addition of chemicals, usually oxidising agents, such $KMnO_4$ chlorine, etc. Though permanganate treatment is costly, even then the oxidising power of permanganate eliminates all coliform organisms by the time the water leaves the primary clarifiers and acts similar to free residual chlorine, in reduction of colour, and it also aids in coagulation saving the coagulant costs (2).

The Diagnostic Centre of the Ahmednagar municipality, has a small laboratory where a few pathological tests are carried out. The same laboratory may be used to carry out few important tests such as (a) Determination of residual chlorine of the samples from distribution system, (b) to find out the dose of chlorine; and (c) if possible the Bacteriological analysis of water samples collected daily.

It was noticed that the alum dose is not based on the requirements. It is therefore, necessary to determine the dose of alum by Jar-test experiments.

At the Waterworks, it was noticed that the sludge chamber received sludge water from the clarifier, but the flocculator does not have proper provision for its disposal. There is only one pump running on diesel oil which pumps this sludge from the deep sludge chamber and disposes it off on an open land at some distance away from the treatment plant. There must be some arrangement for the disposal of sludge by gravity at a suitable place.

First and the foremost essential requirement for water treatment plant is that it must have a continuous supply of electric power and some standby arrangement. At present, the engines and motors are running on generator working on diesel oil. The next important necessity is the provision of telephone connection, as this being an essential service.

Acknowledgement

It is a great pleasure to acknowledge the sincere co-operation extended to us during these studies by Shri A. D. Patwardhan.

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Problems In Water Treatment for Individual House and Rural Communities

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Introduction

According to 1961 census, the rural population in India is nearly 360 millions living in about 5.597 lakh villages and forming 81 per cent of the total population. The size of the villages vary greatly. The maximum village population is generally considered as 5,000, while the average population per village is 529.

At present, it is seen that there are practically no treatment facilities to give safe drinking water supply to rural communities. As a result, where these communities, particularly depend on the surface water supplies, the water in almost all cases is subject to pollution. This is one of the major factors in the spread of waterborne diseases in the rural communities.

The provision of safe water supply to the villages, both acceptable in quality and quantity, poses a variety of problems varying between regions and most often within the same region, depending on the local hydrogeological features. The vastness of the area apart from the large number of villages adds to the magnitude of the problems. The Report of the **National Water Supply and Sanitation Committee** (1961), "The technical, administrative, financial, procedural and maintenance problems of a programme to encompass the entire rural area are a challenge to effective planning, with above 80% of the country's population living in the rural areas, rural water supply and sanitation forms the single potent factor for improving the national health" has properly stressed the importance of safe water supply to the rural communities.

Sources of rural water supplies

The common sources of water supplies in the rural areas, are:

A. Under-ground Sources: (i) Tube wells, and (ii) Open wells.

B. Surface Water Sources: (i) Rivers and nallas; (ii) Reservoirs and Tanks; and (iii) Canal.

Nature of Problems

The problems are of varied nature due to the local different hydro-geological features and more difficult as the individual requirements of water supply are small. Therefore, the water treatment method, normally adopted for city water supplies, may not be practicable for adopting for the rural communities, as the capital and the maintenance costs will be prohibitive for undertaking such treatment methods. So the main problem in water treatment for the individual house and small rural communities is to investigate cheaper type of treatment methods which will be easily maintained at reasonably low costs.

A. Under-ground Sources

(i) Tube Wells: There are generally no problems in the water treatment as the source is free from surface pollution.

(ii) Open wells: The main problem in this source of water supply is, how to give safe drinking water when the existing wells which are open, unprotected, poorly located and constructed are yielding unsafe water and usually spread the water-borne disease of enteric type. The best way to tackle this problem is to convert these wells into sanitary wells by improving the existing wells and protecting against out-side pollution. It is therefore very necessary to impress upon the concerned Govt. and local authorities to plan a systematic programme for improving the existing wells. This will need trained supervising staff and some form of financial help in the form of subsidy to the village panchayats or bodies for speedy execution of the programme.

The next problem is how to treat such polluted water for individual users, where the well water is polluted.

Following methods may be developed for the treatment of polluted well water.

(i) Standard Chlorine Solution and Tablets:

This may be simple but effective method. From one kg of liquid chlorine about 1,800 bottles of ½ lit. capacity and of 1,000 mg/lit. strength solution can be prepared. The cost of solution alone may not be more than 1 paisa per bottle. Adding the cost of polythene bottle and the distribution charges, a bottle may be sold in a village at 10 paise at the most. One bottle of 500 ml solution will last for 50 days to give a daily dose of 0.5 mg/lit. for 2 buckets, or one teaspoonful for a bucket of drinking water for an average family. Thus the cost per day for chlorination may not be even one paisa per day.

Chlorine and iodine compound tablets can be manufactured on a large scale for individual house use. Some commercial tablets such as Halazone are also available. The use of these tablets may also be a simple and cheap method for individual house water disinfection.

The difficulties in adopting these methods are : first, there will be problem of manufacturing the standard chlorine solution and tablets, but this can be solved by State Govt. Secondly, the distribution to the village, which also may be solved with the help of community block centres. Third and the most important will be how to make people adopt this method, but will have to be tackled mainly through public health education. Govt. can also give suitable subsidy till such scheme is popularised.

(ii) Continuous Disinfection of Wells:

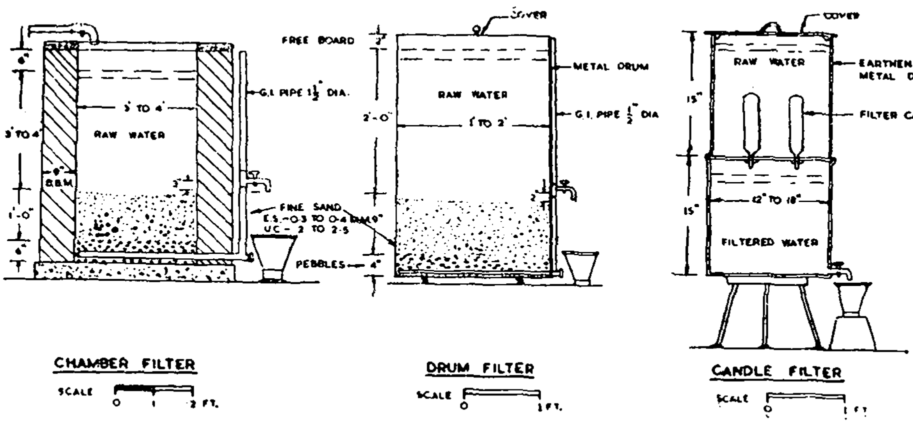
Experiments on cheap methods for continuous disinfection of wells based on chlorination through earthen pots are under progress in CPHERI, Nagpur and some cheap methods may be developed in the near future.
(iii) Individual House Filters

Following types of house filters may be designed and developed. (i) Small chamber or tank filters for group of houses, (ii) A small drum filter for an individual house, and (iii) Ceramic filter.

House Filter: The filter may be designed for the rate of filtration at 2 to 5 gal/sq ft/hr at the beginning of the operation, when the filter is washed and water level is full. The outlet tap may have to be designed for this maximum draw-off. The washing of the filter will be done when the rate of flow will be reduced below a certain minimum flow, which can be found out by filling a pot of measured volume in a fixed time for the minimum flow. The washing operation will be just to scrap ½ in depth of sand at the surface and replacing the same immediately after properly washing. After a certain period the whole sand may have to be washed. The details of the proposed sections through such filters are shown in Fig. 1.

Such types of filters in one or other form may be in use and it is necessary to have various types of experiments conducted in different corners of this Country to develop most effective, simple and cheap type of house filters. Disinfection with chlorination will have to be done after filtration as stated above in details. In addition, for highly turbid waters, alum treatment may also be necessary in a separate drum before filtration.

Ceramic Filter: It is an urgent necessity to develop non-pressure type ceramic filters in India. At present, British and German make Berkfield candle filters are available but the cost is exorbitantly high. These are manufactured out of typical diatomaceous earth or porcelain and it may be possible to develop such type of filters and to manufacture them in India at a low cost, so as to be adopted in a village house. With such type of candle filters, chlorination may generally be not required. The limitation of such candle filter is that the filter is likely to get choked up by turbid water and so this will have to be adopted for fairly clean or coagulated water.



INDIVIDUAL HOUSE FILTERS

Fig. 1

B. Surface Water Sources

(i) Slow Sand Filtration: For the rural water supplies, where filtration is necessary, slow sand filtration process can be adopted due to following advantages: (a) The construction cost can be lowered by adopting suitable designs. (b) Skilled personnel are not required for routine maintenance and operations. (c) Maintenance cost is cheaper than other filtration methods.

Design Aspects: It is necessary to design and to try simple structures for slow sand filtration for small communities in the rural areas. A proposed section through such a simple type of slow sand filter is shown in Fig. 2. This section is similar to an artificial infiltration gallery while the design is based on slow sand filtration process.

The surface area may be designed for 2 to 5 gal/sq ft/hr. Routine surface washing of this filter may be adopted which is not done for normal slow sand filters. This surface washing operation may be more effective if the surface water is kept flowing on the filter bed during the washing period of the filter which may lengthen the time of scraping of the surface sand as per normal practice for slow sand filters.

Pre-treatment for raw water can be given where necessary by providing plain sedimentation or by coagulation process.

This type of slow sand filter section may be possible where the source of water supply is from river, tank or canal. The problem of bringing the water from the source to the gallery by gravity or by pumping is a separate issue not connected with the present subject, but gravity supply will generally be desirable and cheaper from maintenance point of view.

(ii) Infiltration Galleries: Many villages are situated near the rivers or streams and, where the river beds are sandy or gravelly, the possibilities of finding sand or gravel pockets along a bank are excellent. For obtaining naturally filtered water, the gallery should be located 50 ft or more from the bank of a river. The water can be collected from the wa-

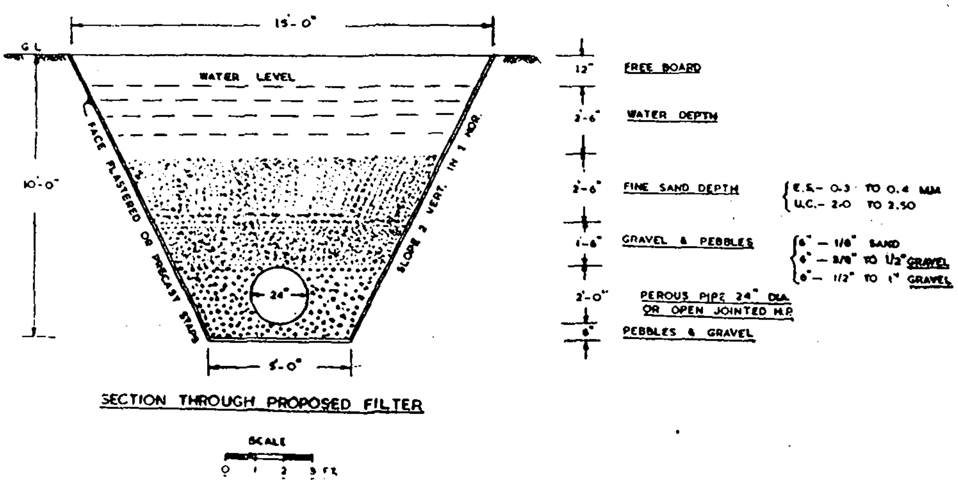


Fig. 2

ter-bearing strata through perforated pipes or porous pipes or masonry gallery, into a jack well or collecting well for pumping to required place.

A systematic exploratary boring along a bank and careful tests to measure capacity are necessary for finding out such locations. It is therefore suggested that such infiltration galleries in sandy banks may give excellent possibilities for potable water supply to the villages where the conditions are favourable.

Conclusion

From the above discussion, it will be seen that for providing safe domestic water supply to rural communities, it is necessary to investigate and adopt practicable effective and cheap methods for the treatment of water. As the problem is colossal, large scale efforts will have to be made to achieve the goal of safe drinking water supply to the rural communities.

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DISCUSSION

PROF. C. H. KHADILKAR (Baroda): I wish to draw the attention of the technicians to the importance and magnitude of the problem of water treatment in rural areas. All the known methods are costly in India. I find that in foreign countries, the cost of the design and execution of water supply scheme seems to be less than what it is in India.

It is the responsibility of the Government to supply pure drinking water to its people. Therefore to solve this problem, government organisation must be set up and this organisation should design, execute and operate the treatment units, making use of local labour and materials as it is done in Netherlands and other developed countries. Only then, we may be able to make some head-way in tackling this pressing problem.

SHRI J. N. KARDILE: Government of India has already set up investigation divisions in various states for designing the rural water supply schemes. The execution of rural water supply schemes will be done on large scale in the Fourth Five Year Plan, through the agencies of State Govt.

DR. E. V. ABBOT (Hoshangabad): For a long time to come, the water supply of the villages will depend on wells. Wells can be made safe and water in them can be protected from contamination from outside by sealing the well and fitting a dependable hand-pump. We should work to improve hand-pumps, make them dependable and teach the villagers to maintain these pumps.

Secondly, new wells of smaller diameter, can be completely sealed as described in our paper "Safe Sanitary Economical Well" available from Friends Rural Centre, Rasula, Hoshangabad. This paper describes a dug well that has been popular in Sambalpur District of Orissa. It has all advantages of the shallow tube well as far as the relative safety against contamination is concerned. Yet it is cheaper to install than a conventional dug well with its expensive masonry lining.

Once the villagers have learnt to have faith in a hand-pump as they did in Barpali, Orissa, they will tell us that their open wells should be covered and fitted with pumps.

SHRI J. N. KARDILE: We should give first preference to provide safe water supply through sanitary wells. The "Sanitary Well" as I mentioned in my paper, includes all the protection methods including hand-pump, etc., used for drawing water from the well. I agree with the views regarding the necessity of improvement in the hand-pumps. I also agree with the suggestions made for providing safe sanitary economical wells for places where we will be having new wells. I wish that the W.H.O. should try to impress the Government of India and concerned authorities to provide funds for only safe sanitary type of wells in future.

There are many villages, in Maharashtra as also in other States, where well water supply is not possible due to the geographical conditions, and surface water is the source of domestic water supply. I have tried to suggest cheap methods for the treatment of water for such villages.

DR. N. U. RAO (Nagpur) : It is very true, as Dr. Abbot rightly pointed out, that we should cover all the wells and fix a reliable hand-pump. But most of the existing wells are of very large diameter and they are open. Hence a device should be designed so that it can continuously give out effective concentrations of chlorine in the well. The chlorine cartridge method on which the initial report was published from **CPHERI**, is a step in the right direction for chlorination of well water.

SHRI J. N. KARDILE: The sanitary well as I mentioned in my paper includes all the protection methods including pump used for drawing safe water from the well. Majority of the existing wells are not of very large diameters and can be sealed and improved as sanitary well.

I agree with the views on a continuous chlorination of wells.

SHRI J. S. JAIN (Nagpur): The author mentioned the problems in water treatment for rural communities. The suggestion for individual households in rural areas is not at all practicable either from economy point of view or otherwise. Even in the emergency, the villagers are not in a position to appreciate the importance of using disinfecting tablets available in the market. Individual filtration unit is not only impracticable in rural areas but also in urban areas in India. The only possible solution is to have a community water supply which has a complete treatment before supply.

SHRI J. N. KARDILE: I have suggested some methods for individual water supply only when the community water supply is not possible. The individual house filter will have to be tried in the laboratory, if found fool-proof and economical then only it can be suggested for individual house use. We must provide community water supply wherever possible and I have suggested the cheaper methods for water treatment based on slow sand filtration.

SHRI S. K. GAJENDRAGADKAR (Bombay): The filters suggested are very costly and the villager using them is illiterate. Therefore the treatment to be given should be not only cheap but fool-proof. There should be no skilled operation involved.

The infiltration galleries are possible only under certain conditions like river flow, sand and site. Therefore, no generalisation can be made.

SHRI J. N. KARDILE: I agree that the individual house filter should be fool-proof and that unless it is proved, it should not be recommended. I have made my suggestion that this may be tried in the laboratory.

I have not suggested the infiltration gallery as a general method. It is possible only in a favourable location where good sand or gravel pockets are available, in the river bank.

SHRI D. A. NAIR (Ranchi): Water purification, by and large, is a method of cure in so far as the water is concerned and as the old saying goes "Prevention is better than cure". This is particularly significant in the case of rural water supply where economy is the main criterion, especially when the villager is to directly bear the cost.

Therefore, we should provide a source of water for the villager and prevent contamination. This can be achieved by ground water supply. A sanitary dug well will serve this purpose.

If necessary, during the epidemic period, let the villager boil the water. But let us not ask him to instal a filter and chlorinate the water.

SHRI J. N. KARDILE: We must give first preference to well water supply and that too by providing sanitary wells.

I have suggested treatment methods for the surface waters only when well water supply is not possible due to the geography of the place and when the people are using surface water for their domestic use. There are may villages in Maharashtra where people depend on surface water supply.

DR. A. K. ANWIKAR (Nagpur): I wish to submit the following observations in this connection. From the experiment on the domestic chlorination of water conducted at Sewagram for 3 years, our experience was that the chlorine stock in the bottles was exhausted within 3 days or earlier due to exposure to the sun and shaking; that the children threw off the cork with the result that chlorine was lost in 10-12 hours; and that 78 per cent of the villagers failed to refill the chlorine bottles indicating that their enthusiasm was lost.

The domestic sand filters used in railway station proved a failure since the filtered water was not found to be free from contamination. As for the drip chlorination, the CPHERI type may be recommended.

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Copper Sulphate as an Algicide and its Effect on Fishes

M. G. GEORGE, N. K. KAUSHIK, S. K. SRIVASTAVA, K. R. BULUSU and J. K. BEWTRA

CPHERI Zonal Centre, Delhi

Introduction

Chandrawal Water Works supply about 90 mill gal water per day to the metropolitan city of Delhi. The raw water is pumped from Wazirabad reservoir on river Yamuna. This reservoir has a capacity of about ten days demand and when it stagnates in May and June, the algal population increases considerably. An algal count of 21,93,000 cells/lit. in Wazirabad reservoir in third week of June, when compared to 6,62,500 and 3,06,000 cells/lit. respectively at 10 and 15 miles upstream the barrage, indicates the rapid growth of algae in the reservoir. Every summer, Delhi faces an acute shortage of water and the problem is further accentuated by the choking of filters by algae. The alga that causes nuisance at the Water Works is a diatom, **Synedra**, which originates from Wazirabad reservoir. The application of copper sulphate in the control of algae is well known, but little information is available in India on the dose of copper sulphate that can kill different species of algae. An important compilation on the dose of copper sulphate, to be given for controlling different organisms including **Synedra**, is given by Hale (1).

Since the efficacy of copper sulphate in the control of micro-organisms varies with the physical and chemical characteristics of water, it was considered essential to determine the dose required to reduce this alga in the raw water supply from Wazirabad reservoir. The reservoir supports a rich fish fauna and it is necessary to use as small a quantity of copper sulphate as possible because the fishes are susceptible even to small doses of copper compounds. Thus a study on the toxicity of the chemical to local fishes became imperative as the death and decay of the fishes will add to the problem of any reservoir control. The present paper deals with the laboratory studies on the use of copper sulphate for control of algae and its likely danger to fishes.

Material and Methods

In the present study, a different method than those tried by earlier workers (2, 3) was used to find the optimum dose of the copper sulphate for algal reduction. Fifty lit. of water were put in each of the six aquaria of 30 in x 12 in x 15 in size from raw water channel. One aquarium was kept as a control and different doses of copper sulphate were added in the others. If the dose is effective, the algae will be killed and settle down with time. Therefore, water samples were collected from the surface of the aquaria and the algal count was made by the use of an Inverted Microscope, both at the beginning of the experiment and after 24 or 48 hr. A contact time of 24 to 48 hr was used, as this detention is always available in this reservoir. The optimum dose was determined from the percentage reduction of algae. This method, with the direct count of algae, gives not the quantity of algae killed but the reduction of algae after contact with chemical followed by settling. In actual practice, the later information is more realistic for algal control in reservoirs.

The details of the method for determining the toxicity of copper sulphate on fishes are given in an earlier paper (4). The present study had the added advantage of conducting the tests at 25°C in an airconditioned room. The fishes employed were **Puntius ticto** Hamilton, **Labeo Labeo dero** (Hamilton) and **Mystus tangara** (Hamilton).

Results and Discussion

The chemical characteristics of water are given in Table I. The details of the copper sulphate dose and the corresponding percentage reduction of algae are given in Table II. In the first set of experiments, conducted in March, a contact time of 48 hr was given, at the end of which the control showed an algal reduction of 53 per cent. From the different doses tried, it was observed that 0.5 mg/lit. dose gave 91.8 per cent reduction and 1.1 mg/lit. dose effected 96.2 per cent reduction in the algal concentration relative to control after 48 hr.

The results obtained in May, when the algal count was 3,74,000 cells/lit. were slightly different. In this experiment, a contact time of 24 hr was given. The percentage reduction with 1.1 mg/lit. dose was 70 per cent, and with 0.5 mg/lit., it was 83 per cent relative to control after 24 hr which itself showed algal reduction of 35 per cent.

The optimum dose of copper sulphate required for 80-90 per cent reduction of **Synedra** and other algae in Yamuna water is 0.5 mg/lit. It may be pointed out that this value of 0.5 mg/lit. is comparable with the dose of 0.36-0.50 mg/lit. suggested by

Table I—Characteristics of water, measurements of fish and TLm

Date	pH	Total alkalinity as $CaCO_3$ mg/lit.	Total hardness as $CaCO_3$ mg/lit.	Dissolved oxygen mg/lit.	Test fish	Average length mm	Average weight	TLm (48 hr) $CuSO_4$ mg/lit.
12.3.64	8.4	170	166	7.1	P. ticto	84	9.1	2.4
5.6.64	8.4	170	178	6.1	M. tengara	70	3.9	4.6
17.6.64	8.5	162	172	5.8	L. dero	102	8.8	2.7

Table II—Copper Sulphate dose and percentage reduction of algae

	Control at start	Control after 48 hr	Copper Sulphate as $CuSO_4$ mg/lit.				
			1.1	0.9	0.7	0.5	0.3
			Cells/lit. after 48 hr.				
On March 12, 1964							
Fragilaria	87000	41400	1500	3500	3600	3400	5800
Rest of the Plankton	4000	1400	100	...	300	100	200
Total	91000	42800	1600	3500	3900	3500	6000
% Reduction relative to control after 48 hr	...	0	96.2	91.8	90.8	91.8	85.9
On June 5, 1964							
Fragilaria	314000	230000	67000	55500	49000	37500	57000
Rest of the Plankton	60000	12000	5500	6500	3000	1500	6500
Total	374000	242000	72500	62000	52000	39000	63500
% Reduction relative to control after 24 hr	...	0	70.0	74.3	78.5	83.8	73.7

Hale (1) for controlling **Synedra** in temperate waters. It is interesting that with copper sulphate treatment, there is considerable reduction of other algal species and zoo-plankton organisms present in addition to **Synedra** (1).

Every year, the algal problem occurs in May and June. After the first copper sulphate dosing in early May, the frequency of treatment should be determined by following the trend in the subsequent increase in algal population. A part of the copper will settle down and even if the bottom water in the reservoir is pumped, the amount of copper present in it will be less than the maximum permissible limit. The copper accumulated in the reservoir during the treatment will be washed out at the time of floods.

The results of the evaluation of toxicity of copper sulphate to fishes are given in Table I as 48 hr TLm (median tolerance limit). The 48 hr TLm for **Puntius ticto** was 2.5 mg/lit. and for **Labeo dero** 2.7 mg/lit. After the 48 hr test, the experiment was continued for another 4 days and there was no mortality of the fishes in the test aquaria with 1.0 mg/lit. or less of copper sulphate. The 48 hr TLm for **Mystus tengara** was relatively high, the figure being 4.6 mg/lit. In higher concentrations, the toxic effect of the chemical on fishes was discernible in 10 hr and the fishes became sluggish within this time.

There was no mortality of fishes with less than 1.0 mg/lit. concentration. Even after several days, the fishes in these lower concentrations were healthy and showed no signs of distress. This indicates that if the copper sulphate concentration does not exceed 1.0 mg/lit., it is safe for the fishes. According to the data given by Hale (1), the limiting safe dosages of copper sulphate for carps and cat-fishes are 0.33 and 0.40 mg/lit. It is worth pointing out that experience differs with water of different composition, and with different species of fish. This leads to an important suggestion that, before copper sulphate is used for algal control, its toxicity to the local fishes, depending upon the nature of water, has to be ascertained along with the tests for control of algae with copper sulphate.

Acknowledgement

The authors are grateful to Shri R. B. Raizada, Deputy Warden, Delhi State Fisheries and his staff for the help in collecting fishes.

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DISCUSSION

SHRI G. S. BHATTACHARYYA (Sindri) : Would you kindly enlighten me about the age of group of fishes studied by you and the weight of each fish that could stand 1 mg/lit. of $CuSO_4$?

SHRI K. R. BULUSU : The age group of **P. ticto** and **L. dero** could be precisely, determined due to the slow growth and small size. **M. tengara** belonged to the zero age group. The measurements of the fish and TLm are given below.

Test Fish	Average Length in m.m.	Average Weight in gms	TLM (48 hrs) $CuSO_4$ mg/lit.
P. ticto	84	9.1	2.4
M. tangara	70	3.9	4.6
L. dero	102	8.8	2.7

SHRI G. S. BHATTACHARYYA : Your observation showsthat 1 mg/lit. of $CuSO_4$ was not toxic to fishes. May I know whether this was applied dosage or residual $CuSO_4$ after certain period of contact time ?

SHRI K. R. BULUSU : This was applied dosage as $CuSO_4$. Even after several days, the fishes in this concentration were healthy and showed no signs of distress.

SHRI O. K. SHARMA (Patiala) : We store water in big storage tanks that can not be cleaned often. I would like to know whether the copper, after destroying the algae, can again pass back into solution and what the effects are, in case it does.

SHRI K. R. BULUSU : Storage tanks will have to be cleaned often. If such facilities are not available, the dosing of copper sulphate should be avoided. The amount of copper passing back into solution will be small.

SHRI T. S. BHAKUNI (Nagpur) : Literature shows that activated carbon can be used for algae blackout. Can we consider it as a feasible method in this country ? If so what will be the comparative cost ?

SHRI K. R. BULUSU : Yes, activated carbon can be used for algae blackout. But it may not be an economical proposition in India. Even the use of a cheap chemical like copper sulphate is not within the reach of many municipalities.

SHRI C. B. KHARKAR (Bhilai) : I beg to differ from you regarding your statement that the organic algicides have toxic effects in water environment and therefore they are not recommended. There is a vast range of amino organic compounds, etc. which are more efficient and less toxic than copper sulphate. Even penicillin is also known to be very efficient algicide. Please comment.

SHRI K. R. BULUSU : Considering economy, copper sulphate is the most suitable algicide in India.

SHRI D. A. NAIR (Ranchi) : About current trends in water treatment, an eminent sanitary engineer said, "Are we supplying water or medicine" ? This comment is an apt rejoinder to those who advocate addition of chemicals for algal removal, aiding coagulation, corrosion control, hardness removal etc. Moreover we are creating fresh problems like toxicity to fishes and other aquatic life by adding chemicals.

Secondly, application of chemical is an important factor. Even in a small water works, we have difficulty in dosing a chemical properly. How can we, therefore, ensure economical dosing of copper sulphate in large bodies of water where a thorough dispersion of the chemical is difficult to achieve.

Therefore considering these disadvantages and the recurring cost involved in buying the chemical, we should stop thinking of chemicals for removing algae. Physical methods should be thought of. For example, micro-mesh strainers can be used for the removal of algae. But such equipments are to be imported. Therefore we should design such equipment in India.

SHRI K. R. BULUSU : Prevention is better than cure. Why should we allow algae to multiply in the reservoir and then remove it mechanically? Addition of 0.5 mg/lit. of $CuSO_4$ does not contribute significantly to already mineralised waters. This dose is not toxic to fish as shown by several bio-assay experiments.

Spreading of this chemical on a large body of water is not difficult and has been adopted successfully at many places.

SHRI K. G. VEERARAGHAVAN (Madras) : I wish to know whether there is a more specific method of determining if the applied dose of the copper sulphate kills all the organisms in water or affects them in any other way. This is important because it is difficult to rely on the efficacy of the method of depositing the chemical on the water and because it might have been quite successful in the laboratory but the environments in the field are entirely different.

SHRI K. R. BULUSU : After the application of copper sulphate and settling, we count the number of organisms present. This gives an idea about the amount of algae killed for the particular dose.

SHRI K. G. VEERARAGHAVAN : In this connection, I wish to mention about the team of scientists that visited Madras in 1939 for the algal control in the lakes. About 17 reservoirs were selected for study. The effect of seasonal variation was also considered. A regular programme of application of copper sulphate was carried out for about 45 to 60 days. This really improved the quality of raw water as understood by reduced odour problem, increased filter runs and decreased chlorine consumption of the finished water.

Regarding the effect of copper sulphate on health, it can be applied up to 10 mg/lit., without any health hazards. The long detention time that is necessary for acting as algicide is also enough to precipitate the excessive $CuSO_4$. $CuSO_4$ is not a cumulative poison.

Regarding dosage, it is generally felt that a dose of about 0.3-0.5 mg/lit. is sufficient. But I have seen places where the blue green blooms require a high dose of 5 mg/lit. alternated with chlorine because copper sulphate alone did not give the anticipated result.

Finally, I would like to welcome as much information as possible about methods of application of these algicides on the water surface in the reservoir. Normally, we have seen boats and rafts tied with drums used for this purpose. But motor boats on the water works reservoir are completely absent. Therefore I strongly plead that for every impounding reservoir motored vehicles should be provided along with mechanical arrangements to spread the $CuSO_4$ uniformly on the surface. This uniform application of the chemical is once again emphasised as otherwise we will be wasting the copper sulphate on the water.

SHRI J. S. JAIN (Nagpur) : In this connection, I wish to tell my experience in dispensing hexadecanol, a chemical used for suppressing evaporation from big reservoirs. In conducting experiments on evaporation control at Walwhan lake at Lonavala, we used a motor boat mounted with a pump. The boat had built-in-tanks to carry the emulsion of the chemical. The emulsion was pumped on to a pipe fitted with muzzles and the spraying was done successfully on a water surface of about 1000 acres. I feel that this method can be used for dispensing the copper sulphate also. If copper sulphate is to be applied in powder form, dispensers are available in the market for this purpose.

SHRI K. R. BULUSU : We carried out experiments on spreading the copper sulphate in Wazirabad reservoir with the help of a motor boat. Copper sulphate was filled in double gunny bag and was tied to the motor boat so as to submerge about 1-2 ft below water surface. The boat was run at a speed of 4-6 ft per second in parallel strips about 15-20 ft apart. After covering an area of about 500 ft x 500 ft the boat was run criss-cross on this surface. This method had given a good distribution of the chemical in the upper layer of 5 ft deep with a dose varying between 0.3-0.7 mg/lit.

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Algae in Water Supplies

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The usual sources for drinking water are streams, rivers, tanks, lakes, wells and infiltration galleries. These waters are mostly exposed to sunlight and are normally infested with algae. The main factors, important to algal growths in the waters, are light, temperature and dissolved nutrients. These factors are available in abundance in tropical waters. Constant water pollution by sullage, sewage, industrial wastes and drainage from irrigated lands make the surface waters rich in nutrients and hence useful for algal growth. The presence of daily diurnal stratification in most of the Indian waters brings about a mixing up of surface layers of a body of water with those of the bottom layers. This results in greater biological productivity of the waters. The algal periodicity in Indian waters is very pronounced. Normally, the seasonal algal succession starts with diatoms followed by the greens and blue-greens and ends in diatoms. Summer and winter algal maxima are very common.

Palmer (1) divided algae of importance in water supplies into: (i) Taste and odour algae; (ii) Filter clogging algae; (iii) Polluted water algae; (iv) Clean water algae; (v) Surface water algae; and (vi) Algae growing on reservoir walls. Biswas (2) gave a list of fresh and brackish water algae of India and Burma. Subsequently, numerous systematic publications on algal flora of various regions of India have appeared from time to time. The list of algae given by Palmer (1) under various heads of classification almost tallies with Indian algae.

Algae in normal numbers are valuable in the biological cycle. Algal presence in waters brings in reoxygenation, mineralization and production of food chain (3). However, occasionally algae become so numerous as to give water a thickened green or blue green appearance and consistency. This state is normally referred to as water bloom. These will create difficulties to man by (i) bringing aesthetic harm due to colour, taste and odours developed; (ii) building up of BOD of the water; and (iii) leading to fish mortality, since algae may impart toxic substances to water or may be poisonous in nature. The presence of algal blooms in water supplies may (i) interfere with the coagulation, sedimentation, filtration and disinfection processes; (ii) corrode the concrete and steel tanks; and (iii) may carry objectionable bacteria unharmed by sterilization in water treatment.

These effects have led man to find out ways and means to eradicate the heavy growths of algae in surface waters and at the same time make the best use of their restricted presence. Matheson (4) discussed in detail about the effects of algae in water supplies. McKee and Wolf (5) bought out a very good review on algae as biological pollutants.

For a proper domestic water supply, the quality of water at the source of the supply and at the point of use should be considered. The significance of algal growths in water supplies and public health aspects will be considered in this Paper.

Economic Aspects of Algal Growths in Water Supplies

The sources of water supply are normally tanks, lakes, streams and rivers. These are full of fish life. Due to eutrophication, the Indian waters are rich in nutrients. Ganapati (6) stated that the inland waters are highly productive in fish. **Catla catla, Cirrhina mrigala, Labeo fimbriatus, Cyprinus carpo** and **Chanos chanos** have shown remarkable growths in tropical waters. Tanks infested with algae at Madras are more productive giving double yields of fish since most of the fishes feed on phyto-plankton. Lakshminarayana (7) discussed about the phyto-plankton relation to fish population. Fish are highly effective for balancing the aquatic life in reservoirs, etc. Certain of the so-called scavenger fish such as carp and suckers are consumers of organic materials. Proper balance of fish forms in waters will reduce the algal population and thereby eliminate the need for application of algicides. Selective killing of unwanted fish forms like carps, which grow prolifically and destroy spawn and all other forms, should be resorted to if necessity arises for proper fisheries. Singh (8) had given methods for organic and inorganic enrichment of fish ponds in India for proper maintenance of healthy algal blooms useful for pisciculture.

Fish Mortality : Algae can be severe pollutants to fish life in two respects either by direct poisoning or through oxygen depletion.

Fish mortality by direct poisoning had been attributed to any of the following: (i) Haff's disease (9); (ii) red-water due to the presence of **Gymnodimium** or **Glenodinium** (10); (iii) the presence of hydroxylamine and hydrogen sulphide due to blue-green algal decay (11); (iv) the clogging of gills by dead algal matter (12); and (v) any algal toxin. Fish mortality due to oxygen imbalance is very common in Indian inland waters (6, 8), but till now fish mortality due to algal poisoning in Indian waters has not been reported. In the absence of such reports, algae are useful as fish food. But one has to maintain the biological growth balance in bodies of water that produce fish so that oxygen imbalance or overgrowths of algal blooms may not take place.

Antibacterial Properties of Algae : There is some evidence indicating the production of antibiotic substances by algae. Pratt **et al** (13), Spoehr **et al** (14) reported the production of Chlorellin by **Chlorella sp.** Davidson (15) showed the antibacterial activity of **Oscillatoria formosa** on **Salmonella enteritidis, S. typhosa, Shigella dysenteriae** and **Staphylococcus aureus.** Davidson (16) also proved the antibacterial activities of **Anabaena variabilis, A. Olivace, Nostoc** sp. and **Lyngbya** sp. against **Salmonella enteritidis** and **Staphylococcus aureus.** The antibacterial properties of algae are useful for the inhibition of bacteria in general and pathogenic organisms in particular in natural waters which are used for drinking purposes. If proper types of algae are maintained in permissible concentration in raw water resources, the waters are expected to be free from some of the disease producing organisms.

Autoinhibition Properties of Algae : A survey of literature shows that there are many reports on the effects of one algae on another in mixed cultures (17-19). Fogg (20) had discussed in detail about the autoinhibitory effect of algae. Proctor (21) identified a fatty acid from the cultures of **Chlamydomonas reinhardi** which appears to suppress the growth of **Haematococcus pluvialis**. Pratt (22), Oneto and Pratt (23), Pratt and Fong (24) discovered an autoinhibitory, **Chlorellin,** in old cultures of **Chlorella vulgaris.** Spoehr **et al** (14) also found fatty acids from some species of **Chlorella** possessing autoinhibitory properties. This property may help in the proper maintenance of useful algal blooms in water supply sources.

Public Health hazards due to algal presence in water supplies

Algal Toxicity : There have been many reports, mostly from temperate countries of the World including U.S.A., of mortality of a great variety of animals after drinking water containing high concentrations of blue green algae, such as **Anacystis, Aphanizomenon, Nostoc, Rivularia, Nodularia, Gloeotrichia, Gomphosphaeria,** and **Anabaena.** Waterbloom poisoning is reported to be very similar to shellfish poisoning. Scobey (25) stated that the plankton organisms consumed by mussels are the cause of paralytic shellfish poisoning in humans.

Algal contamination of drinking water has been suspected as a factor in outbreaks of gastro-enteritis of unknown etiology—Tisdale (26), Veldee (27), Palmer (28), Lackey (29). Lackey (3) and Heise (30) have reported that **Pseudomonas** and members of the **Oscillatoriaceae** are poisonous in nature. Wheeler **et al** (31) pointed out that algal poisons usually act on the central nervous system and skin rather than on the gastrointestinal tract. Steyn (32) believes that the algal poison produces cirrhosis of liver and/or reduces the resistance to disease in many human beings. Rand (33) is studying the possible relationships between cancer producing compounds and geriatric disorders. The filmamentous marine algae, **Lyngbya majuscula** was believed to have been responsible for numerous cases of dermatitis in beach areas of Hawaii (34). A toxin has been isolated from **Anacystis** and identified as an alkaloid (35). **Nostoc rivulare** toxin administered to mice in food and drink gave the same results as intraperitoneal injections. Heat toxicity studies of **N. rivulare** suspensions showed that autoclaving destroyed toxicity, and the minimum lethal dose to mice is 0.0933 mg of algae per gram of body weight. The toxic factor is soluble in ethanol and affects the neuromuscular and respiratory systems (36).

With Canadian Water-Bloom samples of blue green algae—**Anacystis** aeruginosa, **Coelosphaerium**, **Anabaena**, **Aphanizomenon**, **Gloeotri** and **Lyngbya**—it was reported that toxicity increased to a maximum after 18 to 26.5 hr incubation of algal injected mice. The authors further stated that: (i) the toxicity of one sample was markedly reduced by storage at 3°C for 18 days followed by incubation at 27°C for 18 hr; and (ii) the toxicity develops only gradually in blooms, and decreases again as the algae decompose (37). Singh (18) stated, from his experiences on Indian water-blooms, that many experiments with several types of blooms and their effects on different animals—guinea-pigs, rabbits, squirrels, etc.—have definitely proved that Indian water-blooms are never poisonous or fatal, although the same species of algae as in other countries where such effects have been noticed, are involved. Ganapati (6) also opined that Indian water-blooms are not toxic. This can be attributed to : (i) lack of scientific information on this problem; and (ii) high temperature and other physico-chemical characteristics of Indian waters. Further studies are necessary to enlighten this aspect. In the absence of any reports of cases of algal poisoning, and virulence of the water-blooms in Indian waters, it may be stated that the Indian algal blooms are not toxic.

Colour Taste and Odours: Algal growths produce colour, taste and odour in water supplies (38). Silvey and Roach (39) observed that the taste and odour problems are created more by the presence of actinomycetes themselves than the alga like **Cladophora** which harbour them.

The mould-like bacteria, Actinomycetes, cause taste and odour problems in many of the water treatment plants. **Actinomyces, Streptomyces, Nocardia,** and **Micromonospora** are the principally known taste and odour-producing Actinomycetes. Silvey and Roach (40) stated that the aquatic actinomycetes develop with various plankton or organic matter rich in nitrogen. The secondary stage, i.e., the mycelial growth, requires available oxygen, potassium, source of organic carbon, nitrogen and the temperature of 10°-32°C. Further, he stated that 2 to 4 mg/lit. of potassium supports a luxuriant growth of these organisms. In the culture medium, copper has a stimulating effect on all the aquatic antinomycetes. Silvey (41) pointed out that calcium, sodium and magnesium will also stimulate the growth of some of these species. Ives (42) mentioned about the existence of the symbiotic relationship between **Streptomyces** and the alga, **Cladophora.** Silvey (43) indicated an imperfect relationship betwen algae and actinomycetes which, in the absence of sufficient nitrates and phosphates, causes rapid destruction of the algae and release of the by-products of metabolism of the actinomycetes. The type of odour forming compounds, produced by the actinomycetes, include aromatic amines, ketones, aldehydes, saturated fatty acids and unsaturated aromatics (40, 44). Morris (45) reported the actinomycete taste and odour problems. He isolated the chemical neutral fraction from actinomycete cultures, prepared from Cedar river, which gave musty taste and odours. Romano and Safferman (46) found that the addition of 1 mg/lit. of chlorine to spore suspensions of four different actinomycete species, buffered at pH 7.5, was effective in preventing their development. Bartholomew (47) and Silvey (44) indicated the possibility of control of actinomycetes by treatment with residual copper. Hansen (48) stated that $KMnO_4$ and carbon were used for taste and odour control of actinomycetes.

Algal odours, by aeration are not greatly improved, the odour reduction seldom exceeding ten per cent and its effect on woody, swampy and musty odours is slight. Chlorination, chloramine treatment, superchlorination, chlorine dioxide treatment, coagulation with activated carbon and absorbent clay will help in reducing the taste and odour problems (4).

Development of false colour with orthotoluidine when the water is infested with blue-green algae, is very common. This results in serious interference with chlorination. Filtration coupled with chlorination normally removes the color of the water.

Algal Interference with Coagulation and Jiltration : If proper coagulant dose is not applied, algae retards the formation of stable flocs and makes the loosely formed flocs to float on the surface. Algal growths impair the efficiency of slow and rapid sand filters.

Moderate growth of algae on slow sand filters has a beneficial effect in aiding the removal of bacteria because of the intense biological activity proceeding therein. Inhibitory properties of algae may be of some help in this context. However, the slow sand filters existing in India are not giving satisfactory performance due to heavy algal growths. The common algae that interfere with slow sand filters are **Melosira, Asterionella, Fragillaria, Synedra, Tabellaria, Cyclotella, Oscillatoria, Lyngbya, Anacystis, Chroococcus, Aphanothece, Aphanocapsa, Merismopedia, Anabaena, Anabaenopsis, Gloeotrichia, Phormidium, Arthospira, Spirogyra, Zygnema, Pediastrum, Tetraedron Scenedesmus, Chaetophora, Chlorella** and **Cosmarium.** The algal growths clog the filters and reduce the filter runs considerably and sometimes even to the extent of making slow sand filter *ineffective.*

Rapid sand filters are also impaired by the algal growths. Most of the serious algal troubles occur when the natural turbidity is low. Moderate dose of coagulant is ineffective in removing algae and in preventing the shortening of the filter runs. Use of fine sand in filters removes diatoms, etc. Frequent short washes are sufficient to remove the algae, and the use of somewhat more than the normal amount of wash water is the most economical method of handling the problem.

Algal Control

For the control of algal growths in water supplies, physical and biological methods should be used in the first instance. If they fail to improve the condition, one may have to resort to chemical intervention. The accumulation of dead algal matter released into the waters by killing algae by chemical means produces enormous tastes and odours.

Biological Management of Water Supplies : For this, a proper understanding of the factors involved is required. The provision of a qualified limnologist and an adequately trained staff with proper laboratory facilities to conduct frequent and regular physical, chemical and biological surveys is very essential. If the water purification plants are to be operated efficiently and economically, it is essential to know about what takes place in the water supply and what is to follow (4). Good housekeeping is one of the primary requisites for proper maintenance of the water plants. Cooperation between a biologist, bacteriologist, chemist and public health engineer is required.

Physical Control of Algal Growths : Aquatic weeds like **Chara, Nitella, Vallisparia, Najas, Potamogeton, Certophyllum,** etc. should be removed from the water treatment units by physical means. The connecting channels from one unit to the other should be covered in order to cut the light which encourages the algal growth. The walls of the treatment units should be white-washed preferably with a mixture of lime and copper sulphate. Whenever algal patches on the walls of the treatment units appear, they should be thoroughly scraped and removed. Algal mats, if found in the units, should be removed by wire mesh ladles.

Proper control of the watershed necessitates regular and continuous inspection of the area, the mapping and location of all points where pollutants are entering the stream or reservoir and the diversion and treatment of such contaminants whenever possible. This will minimise the introduction of nutrients useful for algal growth. Silting in the raw water sources should be checked. Reforestation of the surrounding area of the raw water source will help to a certain extent in reducing the silting problem.

Covering of slow-sand filters reduces algal growths. Whenever slow sand filters are washed, it would be better to remove the sand to deeper layers of 1 to 1.5 inches. It is good to examine core samples of sand from filters under the microscope and determine the depth of the sand to be removed for washing. Otherwise, motile algae and algal spores may remain in deeper layers of sand and this will again create algal blooms resulting in short runs of the slow-sand filter.

By shift draft system, one can avoid algae entering the water treatment plant from the raw water reservoirs. For this, knowledge of the changes in algal flora and its periodicity is necessary. Mixing of raw water with filtered or partly treated or pure water for the supply to the consumer should be avoided. Otherwise, it will result in heavy biological growths which impart colour, taste and odour.

Use of micro-strainers will remove the algae and cut filter back-washings and reduce the chlorine demand. Experiments conducted at Central Public Health Engineering Research Institute, Nagpur with a pilot micro-strainer unit resulted in the removal of about 92 per cent algae from Ambazari lake.

Biological Control of Algal Growths : Pisciculture in raw water reservoirs will help in the algal control (4, 6, 8).

Chemical Control of Algal Growths : (i) *Copper Sulphate ;* Copper sulphate traditionally serves as an eradicant of algae. When added to alkaline waters, it is largely precipitated as a finely divided carbonate. Being insoluble, copper carbonate remains suspended in the water for varying lengths of time, and maintains a small and a definite concentration of copper. Nichols **et al** (49) presented the most conclusive proof of accumulation of copper in the bottom sediments. Amongst the major objections for copper sulphate treatment, the gradual accumulation of copper in the bottom sediments in the body of water occupies the first place. Algae are known to become resistant to frequent copper sulphate applications. The precipitation of insoluble copper is greatly retarded if a mixture of sodium citrate, and copper sulphate is added. The cost of treatment may work out to be high but the effectiveness is greater (50). Alternate addition of copper and chlorine will help in reducing the emergence of algae resistant to copper sulphate. Monie (51, 55) worked out the A, B, C of copper sulphate application for algal control. He stated that an efficient algal treatment depends on: (i) the ability to determine whether it is necessary to treat a supply; (ii) the correct amount of copper sulphate to be applied while treating; and (iii) the ability to distribute the copper sulphate uniformly. Monie (55) states that no fixed dose of copper sulphate is possible for algal treatment. He further observes that the David Monie test (D.M.) works out the actual dosage of copper sulphate to be applied for each and every situation. Studies by Monie (55), Hirsch (56), Coffin (57), Hartman (58), Diven (59), Marquis (60), Hale (61, 62), Derby and Graham (63), Bartsch (64), McVeigh and Brown (18) and others showed that copper sulphate treatment for the prevention of algal growth, specially in reservoirs, has high potentiality.

(ii) *Activated Carbon :* Activated carbon, which is frequently used in water treatment is a very fine black powder. It acts on the principle of absorption. So great is the surface exposure attainable with activated carbon that it has been calculated that one cubic inch of activated carbon can account for the internal and external surface of approximately ten thousand sq yards (65). It has been also estimated that one gram of activated carbon will contain approximately 120 billion particles. Activated carbon is used for the control of taste, odour, and algae. It can be added to the raw water as it enters the plant, or at the coagulation and flocculation stage or in settling tanks or as it enters the filters. Most efficient absorption with activated carbon is usually accomplished at *p*H values below 9.0 (66). The best dosage is the one which produces the desired results with the least amount of activated carbon. In the treatment process, it is best to start with a high dosage and reduce it by steps until the point is found where the tastes and odours are eliminated.

Chlorine and carbon, when mixed in dry condition, will result in an explosive chemical reaction. Hence they should be applied separately at different points of treatment.

Activated carbon acts as a good coagulant aid and at the same time is capable of removing colour, odour and taste and also control the growth of algal population.

Opie (67) and Hartung and Lischer(68) used activated carbon to black-out algae and to remove the taste and odour. Palmer (69) indicated that activated carbon was very useful at Los Angeles, California, for the control of algae and other interference organisms in water supplies. He also stated that Culver city has filters of activated granular carbon to eliminate taste and odours from a heavy infestation of iron and sulphur bacteria in the underground water supply. Sigworth (70) used an installation of a pressure filter with granular activated carbon for treatment of conditions attributed to synthetic detergents. Flentje and Culp (71) and Shane (72) have also given instance of successful utilization of activated granular carbon for black-out of algae. Shane (72) stated that utilization of copper sulphate at the Porter Reservoir along with activated carbon resulted in lengthened filter runs in the water purification plant. In addition, economies have been effected in chemicals required for coagulation and disinfection. Riser (73) describing the reductions in algae, taste and odours with copper sulphate and activated carbon at Lake Bloomington stated that the chlorine demand of water was considerably reduced due to the copper sulphate—activated carbon treatment.

(iii) *Potassium Permanganate :* Potassium permanganate is an extremely versatile oxidant, able to function in all *p*H ranges making it a useful tool in the water treatment. It is useful for taste and odour control, iron and manganese removal and algal eradication. It is also effective against hydrogen sulphide, unsaturated organic acids, mercaptans, acrylates, esters, aldehydes, ketones, nitriles, olefines, alcohols, amines, agricultural chemicals and fish poison. Potassium permanganate reacts with soluble or insoluble organically bound iron and manganese oxidising them to corresponding insoluble oxides which are readily removed by coagulation, sedimentation and filtration. There are no resultant side effects such as poor coagulation, incomplete oxidation or formation of objectionable taste and odours due to potassium permanganate application. Potassium permanganate is compatible with chlorine, lime, alum, ferric salts and some coagulant aids. Copperas—Ferrous sulphate—and activated carbon should not be added until the permanganate reaction is complete. When used in conjunction with activated carbon treatment, the permanganate should be added in pretreatment with the carbon applied directly ahead of the filters. The field dosage ranges from 0.25 to 16 mg/lit. and the usual dosage is between 1-5 mg/lit. The potassium permanganate can be fed with any conventional gravimetric or volumetric dry feeder. Cherry (74) states that the severe taste and odour problems in the Cedar Rapid (Iowa) water supply in the summer of 1961 were removed by the application of potassium permanganate. Activated carbon was used for absorption before the filters in the treatment plant. The organisms that are involved in creating septic odour are mostly **Micromonospora, Streptomyces, Synedra, Melosira, Scenedesmus, Dictyosphaerium, Actinastrum, Anacystis** and **Oscillatoria.** Fitzgerald (75) evaluated potassium permanganate as an algicide. He stated that 10 mg/lit. of potassium permanganate with 4 to 6 hr treatment time is required to kill the algae.

(iv) *Chlorine and its Compounds:* The use of chlorine as a disinfectant or an algicide was discussed in detail (38). The algicidal uses of chlorine and its compounds are numerous. When Cupri-chloramine is applied to water infested with algae, reductions in algal numbers occur. This is due to the drop in *p*H of the water. Depending on the type of water treatment and the necessity, one may resort to any one of the following methods for the elimination of algae. (1) Simple chlorination; (2) Chloramine treatment; (3) Break-point chlorination; (4) Super-chlorination; and (5) Chlorine dioxide treatment.

Chlorine can be used in conjunction with copper and with most of the well-known algicidal chemicals.

(v) *Algicides :* The terms algicide and algistat are commonly used to describe chemicals which at certain concentrations will kill or inhibit the growth of algae respectively. It is important to know whether a chemical is algicidal or algistatic at a specific concentration. This can be determined with the help of pure algal cultures.

Palmer (76) reviewed the evaluation of various chemicals used as algicides for water supply purposes. He stated that the screening test for algicides so far conducted served to indicate that there are a number of chemicals like inorganic salts, organic salts, rosinamine compounds, antibiotics, quinones, substituted hydrocarbons, quaternary ammonium compounds amide derivatives and phenols which are algicidal. Maloney (77) discussed the use of chlorophenyl dimethyl urea for the control of algae. Fitzgerald (75, 78, 79, 80) studied exhaustively the use of algicidal chemicals for eradicating algae in cooling towers and swimming pools. On the basis of results obtained, he stated that Algimycin, Algae-Nox, Exalgae, Hyamine-2389, Algae-kill and Berkite No. 4 are respectively ranked as commercial algicides for eradicating the growths of **Chlorella pyrenoidos, Phormidium** and **Oscillatoria.** Copper at an average concentration of about 6 mg/lit. corresponding to about 24 mg/lit. of commercial copper sulphate was found to be necessary to kill the algal growths. Fitzgerald (75) stated that potassium permanganate, copper sulphate, Armazide and Algimycin, MT—4 are useful as algicides for water cooling towers. Artonides and Tanner (81) stated that the swimming pools could be maintained effectively free from algal growths with concentrations of Armazide in conjunction with low concentration of chlorine.

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Biological Characteristics of Water Quality

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Introduction

Sources of raw water have to be carefully assessed for quality and quantity. The sources of pollution are associated with the habits of the people and their civic consciousness. These sources in India are many and varied. Owing to rapid industrialisation, the industrial wastes have now added to the causes of pollution.

The quality of water with reference to pollution levels is determined by chemical methods. These include measurements of turbidity, *p*H, alkalinity, hardness, suspended solids, total solids, dissolved oxygen, chemical and biochemical oxygen demand. The procedures for such estimation have been standardized (1) and have been widely in use.

Biological methods, however, are of comparatively recent origin. Unfortunately, the data obtained in one country or one climatic zone would not be useful for another country or zone. But the principles underlying the interpretation of data obtained are of universal application. The use of biological data is becoming an integral part of programmes for water treatment in many parts particularly in the United States and Europe (Selected references are given as Appendix A).

The programmes involve collection of plankton from various localities for a number of years and the study of ecology of the planktonic forms. The conditions at the surface may not be the same as at levels lower down. Aquatic organisms reflect the history of a body of water while chemical analysis is only valid for recent conditions (2).

By and large, the planktonic organisms have to be very correctly identified. Species of the same genus are present in different countries and hence the necessity of identifying the forms collected, which reflect the degree of pollution. Such studies, apart from the difficulties of identification, have other limitations, e.g., the complex nature of organisms and their environment (3) and the ability of organisms to survive in changed conditions (4).

Ingram & Bartsch (5) as a result of extensive survey programmes, have prepared lists of organisms, providing the biologists with valuable data. But the available data are of little use to workers in India because of the differing geographic and climatic conditions.

It is against this background that the planktonic surveys of various bodies of water with reference to pollution levels have been undertaken. Such surveys have to be made over many years and in various areas before the results could be of value. Due to various limitations, only the study of planktonic shore forms and of some groups of animals, **viz.**, Protozoa, Rotifera, Oligochaeta and Gastrotricha was undertaken and the results presented in this paper.

Materials and Methods

I. Biological samples were collected every week using a plankton bolting silk net (200 mesh) from the following water bodies:

(i) Kanhan-River and Water Works) (ii) Gorewada-Lake and Water Works) (iii) Ambazari Lake)	Potable water reservoirs and river which supply water to the city of Nagpur
(iv) Jumma Tank (Gandhi Sagar) (v) Sakaradhara Tank)	Medium polluted tanks of Nagpur
(iv) Sewage Oxidation Ponds)	Bezon Bagh, Nagpur treating domestic sewage
(vii) Maharaj Bagh Sampling Station)	One of the sampling points on Nag Nala grossly polluted.
(viii) Nag Nala)	Polluted stream running in the heart of the city of Nagpur with 13 sampling points extending over 14 km.

The collections were brought to the Laboratory, the fauna studied in the living condition, and later fixed with formalin (5 per cent) or Schaudin's fixative for **Protozoa** and *Bouin's fluid for* **Oligochaeta.**

The animal communities collected were isolated broadly into groups like **Protozoa, Rotifera, Oligochaeta** and **Gastrotricha** and for other minor groups.

The quantitative estimation of various plankton population (no/lit) was carried out using both Utermohl's inverted plankton microscope and the Sedgwick-Rafter ocular whipple micrometer method.

II. Simultaneously samples for chemical analysis were collected and all the physical and chemical analyses (temperature; *p*H; 4-hr Oxygen-Absorbed, Dissolved Oxygen; Biochemical Oxygen Demand; total alkalinity; free carbondioxide; carbonates; and chlorides) were carried out (Table I) following the procedures in Standard Methods (1).

III. Bottom samples were also collected from time to time using an Ekman dredge and the bottom fauna

Table I—Physico-Chemical Analysis+ of Water and Wastewater Samples

Nature of Analysis	Kanhan River at Water Works	Gorewada lake	Ambazari tank	Gandhi Sagar	Sakardhara tank	Maharaj bag Nala	Nag Nala	Oxidation Pond I (influent raw-sewage)
Turbidity	170	10	10	550	30	50	10-600	—
*p*H	7.8	8.0	8.0	8.1	7.9	7.8	7-8.9	7-8.9
Dissolved solids	250	170	110	—	—	—	—	300-500
Total alkalinity (As $CaCO_3$)	200	145	109	510	200	360	100-700	250-350
Total hardness	160	120	100	300	300	296	150-500	250-350
Chlorides (as Cl)	15	10	10	122	45	60	10-250	50-120
Oxygen consumed (4 hours' test)	0.5	0.5	0.5	50	30	50	5-400	15-50
Dissolved Oxygen	7.8	7.0	8.0	12.8 (3-4 PM)	7	0-1	0-8	0-19 (3-4 PM)
*Biochemical Oxygen Demand	5	10	5	60	50	50-80	5-350	150-250

*At 37°C

+All values except pH are expressed in mg/lit.
Average values for over a year

isolated and studied qualitively and quantitatively. The detailed soil analysis was also carried out with reference to nitrogen, ammonia, and organic matter in relation to the **Oligochaeta** environment.

Analysis of Biological Procedures : Biological methods fall into two groups "Direct" or "Ecological" and "Indirect" or "physiological". In the former are included the collection and identification of organisms at various levels in a body of water, frequency of occurrence and their association with other animals (7). Besides, any water body in which sewage is discharged shows several zones of pollution each with its specific fauna and flora, leading from polysaprobic (gross pollution) to oligosaprobic through **alpha** and **beta** mesosaprobic conditions (8-11). The chain of events relates to changes in the dissolved oxygen, ammonia and sulphide contents and the available food material. The saprobien-system originally dealt with sewage, but since has been extended to other waters including those in which industrial wastes are discharged (12-15). The exact biological condition of each zone need not be considered in detail (these have been dealt with by Hartmut Bick) (16).

Observations

Tables II, III, IV and V indicate micro-organisms, i.e., species of **Protozoa, Rotifera, Oligochaeta,** and **Gastrotricha** respectively collected from various water bodies and the quality of water. In all, 39 species of **Protozoa,** 26 of **Oligochaeta,** 41 of **Rotifera** and 12 of **Gastrotricha** have been collected and identified up to the genus level at least. In all groups, certain species occur only in certain types of water and some are ubiquitous. Some salient points regarding their distribution are discussed as follows.

Table II—List of protozoa collected and their habitat

	Potable water	Medium Polluted water	Heavily Polluted water
Class **Mastigophora** or **Flagellata**			
1. Ceratium sp.	+	+	—
2. Chilomonas paramecium	—	+	—
3. Heteronema sp.	—	+	—
4. Codosiga sp.	—	—	+
5. Paranema sp.	+	+	—
6. Astasia sp.	+	+	—
7. Entosiphon sp.	—	+	—
8. Phacus	+	+	—
Class **Rhizopoda** or **Scarcodina**			
9. Arcella sp.	+	+	—

(Table II contd)

10. Difflugia sp.	+	+	—
11. Amoeba sp. (mud form)	+	+	—
Heliozoa			
12. Vampyrella	—	+	—
13. Actinosphaerium sp.	+	+	—
Sub Phylum Ciliophora			
Class **Ciliata**			
Order **Holotricha**			
14. Paramecium polycarium	+	+	—
15. P. caudatum	—	+	+
16. P. aurelia	—	+	—
17. P. jenningsii	—	+	+
18. Coleps elongatus	—	+	+
19. Colpoda sp.	—	+	—
20. Dileptus	+	+	—
21. Colpidium sp.	—	+	—
22. Holophrya sp.	—	+	—
23. Didinium sp.	—	+	—
24. Leucophrys sp.	—	+	—
25. Tetrahymena sp.	—	+	—
Order **Spirotricha**			
26. Stentor sp.	+	+	—
27. Bursaria sp.	—	+	+
Order **Heterotricha**			
28. Spirostomum ambiguum	—	+	+
29. Blepharisma undulans	—	+	+
Order **Oligotricha**			
30. Halteria sp.	—	+	—
Order **Hypotricha**			
31. Stylonichia pustulata	—	+	+
32. Euplotes aedicudlatus	—	+	+
33. Gonostomum	—	+	+
Order **Peritricha**			
34. Carchesium sp.	—	+	—
35. Vorticella sp.	—	+	+
Class **Suctoria** or **Acineta**			
Order **Acineta**			
36. Acineta sp.	+	+	—
37. Podophrya	—	+	—

Table III—List of rotifera and their habitat

	Potable water	Medium Polluted water	Heavily Polluted water
Class **Digononta**			
Order **Bdelloidea**			
Fam. Philodinidae			
1. Rotaria rotatoria Scapoli 1777	—	—	+
Class **Monogononta**			
Order **Flosculariacea**			
Fam. **Flosculariidae**			
2. Sinantherina spinosa (Thorpe) 1893	—	+	—
3. Sinantherina triglandularis sp. nov.	—	+	—
4. Lacinularia flosculosa (Muller) 1758	—	+	—
Fam. **Conochilidae**			
5. Conochiloides dossuarius var. asetosus var. nov.	—	+	—
Fam. **Filinidae**			
6. Filinia longiseta Ehrb. 1834	—	+	—
7. Tetramastix opoliensis (Zacharias) 1898	+	—	—
8. Pedalia fennica var. Oxyuris Sernov 1903	—	+	—
9. Filinia terminalis (Plate) 1886	—	—	+
10. Pedalia intermedia Wisniewski 1929	—	—	+
Order **Ploima**			
Fam. **Notommatidae**			
11. Scaridium longicaudium *(Muller) 1786*	—	—	+
12. Polyarthra multiappendiculata sp. nov.	—	+	—
Fam. **Asplanchnidae**			
13. Asplanchna intermedia Hudson 1886	—	+	—

(Table III contd)

Fam. **Brachonidae**
Sub-fam. **Brachioninae**

14. Brachionus aculeatus (Hauer) 1937	—	+	—
15. B. aculeatus forma lateralis Gillard 1948	—	+	—
16. B. caudatus Barrois & Daday 1894	—	+	—
17. B. forficula Wierzejski 1891	+	—	—
18. B. anguluaris var. bidens (Plate) 1886	—	—	+
19. B. budapestinensis var. punctatus Daday 1885	—	+	—
20. B. falcatus var. lyratus Lammerman 1908	+	—	—
21. B. urceolaris (Muller) 1773	—	+	—
22. B. quadridentatus var. melheni (Barrois & Daday) 1894	+	—	—
23. B. calyciflorus var. dorcas (Gosse) 1851	—	+	—
24. B. calyciflorus var. dorcas f. spinosa (Wierzeski) 1891	—	+	+
25. B. calyciflorus var. dorcas f. amuraeformis Brehm 1909	—	—	+
26. B. calyciflorus var. dorcas. f. pala (Ehrb.) 1838	—	—	+
27. B. calyciflorus var. brycei de Beauchamp	—	+	—
28. Keratella cochlearis (Gosse) 1851	+	—	—
29. K. tropica (Apstein) 1907	—	+	—
30. K. tropica f. monospina Klauseuer 1908	—	+	—
31. K. tropica f. reducta Fadeev 1927	—	+	—
32. K. tropica f. aspina Fadeev 1927	—	+	—

(Table III contd)

33.	K. valga (Ehrb) 1834	—	+	—
34.	Platyias longispinosus sp. novo	—	+	—
35.	P. palutus Muller 1786	+	—	—
36.	Trichotria tetractis (Ehrb) 1830	—	+	—
37.	Lecanae lcontina (Turner) 1892	—	+	—
38.	L. bulla (Gosse) 1851	—	+	—
39.	L. quadridentata (Ehrb) 1832	—	+	—
40.	L. curvicornis var. padespares var. nov.	—	+	—
41.	L. dorsicalis sp. nov.	—	+	—
42.	L. tesselata sp. nov.	—	+	—
43.	L. curvilinealis sp. nov.	—	+	—
44.	L. longidactylus sp. nov.	+	—	—
45.	Mytilina ventralis (Ehrb). 1832	—	—	+

Table IV—List of oligochaetes and their habitat

	Potable water	Medium Polluted water	Heavily Polluted water
Fam. **Aelosomatidae**			
1. Aelosoma bengalensis	+	—	—
Fam. **Naididae**			
2. Chaetogaster diastrophus	—	+	—
3. C. cristallinus	—	+	—
4. Nais communis	—	+	—
5. N. andina	+	+	—
6. Branchiodrilus sp.	—	+	—
7. Dro digitata	—	+	—
8. D. zeylanica	—	+	—
9. D. cooperi	—	+	—
10. D. nivea	—	+	—
11. Aulophorus furcatus	—	+	—
12. A. michaelseni	—	+	—

(Table IV contd)

13. A. hymanae	—	+	—
14. A. moghei	—	+	—
15. A. tonkinensis	—	+	—
16. Allonais gwaliorensis	—	+	—
17. A. rayalaseemensis	—	+	—
18. Pristina acquiseta	—	+	—
19. P. longiseta longiseta	—	+	—
20. P. probobsidea	—	+	—
Fam. **Tubificidae**			
21. Limnodrilus hoffmeisteri	—	—	+
22. Aulodrilus remex	—	—	+
23. Branchiura sowerbyi	—	—	+
Fam. **Enchytraedae**			
24. Enchytraeus sp.	Recorded from sewage irrigated soil		
Fam. **Megascolecidae**			
25. Ocnerodrilus	—	+	—

Table V—List of gastrotricha collected

Species of Chaetonotus	Other species of Gastrotricha
Chaetonotus tachyneusticus Brunson 1948	Ichthydium monolobum
C. noverarius Grueter 1917	Polymerurus nodic audus
C. trianguliformis. sp. novo.	P. magnus sp. novo.
C. monobarbatus sp. novo.	Neogossea antennigera
C. laterospinosus sp. novo.	Stylochaeta abarbita sp. novo.
C. caudal spinosus	
C. sextospinosus sp. novo.	

(All the specimens were collected only from the medium polluted Sakardhara tank)

A. PROTOZOA

I. Occurrence of individuals:

(i) Forms which occur exclusively in very polluted waters are species of **Metopus, Codosiga, Frontonia,** and **Gonostomum.**

(ii) Forms like **Arcella, Difflugia, Paranema, Dileptus Acineta, Astasia** and **Paramecium policarium** are always associated with medium polluted water bodies. They have also been collected from clean waters but these forms have not been collected at all from heavily polluted waters.

(iii) Forms like species of **Vampyrella, Chilomonas Paramecium, Hetronema, Entosiphon, Paramecium aurelia, Paramecium jenningsii,** and species of **Colpoda, Halteria, Colpidium, Didinium, Leucophrys, Tetrahymena** and **Podopyra** have been collected only from medium polluted tanks.

II. Occurrence in communities: Plankton.

Data is available not only for Gandhi Sagar (a medium polluted tank). The quantitative and qualitative plankton population collected every week over a year is available (17-18). Table VI shows dominant and subdominant groups. To a limited extent, plankton data is also available for Kanhan river. The following samples have been selected to show the dominant group and the community in which they occur, (Table VII).

B. ROTIFERA

I. Occurrence of individuals

Rotifera are present in all bodies of water but some species are restricted to definite pollutions and can thus be used as indicators of pollution (19-20).

Forms like **Brachionus falcatus, B. forficula, B. quadridentatus** and **Keratella cochlearis have** been recorded only in potable waters (21-22).

Table VI—Dominant groups + in Gandhi Sagar

Date of collection	Protozoa	Rotifera	*Moina dubia*	*Copepods*
20-11-1961	2732	13526*	322	722
1- 1-1962	7097*	5604	1125	1447
15- 1-1962	17851*	5903	1275	6240
19- 3-1962	3925	1483	447	4157*
12- 2-1962	5096	1468	8367*	4688
19- 2-1962	24047*	559	1442	4562
12- 3-1962	8791*	595	1011	1031
2- 4-1962	4999	3623	741	4012

(Organisms expressed per litre of the sample of water. Values are averages of the collections made round-the clock at the interval of 3 hr once a week)

+ (Data regarding dominant species in each group is not available).

* Denotes dominant group

But forms like **Asplanchna intermedia, Brachionus aculeatus, B. caudatus, Filinia longiseta, Keratella tropica, K. tropica** forma **monospina** and other forms as indicated in Table III have been collected only from medium polluted water bodies.

Forms like **Brachionus calyciflorus** var. **dorcas** forma **anuraeformis, B. calyciflorous** var. **brycei, B. calyciflorus** var. **dorcas** forma **spinosa, Rotaria rotatoria, Polyarthara multiappendiculata, Asplanchana intermedia** have been collected only from heavily polluted water bodies as well as in medium polluted water bodies. It is provisionally concluded by Arora (20) that:

(a) Rotifera like **Tetramastix opoliensis** and **Pedalia fennica** are inhabitants of water of good quality;

(b) Rotifera like **Polyarthra multiappendiculata, Rotaria rotatoria** are inhabitants of foul waters;

(c) Rotifera like **Filinia longiseta** are inhabitants of foul and good waters.

Out of the eight species of **Brachionus** collected and reported by one of the authors (21,HCA) it has been found that this genus is extremely interesting because it has a wide range of occurrence. They are more abundant in moderately polluted waters from which ten different specimens and varieties have been recorded from one collection.

II. Occurrence in communities:

Data on the occurrence of certain dominant **Rotifera** in association with other animals are not available, but the association of dominant species of Rotifers with other species is shown in Table VIII.

C. OLIGOCHAETA

Goodnight Whitley (23) suggested that among **Oligochaeta** both planktonic and the forms dwelling in the bottom mud are useful as indicators of pollution. He confined his remarks to tubificids found in the bottom mud

In all 20 species of planktonic forms, three species of mud-dwelling forms and two species of soil forms have been recorded (Table IV 24).

I. Planktonic forms

(i) Of the planktonic forms, only **Aelosoma bengalensis** (family **Aelosomatidae)** has been recorded in potable waters.

(ii) **Nais andina** is the only form which is recorded in clean water and in medium polluted water but not in heavily polluted waters.

(iii) The rest of the planktonic forms (see Table IV) have been collected only from the medium polluted water bodies and not from either clean or heavily polluted places. Thus planktonic oligochaetes are absent in heavily polluted waters.

II. Mud-dwelling forms

The mud-dwelling forms such as **Limnodrilus holfmeisteri** (tubificid), **Aulodrilus remex** and **Branchiura sowerbyi** have been collected only four stations from which collections quantitative analysis of the macrofauna of the bottom sludge of the four stations from which collections were made have been shown in Table IX.

Thirty thousand to fifty thousand individuals of **Limnodrilus hoffmeisteri** per sq. ft. have been collected, from one of the heavily polluted lo-

Table IX—Biological r

Stations	Limnodrilus hoffmeisteri Min.	Max.	Branchiura sowerbyi Min.	Max.	Eristalis sp. Min.	Max.
Ambajhari ** (Potable Water Reservoir)	...	...	...	...	...	...
Sakardhara (Medium polluted tank)	...	...	...	...	...	...
Gandhisagar *** (Medium polluted tank	...	...	...	...	...	...
Maharajbagh (grossly polluted place)	4,096	50,592	...	1	16	32

* Values expressed are individuals per square foot of sample

** In all the samples from Ambazari, only dead shells of Mollu

*** No macro-fauna recorded from Gandhisagar, but sometimes cord of macro-fauna from bottom sediment

Chironomus		Vivipara dissamilis		Vivipara bengalensis		Malanidae		Bivalves	
Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
...	...	16*	32	8	...	16	...	4	28
...	...	16	36	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...
96	169	...	...	...	...	...	...	...	...

scs were recorded

certain Sp. of ciliate (unidentified) were noted.

Table VIII—Rotifer forms collected from various water bodies

Months of Collection	Jumma Tank (Gandhi Sagar) (medium polluted tank)	Sakaradhara Tank (medium polluted tank)	Gorewara Lake (potable water)
1961-62 January, February and March	**Brachionus angularis** * **Keratella tropica** **Brachionus calyciflorus** **Filinia longiseta**	**Brachionus caudatus** **Keratella valga** **Brachionus angularis** **B. calyciflorus** **Lecane quadridentata** **Platyias patulus** *	**Keratella valga** **Brachionus falcatus** **Tetramastix opliensis** *
April, May & June	**Brachionus angularis** * **B. quadridentatus** **Platyias patulus**	**Brachionus angularis** **Lecane quadridentata** * **Brachionus calcyciflorus** **Polyarthra multiappendiculata**	**Lecane. sp.** **Brachionus falcatus** * **Tetramastix opoliensis** **Keratella valga**
July, August & September	**Brachionus angularis** *	**Brachionus angularis** **Rotaria rotataria** **Platyias patulus** * **Sinantharina spinosa** **Lacinularia flosculosa**	**Brachionus falcatus** **Tetramastix opoliensis** **Keratella valga**
October, November and December	**Brachionus angularis** * **B. quadridentatus** **B. calyciflorus**	**Platyias patulus** * **Rotaria rotataria**	**Keratella valga** **Tetramastix opliensis** *

* denotes dominant forms

cality. Table IX indicates macrofauna in relation to **Limnodrilus hoffmeisteri. Aulodrilus** and **Branchiura sowerbyi** have also been recorded in association with **Limnodrilus hoffmeisteri** in the same locality, however, these forms are not so abundant as **L. hoffmeisteri.**

Table X indicates the chemical analysis of bottom sludge at the points of collection of the above forms and indicates the organic enrichment and favourable ecological conditions in which the bottom dwelling forms have been recorded.

D. SOIL FORMS

Enchytraeus sq. (Family Enchytraedae) and **Ocnaerodrilus** sp. (Family Megascolecidae) have been collected only from soil which is much irrigated by sewage. These forms can not be regarded as indicators of pollution since only few collections have been made. **Dero** and **Aulophorus** in large numbers have been

Table X—Physico-chemical analysis of bottom sediments

	Item of Analysis	Ambazari (Potable water)	Sakardhara (medium polluted)	Gandhi Sagar (medium polluted)	Maharaj Bagh (grossly polluted)
1.	Temperature, °C	29.5	28.1	29.1	28.5
2.	Colour	Brown soily red	Blackish Brown	Black (always showing presense of H_2S and CH_4)	Black
3.	pH	8	8	8.3	8.1
4.	Alkalinity, mg/lit.	125	155	390	350
5.	Loss of H_2O (at 105°C)	28.20	61.5	61.24	73.2
6.	Volatile matter	2.67	9.2	12.93	25.2
7.	Total solids	71.80	38.5	38.76	26.8
8.	Free Ammonia	0.0466	0.112	0.256	0.117
9.	Organic Nitrogen	0.0938	0.139	0.161	0.683
10.	Total Nitrogen*	0.130	0.251	0.417	0.800
11.	Phosphorus* as P_2O_5	0.204	0.438	0.365	0.523
12.	Potassium*	0.131	0.243	0.278	0.258
13.	Sulphates*	0.515	0.603	0.83	0.14
14.	Calcium*	3.22	4.4	5.63	10.45

* Values expressed on dry weight basis.

+ Values for items 5-14 are expressed as %.

mostly collected among decaying flowers, leaves, grains and other putrified material and as such their presence is definitely indicative of pollution (26). The correlation of collected forms to chemical nature of the water indicates that the Oligochaeta could be used as indicators of pollution.

I. **Occurrence in communities and association of Oligochaeta:**

The following planktonic oligochaetes have been present in one collection from a medium polluted water body. Associated with them are certain Ciliates and it is interesting to note that these Ciliates are normally present in medium polluted water.

Place of collection	Planktonic Oligochaetes collected	Ciliates and other forms associated
A puddle — medium polluted water body	**Dero nivea** **D. digitata** **Chaetogaster cristallinus** **Pristina longiseta longiseta** **Aulonais gwaliorensis** **Dero cooperi** **Aulophorus furcatus** **A. hymanae**	**Stentor** **Astasia** **Englena sp.** **Paramecium aurelia** **P. jenningsii** **and** **Gastrotricha sp.**

In another collection at the same spot but on another date when it was more foul and septic **Limnodrilus hoffmeisteri** was collected and **Gonostomum** and **Codosiga** were present. This is another interesting point in the sense that **Limnodrilus** is indicative of gross pollution, the ciliates associated were also indicative of gross pollution.

The third collection from one of the medium polluted tanks (Gandhi Sagar) revealed the following planktonic oligochaetes in association with **Carchesium** sp. (Peritrichous ciliates).

Pristina longiseta longiseta
Dero digitata
D. nivae
Pristina aquiseta
Chaetogster sp.
Dero zeylanica

These forms are always associated with medium polluted waters and it is interesting to note their association with **Carchesium** colonies which by themselves indicate medium pollution.

In one collection, from a grossly polluted (Maharaj Bagh nallah) area, **Limnodrilus** was recorded by one of the authors in abundance. **Branchiura sowerbyi, Eristalis sp.** (rat tail maggot) and **Chironomus larvae** were also found. These forms are again well established indicators of gross pollution. The data with reference to the association and animal community is rather limited and only available data has been presented here.

E. GASTROTRICHA

All the forms collected (Table V) belong to a medium polluted locality. There is complete absence of the forms in clean waters and the condition of turbidity does not favour their occurrence in very polluted waters (27-28). Forms are difficult to recognise and the numbers in total planktonic collection is very small.

Discussion

The available data is of a limited nature. While lists of forms in total samples of plankton from various localities have been compiled, sufficient data on the occurrence of dominant and sub-dominant species in communities to warrant any generalisation have not been obtained. This aspect is important.

Aquatic organisms have been used for many years as indicators of ecological conditions affecting their occurrence (29). If environmental conditions, for instance, the physico-chemical character are altered, there is always a change in the dominant population and it is replaced by another species of the genus. Hence the importance of studying planktonic communities. The macro-invertebrates are also valuable indicators of organic enrichment.

Exhaustive work dealing with macro-invertebrates as indicators of organic enrichment was carried out by Gaufin and Tarzwell (30) in Lytle Creek. They conclude in general that the community of aquatic invertebrates that was not characteristic of septic zone in Lytle Creek consisted of the turbificid **Limnodrilus,** the pulmonate snail, **Physa integra, Eristalis bastardi** (Rat tail maggot), **Culex pipiens** (mosquito larva), and **Chiromonus riparus** (midge larvae).

Ruth Patrick (31) investigated the Connestoga Basin, Pennsylvania as regards the biological means of stream conditions. The results of her study indicate that under healthy conditions a great many species representing various taxonomic groups should be present but no one should be represented by a great number of individuals. That is what biologically would be expected in a stream for healthy conditions. Patrick (31) further remarks that the general effect of the pollution seems to be a reduction in species number with the most tolerant forms surviving. In general polluted areas contain fewer species but certain organisms become exceedingly abundant (Gaufin, 4; Ingram and Towne, 32). The result of the first effect of toxicity or a pollutant would be a reduction in species number and greater abundance of the remaining.

Some investigators such as Kolkwitz and Marsson (8-9) Weston and Turner (33) and Richardson (34) have attempted to definitely associate individual species with different degrees and types of pollution and have published lists assigning such species to different zones or subzones of pollution. Careful comparison of these lists with those compiled by the authors indicates that there is lack of agreement as to the status of indicator organism. A particular species designated as an indicator of pollution and water quality by a worker is specific for one area and may neither be reported by others nor collected from other localities. This emphasizes the need for a careful assessment of physico-ecological conditions affecting the occurrence of micro-and macro-organisms. Generally, extremely polluted waters show an abundance of micro-organisms but there is a limited number of these in cleaner situations also. A similar observation has been recorded in Lytle Creek (Gaufin and Tarzwell, 30) with reference to macroinvertebrates. The macroinvertebrate forms such as **Limnodrilus, Chironomus** larvae, **Eristalis** larvae and **culex** species, have been actually recorded in abundance round the year in the septic zone of Nag Nala. These have also been recorded by Gaufin and Tarzwell in the septic zone of Lytle Creek. But in addition to these macro-invertebrates, two ciliates namely **Metopus sp.** and **Codosiga sp.** have been recorded in the present investigation in the septic zones in abundance.

Metopus and **Codosiga** have also been recorded in a grossly polluted puddle as well as in another similar locality. It has been observed by Ruth Patrick that, in general, the effect of pollution is the reduction of species and the dominance of most tolerant forms.

During the course of observation in the Gandhi Sagar during the rainy season, when the water is very much diluted and much cleaner, it is found that there are a large number of animal communities of both micro- and macro-invertebrates. But when more and more sewage is dumped by a nala into this tank and especially in the hot season when the water becomes much polluted only certain species of Rotifers (**Brachionus angularis** and **B. quadridentatus**) and certain planktonic Oligochaetes (such as **Dero** sp., **Pristina**) and a peritrichous ciliate (**Carchesium** sp.) alone dominate. The quantitative analysis also shows absence of one particular species.

Ahlstrom (35) states that the genus **Brachionus** is not cosmopolitan though the distribution is wide. He further observed that these forms are associated with alkaline waters although a few species have been recorded by him in other extremes.

Similar species have been collected in Gandhi Sagar where the alkalinity is 378 mg/lit. Species recorded: **Brachionus budapestinesis, B. caudatus, B. falcuatus,** and **B. forficula.**

One species of the genus (**Brachionus aculeatus** and **Brachionus aculeatus** forma **lateralis**) has been collected by one of the authors (HCA) in abundance from Gorewada Lake.

Williams* (1963) has collected dominant planktonic rotifers of major water ways of United States from 128 sampling stations. He remarks that differences in abundance of dominant species appear to be the best criteria for indicating differences in water quality or pollutional status. From his studies, he concludes there was no evidence to support the indicator organism concept among the the dominant organisms present.

Goodnight and Whitley (23) suggested that among oligochaetes both

* In an advance communication in press.

planktonic forms and forms dwelling in bottom mud are useful as indicators of pollution. Purdy (36) studied the bottom fauna of some polluted rivers and came to the conclusion that **Limnodrilus** (Tubificidae) prefers an environment of heavy pollution. This was also confirmed by Gaufin and Tarzwell (30). During the course of the collection of oligochaetes in general from various bodies of water, **Limonodrilus hoffmeisteri** has been collected in abundance from one of the heavily polluted localities round the year. The physical and chemical properties of bottom sediment from which the collection of these were made (see Tables IX & X) show some features in the bottom sediment of the heavily polluted locality. The striking features are: moisture percentage, percentage of organic matter, total and organic nitrogen, calcium and phosphate concentration and *p*H. The sludge in nature shows loose packing arrangement having sufficient air spaces in between where **Limnodrilus** can make an easy lodging. Confining the remarks to tubificidae, it is found (25-26) that they occur in certain localities characterised by: (i) high content of total organic matter, calcium, potassium and phosphorus; (ii) high BOD (50-100 mg/lit.); (iii) low oxygen saturation (40 per cent). Mud from localities where tubificids were present (plus locality) and from localities where they were always absent (minus locality) was analysed and the difference in composition explained the favourable conditions for the presence of tubificids and of pollution.

As remarked in an earlier paper (28), redox potential is an important factor in demonstrating the relation between bottom mud and water. Hutchinson (37) suggested that redox potential is an important determining factor and demonstrates a relation between the **Chironomid** population in a series of lakes and the redox potential of the bottom water during thermal stratification.

In the present investigation, one of the authors (HNS) determined the redox potential value of the plus and minus localities and they are given below:

	Potable water (Ambazari)	Medium polluted (Sakardhara)	Medium polluted (Gandhi Sagar)	Heavily polluted
Redox potential	-021 mv	-070 mv	-162 mv	-229 mv

(The values expressed are without the addition of the potential of calomel electrode, which is measured by reverse polarity of the electrodes).

One important point is that the assessment of pollution can never be attributed to the occurrence or absence of one or other species. Rather the whole animal community and population should be taken into consideration which should also be supported by chemical and ecological data. The correct mode of application of the biological systems of pollution needs a lot of identification of the organisms concerned. Therefore a knowledge of taxonomy is very essential.

Beck (38) advocates that instead of investigating the presence of pollution, one should concentrate on finding the absence of pollution. As a matter of fact, a species can become a biological indicator provided its environmental requirement, elasticity in adaptations and relative resistance to various toxic substances become known. This can only be studied by a series of laboratory experiments. In recent years, much emphasis has been placed on recognising macroinvertebrates as more reliable indicators of organic pollution. They are preferred because of the technical difficulties involved in identification of Protozoa and other micro-fauna but macro-invertebrates are easy to process for identification and presentation.

It may not be out of place to draw pointed attention to the fact that in almost all Pulic Health Engineering Research Programmes, the task allotted to the zoologists is a survey of Planktonic forms and other animal populations on an extensive scale. The richness of the data is the only method by which definite generalizations can be made. Such extensive data, with limited resources at our disposal, is not available because it can only be obtained by work extending over many years.

Summary

1. Micro-and macro-fauna have been collected over five years from potable waters, medium polluted waters and heavily polluted waters. The collections have been studied under four groups, viz., **Protozoa, Rotifera, Oligochaeta** and **Gastrotricha.** Lists have been compiled showing the habitat of these forms with special reference to the quality of water.

2. Detailed data on animal communities are not available and no generalisations can be made from the available data.

3. Certain Protozoa and Rotifera occur only in some types of waters.

4. Tubificids definitely indicate pollution and waters in which they occur are characterized by high content of organic matter, total and organic nitrogen, calcium and phosphorus concentration.

5. Comparison of the physical and chemical properties of the water of these stations shows that the occurrence of Naididae (**Chaetogaster, Dero, Aulophorus, Pristina** and **Nais**) is a fair indication of medium pollution.

6. Occurrence of certain organisms in specific localities has been discussed with reference to available literature.

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APPENDIX A

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Biochemical Oxygen Demand of Water Supply Resources

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Introduction

Water with high BOD is positively polluted. The pollution is organic, mainly carbonaceous and nitrogenous, and is readily assimilable by bacteria. Generally, a river or lake, which serves as a raw water supply source, is always prone to pollution. Water, without any BOD, does not occur in nature; and if so occuring, it is a boon to all the Public Health Engineers. However, water would never remain so due to onslaught of so called urbanization and industrialization leading to its constant use and reuse.

Causes for BOD

No specific raw water standard for BOD exists although it is assumed that water with 5-10 mg/lit. BOD is bad. The origin for BOD is either internal or external to the water source. Internal causes are usually the bottom organic sediments, as in boggy and peat soils. The BOD of these waters is often very high, of the order of 50 mg/lit. Such waters are to be rarely used for drinking without proper treatment. This organic matter is mostly in the colloidal form and often in the particulate form. Analyses of these waters (1) show that the nitrogenous content is of the order of 50-130 mg/lit. which would on normal decomposition consume 2-3 times this value of Oxygen. The carbonaceous content of these waters may consume more oxygen than the former. Carbon is either partially converted to carbon dioxide or its derivatives or incompletely to methane. Nitrogen is converted either to nitrate or free ammonia. Sulphur and phosphorous of the organic material undergo oxidation to either sulphates or H_2S and phosphates respectively, depending on the availability of oxygen and other biochemical conditions.

The major external factors contributing to BOD are sewage and the domestic and industrial waste waters. Other minor contribution is by the decaying and dead biological materials, present in the water. These biological materials are basically derived from the aquatic algae, fungi, phanerogams and dead animals. The other demand for DO is by the living animals for their respiratory process. Demand by the aquatic vegetation is during the night, when the photosynthetic oxygenation is absent. So the biological productivity does contribute to the demand for the oxygen in water.

Taking the example of the green algae (2 & 3) (Appendix I & II) which contribute quite a sizeable amount of the dissolved oxygen in the water while photosynthsis is taking place. also contribute about 45 mg/lit of BOD on death. This demand value is some what higher for the blue green algae and is of the order of 60-70 mg/lit. This difference is mainly due to their chemical composition.

APPENDIX I

SOME ALGAE OF THE UPPER LAKE OF BHOPAL

CHLOROPHYCEAE

Volvocales	**Pandorina monum**
Chlorococcales	**Coelastrum microporum**
	Scenedesmus bijugatus
	Kirchneriella lunaris
	Pediastrum sq.
Chaetophorales	**Coleophate scutata**
Oedogoniales	**Bulbochaete** sp.
Conjugales	**Spirogyra tumida**
	Zygogonium erecetorum
	Mougeotia transeau
	Closterium sp.
	Cosmarium sp.
Charales	**Chara coralina**
	Zeylanica

CYANOPHYCEAE

Chroococcales	**Gloeothece rupestris**
	Microcystis aeruginousa
	Merismopedia marsonnii
Nostacales	**Anabaenopsis Raciborskii**
	Anabaena Iyengarii
	A circularis
	Cylindrospermum majus
	Oscillatoria sp.
	Calothrix sp.
	Dichothrix arsiniana
	Gloeotrichia Raciborskii
	G. sp.
	Rivularia aquatica

The forms presented above are only representative of the large number of the algae and show a way for intensive work.

APPENDIX II

SOME ALGAE OF THE RIVER KHAN NEAR UJJAIN

BACILLARIOPHYCEAE

The following genera are found abundantly in the clean water zone flowing near the city of Ujjain. **Navicula; Cymbella; Cocconeis; Syndra; Pinnularia; Gomphonema; Coccinodiscus; Cyclotella; and Fragillaria, Chlorophyceae, Characium** sp; **Spirogyra** sp; and **Hydrodictyon.** Of the higher plants, the following Phenerogams were also identified: **Lemna; Hydrilla; Villisneria; Potomogeton;** and **Polygonum.**

Sewage normally has a BOD of about 200-300 mg/lit. and commonly finds its way into the raw water sources more so, when the city is unsewered. The other major consumers for DO from the water are the organic industrial wastes. The nature of water of the Upper Lake of Bhopal was examined with this point in view. Table I shows that the BOD of the Lake water is between 0.5-3.0 mg/lit. The higher values can be attributed to the waste material which is finding its way into this water.

The other example is the source of water supply to Ujjain. Khan river, partly fed by the sewage of Indore city and industrial wastes, is the drinking water source after a flow of about 30-35 miles. The river water in the vicinity of Ujjain has 6-15 mg/lit. BOD (rarely 20 mg/lit.) relatively higher than that of the Upper Lake water. Phelps (4) is of the opinion that the dissolved oxygen content of the water is a good indicator of the pollution condition of the river. This is quite true, when the flow is quite considerable and other contributions of algal oxygenation is negligible. The Khan river is shallow with meagre flow and the algal vegetation is quite

Table I — BOD of Upper Lake water

Year 1962	Sampling stations 1	2	3	4	5	6	7	8 to 10
April	1.85	1.8	2.0	3.1	3.3	3.0	2.5	
May	2.4	2.3	2.9	—	—	—	—	0.7
June	2.2	2.2	2.7	1.6	—	2.3	2.0	to
July	1.9	1.8	2.8	1.9	2.2	1.5	2.0	1.5
Aug.	1.3	1.3	1.4	0.5	1.2	1.0	—	
Sept.	1.7	1.7	1.7	1.5	2.1	2.2	—	
Oct.	1.75	1.5	1.9	2.4	2.6	3.2	—	
Nov.	1.6	1.7	2.1	1.8	2.2	1.8	1.3	
Dec.	1.7	1.8	2.7	2.2	1.6	1.8	—	

Note: All values are in mg/lit. and average of 5 readings during the month.

high. BOD thus poses various difficulties in water treatment process.

Dangers due to BOD Contributing Material

The presence of BOD contributing materials in the water is wrought with these operational dangers. First and foremost, the bacteriological population is directly dependent on the BOD present. The bacteria may or may not be harmful from the public health point. Secondly, such matter is usually organic and as a colloid, which would demand an additional dosage of the chemical coagulants, and no water engineer would like to waste this luxury material. Thirdly, due to high BOD, filter-beds usually get choked by the heterotrophic organisms, like fungi and zoo-organisms, which greatly hamper the filter run. No operator would like to wash the filter very often as it affects his demand for water. Odour and taste imparted by the offensive organisms, either in the filteration plants or in the water supply system, are also troublesome. Thus for a safe and adquate water supply, filtration involves extra cost.

Remedial Measures

Various remedial measures are suggested for mitigation of BOD pollution. First and the foremost preventive measure is avoidance of pollution of raw water. When raw water is already polluted, the other way open is destroying the polluting material by physical or chemical processes. Second way is to check the abnormal growth of the biological flora. To some extent, stagnation, can remove the BOD material by Biochemical Oxidation. This is usually achieved in practice by providing an abuttment or bund for the water course. The storage capacity of the water supply reserve will serve this purpose. Whenever the time involved for oxidation is insufficient, additional aeration facilities like cascading or fall, for the water have to be provided to give more contact with the atmospheric oxygen. The primary settling tank in the water treatment process serves this purpose. But these are rarely provided because of the consideration of space required. Here also great care has to be exercised in that the detention time does not permit excessive biological growth. This extra growth may create odour and taste nuisance in water. Pre-chlorination provides a solution to the problems of excessive biological growth and also destroys excessive BOD, and except for the additional cost involved is quite satisfactory in the hands of a careful operator. Fair and Geyer (5) discussing BOD reduction by pre-chlorination conclude that there exists no substantial data to use this method solely for this purpose. The after-effects, of extra dosage of chlorine, yield disastrous results in water treatment.

Conclusively, it can be stated that presence of BOD is always prone to create major problems in the treatment of water.

Acknowledgements

The subject matter has been suggested as a problem by the Madhya Pradesh Government, and my colleagues have assisted to their best in these studies, to both of whom, thanks are due. Thanks are due to Shri M. S. Agharkar for identifying the algal flora of the Upper Lake.

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DISCUSSION

SHRI K. G. VEERARAGHAVAN (Madras) : The speaker may please explain his contention that high BOD in water will cause increase in bacterial pollution.

SHRI M. V. SRINIVASAN : The bacterial population present in any community has a direct proportion to the BOD present because the food available (as putrescible matter) for the bacteria is much larger in quantity.

DR. J. K. BEWTRA (Delhi) : I agree with the speaker that BOD is an indicator of pollution in drinking water source. During last monsoon, when Najafgarh **nalla** carrying sullage water was overflowing its banks to meet river Yamuna upstream of Wazirabad in-take at Delhi, about twenty-one samples collected at the intake had shown the best correlation (r = 0.62) between coliform organisms and BOD (20°C — 5 days) as compared to other indicators of pollution. However, the highest value of BOD recorded was less than 2 mg/lit. when the coliform count was running into several lakhs in 100 ml sample. This value of BOD was far less than 6 mg/lit. mentioned in the latest edition of International Standards for Drinking Water. This suggests that whenever BOD is used as an indicator of pollution, its correlation with coliform organisms should be obtained in order to determine its signifinance as indicator of pollution.

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Stream Pollution and its Effect on Water Supply: A Report of Survey

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One of the important problems in the field of water treatment today is to obtain a raw water supply of satisfactory quality. With rapid growth of industries and increasing use of river water for irrigation purposes during the last two decades, the amount and complexity of the wastes are increasing in the water courses used as sources of public supply. Contamination of a natural water course by waste waters of a community, especially by industrial wastes, may at times reach such a proportion that they may render the water completely unfit for satisfactory treatment in a water works normally using the processes of coagulation, sedimentation, filtration and chlorination. A problem of such serious contamination of raw water supply was experienced by the J. K. Rayon Ltd., at Kanpur in the last summer, and the results of investigation carried out by this Institute are reported in this paper.

The J. K. Rayon Factory manufactures viscose rayon and uses large volume of water for their different processing departments and for drinking and other purposes both in the Factory as well as in the residential colony. The total requirement of water was estimated by the Factory to be about 4 mill gal per day for their maximum production target, but about 2.75 mill gal/day presently used, of which about 10 per cent is utilized for domestic consumption. In view of this high demand for water which could not be met from the municipal supply, the Factory installed their own water treatment plant of 4 mill gal/day capacity, with the river Ganga as the source of raw water supply.

The Factory is located in an area called Jajmau which is about 8 miles east of Kanpur and downstream of the Ganga. In this area, a large number of tanneries are located mostly on the banks of the Ganga. The intake point for raw water of the Factory is located in the river downstream of the tanneries Fig. 1 shows the location of the tanneries and the raw water intake point of the J. K. Rayon Factory. Although the tanneries at Jajmau have facilities for discharging their effluents into municipal sewer, because of chokage of the sewer in that area, most of them have been discharging their effluents directly or indirectly into the river for the past one year. Owing to low flow of the river in summer months, the pollution load in the river is consequently high in this region. The results of analyses of the river water at the J. K. Rayon's water intake point and at two different points upstream are summarized in Table I.

Examination of Table I indicates that the quality of the river water in summer has progressively deteriorated as it passed from the Bhaironghat Pumping Station to the J. K. Rayon's water intake, a distance of about 8 miles, receiving varying degrees of pollution load from a number of sewage outfalls within this stretch. The condition of the river has been further aggravated near the point of intake of the J. K. Rayon Factory by the discharge of tannery wastes through storm water drains about a mile upstream.

A survey was carried out on the performance of the water treatment plant of the J. K. Rayon Factory treating the polluted river water in the summer of 1964. The water treatment plant is of conventional design featuring a chemical dosing tank, one flash mixer, two flocculators having a total theoretical detention period of about 25 min, one clarifier with a theoretical detention period of 2.35 hr, four sets of rapid filter having a total surface area of 1,580 sq ft with a designed rate of filtration of about 1.75 gal/sq ft/min, a chlorinator and an underground storage tank for filtered water (Fig. 2).

Since the foregoing are the design values for treating 4 mill gal/day of water of reasonably good quality, in view of the new situation, the rate of flow was reduced by the Factory as far as possible so as to give more retention time in the different units in an attempt to minimize the concentration of contaminants at different stages of treatment of the water. Pre-chlorination at the rate of 2 mg/lit. was also done at the raw water intake point. Dosage of alum was also increased from 2 gr/gal to 3.5 gr/gal or about 50 mg/lit. Flow

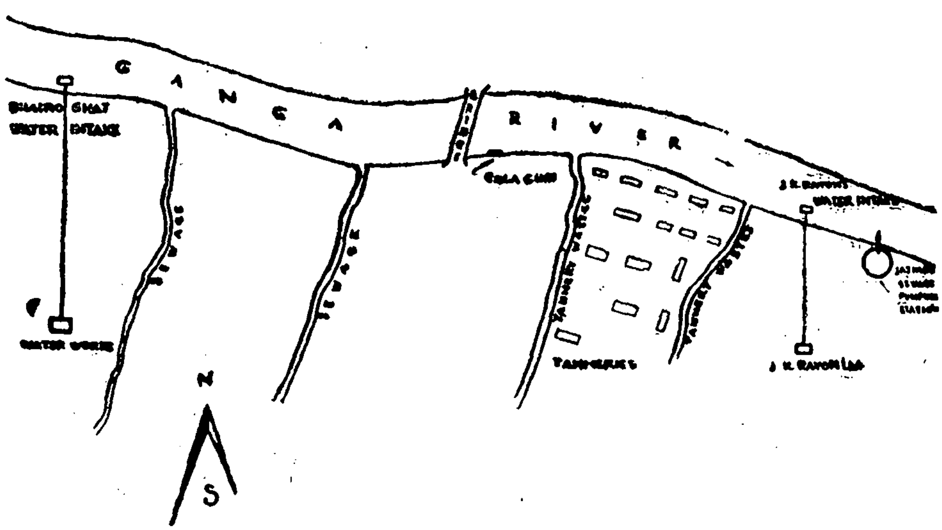

Fig. 1—Location of J. K. Rayon's water intake point with respect to waste outfalls in the Ganga at Kanpur.

(Not to scale)

Table I—Characteristics of the Ganga water at three sampling stations*

Items of Analysis	Bhaironghat Pumping Station (City's Water Intake)		Golaghat		J. K. Rayon's Water Pumping Station	
	Range		Range		Range	
Colour (Platinum-Cobalt Unit)	—	—	—	—	40	70
*p*H	8.4	9.1	8.2	9.0	8.2	8.6
Turbidity (as SiO_2)	15	38	15	25	10	18
Total Alkalinity (as $CaCO_3$)	180	220	182	224	192	222
Total Hardness (as $CaCO_3$)	106	130	114	130	104	132
Chloride (as Cl')	16	18	16	25	22	25
Sulphates (as SO_4)	23	37	28	38	27	43
Dissolved Oxygen	7.0	10.4	3.5	6.0	2.0	3.4
Oxygen consumed (from $KMnO_4$)	1.2	1.2	2.0	2.4	2.8	6.8
5 Day BOD (37°C)	--	—	22	30	13	34
Phosphate (as PO_4)	0.5	0.5	0.5	0.5	0.5	0.5
Coliform count, MPN/100 ml	450	1800	110,000	280,000	28,000	560,000

* Observations in June 1964

All values except *p*H unless stated otherwise, are in mg/lit.

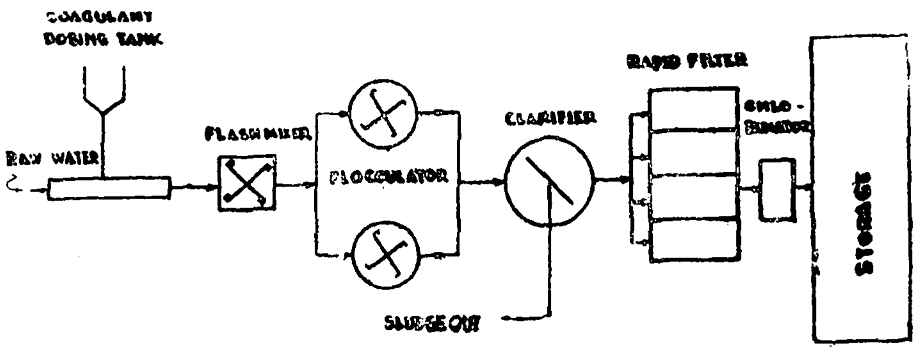

Fig. 2—Flow-sheet of water treatment plant at J. K. Rayon Ltd., Kanpur

(Capacity. 4 mill gal/day)

was maintained at about 2.75 mill gal/day and, at this rate, the theoretical detention periods in the flocculators and the clarifier were 32 min and 3.4 hr respectively. Two units out of four of the rapid filter were run and the rate of filtration was maintained at 2.45 gal/min/sq ft.

Since bulk of the tannery waste discharge in the river occurs in the morning, the pollution load in the water at the Factory's intake point reaches its maximum value at this time. Continuous sampling of the water at different stages in the treatment was therefore, carried out from 7 a.m. to 2 p.m. for a few days in June 1964, and the samples were analysed to find out the degree of removal of the contaminants in the different stages of treatment. The results are summarized in Table II.

It is found from Table II that the quality of the water reaching the treatment plant in the morning is extremely polluted as indicated by its high concentration of colour, BOD, phosphate, nitrite nitrogen and coliform counts, and low dissolved oxygen. Higher dosage of coagulants added and increase in the retention time in the flocculators and clarifier did not remove the colour and BOD by more than 50 per cent and turbidity by 33 per cent. Considerable removal of phosphate was, however, effected, but the nitrite nitrogen was not removed appreciably. Further appreciable reduction of the above values was noticed after filtration,

Table II — Characteristics of water at different stages of treatment

Items of Analysis	Untreated	Coagulated and clarified	Filtered	Storage (After chlorination)
Colour, Pt-Co unit	50	25	15	10
H*p*	7.9	7.4	7.4	7.7
Total Alkalinity (as $CaCO_3$)	214	214	208	204
Turbidity	25	16	11	5
Total Hardness	140	138	142	142
Chloride (as Cl')	27	27	26	26
Sulfate (as SO_4)	38	39	39	39
Dissolved Oxygen	2.2	2.6	—	—
O.C. from $KMnO_4$ (½ hour)	3.4	1.5	1.3	0.9
BOD (5 days 37°C)	25	12	9	6
Phosphate (as PO_4)	0.5	Traces	Traces	Traces
Nitrite as N	0.02	0.017	0.014	0.006
Coliform count MPN per 100 ml.	400,000	—	28,000	9,200

All values except *p*H, unless stated otherwise, are in mg/lit.

but even then the residuals were too high to be permissible in a finally treated water. Part of the finally treated water was recirculated through the filter, but it did not prove very effective in improving the quality of the water. Chlorination of the filtered water at the rate of 0.3 mg/lit. had little effect, since the residual chlorine of the water supplied from the storage tank was found to be *nil*, although some reduction in the coliform count was noticed after chlorination.

The values of the chemical and bacteriological characteristics of the finally treated water suggest that the water should be subjected again to the same order of treatment so that the quality may conform to the drinking water standards. In the bacteriological analysis of the water, only the number of coliform organisms were estimated, but it is possible that some other dangerous organisms like Anthrax might be present, since the water was particularly contaminated with tannery wastes in which Anthrax bacilli always thrive.

The study indicates that there should be a limit to the concentration of contaminants in a raw water which could be satisfactorily removed by the conventional methods of treatment, and therefore, proper control should be exercised in abating pollution of a water course used for public supply.

Acknowledgement

The authors express their sincere thanks to Shri S. S. Mishra. General Manager, and Shri L. N. Dube, Chief Engineer of M/s J. K. Rayon Ltd., Kanpur, for their excellent cooperation during the investigation.

DISCUSSION

SHRI S. S. MISHRA (Kanpur) : I *wish to know whether we can use* any other chemical in the place of $CuSO_4$ to remove algae.

Will you suggest a method of removing colour of water due to the pollution of tannery wastes?

How do we treat the water of low turbidity effectively?

SHRI R. N. CHAKRABARTY: $CuSO_4$ in combination with chlorine has been found to be most effective in killing algae. I do not know of any other organic algicide which is equally effective. Even if there is one, I am not sure whether it can be precipitated properly during the process of coagulation, with alum or other coagulants. Generally, the dose of $CuSO_4$ is not very high, and it is almost completely precipitated with the usual coagulants. However, in your case, some laboratory experiment should be done to determine the extent to which the copper is eliminated by the process of coagulation because probably traces of copper may affect the quality of rayon that you manufacture.

Colour of a water, be it from tannery waste or from any other source, is generally removed to a considerable extent in pre-chlorination, coagulation and filtration, but if the residual colour is found to be too high, then the filtered water should be given a treatment with activated carbon. Water with very low turbidity can be effectively treated with addition of clay to create artificial turbidity and by subsequent coagulation and filtration.

SHRI K. G. VERRARAGHAVAN (Madras) : The speaker mentioned the possibility of introducing a trickling filter as a pre-treatment process. In this connection, I would like to point out the experiments carried out at the experimental filter station at Madras on the use of trickling filter for pretreating heavily algae laden or organic matter laden water prior to sand filtration. We obtained very good results and I suggest that this method may be worthwhile trying in other places where facilities permit.

SHRI SUBBARAO (Singur) : I suggest that aeration may be tried to treat the heavily polluted water at the source of pollution.

DR. J. K. BEWTRA (Delhi) : Regarding this suggestion of aerating the raw water to reduce its BOD value, I wish to mention about my experience in a similar trial. During our study on Agra Waterworks (a paper presented in this symponium), the raw water with BOD of 14 mg/ lit. was aerated for eight hours and it showed only a small reduction in BOD value. If the organic matter present in these streams was oxidisable in a short time by simple aeration, it would have happened in natural flow of stream having 4-16 mg/lit. of dissolved oxygen.

SHRI J. N. KARDILE (Bombay) : May I ask whether you have considered the possibility of shifting intake works to the upstream of the river where the pollution is low as at the intake of Kanpur waterworks. I would also suggest to compare the economy of different methods, while finalising one to reduce the pollutional effect. If the intake is to be shifted, the rough cost of 21 in dia rising main for about 8 miles will be about Rs. 20 lakhs.

SHRI R. N. CHAKRABARTY : I think that if the Factory has to spend about 20 lakhs of rupees for the pipeline to bring in a less contaminated water, to their treatment plant, then I imagine that they would prefer to have several tube wells at their factory site itself at probably half this cost. In that case, they would not have to bother about treating the water in a treatment plant, except chlorinating it and softening a part of it as they do for their industrial water. I hope you will, therefore, appreciate that when they have unfortunately a water treatment plant, they have to run it by any means.

SHRI J. M. DAVE (Nagpur) : This is the problem where ordinary technique of water treatment can not be adequate but advanced technique may have to be considered. They should also think of the possibility of using other chemicals.

SHRI R. N. CHAKRABARTY : This may be true but I am wondering which method would be practically and economically feasible. We have two alternatives before us. One is stopping the pollution of the river by sewage and industrial wastes, and the other is to overlook this and go on arranging for elaborate treatment of water irrespective of the amount of pollution that it may receive. Now we have to choose either of these two alternatives. Again the problem is that one is polluting the water and the other is paying for it. If the polluter pays the extra cost of water treatment to the user, that would certainly be welcome. But will the polluter do it ?

SHRI P. R. GHAREKHAN (Koyali) : The high MPN of raw water and treated stored water shows the seriousness of the problem. The following methods are suggested in this connection : i) If possible, the river intake may be shifted. The tannery industries owners may be compelled to collect all the waste water from the industries and discharge it at a point, sufficiently downstream of the intake. ii) Tube wells on the bank of River Ganga are likely to yield a good amount of water of good quality. A tube well of 12 in dia will give about 50,000 gal/hr or approximately a mill gal/day. Therefore, this may be tried. iii) Pre-chlorination with a high dose may also be tried.

SHRI R. N. CHAKRABARTY : Actually in U.P., there is an Effluent Board which has statutory powers to control indiscriminate discharge of effluents from factories. In Kanpur, the tanneries were asked by the Board to give proper treatment to their effluents before discharging them into the municipal sewers. The tanneries are presently taking steps in this direction. But the Effluent Board has at present no power to control the discharge of untreated sewage into a surface water.

Two other suggestions are quite welcome and they invite the attention of Mr. Misra, General Manager of the J. K. Rayon Factory for his scrutiny.

SHRI P. L. NANJUNDASWAMY (Bangalore) : The industries are coming up towards the downstream of the Ganga and many of these industries would like to have unpolluted water from this river and many encounter the same difficulties. Why should not, therefore, the industrial waste and sewage from the city be let into the river downstream of all these intakes for water supply ?

If the above suggestion is not possible, why should not the industries be insisted upon to treat their wastes before letting them into the river ? This will avoid nuisance like odour and ugly sight of floating scum and sludge banks in a city like Kanpur.

SHRI R. N. CHAKRABARTY : In Kanpur, all the domestic sewage and industrial wastes are collected in a pumping station, although there are also a few sewage and industrial waste outfalls into the river from the city; and the pumping station is located at the end of the Jajmau area and bulk of the waste water is pumped into the river. The site for future industries is not exactly along the bank of the river downstream of the sewage pumping station, but extends away from the river towards south east. Therefore many of the factories to be installed in future may have to depend on water from tube wells.

As I mentioned earlier, the Effluent Board in U.P. is taking steps in this direction. But we must remember that unless the pollution by sewage is also stopped, little would be achieved in the matter of abatement of stream pollution and ensuing satisfactory quality of the water supplied to the consumer.

DR. G. K. SETH (Hyderabad) : I would like to know whether the J. K. Rayon Factory cannot synchronise their pumping schedule with the discharge of tannery wastes. There appears to be a gap when tannery wastes are not discharged into the river. It will be worthwhile if the major quantity of raw water is pumped in that interval.

SHRI R. N. CHAKRABARTY: Still there are sewage outfalls that are polluting the river. Regarding your suggestion, I think that the General Manager of the J. K. Rayon Factory should consider the possibility of doing the same.

SHRI G. S. RAGHAVENDRA (Bhopal) : It is not understood how pre-chlorination and other processes including post-chlorination were done without determining the extent of chlorine demand. If pre-chlorination had been done after assessing the chlorine demand, it would have been possible to reduce the pollution to within suitable limits before coventional treatment was given. This would have made post-chlorination also successful.

Further, it is said that residual chlorine content of stored water was found to be exhausted within a short time. We are aware of the fact that the residual chlorine is measured after a suitable contact period of 20 to 30 min. What was the contact time allowed in your case? If the contact time was all right, then perhaps the storage tank was getting polluted by some means. Was this examined?

SHRI R. N. CHAKRABARTY: Since the data collected on the raw water quality prior to studying the operation of the plant indicated a very high BOD of the order of 25 mg/lit. on the average, the chlorine demand was obviously high, i e., about 50 mg/lit. if 1 mg/lit. of BOD is considered to be equivalent to 2 mg/lit. of chlorine. Therefore, pre-chlorination to the extent necessary to bring down the BOD from 25 mg/lit. to say 6 mg/lit. was impractical.

The storage tank had about 1½ hour detention period and there was no residual chlorine in the water at the outlet end of the tank. It is possible that the storage tank was not cleaned for a long time.

SHRI G. S. RAGHAVENDRA: It is no use considering the MPN of coliform count in polluted water. Fair and Geyer specifically state that MPN index is reliable only in the case of finished water and not in the case of all kinds of polluted water. Hence the MPN figures in your paper may be misleading. The author should have depended only on the BOD values.

SHRI R. N. CHAKRABARTY: Coliform count of a water, be it polluted or unpolluted, is one of the most important criteria by which one can know its suitability or otherwise as a source of public water supply. However the data on both the coliform count and BOD have been given in this paper. I may point out here that both USPHS and the Indian Standards Institution have suggested a limit for the coliform count of a raw water for conventional treatment and supply as drinking water. You may contact the ISI for a copy of the publication on this subject.

DR. N. U. RAO (Nagpur): The speaker mentioned that **B. anthracis** is dangerous when swallowed. It does not do any harm when taken orally.

If coliforms are present in raw water in excess of 5,000 MPN, one should introduce either pre-sedimentation or pre-chlorination.

SHRI R. N. CHAKRABARTY: There is evidence in the literature that Anthrax bacilli may be dangerous when taken orally, so it would not be desirable to have them in drinking water. As regards the coliform count in the raw water, it was of such a magnitude that even with pre-chlorination at the rate of 2 mg/lit. and subsequent coagulation and clarification, the residual count could not be reduced below 28,000 per 100 ml.

I may in this connection request Dr. Rao to conduct experiment, if possible with **B. anthracis,** as it has been reported by Bichawn and others that inhalation of the organism may produce the so called woolsorter's disease, a very acute and malignant type of pneumonia.

DR. N. U. RAO: Woolsorter's disease, as you say, is a well known Pneumonia, But anthrax is never reported to have occured through drinking water.

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Coagulation—Theory and Recent Trends

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Introduction

So far, alum and, at times, ferric chloride only have been used as coagulants by the water works engineers to remove turbidity from water before its supply to community. Unfortunately, almost none of the engineers or chemists related with water works had a scientific knowledge of the theory and process of coagulation. With the rapid advances in the economic level and the industrial growth in India, it has become vitally necessary to have protected water supply systems working on modern lines.

Recent theories of coagulation have made it clear that it is no longer necessary to depend entirely on alum and ferric chloride. The coagulation can be achieved much more readily and to a greater degree by using various coagulants and coagulant aids discovered and developed during the last two decades. This is of utmost importance to India because the use of these agents will reduce optimum dose of coagulant, flocculation time and sedimentation time, resulting in smaller dimensions of sedimentation tanks dealing with much larger volumes of water than could be dealt with conventionally. As is obvious, this leads to a considerable saving in capital and recurring costs of a water supply system.

Historical Background

Investigations on coagulants and their use in clarifying turbid water are not new. Man's needs for a clear and safe supply of drinking water led him even in ancient times to search for better methods of water clarification. He found that many waters would not get purified adequately in the simple sedimentation devices or crude stone filters then being used. In Egypt, it was found that crushed sweet almonds stirred into a jar of turbid water produced a much clear settled water in less time than sedimentation alone. In India, a similar technique was described in 400 A.D. and has probably been in use for many centuries earlier (1). The use of alum for this purpose had also been known in China for centuries (2). This clearly shows that people in the olden times were in the know of most of the coagulants which are being used at present. What they have not done is only the coining of different names like polysaccharides, polyelectrolytes, chemical coagulants and so on. They used different substances, clarified the water, but never took the trouble to study the characteristics of these substances and to study the reactions brought about by them. They did not take the troubles for so many obvious reasons like want of scientific education, inadequacy of scientific instruments and number of others. But the most plausible reason seems to be that, in those days, the problem of pollution of water was not so acute as it is today.

In the modern urban and industrial civilization, purification of water for a safe and protected water supply is achieved by the widely used coagulation process. The process is gaining importance steadily, because of :

i) increasing pollution of water sources; and

ii) necessity to tap otherwise undesirable sources due to water shortage.

Before discussing the various theories of coagulation, it is imperative to know exactly what is meant by turbidity, coagulation and flocculation.

Turbidity and Coefficient of Fineness

Turbidity is not simply a measure of the weight of suspended articles but is also affected by their size. Scientifically, turbidity is defined as the "absorption coefficient of a particular medium." In public health engineering, all suspended matter in raw waters has historically been considered as turbidity regardless of particle size. Such matter consists of finely divided silt and clay and organic matter undergoing microbial decomposition. Included in the latter category are algae, plant proteins and domestic and industrial waters. In short, turbidity may be present as a suspension or as colloidally dispersed. Broadly, one can classify turbidity as follows :

Turbidity

- Coarse fraction (particle size ranging from 1 mm to 1 micron)
- Colloidal fraction (particle size ranging from 1 micron to 10 angstrom units)
  - Hydrophobic colloids in the suspensoid stage-easily coagulable
  - Hydrophilic colloids in emulsoid stage-less sensitive to the action of electrolytes

One thing must be borne in mind that a certain weight of suspended solids when very finely divided has a much more turbidity than the same weight of coarse solids. Suspended solids divided by the turbidity gives the "coefficient of fineness." This coefficient is important in coagulation

While the coarse fraction can be successfully removed from raw waters by conventional "alum coagulation," the fine fraction can not be removed. Coarse particles follow Stoke's Law for settling, i.e., the rate of settling of coarse particles depends on their particle size, particle density and viscosity of the medium through which they travel. The colloidal nature of the fine fraction prevents sedimentation and its electronegative zeta-potential prevents agglomeration.

Coagulation and Flocculation

Agglomeration and settling of the particles are brought about by means of a chemical process called as coagulation. The principal function of chemical coagulation is destabilization, aggregation and binding together of colloids. In waterworks, coagulation involves the formation of chemical flocs that absorb, entrap or otherwise bring together suspended matter that is so finely divided as to be colloidal. It is observed experimentally that mere addition of coagulant is not sufficient to produce the desired effect. After the addition of the coagulant, water must be thoroughly mixed by means of flash mixers or other devices to ensure uniform dispersion of the chemical throughout the body of the water. Here, flocculation, the process of bringing together separate particles into groups comes in. The process is usually carried on by the use of electrical, mechanical or chemical forces, or their combination. In water treatment, flocculation is used to consolidate the many fine particles of suspended material present in water into relatively large masses. The process usually employs a coagulant which reacts with water to form hydrous oxides of a sticky, gelatinous nature which serve to bind together the separate particles. This flocculation or floc formation, it is found, is in direct proportion to the velocity of agitation which affects the formation of floc. This is popularly known as velocity gradient and is expressed as ft/sec/ft.

After knowing about turbidity, coagulation and flocculation, various theories regarding coagulation, put forward by so many scientists, can be studied thoroughly.

Theories of Coagulation

A. In 1948, Black tried to summarise the existing theory of the mechanism of coagulation (3). He postulated that organic colour and turbidity were negatively charged colloidal particles or, in other words, colloids with negative zeta-potential. According to him, coagulation takes place in the following three phases:

(i) Aluminium or ferric ions become available in their ionic stage as soon as they get into solution and they neutralize the negative charge on the particles. This is the most important phase of coagulation and it takes place long before the visible formation of floc particles. This requires intimate contact with the material, and hence, the rapid mixing is a 'must.'

(ii) When the positively charged aluminium or iron neutralize a considerable portion of the negatively charged colloidal particles, the resulting particles are called as micro-flocs. Since these micro-flocs are still beyond the limits of visibility and far too small to sediment, these serve as nuclei, and gather microflocs together.

(iii) In order to collect tiny microflocs together for the formation of flocs steadily increasing in size until they are in a position to sediment, there is a necessity for some mechanical treatment. This phase therefore is generally accompanied with low stirring termed as conditioning. The amount of surface area exposed by these innumerable particles of floc is very great, and hence the impurities in the water get adsorbed on these active surfaces. It should be emphasised, however, that the formation of a large and well formed floc, though important from the standpoint of sedimentation, is not necessarily the criterion of successful coagulation, since neutralisation of charge, the most important function of coagulation, takes place before the floc ever attains visible size.

Langelier and Ludwig (4), Mattson (5), Pilipovich (6), and others have tried to explain the theory of coagulation based on their observations. All these theories include the concept of zeta-potential and its neutralization by tri-positive aluminium or ferric ions.

B. Langelier and Ludwig were among the first to emphasize the chemistry of clay suspensions.

According to Langelier and his associates, the rate of coagulation depends on the exchange capacity of the colloids to be removed. The exchange capacity is a measure of the tendency for replacement of low valence cations with ones of high valence. On entering the liquid side of the fixed portion of the double layer, these high valence ions depress the charge and its effective distance and thus lower the stability of the colloid. When the exchange capacity is low, the process is slow unless a binding agent is present. If exchange capacity is high, the need for binder material is less important and coagulation results chiefly from destabilization of colloids originally present in the water. Exchange capacity is due primarily to the presence of particles smaller than 1 μ in diameter. The presence of such particles is therefore important for destabilization and coagulation. If such particles are not present in the water or waste water to be treated, it may be advisable to add them. Clay, activated silica and other so called coagulant aids serve this purpose. Particles larger than 1 μ diameter also assist coagulation. They provide nuclei on which floc can grow, add weight, and cause a more rapid settling.

Langelier and Ludwig believed that the zeta-potential was neutralised by tri-positive aluminium or ferric ions. They proposed that a small amount of excess alum was necessary to hydrolyse and serve as binder material to tie the flocs together. Mattson, on the other hand, concluded that the hydrolysis products were more important in neutralizing the zeta-potential. He found that the zeta-potential did not have to be neutralized for rapid coagulation to take place. Pilipovich and others using electrophoretic techniques found the hydrolysis products of alum to be stronger coagulating agents than the tripositive aluminium ion.

C. Electrophoretic theory is based on the neutralization of zeta-potential. The difference of potential between the charge of the ions attached directly to the stable colloid and that of the counter ions constituting an electrical, double layer, or in other words, the charge of the dispersing medium, is called zeta-potential. In his concept of double layer, Helmholtz postulated a rigid single layer of oppositely charged movable ions neutralizing the fixed surface layer of ions, the two layers being within molecular distance of each other. A more useful concept has been the diffuse, electric, double layer suggested by Gouy. This diffuse layer is formed by the electric forces of the charged particle, which attract ions of opposite sign and repel ions of like sign. A counter-acting force, which acts on all the ions, is their tendency to diffuse away from the surface. At equilibrium, there results a statistical distribution of ions so that the number of oppositely charged ions near the particle will be, at any given time, greater than the number of ions of the same sign. Thus an ion atmosphere is built up, extending from the surface of the particle to the bulk of the solution. The thickness of this diffuse double layer — the distance from the surface to the boundary of the ion atmosphere that moves with the particle — may reach microscopic dimensions. The movement of a particle in an electric field depends, among other things, upon this zeta-potential, rather than the charge of the particle. At the iso-electric points, this zeta-potential is zero, at which stage, maximum coagulation is obtained.

Coagulants : Compounds of iron and aluminium generally used for removing turbidity, bacteria, colour and other finely divided matter from water and waste water are coagulants or electrolytes, i.e., substances that ionise in water to produce a solution that will conduct an electric current. They produce cations and anions of high valence and react with alkalinity to form insoluble hydrous oxide precipitates. The cations destabilize the negatively charged colloids and the anions, the positively charged hydrous ferric or aluminium oxides. The reactions are sensitive to pH of the water and also the ioned balance. Negatively charged particles, particularly those producing colour, colloids, coagulate best at low pH values, whereas hydrous oxides are generally least soluble and flocculate best at higher values. Overdozing with electrolytes may reverse the zeta-potential and interfere with the coagulation of colloids. However, when very large amounts are applied, the zeta-potential may again be driven forward towards zero.

Coagulant Aids : It has been found that sometimes mere addition of a coagulant or electrolyte does not help purification of water. In addition to a coagulant, something else to increase the strength of the floc so as to settle it rapidly is needed. The floc strengthening agents add materially to the power with which the floc binds the sediment particles in the water. These substances — coagulant aids — usually improve the rate of sedimentation.

Since World War II, a good deal of information has been issued on the new organic flocculation aids (8). These are easy to handle. Some of them are admixed with bentonite.

Polyelectrolytes : Recently, it has been shown that long chain linear polymers or polyelectrolytes act as coagulants. The generic term polyelectrolytes describes a variety of compounds, some of which have been found to be effective coagulants and aids. Their use may seem to be a new development in the field of coagulation. But the process is, in fact, at least 4,000 years old. Sanskrit literature, about 2,000 B.C., suggested a number of vegetable substances notably the seed of **Strychnos potatorum**, as a means of clarifying water. It now seems fairly clear that such organic compounds as starch and starch derivatives, cellulose compounds, polysaccharide gums and proteinaceous materials may be used as coagulant adjuncts. In spite of their varied sources, compounds may be collectively described as bicolloids which are naturally occurring polymers carrying electric charges or ionisable sites.

More recently, several commercial firms have made coagulants available, but so far not much has appeared in the literature to indicate how these materials will act. All these compounds contain recurring units of small molecular weight, chemically combined to form a molecule of colloid size, and each of the recurring units carried one or more electrical charges or ionizable groups. Because these compounds have the characteristics of both polymers and electrolytes, they have been called polymeric electrolytes, or more frequently, polyelectrolytes. Michaels (7) has suggested that the most effective polyanionic contain a mixture of ionic and unionized hydrophilic groups. He has suggested that the unionized groups are adsorbed on the particle surface and the ionized groups keep the polymer in an extended position. This leads to particle bridging and coagulation. One of the first synthetic polyelectrolytes studied was polyacrylic acid, a polymer of recurring units of acrylic acid.

Starch (Glucose Units) —(Natural)	Ionisable groups—carboxyl & hydroxyl	
Polyelectrolytes— (Synthetic) .	i) negatively charged, e.g., caustic hydrolysed polyacrylamide. Anionic Polyampholytes	
	ii) No charge Polyampholyte	Having both positive tive and negative charges. Proteins and polypeptides natural polyampholytes.
	iii) Positively charged, e.g.,	Polyvinylpyridinium bromide Cationic **polyelectrolyte.**

Some work has been done on the polyelectrolytes **Nirmali** seed **(Strychnos potatorum)** and Floccal N product in this Laboratory. It is observed that these polyelectrolytes are far more efficient than the conventional coagulants such as alum or ferric chloride. This will be clear from the Table I showing the comparative data for the removal of turbidity from the same source of water using conventional coagulants and polyelectrolytes.

The above discussion makes it quite clear that coagulation goes further than precipitation. A good floc is a hydroxide particle that may be as large as 3/8 in. The floc particle starts as a pre-precipitate in the water, which, during the process of agitation, comes in contact with and adsorbs nearly all objectionable suspended material, colour and bacteria from the liquid. This particle, with its occluded foreign material, finally grows to a large size and, in this form, settles down readily under the quiescent conditions that should prevail in the settling basins. In this way, the objectionable material has been mechanically incorporated and removed with the floc in the settling basins. It is known that, apart from the silt and clay material, 60 per cent of the threshold odour of water and 60-85 per cent of the bacteria in the water are removed by coagulation and sedimentation.

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Table I — Comparative study of turbidity removal

by S. **potatorum**, Floccal-N, $Al_2(SO_4)_3$ and $FeCl_3$

(Initial turbidity of water used, 1,000/mg/lit.; *p*H, 8.2)

Characteristics	Conventional coagulants		Poly electrolytes	
	$Al_2(SO_4)_3$	$FeCl_3$	Nirmali-seed	Flocal-N
Flocculation Time, min	30	30	20	20
Sedimentation Time, min	15	15	5	10
Effective Dose, mg/lit.	14	8	0.45	0.5
Residual Turbidity, mg/lit	14	7	7	8

DISCUSSION

SHRI S. AHMED (Sindri) : When using polyelectrolytes, the charges on the colloids have to be determined because these polyelectrolytes can be either cationic polymers, ionic polymers or polyampholytes. This means that at every treatment plant an instrument which could give the nature of potential must be made available and this may not be feasible in our country till we ourselves develop such an instrument. Further, activated silica may be better than metallic hydroxides as it is readily available.

DR. W. M. DESHPANDE : What you say is correct as far as theory is concerned. But in waterworks, the turbidity is due to colloidal particles which always carry negative charge only. As such we can add polyelectrolytes bearing positive charge without the help of any instrument.

SHRI A. R. TIWARI (Bhilai) : Mention was made of the **nirmali** seeds. May I know whether it is used as a coagulant or coagulant aid and how the extract and the dose are prepared ? We tried the **nirmali** seed and did not get any satisfactory results with the low turbidity water. Please state limitations, if any.

If **nirmali** seed is successful as a coagulant or coagulant aid, is it advisable to adopt it on larger scale.

DR. W. M. DESHPANDE : The **nirmali** seed is used as a coagulant and not as a coagulant aid. The extract is prepared by boiling the **nirmali** seed powder in water for 15 minutes. Dose was calculated on the dry weight basis of the extract.

I have tried this successfully with water of turbidity of 80 mg/lit. Regarding its use on large scale, I can not say anything at this stage because toxicity studies are still under investigation.

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The Problems of Pollution in the Bhopal and Indore Water Supplies

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Bhopal Water Supply

There are regular conventional filtration plants at Bhopal and the supply is chlorinated. There have been numerous complaints of dysentery and diarrhoea. Often people complain of stomach aches. Therefore, though treatment given appeared to be adequate, most of the higher income people drink only boiled water even now. Therefore, there was dire need to look for the causes that lead to such complaints.

There are two big lakes in the heart of the present city (Fig. 1). One is called the Upper Lake or Bara Talab, and the other, Lower Lake. All water supply is from the Bara Talab. Each one of these two lakes has a separate, independant catchment. The capacity of the Upper Lake has recently been almost doubled. It gets its water mainly from the Kolans river which comes from the North-west direction. The catchment area is 141 square miles. The construction of the big earthen bund across the Kolans river to form the Upper Lake dates back to the period of Raja Bhoj in the 11th Century, A.D. The Lake is surrounded on all sides by human habitation and consequently pollution is considerable.

On account of the peculiar topography of the place, the Lake has been receiving all sewage and sullage in a part of the Lake, as seen from analysis data in Table I.

The population fringing the Lake, the effluent from Hamidia Hospital, Shamla Hill area, Ahmedabad area are the potential sources of pollution wherefrom waste products and sullage flow into the Lake. Bathing ghats, washing of cattle, Bairagarh sewage, villages in the catchment area also add to the pollution. But the most significant contamination are the human excreta and the hospital wastes. Both these cause serious organic contamination. The Public Health Engineering Department undertook intensive investigation and the results of their findings were :

(i) That the Lake is being polluted and the pollutional load is heavy.

(ii) The effect of pollution can be traced even in the raw water which is being fed to the treatment plants.

(iii) The treatment techniques can not cope up with the pollutional load.

(iv) Entire reliance has been placed on chlorination, and it is a matter of conjecture, whether chlorination alone will be able to shoulder the heavy responsibility.

(v) The whole system needs a thorough overhaul, and attention has to be paid to: (a) Sanitation of the Catchment; (b) Proper location and operation of intakes; and (c) Adoption of such treatment techniques as demanded by circumstances.

Normal treatment was found inadequate so that incidence of Infective Hepatitis was reported in Bhopal during 1957. This disease is associated with virus infection. The P.H.E. Dept. has no means to detect virus for it requires a special equipment. And, no adequate treatment to kill virus is yet definitely known except boiling of water. Long period of contact with chlorine (over

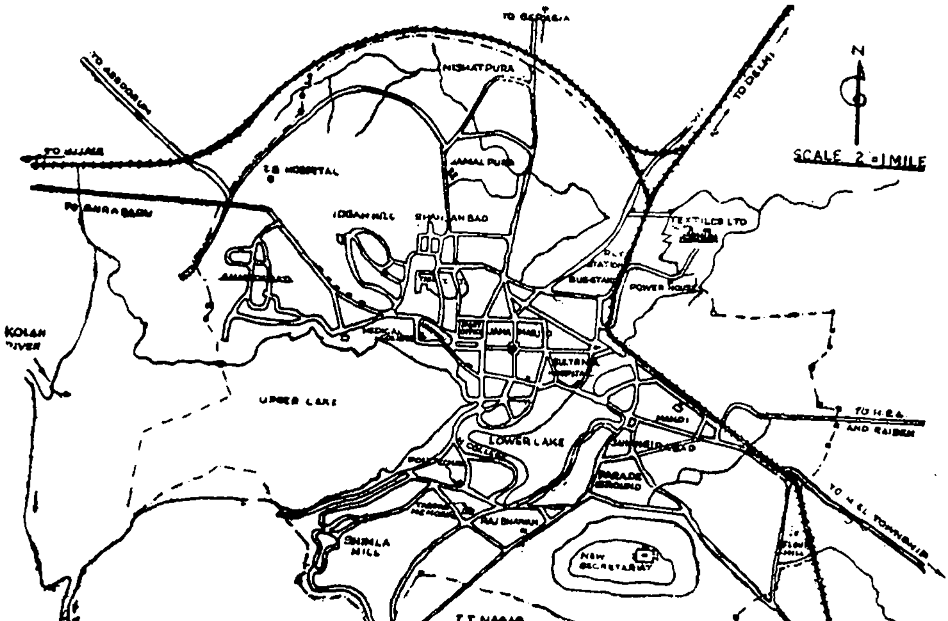

Fig. 1—Map of Bhopal city

30 minutes) has, in some cases, been reported to effect a good kill of the viruses.

Main measures to be adopted are mostly related to sanitation of the catchment area. These, as suggested for Bhopal, are in brief as follows:

(i) No melas to be held near the intake of pumping station.

(ii) Periodic watch over the gastro-intestinal diseases in the catchment.

(iii) All villages in the catchment to have priority for provision of water-seal latrines.

(iv) Interception and diversion of Bairagarh sewage.

(v) Night-soil dumping grounds of Bairagarh to be removed.

(vi) Provision of intercepting and collecting sewer in the fringe area and disposal of all sewage and sullage through this sewer to a point outside the town.

(vii) Acquisition of all properties beyond the sewer towards the lake dismantling these properties, and converting the area into a boulevard around the lake.

Table I — Analysis of water samples from Upper Lake, Bhopal

S. No.	Test	Station Lake near Culvert	At Ret-Ghat.	At Yacht Club	At Pulpukhta	At Idgah.
1.	Colour	Pale Yellow	Dark Grey	Hazy	Hazy	Hazy
2.	Turbidity	Turbid	Turbid	—	—	—
3.	*p*H	8.3	8.4	8.4	8.3	8.8
4.	Alkalinity	101.29	90.28	88.83	92.4	83
5.	Hardness	62.68	71.64	88.00	90.00	72
6.	Oxygen Absorbed	4.94	7.78	1.67	1.54	2.28
7.	Chlorides	10.7	9.8	10.7	12.1	10.7
8.	Free and Saline NH_3	0.225	0.012	0.02	0.01	0.017
9.	Albuminoid NH_3	0.42	0.72	0.31	0.37	0.44
10.	Nitrate	—	—	4.00	—	0.04
11.	Nitrite	0.0126	0.009	Nil	—	Nil
12.	Total solids	200	—	—	—	—
13.	M.P.N. of coliforms	2400	2400	250	350	2400

All values except pH are expressed in mg/lit., unless otherwise stated

Until action as in (vii) above is possible, three temporary pumping stations for sewage on the lake edge (one inside the lake, for want of space on the bank) are provided to collect hospital effluent, effluent from area near Sadar Manzil and P.W.D. Workshop, and pumping the sewage away into a portion of collecting sewer (Beyond Pull Pukhta) already laid.

For complete prevention of pollution, it is necessary that break-point chlorination is done with long contact period leaving a high-residual as a second line of defence.

Chironomus Larvae in the Water Works system of Indore (March 1959)

Indore town has a population of about 4 lakhs. The water supply system consists of a reservoir on the Gambhir river. The raw water is pumped to a hill popularly called Deodharam nearly 6 miles from pumping station and half-way between the town and the Yeshwant Sagar, the reservoir. On this hill, there is a complete treatment plant consisting of raw water balancing tanks, mechanical flocculators, hopper bottom primary and secondary settling tanks, rapid gravity filters and clear water reservoir of 7 mill gal/day capacity, divided into two compartments. The compartment on Indore side is called Indore tank and that on the Yeshwant Sagar side as Badarkha tank. The supply of filtered water in 1959 was about 8 mill gal/day. Aeration is necessary, which is provided by a hydraulic jump. For further removal of odour in summer months, carbon is used.

The characteristics of the worm must be known to appreciate the treatment.

Of the larvae observed in the distribution system some were red and others white in colour and about half an inch long. The larva is most frequently aquatic and resembles a geometrid moth caterpillar in form and appearance. Even green and blue green larvae are also found. The red ones are usually termed as 'blood worms.'* Therefore blood worms (for Engineers) can neither be taken as indicative of pollution nor can these be neglected as harmless clear water organism. The larvae of either type are bacteriologically innocent creatures by themselves and these are not reported as ever causing any taste or odours in water. Larvae are not any danger to human life. Their presence is, however, certainly objectionable from aesthetic point of view, and a warning to the water operator to look out for possible pollution of the water source. The larvae develop into a fly.

The flight of an adult fly can be anything up to half a mile. The larvae do not come to the water surface and therefore a heavy infestation may occur before it is suspected. The entire life cycle from egg to adult fly may occur in one to five

* Blood worms are used as indicators of stage of purification in a stream or lake. This indicates recovery and conversion of waste into fish food (of recovery). Richardson has, however, shown that certain species of blood worm (midge larvae a chironomid) prefer strongly pollutional habitat while other species are tolerant or indifferent and still others are confined to clean waters.

weeks. Eggs are microscopic in size. They live and grow on the bottom sediments of tanks.

The following measures were taken immediately to kill the infestation and clean the entire system in Bhopal.

(i) On 4th March 1959, the larvae came to be noticed first at the treatment plant.

(ii) Both compartments of the clean water reservoir were got cleaned of all bottom sludge on 4th and 5th March. The tanks were disinfected with bleaching powder.

(iii) Manholes, ventilators and other openings of the tanks were thoroughly disinfected.

(iv) Samples from filter effluent before it entered the clear water reservoir were taken and were incubated for one week. Microscopic examination after incubation revealed no larvae which would have been there if there were eggs in the filter effluent. Hence the growth could not have travelled from settlement tanks through filters to the pure water reservoir even in the shape of eggs. Obviously, the growth had started in the pure water reservoir itself which travelled through the service main to the town.

(v) Normally, for cleaning purposes, no insecticide except potassium permanganate or bleaching powder is used in drinking water reservoirs. Raw water tanks, primary and secondary settling tanks were sprayed with bleaching powder solution for 32 hours, and repeated many times over.

(vi) The chlorine dose was increased to 2.4 mg/lit. as against normal dose of 1 mg/lit.

In the next ten days, however, fresh and heavier infestation either from some eggs, (being microscopic in size) which remained unwashed or freshly laid eggs (through Key-holes in manhole covers, etc.) came up in a violent form. This may have been due to the presence of midge fly in the village around the plant site. There was a large infestation of mosquitoes and flies in this area. In all probability, the midge fly may have come back from there, for there were dirty water ditches around. Alternatively, some larvae came from the Yeshwant Sagar along the water in the pumping main and grew to be flies in the raw water tanks and then laid fresh eggs everywhere where these got a resting place including the pure water reservoir. Being only a few, these remained unnoticed, at first, until it became a huge infestation. While this infestation came up, it was revealed by some old employees that there was a similar infestation in 1951 at the filtration plant when it took months to combat the infestation before it could be arrested with DDT spray all around. But, that time, no larvae were reported from the distribution system. Here it is believed therefore that present appearance in the distribution system could possibly be the result of an inadvertent mistake of emptying the full depth of clear water tank into service main before cleaning was started on 4th and 5th March. In doing so, eggs or larvae went with the bottom sludge into the service main and onward journey into the entire distribution system. This is never done. Usually two feet or more of the bottom depth is let to waste to drain out bottom sludge. This, however, could not be confirmed for obvious reasons as no operator accepted having done so.

With this second and heavy infestation, most intensive and quick measures became necessary so that no chance was left for possible reccurence. These are:

(i) To kill all adult flies and the larvae, DDT spraying of the entire area around the water works and on the raw water tanks and the settlement tanks was done.

(ii) All water pools were sprayed with oil emulsion DDT for a radius of half a mile all around the water works. This was repeated at weekly intervals until the end of April 1959, till it became too hot for the flies.

(iii) All growth of wild vegetation was got cut to leave no resting places for the adult flies.

(iv) In the filter station itself in the colony and on the lawns everywhere, DDT spraying was done with low percentage of DDT powder in water.

(v) Both the compartments of pure water reservoir were immediately cleaned one after the other. As soon as one compartment was cleaned, it was put in commission.

(vi) Spraying of DDT as a special case inside the tanks where the infestation was very heavy was allowed. The tanks were allowed to completely dry after DDT spray. Then the tanks were washed with bleaching powder solution thoroughly. The whole tank floor and walls were brushed and swept with wire brushes while washing was on. It took 12 hours to complete this job in one compartment when the filling was started. The supply to the town was restored soon after so that the dislocation of water supply remained for the shortest period possible.

(vii) Walls of the filter beds were also cleaned and 20 lb of bleaching powder was also spread on each filter bed.

(vii) Simultaneously cleaning of settlement tanks was also taken up.

(ix) Raw water balancing tanks had been sprayed intermittently with DDT to stop multiplication of any larvae that might have been coming in from the rising main or that might be available there. These were therefore taken up for cleaning one by one after ten days by which time clear water tank storage was built up. Use of DDT in raw water tanks was not considered dangerous for it was done a few times only and as the complete treatment including coagulation and chlorination was to follow.

(x) The chlorine dose was maintained at 2.4 mg/lit. for thirty days until all tests gave fully hundred per cent negative results. For this purpose samples were drawn from all the units and even from many stand posts in the town. Each sample collected was bucket full, for in smaller jars it is likely to miss the larvae. Samples from bottom of the tanks were also taken.

(xi) The complete distribution lines in the city were scoured and washed.

(xii) Simultaneously over-head reservoir in the town was also cleaned intensively as the clear water tank at the filtration plant. This tank also was found heavily infested with larvae. Incidently this wash water was used by the Municipal Corporation to wash all streets and lanes.

(xiii) The service main was completely scoured and washed before it enters the town near Pillia Khan Nallah.

(xiv) Manholes, and particularly the edge crevices and keyholes were sprayed with DDT lean mix continuously for 30 days so that the adult flies do not lay eggs anywhere.

(xv) Daily tests were done on samples from different places for thirty days.

(xvi) After fifteen days, one more intensive and complete cleaning-up drive as detailed above was repeated.

The entire situation was brought under control in just less than 24 hours after which no larvae were detected in any of the samples.

All this happened in March 1959. Looking at it now in retrospect, one is inclined to believe that the infestation was as a result of larvae brought in only from Yeshwant Sagar. There are no means to check their growth at that place for the reservoir is an ideal place for their growth. The only care needed is :—

i) To look for such insects at intervals at the filtration plant by random sampling from the inlet raw water.

ii) In the sludges from settling tanks and clear water tanks whenever these are desludged, cleaned or washed.

iii) The entire plant area and the village around kept clean of water stagnation and wild growth of plants so that the adult flies do not find resting places.

Conclusions

Adequate treatment of water is closely related to prevention of contamination at source, at the treatment plant and in the distribution system. If prevention is neglected, however much one may try, treatment of water can not be said to be complete. Again as Rosenau puts it.

"The General improvement in our water supplies should not lull us into a false sense of security. Eternal vigilance over methods of control for water supplies and water purification must be practiced. Laxity invites disaster".

DISCUSSION

SHRI H. C. ARORA (Nagpur) : May I know whether any biological method was adopted to eradicate the larvae in Yeshwant Sagar ?

SHRI P. N. QAZI : No. We have not tried any such method yet.

SHRI H. C. ARORA : During my visit to that place, I was given to understand that the fishes were hauled out and I would like to point out that the fishes in the lake feed on chironomus larvae.

SHRI P. N. QAZI : All the fishes are not removed and some of them are allowed to remain in the lake.

SHRI T. P. SHARMA : (Bhopal) : I am in touch with Bhopal water supply for the past six years. Shri Qazi has mentioned that the cases of dysentery, diarrhoea and infestious hepatitis are common in Bhopal and that the higher income group persons in the city drink only boiled water though the water is filtered and chlorinated. But I wish to point out that Bhopal city has a large floating population that suffers from dysentery and diarrhoea and that the Medical College Hospital has received these cases for treatment. When I visited the hospital to enquire about the cause of those cases, I was told that they could not say that those people were affected after drinking water in Bhopal.

SHRI QAZI : My remark that the cases of dysentery and diarrhoea are common in Bhopal does not entirely relate to the quality of the water. I have not mentioned about the occurence of infectious hepatitis.

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Activated Silica In Coagulation

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History

Activated silica although its application to water treatment is relatively new actually has a long history. More than 150 years ago, Pitt reported the preparation of 'semi-solution of silica', but Graham is usually credited with the discovery of silica solution. Graham added water glass and weak HCl to form silica solution as early as 1884. However. Baylis used silica solution on a large scale in water treatment first time, that was in 1936. Before starting the discussion proper, the terms which will be used very often are defined.

Activated silica : This term designates a negatively charged colloidal particle formed by the reaction of a dilute sodium silicate solution with some activant.

Sol. : This general term is applied to colloidal dispersons as distinguished from true solutions.

Gel.: A silica gel is heavily hydrated interlaced fibrillar or a 'brush heap' structure of very large polysilicic acid molecules with spaces filed with water of dilute silicate solution

Miscelle : An internal phase particle that posseses double layer of charges of opposite signs adjacent to the surface. In this case, it refers to a particle size varying from 0.1 to 1 millimicron.

Percentage Neutralisation : Taking of 1:1 Mole ratio (Ratio of No. of activant to the no. of moles of sodium oxide in the silicate) as unity or 100%. This term expresses as a % the ratio equivalent of activant to the equivalent of sodium oxide content added in the neutralisation process.

ppm. of activated silica : This term represents the ppm. available SiO_2 miscelles present. These have -ve charge and should not be confused with SiO_2 as normally found in water.

In recent years, a great deal of interest has been developed in activated silica as a coagulant aid in water treatment. The use of silica sol, produced by neutralisation of free-alkali of sodium silicate solution, offers many operating advantages. All the methods generally speaking reduce the power of strongly alkaline NaOH to hold silica in solution. The solution becomes unstable and miscelles form, which increase in size until a viscous liquid is formed. (They may continue to enlarge until a solid gel. results.) Hurd and Miller (2) state that the internal phase fibres of a silicic acid gel. are regarded as consisting of silicic acid molecules, that form long branched chains, produced by the splitting of water, containing silicic acid solution, starting at first by reaction between simple molecules and continuing between larger molecules until net work develops. The vast surface created by 'sheap structures' of combined silicic acid molecules can account for the absorption of water molecules and for their being held in more or less rigid condition. And condition that tends to alter the rate of reaction affects the rate of settling of gel. During the aging period, the low molecular wt. polymers of silicic acid formed by the neutralisation of silicic alkalinity, increase in size. By controlling the aging time, the size of silica miscelles can be varied over a wide range. By this theory, fast gelling should occur near *p*H of least ionisation where there is minimum repulsion force between similarly charged silicic acids or hydroxides. This occurs at *p*H=7. The increase in *p*H during aging and gelation incates that polysilicic acids formings are weaker. The actual point of gel. formation is usually determined by the loss of uniform field flow, the appearance of breakage planes, when mixture is tilted and adherance to the container. For the best action in coagulation, the aging time should be ¼th of the gel. formation time.

Numerous methods of preparation of silica solutions are known (1-3, 9, 11, 13, 5, 6). These include: (i) the 85% neutralisation of Na_2O content by H_2SO_4 (ii) The partial neutralisation by alum (iii) using Bicarbonate (iv) Chlorine (v) Ammonium sulphate (vi) sodium bisulphate (vii) CO_2 gas.

The type of the activating agent is not important as far as final result is concerned. The general action is

$$2HA + Na_2SiO_3 = H_2SiO_3 + 2NaA.$$

This is the simplified equation since the reactions are very complicated. H_2SiO_3 hydrates to $Si(OH)_4$ which polymerises.

The activated silica behaves as a negatively charged colloid. Electrophoretic studies indicate that the colloid has an iso-electric point at *p*H 3 to 4 the colloid is amphoteric in nature and at the thermal *p*H values normally found in water, the colloidal particles ionize strongly to produce hydrogen ions leaving a colloid having a definite negative charge (14). Obviously, since such particles would have the same charge as the normal water impurities, these two would tend to repel each other. On the other hand precipitated alum, in a bicarbonate water would have a higher isolectric point than the silica and would tend to be positively charged. The two particles would tend to mutually attract each other, and this may be how the activated silica acts.

Colloidal silica probably forms micro-crystals having diameters varying in size from 2 to 40 millimicrons. If we assume that the average particle size is 6 millimicrons in diameter and is perfectly spherical it would have a surface area of 125 square millimicrons. This big surface area will help immensely in coagulation.

The preparation can be batchwise or continuous. In recent years, latter has been coming into practice more since it is less time and space consuming. Batchwise preparation has main disadvantage that large capacity storage tanks are required and the chemicals should be very carefully handled. However, batch method is preferable if the flow of water is intermittent or varies over a wide range.

While preparing the activated silica solution, polymerisation has to be checked, before gelation occurs. In case of batch process, this prevention is achieved by diluting the solution after a suitable aging period. In continuous preparation, dilution is not necessary as solution is normally used immediately after aging period. In order to determine whether or not the activated silica may benefit the plant, Jar tests are run.

(1) Baylis was the first of the investigators to patent the silica solution. Activated silica hydrosol was prepared by employing a reactant with suitable grade of sodium silicate such as having part of Na_2O. 3.2 parts of SiO_2 A typical analysis was -Na_2O, 8.9%; SiO_2, 28.7%; and H_2O, 62.4%

Eqn : $H_2SO_4 + Na_2O.\ 3.2\ SiO_2\ H_2O$

$= Na_2SO_4 + 3.2\ SiO_2 + (x+1)_2\ H_2O$

The degree of activation is controlled by starting dilution of sodium silicate and by the reaction temp. The colloidal condition of SiO_2 is stabilised by secondary dilution of water. The colloidal solution is further diluted by 50% more water.

To feed 1 ppm. of activated silica 29 lbs. of 41°Be' sodium silicate for each m.g.d. is required. Very active and effective solution is gained. Special acid handling precaution should be taken.

(2) A less usual type is developed (5) by mixing 1% alum solution with 1% of silica solution in a ratio 4:1 and fed continuously to the coagulant. This is known as N sloution B.

Excessive care should be taken in diluting. Cost of residual chlorine increased.

(3) Hay prepared activated silica by using ammonium sulphate which is easy to handle, to weigh and is unharmful. Equimolar solution of diluted silicate and $(NH_4)_2SO_4$ are mixed. The mixture is allowed to age for 2 hours (2% silica solution) then diluted below 1.3%. If high pressure water treatment is involved then activated silica is disadvantageous, since copper fittings etc. are acted by excessive ammonia.

(4) Use of sodium bisulphate: This is an effective solution. Being a by-product in different industries its use is attractive.

(5) N. Sol. D :— The reactant used in this solution is $NaHCO_3$. This is also effective solution and has the property of keeping for long period. This can be prepared easily and is used for batch preparation normally.

(6) N Sol. C (15) :—In this process, chlorine is used as activant,

This method is more used for continuous preparations, wherever chlorine is also required for disinfection, nor more chlorine need be added in the treatment.

(7) Copperas (4): Industrially, copperas has been tried. When silica solution preceded copperas in raw water, coagulation enhanced except at low temperature. Economic dosage for silica copperas was found out to be such that sodium silicate dose should be 3/4th of copperas used.

(8) Carbsol (3): The activant used is CO_2. This is also an attractive method where CO_2 is already used for recarbonation as a part of the process, where it may be readily made available. The solutions prepared by this process would be active throughout a much wider range of neutralisation and would be much more stable than that prepared by acid. Experimentally, it has been found out that the approximate stabilizing can be found by the following equations :—

$A = 114/C - 13 \log T$ — for 1.5% to 2% soln. &

$A = 32 - 13 \log T$ for 3% sol.

where A — % neutralisation

C — concentration of sol. as % of SiO_2

T — gel. time in days.

Effect of increasing the concentration of silica is to shorten the gel. time and consequently aging time is shortened.

At higher rate conc., small aging tank is required for continuous process (even at times it may be eliminated). But it requires very fine degree of control. Silica concentration used in case of continuous method should be always less than 2%.

The degree of activity will vary with different agents and also with pH. It is also important to note that if the dissolved solids in raw water are more than 400 ppm., gelation time will be influenced immensely by them. Solutions having a total alkalinity of 1300 ppm. or less attain their max. activity in less than 5 min. The % neutralisation will vary with different activating agents and also with pH (10).

Advantages

1. More effective coagulation during both warm and cold water periods.

2. Larger and denser floc particles are formed.

3. A saving of alum and alkali during periods of easy coagulation. pH range of coagulants is increased (Alum was found workable even at pH 9.27).

4. The effective range of treatment is broadenned.

5. Longer filter runs are experienced even at low ppm. (0.25). The filter run was increased from 7 hours to 16½ hours and head loss permitted was 6.5 ft against 15 ft before addition. There is saving in wash-water (12).

6. Buffers sudden chemical changes.

7. Reduces raw water colour. However if slight excess is added then the efficiency is greatly reduced.

8. Production of a filtered water of higher quality.

9. Reduction of dissolved silica in water.

10. Use of higher rate and coarser sand made possible.

11. Prevention of 'after precipitation' of alum.

12. The use of activated silica has been essential in case of upflow clarifiers (5 to 7 ppm. dosage).

13. Activated silica employed with alum is highly effective in removing traces of radioactivity from water.

14. Organic suspended matter are more readily removed.

Limitations

1. Palin, by experiments (16), has proved at optimum dose of alum, addition of silica dose not remove any **colour.**

2. Also in case of pressure filters, it has no effect on delaying the filter run.

3. It is not effective in case of algae troubles (8).

4. It does not influence the colloidal protein removal.

Conclusion

It can be seen from the foregoing discussion that activated silica is a very effective coagulant aid. Its use has been proved in foreign countries and there are many industries where it is being used. The use of this knowledge should be made in India.

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Effectiveness Of Certain Coagulants In Turbidity Removal From Yamuna Water

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The principle functions of coagulation are destabilisation, aggregation, and binding together of suspended matter more particularly when it is so finely divided as to be colloidal (1). In water treatment practice, chemical coagulation involves the formation of floc that adsorbs, entraps or otherwise brings together suspended matter. Chemical coagulation is commonly accomplished by the addition of alum, ferric chloride or chlorinated copperas depending upon their availability and quality of water.

Delhi gets water from Yamuna river. The physico-chemical characteristics of the river water, studied for about an year, are given in Table I. It can be noted that the water has a comparatively low turbidity and high alkalinity during summer and winter months but a very high turbidity and low alkalinity during monsoon. Since the fluctuations in the characteristics of water are significant, it is important to find a suitable coagulant which would produce a water of low turbidity when applied in low concentrations. With this in view, experiments were conducted using **nirmali** seed, ferric chloride, chlorinated copperas and alum as coagulants. Studies were also made by using **nirmali** seed as a coagulant aid in conjunction with alum and by lowering *p*H of the water by acidification with sulphuric acid before the addition of alum as a coagulant.

Treatment Plant

The plant consists of a pump house, intake sump, distribution chambers with right-angled weirs, and two adjacent circular clariflocculators. Each clariflocculator is 12 ft. in dia with three concentric chambers. The innermost forms the flocculation chamber and the outermost forms the sedimentation zone while the annular space is used for changing the direction of flow and thus prevent short-circuiting. Schematic details of the clariflocculator are shown in Fig. 1 and the flow diagram of the plant in Fig. 2. The paddles were rotated at 9.5 rpm which gave a velocity gradient of 82 ft/sec/ft. Coagulants were added in liquid form in the distribution chambers. They got mixed intimately with raw water during its passage through the pipe connecting the distribution chambers with the bottom of the flocculation chambers.

Results and Discussion

i) *Nirmali Seed :* This seed is an indigenous polyelectrolyte. The effectiveness of such natural products in the clarification of water has long been known in India. With the use of synthetic polyelectrolytes in recent years, studies on the applicability of natural products, such as **nirmali** seed, starch, etc. in the coagulation of water have been forthcoming. **Nirmali** seed was found useful in extremely low concentrations in coagulating the suspended impurities in Yamuna water (2).

Laboratory experiments showed that, with a flocculation and settling time of ten minutes each, water with a residual turbidity of 8.5 to 11.5 mg/lit. was produced from raw water with 1,600 to 3,200 mg/lit. turbidity when 10 to 15 mg/lit. of alum was added three minutes after the addition of 1.0 mg/lit. of the extract. But, if the alum was added three minutes before the extract, other factors remaining the same, the flocculation was poor and residual turbidity was 35 to 52 mg/lit. When alum and extract were added simultaneously, the residual turbidity could not be lowered below 22.5 mg/lit.

The extract was added before alum in the pilot plant studies also, and a series of observations were taken when the turbidity was 1,220 to 1,530 mg/lit. A dose of 1.5 mg/lit. of the extract was applied and the overloading rate was maintained at 1,190 gal/day/sq ft. The residual turbidity was 84 to 113 mg/lit. after 14 minutes flocculation and 44 minutes settling. The above effluent, when further treated with 10 mg/lit. alum, produced water with 22 to 29 mg/lit. turbidity. The final clarified water showed no increase in organic matter as indicated by Tidy's test. It was also seen that for reducing the turbidity from 1,650 to 31 mg/lit. with alum alone, a

Table I—Physico-chemical characteristics of Yamuna water

Month	Temp. °C		*p*H		Turbidity mg/lit.		Alkalinity mg/lit.	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Feb.	24	21	8.2	7.9	700	100	...	...
Mar.	28	21	8.4	7.7	725	42	135	95
Apr.	31	27	8.3	8.1	35	15	179	140
May	34	30	8.6	8.3	20	13	176	163
June	36	30	8.6	8.1	34	14	160	133
July	35	31	8.2	7.9	1650	23	101	76
Aug.	33	30	8.1	7.9	3200	290	100	71
Sept.	30	28	8.2	7.8	3300	700	91	71
Oct.	30	27	8.1	7.8	1850	150	154	85
Nov.	25	23	8.2	7.9	150	60	177	145
Dec.	21	18	8.4	7.5	60	35	196	174

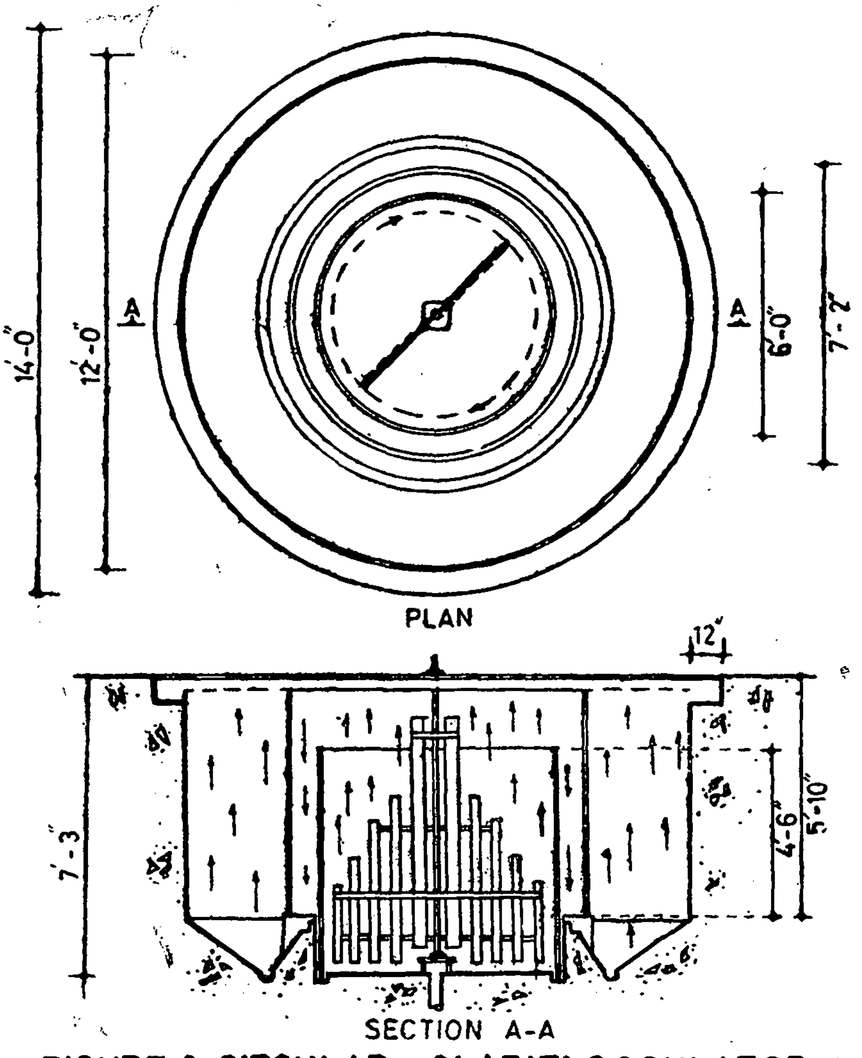

FIGURE I-CIRCULAR CLARIFLOCCULATOR

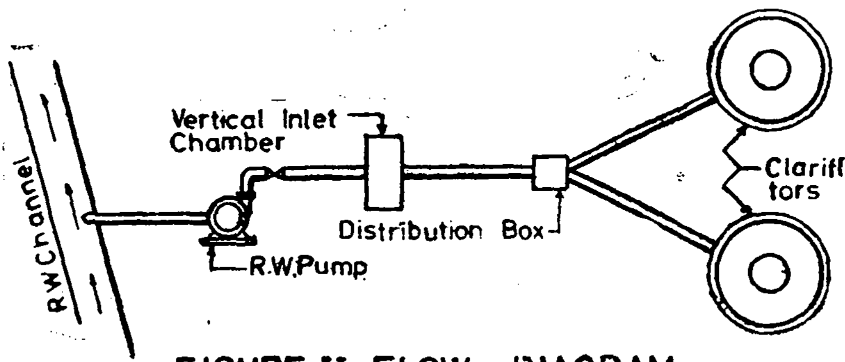

FIGURE II-FLOW DIAGRAM

Fig. 1 & 2

dose of 43 mg/lit. had to be applied. This shows considerable reduction in alum consumption if the raw water is pre-treated with a low dose of extract. The variation in *p*H from 8.2 to 8.6 did not affect the coagulation.

ii) *Ferric chloride :* Turbidity of about 20 mg/lit. was obtained in the laboratary study with 9 to 19 mg/lit. of ferric chloride on a raw water turbidity of 1,400 to 2,400 mg/lit. with five minutes flocculation and ten minutes settling.

With a loading rate of 530 gal/day/sq ft, 32 minutes flocculation and 97 minutes settling in pilot plant, the following results were obtained on the efficiency of ferric chloride.

Raw water turbidity	Dosage	Residual turbidity
(All values in mg/lit.)		
150-900	3 - 8	19 - 24
1,000-2,100	6 - 9	21 - 29
1,400-2,400	9 - 14	21 - 31
225-2,400	4 - 15	18 - 30

It would be seen that with comparatively low dosages, a good reduction is achieved and in no case the residual turbidity in the clarified water exceeded 31 mg/lit. There was no iron in clarified water after filtration. The material was deliquescent and the dosages applied were approximate as exact weighing on a large scale was not possible.

iii) *Chlorinated copperas :* Chlorinated copperas is a mixture of ferric chloride (28.9%) and ferric sulphate (71.2%) prepared by adding chlorine to copperas ($FeSO_4 .7H_2O$) solution. Even though 7.8 parts of chlorine is needed theoretically for each part of copperas, 10 parts were added because of the commercial quality of the copperas and possible presense of organic matter. Because of the instability of the material, solution was prepared fresh daily.

Laboratory studies showed that the raw water turbidity of 100 to 240 mg/lit. was reduced to 22 to 37 mg/lit. with 4.5 to 6.0 mg/lit. of chlorinated copperas. Pilot Plant studies with 800 gal/day/sq, ft overflow rate, 20 minutes flocculation, and 64 minutes settling indicated that it was possible to obtain a clarified water with a turbidity of 13 to 21 mg/lit. when the raw water turbidity was 100 to 265 mg/lit.

Even though the storage of copperas is not as severe a problem as of ferric chloride, handling of chlorine gas and administering it in copperas solution efficiently presents a problem. How best this can be done on a large scale has to be studied in detail.

iv) *Alum :* Laboratory studies indicated that, if alum was applied in correct doses, the turbidity could be reduced to less than 5 mg/lit.

even with a raw water turbidity of 3,600 mg/lit.

Pilot plant experiments were carried out for several months with different loading rates and other varying conditions. The results are summarised in Table II.

The grouping of raw water turbidity was done on the basis of the maximum and minimum observed values in a particular month. Similarly the values given for loading rates dosage, and residual turbidity are the maximum and minimum values.

It was seen that turbidity could be reduced to less than 30 mg/lit. even during monsoon period when the turbidity was high, by suitably altering the dosage. Loading rates as high as 1,725 gal/day/sq ft produced a good effluent with a residual turbidity of 6 to 17 mg/lit. when the raw water had 42 to 725 mg/lit. turbidity. The criteria for selecting the dosage were the residual turbidity and the size of the floc.

v) *pH adjustment :* In summer months, particularly during May and June, the floc formation was poor and large carry-over of floc is observed every year in Water Works. The *p*H of the water during these months was between 8.0 to 8.6 and the alkalinity as $CaCO_3$ was between 163 to 176 mg/lit. Experiments were conducted in the Laboratory to study if there was any improvement in coagulation with alum if the *p*H was lowered with commercial sulphuric acid. Various combinations in the ranges 0-120 mg/lit. acid and 0-70 mg/lit. alum were tried. There was no significant improvement in the residual turbidity as observed in jar tests.

Table II—Pilot Plant studies on turbidity reduction under different conditions

Raw water turbidity mg/lit.	Loading rate gal/day/sq. ft	Dose mg/lit.	Residual turbidity mg/lit.
13 — 20	517 — 595	6 — 7	9 — 14
15 — 35	552 — 570	10 — 16	8 — 19
35 — 60	800	5 — 6	12 — 19
14 — 34	552 — 570	6 — 13	11 — 23
60 — 150	552 — 570	5 — 20	13 — 23
42 — 725	552 — 1,725	50 — 75	6 — 17
23 — 1,650	552 — 1,217	6 — 43	13 — 31
150 — 1,850	552 — 580	20 — 61	11 — 24
290 — 3,200	552 — 628	10 — 55	13 — 27
700 — 3,300	516 — 570	40 — 60	12 — 27

The studies were continued on pilot plant and several runs were made with loading rates of 622 to 677 gal/day/sq ft. The summarised results are presented in Table III. Even though pH was lowered to 6.50 by adding large quantities of sulphuric acid there was no significant improvement in the residual turbidity of settled water.

Conclusions

1. Pre-treatment of raw water with low Nirmali seed dose considerably reduced alum requirement.

2. Alum, ferric chloride, and chlorinated copperas were equally effective in reducing the turbidity of water in river Yamuna.

3. Acidification showed no appreciable improvement in residual turbidity of settled water.

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DISCUSSION

SHRI R. S. MEHTA (Nagpur): Which of the coagulants mentioned by the author is most economical and efficient ?

SHRI K. R. BULUSU: Chlorinated copperas, when handled properly, was found to be better.

SHRI S. SUBBA RAO (Singur): Does **nirmali** seed extract, which I presume is organic in nature, add to the organic content of the water? If so, what are the precautions necessary ?

Table III—Effect of *p*H on turbidity

Raw water turbidity	Experimental unit				Control unit			
	Alum	Acid	Residual turbidity	*p*H	Alum	Acid	Residual turbidity	*p*H
35	15	20	16.5	7.60	15	0	19.5	8.30
	15	30	15.0	7.40	15	0	18.0	8.30
26	11	20	16.5	7.70	11	0	18.0	8.30
	11	30	17.0	7.55	11	0	17.0	8.30
105	16	7.5	28.5	7.80	16	0	29.5	8.10
	16	10	32.0	7.60	16	0	40.0	8.10
115	16	20	27.5	7.50	16	0	32.0	8.20
	16	30	29.0	7.30	16	0	32.0	8.20
100	16	70	28.0	6.90	16	0	34.0	8.00
	16	80	29.5	6.80	16	0	34.0	8.00
	16	90	28.5	6.50	16	0	34.0	8.00

Note: All values except pH are in mg/lit.

SHRI K. R. BULUSU : We conducted Tidy's value test for the effluent and no increase in the value was noticed. In fact, there was a considerable reduction. The reason may be that most of the organic matter got settled during coagulation and sedimentation.

SHRI O. P. GUPTA (Rourkela) : In Rourkela, $FeSO_4$ which is a by-product from the steel plant, is used as a coagulant. Kindly indicate if some other coagulant like **nirmali** seed extract can be used to reduce the dose of the coagulant. If so, to what extent is reduction possible and what are the chemical actions involved ?

SHRI K. R. BULUSU : We have not tried the combination of $FeSO_4$ and **nirmali** seed. However, $FeSO_4$ alone was tried with Yamuna water and no encouraging results were obtained. It is suggested that laboratory studies be conducted at Rourkela to assess the performance of this combination with that particular water. This only can indicate to what extent the reduction, if at all, is possible. The question of chemical reactions involved would arise only afterwards.

SHRI R. K. PANDIT (Bombay) : I would like to know if the **nirmali** seed extract has been analysed. If so, what are the constituents ?

SHRI K. R. BULUSU : To the best of my knowledge, no systematic attempt has so far been made to completely analyse the seed. Only a preliminary analysis was attempted and was given by Haskar, C. N. and Kendurkar, S. G. These results may be seen from the Journal of Vikram University (1960).

SHRI A. R. TIWARI (Bhilai) : It is doubtful whether a dose of 15 mg/lit. of alum preceded by the addition of 1 mg/lit of **nirmali** seed can bring down the turbidity of raw water from 3,200 to 8.5-11.5 mg/lit. Our experience is that a high dose of 65 mg/lit. of alum is requried for a water of 3,500 mg/lit. turbidity and yet the turbidity is of the order of 40 mg/lit. after allowing 2 hr settling period. Detention period may please be given.

SHRI K. R. BULUSU : Several experiments were conducted in the laboratory for a period of over eighteen months and it has been conclusively established that a residual turbidity of 8.5 to 11.5 mg/lit. can be produced from Yamuna water with 1,600 to 3,200 mg/lit. turbidity when 10 to 15 mg/lit. of alum is added three minutes after the addition of 1.0 mg/lit. of the **nirmali** seed. Detailed information on this can be had from the following reference : Sen, A. K., and Bulusu, K. R., **Env. Hlth,** IV, 233 (1962).

Pilot Plant experiments were conducted using Yamuna water with a turbidity of 1,200 to 1,530 mg/lit. The experiment was conducted in two stages. In the first, 1.5 mg/lit. of extract was used and a surface loading rate of 1190 gal/day/sq ft. was employed. The corresponding spill-over velocity, flocculator detention time and clarifier detention time were 0.0273 ft/sec, 14 min, and 44 min respectively. The effluent from this unit with a turbidity of 84 to 113 mg/lit. was fed to second stage where 10 mg/lit. of alum was added. The surface loading rate employed was 660 gal/day/sq ft and the corresponding spill-over velocity, flocculator detention time and clarifier detention time were 0.0151 ft/sec, 26 min and 79 min respectively. This makes a total of 40 min in the flocculation zone and 123 min in the clarification zone. The final effluent had a turbidity of 22 mg/lit. Our experience also suggests that with a turbidity of 3,200 mg/lit., over 40 mg/lit. of ferric alum is necessary to bring down the turbidity to about 15 mg/lit. in the jar tests. This is the case when alum alone is used. However, when used in conjunction with **nirmali** seed (1.0 mg/lit.), the dose of alumina-ferric reduces to 15 mg/lit. in jars. Similarly, in pilot-plant studies, when alum alone was used, more than 35 mg/lit. of dose was required to bring down the turbidity to about 30 mg/lit. This was the situation even with a surface loading of 560 gal/day/sq ft.

SHRI A. R. TIWARI : Can ferric chloride alone be used as a coagulant ? If so, *p*H conditions, etc. may please be given.

SHRI K. R. BULUSU : Ferric chloride was tried successfully on our pilot plant in doses 3 to 15 mg/lit. Experiments were conducted with Yamuna water with a turbidity range of 150 to 2,400 mg/lit. The residual turbidity was between 18 to 30 mg/lit. A surface loading of 530 gal/day/sq ft was employed. The actual problem with this chemical is in its handling and storing.

SHRI A. R. TIWARI : How is the dose of **nirmali** seed determined ?

SHRI K. R. BULUSU : The dose was determined on the basis of seed weight per unit volume of suspension taken in a known volume of sample to be treated and expressed as such.

SHRI T. S. BHAKUNI (Nagpur) : It is felt that polyelectrolytes present in the **nirmali** seed are the agents that bring about the coagulating effect. Do you feel that different methods of extraction may give different type and amount of polyelectrolytes ?

SHRI K. R. BULUSU : No systematic study has so far been made to the best of my knowledge to make one feel or guess as to what could be the agent that brings about the coagulating effect. Sorry, the second part of the question is not clear.

SHRI T. S. BHAKUNI : Have any experiments been carried out on the toxicity of the extract of **nirmali** seed ?

SHRI K. R. BULUSU : No.

SHRI T. S. BHAKUNI : Although polyelectrolytes are high molecule compounds, can we use them both as coagulants and coagulant aids ?

SHRI K. R. BULUSU : The only material I have worked with is **nirmali** seed and it worked very well, particularly as a coagulant aid. I have no experience with the other polyelectrolytes the questioner has in mind.

SHRI V. D. DESHPANDE (Nagpur) : What was the method adopted to get **nirmali** seed extract ? How did you calculate the mg/lit. expression of the seed extract ?

SHRI K. R. BULUSU : The seeds were thoroughly cleaned, dried and finely crushed mechanically. The coarse powdery material was then suspended in distilled water and churned violently in a waring blendor till a homogenous suspension was achieved. An aliquot of conc. HCl was added to this homogenised suspension and the volume made up with distilled water. The suspension so obtained was so homogenous and stable that no settling was observed even after 4 hours settling time. The dose was calculated on the basis of seed weight per unit volume of suspension taken in a known volume of sample to be treated and expressed as such.

SHRI V D. DESHPANDE: Are you sure that the measured extract always contains the same effective quantity of the "reactive material" in the **Nirmali** seed?

SHRI K. R. BULUSU: Experiments were conducted in the laboratory using the same volume of suspension from the same batch on the same day several times and identical results were obtained. This indicates that the effective reactive material is same throughout the container in which the suspension was kept. Also similar experiments were conducted with the aid prepared from seeds of a random pick up from a container and identical results were obtained. This again suggests that the active particle was the same in quality and quantity in the seeds we have received in 1961.

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Studies On Double Vertical Inlet Baffles With Slots In Rectangular Settling Basin

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Introduction

In continuously operated settling basins, the movement of water is an additional factor against the settling of particles to the already existing ones such as specific gravity and shape of particles, coagulation of particles and concentration of particles. Therefore, actual settling velocities may differ significantly from the theoretical ones because of water movement in continuous flow tanks.

It is apparent from the theory developed by Camp (1) that the smallest diameter of particles which will be completely removed is theoretically a function of the surface loading or overflow rate. The surface loading becomes an important criterion when the horizontal velocity in the basin is nearly uniform. But, in settling tanks with improper admittance of incoming flow, water actually meanders through it, either in large mass movements or in well defined relatively high velocity paths or currents, which is known as short-circuiting. The existence of turbulent diffusion will result in decreasing the removal efficiency of the settling basin. Thus, it becomes important to control the horizontal velocity in the settling tank.

An ideal basin is divided into four zones among which the inlet zone comes first. Laboratory experiments have already shown that with very best design of inlet and outlet and devices, inlet and outlet zones will each occupy a portion of length of path of flow at least equal to depth of the tank. In long narrow tanks, the importance of inlet and outlet devices may be neglected because of their relatively small size. But as the proper design of inlet and outlet becomes important now due to want of place in the treatment site and due to high cost also, short rectangular tanks are in use, the proper design of inlet and outlet becomes important.

An ideal inlet is to: (i) distribute the influent as uniformly as possible over the cross-section; (ii) start all of the flow through the settling zone in parallel horizontal paths; (iii) introduce the flow into the tank with a minimum turbulence; and (iv) to present high velocity at the bottom of the tank.

The slotted baffle boards in front of the inlet openings will destroy the kinetic energy of the incoming water. Baffles of this kind contribute to stability of flow.

The aim of this study was to find out the improvement in performance of the settling tank by the use of double vertical slotted inlet baffles. The effect of area of slots, effect of distance between the two baffles and the effect of position of slots were also studied.

Experiments were conducted in the settling tank model available at the College of Engineering, Guindy, Madras. The basin was 6½ ft wide.

Equipment and Methods

The first baffle contributed a slot area of 5.27 per cent of the cross-sectional area of the basin. This baffle was kept at a fixed distance of 13 inches from the wall, throughout the experiment. This was as per the studies conducted by Ramakrishnan (2) on the use of single vertical baffle with slots.

There were three sets of second baffle. Three different ratios of slot area to the cross-sectional area of tank, viz., 10.6, 12.9, and 15.35 per cent were adopted to study the effect of slot area on the performance. In each case, the slots were made at top, middle and bottom of the baffle for studying the effect of position of the slots. The experiment was conducted for two rates of flow. The distance between the baffles was varied and, for each distance, the effect of position of the slots was also studied.

Sodium chloride was the tracer used. Samples were collected at the outlet weir at one minute intervals and chloride content of each sample was estimated. Rate of tracer recovery for each time interval was found. Using the dimensionless parameters t/T and C/Co, dispersion curves were drawn for each run and the performance of the basin was found with other dimensionless parameters such as ti/T, tp/T, tm/T and t90/t10.

Measures of Performance

Dimensionless parameters are calculated to compare the results of study under different conditions. (i) Relative concentration of tracer C/Co where C is the rate of tracer recovery at a time 't';

Co, ratio of weight of tracer added at the inlet well to the theoretical detention time.

This represents the relative concentration of tracer recovered at a time 't'.

(ii) Relative time, t/T.

t = time of collection for an individual effluent sample, measured from time tracer is added to basin inflow.

(iii) tA/T—relative arithmetic mean. This ratio is a measure of dead spaces in a basin. A value of 1 indicates that the volume is utilised 100 per cent, but it does not indicate the absence of short-circuiting. A value greater than 1 shows something wrong in the test. The 'tail' of the tracer recovery curve influences this value.

(iv) Relative time of initial tracer recovery, ti/T. This ratio is a measure of worst short-circuiting in the basin. In an ideal basin, this ratio is 1.

(v) Relative time of peak rate of tracer recovery, tp/T. This ratio represents the relative model detention time. It is a good measure of volumetric efficiency because it is the relative time at which the greatest concentration of tracer is recovered in the basin effluent. This ratio would be 1 in ideal basin.

(vi) Relative 50 percentile, tm/T. This ratio represents the relative probable flow through time. It is a measure of total short-circuiting due to both dead space and non-uniform flow. Because the tail of tracer recovery curve has little effect on this, this is a good measure of volumetric efficiency. This is 1 for ideal basin.

(vii) Dispersion ratio, t90/t10. This dimensionless parameter is the ratio of the time required for the first 90 per cent of the tracer recovered to pass through the basin to the time required for the first 10 per cent. This ratio is equal to 1 for ideal basin. This dispersion ratio is a measure of the uniformity with which the flow is detained in the basin.

Discussion of Results

1. *Comparison of performances of single baffles and double baffles :* Table I gives the performance of the basin with single baffle with 5.27 per cent slot area kept at 13 in from inlet end constantly and the performances of the basin with double baffle with 10.6 per cent slot area kept at 3, 6, and 9 inches from the first baffle. In all the three distances, the performance with double baffle is more effective than that with the single baffle. For 6 in position, the performance with the double baffle appears to be the best.

By the use of double baffle, short-circuiting and dead spaces were reduced considerably as shown by the increased values of t1/T, tm/T and tA/T. Volumetric efficiency and uniformity of flow were also more in the basin as shown by the ratio of tp/T and t90/t10. Fig. 1 shows the improved performance of the basin with double baffle.

2. *Effect of variation of distance between the two baffles :* Table II gives the performance of the settling tank when the second baffle was placed at three different distances, i.e., 3, 6, and 9 in from the first baffle with the slots in the bottom row. Performance of the basin is maximum when all the three types of second baffles were placed at 6 in from the first baffle. The increased values of t1/T, tm/T and tA/T show that there was a great reduction of short-circuiting and dead spaces. Higher value of tp/T represents higher volumetric efficiency at 6 in position. The dispersion ratio varied from 2.8 to 3.1 only and this decreased value of t90/t10 shows more uniform flow in the basin. Therefore, when the distance between the two baffles is 6 in, performance of the basin seems to be better. Fig. 1 shows the efficient performance of the basin at 6 in position.

3. *Effect of area of slots :* Table III gives the performance of double baffle with different area of slots when the distance between the baffles was 3, 6 and 9 in. Baffle having the largest area of slots, i.e., 15.35 per cent. seems to work well at this closest position of the second baffle from the first baffle in reducing short-circuiting, in increasing volumetric efficiency of the basin and in increasing uniformity of flow at 16.03 gal/min. The ratio t1/T,

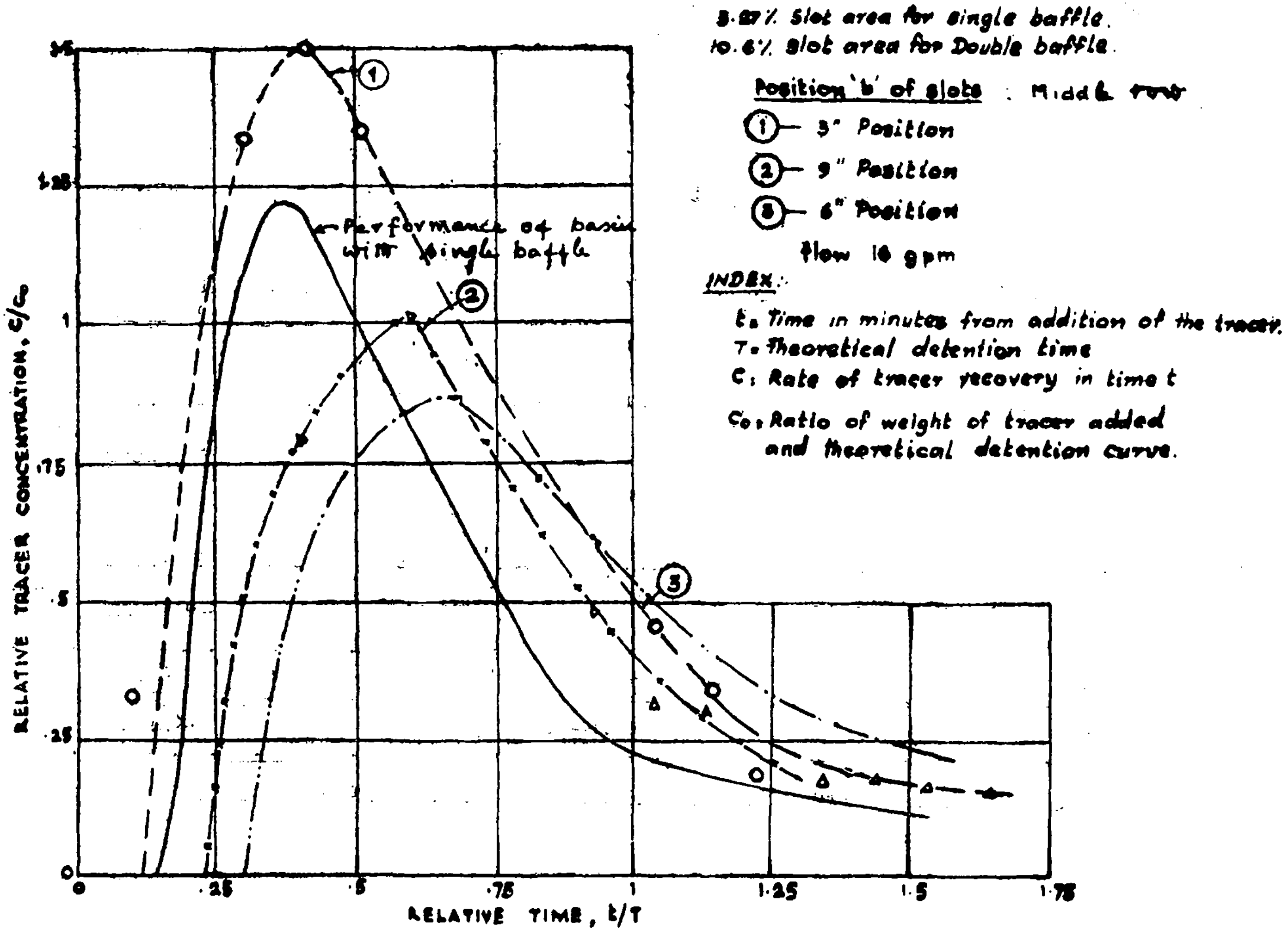
3.27% Slot area for single baffle.
10.6% Slot area for Double baffle.
Position 'b' of slots : Middle row
① — 3" Position
② — 9" Position
③ — 6" Position
flow 16 gpm
INDEX:
t = Time in minutes from addition of the tracer.
T = Theoretical detention time
C : Rate of tracer recovery in time t
C₀ : Ratio of weight of tracer added and theoretical detention curve.
Performance of basin with single baffle
RELATIVE TRACER CONCENTRATION, C/C₀
RELATIVE TIME, t/T
0
.25
.5
.75
1
1.25
1.5
1.75

Fig. 1

Table I—Comparative Performance of basin with single baffle and double baffles

Particulars	Position of slots	16 gal/min					20 gal/min				
		ti/T	tp/T	tA/T	tm/T	t90/t10	ti/T	tp/T	tA/T	tm/T	t90/T10
Single Baffle Slot area 5.27% Distance from inlet and, 13in.	Middle row (Position B)	0.15	0.35	0.65	0.46	4.1	0.1	0.28	0.8	0.59	4.65
Double Baffle II baffle of slot area, 10.6%, at 3 in distance from I baffle	Middle row (Position B)	0.075	0.41	0.685	0.601	4.1	0.1	0.513	0.87	0.74	6.5
Same at 6 in distance	Middle row (Position B)	0.275	0.68	0.87	0.75	3.6	0.275	0.52	0.81	0.75	4
Same at 9 in distance	Middle row (Position B)	0.225	0.615	0.715	0.64	4.2	0.125	0.64	0.88	0.79	4.6

Table II—Effect of distance between the baffles on basin performance

Slot area %	Distance between the baffles in,	16 gal/min					20 gal/min				
		ti/T	tp/T	tA/T	tm/T	t90/t10	ti/T	tp/T	tA/T	tm/T	t90/t10
	3	0.1	0.41	0.65	0.54	4.3	0.125	0.6	0.802	0.71	7
	6	0.3	0.7	0.826	0.85	3.1	0.25	0.64	0.76	0.74	3.6
10.6	9	0.225	0.55	0.81	0.8	3.3	0.075	0.513	0.89	0.77	3.8
	3	0.15	0.62	0.775	0.74	6	0.075	0.64	0.805	0.751	6.0
12.9	6	0.3	0.7	0.85	0.76	3.4	0.37	0.76	0.78	0.77	2.93
	9	0.27	0.70	0.9	0.72	4	0.225	0.66	0.9	0.76	4.8
	3	0.125	0.61	0.89	0.82	4.85	0.125	0.64	0.787	0.64	5.7
15.85	6	0.31	0.85	0.94	0.92	2.8	0.37	0.81	0.897	0.8	3.4
	9	0.175	0.51	0.9	0.73	3.5	0.225	0.513	0.86	0.78	5.6

tm/T, tp/T and t90/t10 are increased. Fig. 2 shows this performance. The second baffle was shifted to next position at 6 in distance from the first baffle.

Baffles having larger slot area, i.e., 12.9 and 15.35 per cent gave better performance at 16.03 gal/min flow than the smaller area of slots, i.e., 10.6 per cent. The increased

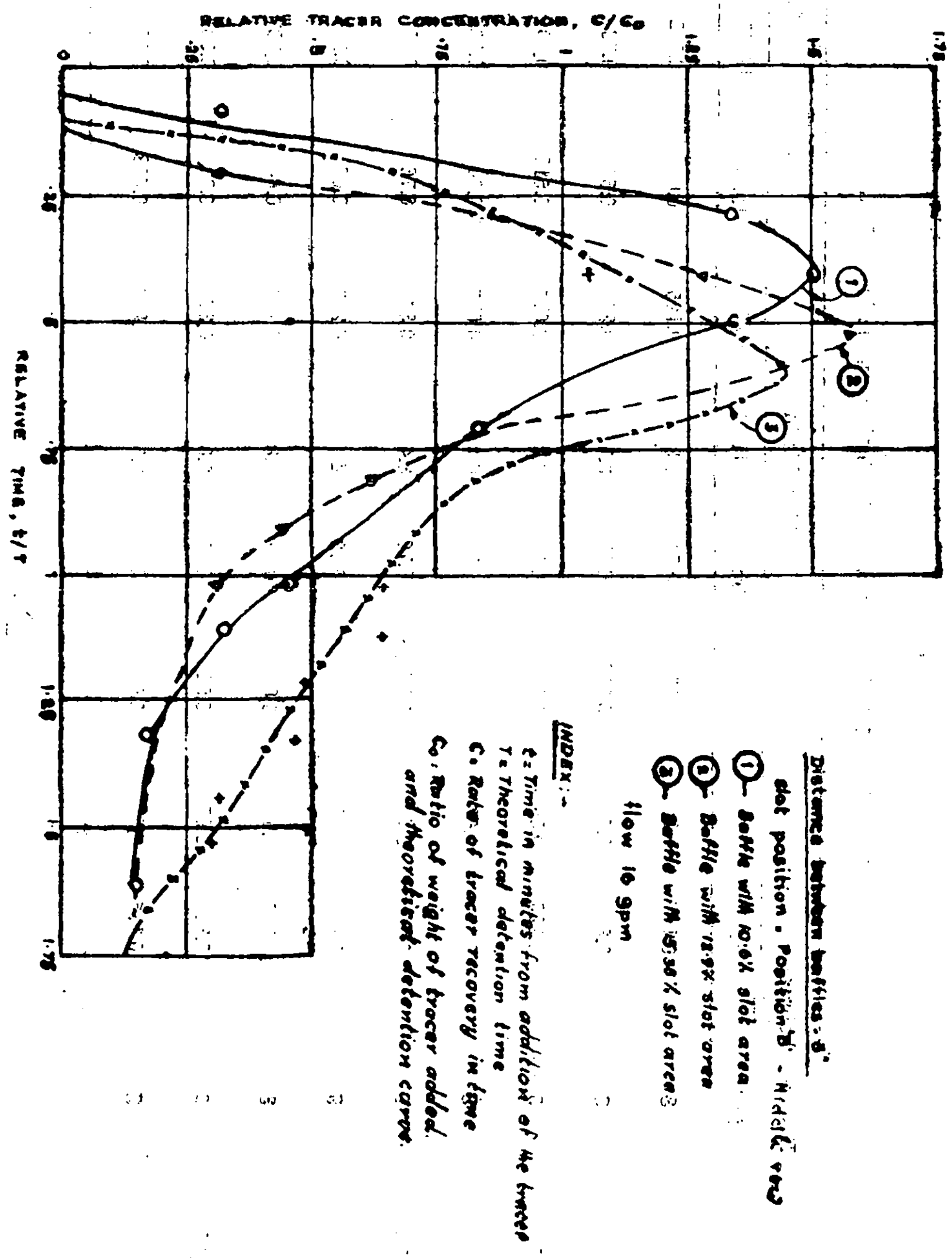

Fig. 2

Table III—Basin performance with baffles of different area, 3, 6 and 9 in apart

Area of Slots %	Position of slots	16 gal/min					20 gal/min				
		ti/T	tp/T	tA/T	tm/T	t90/t10	ti/T	tp/T	tA/T	tm/T	t90/t10
					Baffles, 3 in apart						
10.6	Middle row	0.075	0.41	0.685	0.601	4.1	0.1	0.513	0.87	0.74	6.5
12.9	Middle row	0.125	0.51	0.64	0.6	5.4	0.075	0.64	0.76	0.63	5.4
15.3	Middle row	0.1	0.61	0.76	0.61	4.5	0.1	0.4	0.895	0.83	4.74
					Baffles, 6 in apart						
10.6	Bottom row	0.30	0.7	0.826	0.85	0.1	0.25	0.64	0.76	0.74	3.6
12.9	Bottom row	0.30	0.70	0.85	0.76	3.4	0.37	0.76	0.78	0.77	2.93
15.35	Bottom row	0.31	0.815	0.94	0.92	2.8	0.37	0.81	0.897	0.80	3.4
					Baffles, 9 in apart						
10.6	Top row	0.20	0.615	0.88	0.83	5	0.075	0.64	0.84	0.80	3.2
12.9	Top row	0.20	0.615	0.86	0.82	4.7	0.20	0.45	0.79	0.64	4.3
15.35	Top row						0.125	0.64	0.8	0.74	5.6

values of $t1/T$, tp/T and tm/T show the minimised effect of short-circuiting and dead spaces and increased volumetric efficiency of the basin. At 16.03 gal/min, $t90/t10$ was reduced to 2.8 in the case of baffles with largest area of slots. But at 20.04 gal/min, the dispersion ratio was decreased to 2.34 by the use of smaller area of slots, i.e., 10.6 per cent. Here reduction of area of slots also seems to give comparatively good performance.

Now the second baffle was kept at the third position at 9 in distance from the first baffle. Table III and Fig. 3 give the performance at this position. At 20 gal/min flow, the performance of the baffle, with area of slot 10.6 per cent, was good as shown by the increased values of tp/T, tA/T and tm/T. Dispersion ratio was decreased considerably for higher flow by the use of smaller area of slots. But $t1/T$ value alone was not increased. At 16.03 gal/min, values of parameters compared well with those obtained for 12.9 per cent slot area.

Thus, the variation of slot area has significance in the use of double baffle. For nearer position of the second baffle from the first baffle, baffles with larger area of slots seem to give better performance. For farther distances from the first baffle, smaller area of slots seemed to work well.

4. *Effect of Position of Slots :* Tables IV, V and VI discuss the effect of position of slots.

Table IV gives the performance of the basin when the second baffle having slot area of 10.6 per cent was studied for three distances from single baffle.

For all three positions of the baffle having alot area of 10.6 per cent, top row of slots, i.e., position A seems to have some chances to give good performance. At 3 in position of the baffle, slot position A gave increased values of $t1/T$, tp/T, tA/T at 16 gal/min but not in 20 gal/min flow. Parameter $t90/t10$ was slightly high.

At 6 in position of the baffle, for 20.04 gal/min flow, top row of holes gave good performance of basin. At 16 gal/min flow position, A was not more efficient than position C of slots.

At 9 in position of the baffle, position A of holes gave good values of $t1/T$, tA/T and tm/T. But at 20 gal/min rate $t1/T$ was slightly decreased.

Table V gives the working of double baffle when second baffle having the slot area of 12.9 per cent. was kept at 3, 6, and 9 in positions from the first baffle. Slots of bottom row, i.e., position C seem to give better performance for all distances but for the following effects. At 3 in position, the value of $t90/t10$ was slightly high for slot position C for both rates of flow. At 6 in position, for 16 gal/min rate, position C of slots does not improve the performance much. At 9 in position, $t90/t10$ ratio was increased for slot position C for 20 gal/min rate of flow. Yet most of the parameters had increased values for this slot position C.

Table VI shows the performance of double baffle when the second baffle having slot area of 15.35 per cent was placed at 3, 6, and 9 in from the baffle.

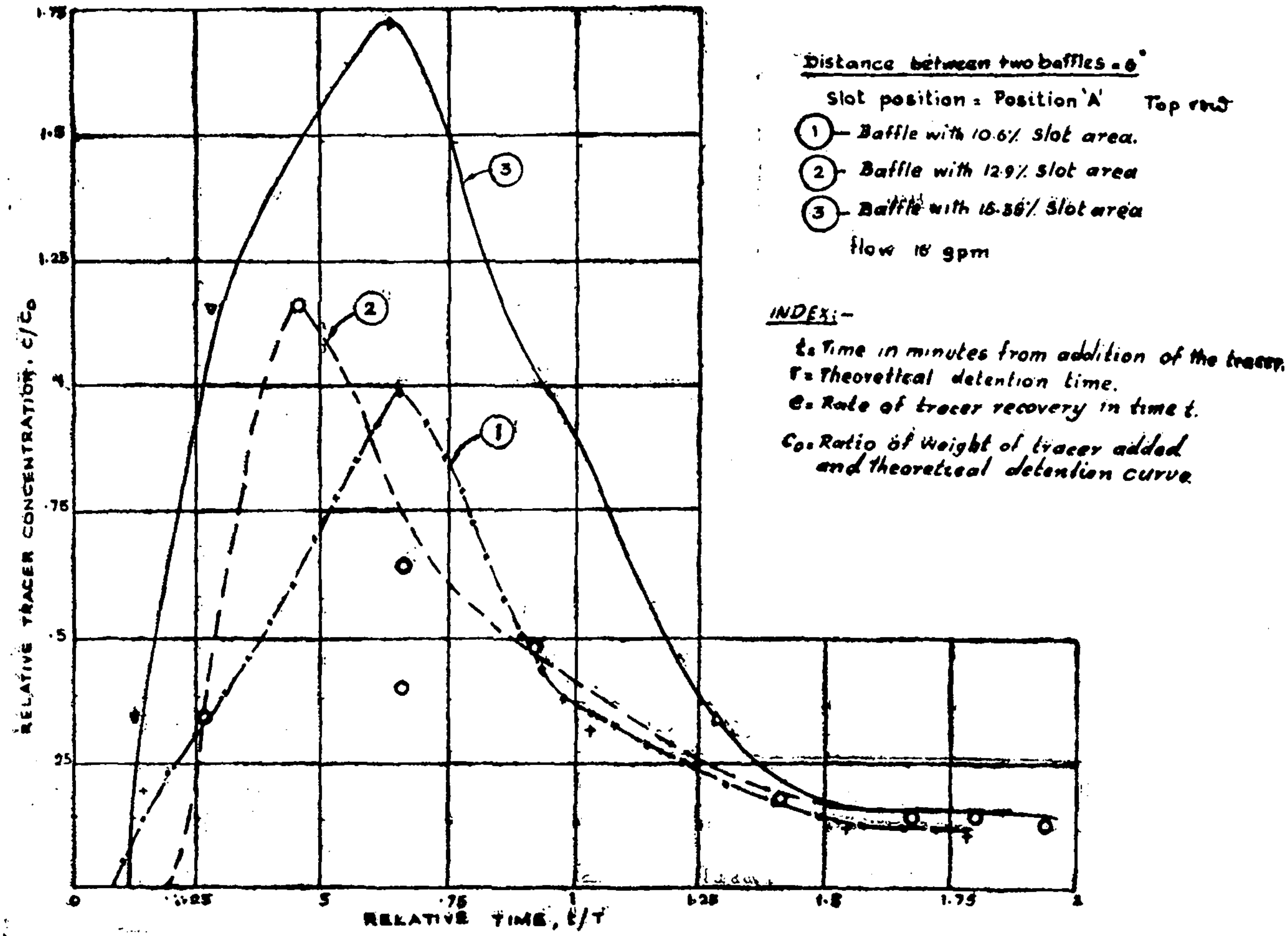
Distance between two baffles = 6"
Slot position : Position 'A' Top row
1 - Baffle with 10.6% slot area.
2 - Baffle with 12.9% slot area
3 - Baffle with 15.85% slot area
flow 18 gpm
INDEX:-
t: Time in minutes from addition of the tracer.
T: Theoretical detention time.
C: Rate of tracer recovery in time t.
C0: Ratio of weight of tracer added and theoretical detention curve
RELATIVE TRACER CONCENTRATION, C/C0
RELATIVE TIME, t/T
1.75
1.5
1.25
1
.75
.5
.25
0
.25
.5
.75
1
1.25
1.5
1.75
2

Fig. 8

Table IV—Effect of Slot position in basin performance

(Slot area, 10.6%)

Distance of II baffle from the Ist baffle inch	Position of slots		16 gal/min					20 gal/min				
			ti/T	tp/T	tA/T	tm/T	t90/t10	ti/T	tp/T	tA/T	tm/T	t90/t10
	Top	A	0.125	0.65	0.86	0.72	4.5	0.1	0.513	0.7	0.85	6.9
3	Middle	B	0.075	0.41	0.685	0.601	4.1	0.1	0.513	0.87	0.74	6.5
	Bottom	C	0.1	0.41	0.65	0.54	4.3	0.125	0.60	0.802	0.71	7
	Top	A	0.25	0.66	0.8	0.73	3.45	0.35	0.77	0.81	0.82	2.34
6	Middle	B	0.275	0.68	0.87	0.75	3.6	0.275	0.52	0.81	0.75	4
	Bottom	C	0.30	0.70	0.876	0.85	3.1	0.25	0.64	0.76	0.74	3.6
	Top	A	0.2	0.615	0.88	0.83	5	0.075	0.64	0.84	0.8	3.2
9	Middle	B	0.225	0.615	0.715	0.64	4.2	0.125	0.74	0.88	0.79	4.6
	Bottom	C	0.225	0.55	0.81	0.8	3.3	0.075	0.513	0.89	0.77	3.8

Table V—Effect of Slot position in basin performance

(Slot area 12.9%)

Distance of II baffle from the Ist baffle inch	Position of slots	16 gal/min					20 gal/min				
		ti/T	tp/T	tA/T	tm/T	t90/t10	ti/T	tp/T	tA/T	tm/T	t90/t10
	A	0.125	0.65	0.86	0.72	4.5	0.075	0.513	0.785	0.7	3.1
3	B	0.125	0.51	0.64	0.6	5.4	0.075	0.64	0.76	0.63	5.4
	C	0.15	0.62	0.775	0.74	6.0	0.075	0.64	0.805	0.75	6
	A	0.27	0.7	0.77	0.73	4	0.325	0.67	0.70	0.65	4
6	B	0.30	0.725	0.84	0.76	2.8	0.25	0.67	0.83	0.74	4.5
	C	0.30	0.7	0.85	0.76	3.4	0.37	0.76	0.78	0.77	2.93
	A	0.20	0.615	0.86	0.82	4.7	0.20	0.45	0.79	0.64	4.3
9	B	0.20	0.615	0.85	0.72	4.65	0.225	0.513	0.9	0.77	4.1
	C	0.27	0.70	0.90	0.72	4	0.225	0.66	0.91	0.76	4.8

Table VI—Effect of Slot position in basin performance

(Slot area 15.36%)

Distance of II baffle from the Ist baffle inch	Position of slots	16 gal/min					20 gal/min				
		ti/T	tp/T	tA/T	tm/T	t90/t10	ti/T	tp/T	tA/T	tm/T	t90/t10
	A	0.175	0.50	0.691	0.63	3.5	0.125	0.51	0.736	0.64	4.55
3	B	0.1	0.61	0.76	0.61	4.5	0.1	0.4	0.895	0.73	4.74
	C	0.125	0.61	0.89	0.82	4.85	0.125	0.64	0.787	0.64	5.7
	A	0.28	0.72	0.85	0.8	3.8	0.31	0.69	0.8	0.7	3.6
6	B	0.3	0.70	0.865	0.72	2.84	0.31	0.77	0.9	0.81	4.0
	C	0.31	0.815	0.94	0.92	2.8	0.37	0.81	0.897	0.80	3.4
	A	...	...	...	...	...	0.125	0.64	0.8	0.74	5.6
9	B	0.25	0.52	0.81	0.7	4	0.13	0.64	0.88	0.77	4
	C	0.175	0.51	0.9	0.73	3.5	0.225	0.513	0.86	0.78	5.6

Table VII—Basin performance in best position

Particulars	20 gal/min					16 gal/min				
	ti/T	tp/T	tA/T	tm/T	t90/t10	ti/T	tp/T	tA/T	tm/T	t90/t10
Single baffle with slotarea of 5.27%	0.15	0.35	0.65	0.46	4	0.1	0.28	0.8	0.59	4.65
Double baffle II baffle with 15.35% slot area slot position bottom	0.31	0.815	0.94	0.92	2.8	0.37	0.81	0.897	0.8	3.4

Position C of slots seems to give good results for all three positions of second baffle from first baffle. But for 3 and 9 in distances, dispersion ratio was increased for 20.04 gal/min flow. Here most efficient performance was obtained for 6 in distance of the second baffle from first baffle. Thus position A of slots is likely to improve the performance of basin with smaller area of slots and position C with baffle having larger area of slots.

5. *Comparison of the basin performances with single baffle and double baffle kept at best position :* When the distance baffles was 6 in, the second baffle having the largest area of slots, i.e., 15.35 per cent appears to give the best performance for the slot position C.

Table VII shows the improved performance of the settling basin with the second baffle, having the slot area of 15.35 per cent at 6 in distance from the first baffle. Performance of the basin with the single baffle alone is also given for comparison.

Conclusions

1. The performance of settling tank obtained by the use of single baffle can be improved further by the use of double verticle slotted baffle.

2. The performance of the basin seems to be maximum for the 6 in position of the second baffle from the first baffle as compared to 3 and 9 in positions.

3. When the second baffle is at the nearer positions from the first baffle, the baffle with the smaller area of slots seems to give good performance of the basin. At farther distances from the first baffle, the baffle with larger area of slots seems to give better results.

4. Top row of holes in the baffle seems to have chances to give good performance of the basin when the baffle with smaller area of slots is used. Bottom row of slots appears to have chances to better the performance of basin when the baffle with larger area of slots is used.

Acknowledgement

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Upflow Solids Contact Tanks

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Literature records that the upflow solids contact tank was built in India as early as 1933. It was a lime-soda softening unit for an industrial establishment. Such tanks have been popular ever since for softening units where "Solids-contact" has proved beneficial for reducing the treatment time. During the last 10 to 15 years, however, these tanks have been increasingly used in turbid water clarification. To-day as many as 900 Municipalities in Europe and U.S.A., besides a large number of industries, are reported to be using such installations with single units ranging from 10,000 gal/day to 35 mill gal/day. Several U.S. and international equipment Companies market such units under various names:

- ACCELATOR (Infilco Co.)
- PRECIPITATOR (Permutit)
- HYDROTREATOR (Dorr-Oliver).
- REACTIVATOR (Graver Water Cond. Co.)
- PULSATOR (Degremont)
- CLARIFLOW (American Well Works)
- LIQUON (Cochrane Corp.)

Upflow tanks have evidently become popular in the United States where several efficient and economic types are in use, but all are generally speaking more complex than the simpler types available in India of the CANDY pattern of which several installations exist in India. In this type, the water flows upwards through an inverted pyramidal shaped tank. It is important to the success of the process that raw water and chemicals are mixed in the presence of previously precipitated solids which have been retained in the tank without being allowed to settle down. This accelerates the chemical reactions and avoids the formation of colloidal precipitates since the precipitation occurs on surfaces presented by the old floc particles.

In the conventional Coagulation-Sedimentation tanks, "perikinetic" coagulation is the first step after addition of chemicals leading to the formation of very fine nuclei of floc particles of colloidal size. These have to be subjected to gentle flocculation ("orthokinetic" coagulation step) for an appreciable length of time to achieve agglomeration of the very fine particles into settleable floc. This is unnecessary in the solids contact tanks where precipitation occurs on an abundant quantum of old floc particles, thus cutting out the colloidal step. Further, the floc particles are continually densified thus increasing their settling rate. The retention time required is, therefore, about half that required for conventional horizontal flow tanks. Generally, 1 to 1½ hr is sufficient, while surface loadings are 2 to 3 times the conventional loading of 700 gal/day/sq ft, thus giving great economy in civil costs. Effluent turbidities less than 5 mg/lit. can be obtained with proper operation.

The short retention period reduces space and capital requirements. Separate tanks for flocculation and sedimentation are not required. The chemical reactions are carried to practical completion. Tastes and odours have less time in which to develop. Density currents are inhibited and the small surface area reduces susceptibility to wind currents. Short circuiting is virtually absent. Sludge removal is relatively simple since mechanical scraping equipment can be omitted.

The Australian Consulting Engineer, Bond (1, 2) has given a very excellent analysis of the behaviour of suspensions in upflow solids contact tanks and it is hoped that the review given in this paper will encourage the reader to refer to the original work.

Theory of Crystallisation

In the solids contact zone, where the chemicals are mixed with raw water in the presence of an abundant suspension of solids, there is supersaturation. Now, in a supersaturated solution, the excess solute may normally be expected to crystallise into the solid form, leaving the solution saturated. Certain substances, included in water treatment processes, exhibit a habitual reluctance to crystallise. In such cases, it is helpful to "seed" or inoculate with old crystals. If old crystals are present, the new reaction products are deposited directly on the surfaces of the old solids thus saving a considerable part of the time required for spontaneous crystallisation.

The Rate of crystallisation can be increased by:

(i) *Giving more surface area for deposition :* This can be achieved by increasing the number of old crystals and by decreasing their size, or in other words, by ensuring that a large number of small crystals are present in the mixing zone.

(ii) *Increasing the rate of diffusion :* This can be achieved by stirring. In upflow tanks, where mechanical mixing is provided, relatively slow speed impellers are used so that the maximum speed does not exceed 5 ft/sec. and the liquid volume circulated is of the order of 3 to 5 times the design inflow. Speed variation arrangement is provided for.

All precipitated compounds have a solubility limit and, in practice, it is difficult to reduce their concentration to this limit, let alone below this limit. It is interesting to note that larger particles have a lower solubility than smaller ones. Hence, if a precipitate contains particles of different sizes, a solution which is saturated with respect to larger particles will be under-saturated with respect to smaller ones and the latter will tend to dissolve and disappear making the solution supersaturated with respect to larger particles and fresh material will be precipitated on them.

It is for this reason that the ideal process is one so arranged that the dosed water is first brought into intimate contact with a relatively large number of very small old particles in rapid movement, and then, the water is brought in contact with a large quantity of the largest possible old particles in a state of relative quiescence.

Sludge Removal

As a tank continues to work, sludge accumulation takes place and some sludge removal arrangement has to be provided to ensure that the solids concentration is kept at *an optimum level.*

The optimum solids concentration is maintained either by time-switches controlling hydraulic or pneumatic actuators or by manually adjusted sludge bleeding and sludge withdrawal arrangements.

Where the tank has been provided with steep hoppers, no sludge scraping mechanism is necessary. In some designs, bottom scrapers are needed, particularly if the raw water brings in sand and grit which can not be kept in suspension hydraulically in the unit.

Bond (1) has explained the design of separate sludge concentrators or hoppers which are particularly useful in the case of lime-soda softening units, where the best compromise has to be obtained between economy of concentrator size and waste of "blow-off" water. Generally speaking, if the rate of withdrawal of solids is the same as the rate of entry to the concentrator, it could be relatively small in size, enough to allow solids to settle. But some storage space has to be provided to allow for errors in setting the slurry bleeding rate.

Upflow Zone

Provision of an upflow zone with vertical sides is inherently unstable. The zone should be uniformly expanding like an inverted cone or pyramid. A cone consumes less material in construction but the pyramid is easier to construct. With such a shape, the velocity gradually decreases in the upward direction and particles of different sizes adjust themselves to the level at which the velocity is able to keep them in suspension. This kind of gradation is not possible if the tank sides are kept vertical.

Wall drag reduces upflow velocity near the walls thus permitting particles to settle on the walls and slide down until they reach a level where the area is so restricted and the upflow velocity so increased that they are again lifted into suspension.

The volume of the solids-contact zone should be such as to give contact for the desired time, generally, 1 to 1½ hr, at the maximum rate of flow.

Slurry Concentration

In order to understand the various factors which affect the concentration of solids in the slurry zone, one must first understand the concept of "hindered" settling.

As a particle falls, it continually displaces the liquid below it. The displaced liquid flows upwards and around it giving "drag" resistance. In a suspension or floc in which the particles are widely separated (i.e. when concentration is low), a particle will not be affected by its neighbours but will fall at the same rate as an isolated individual particle. However, as concentration increases, the particles themselves restrict the area through which the displaced liquid flows up. This increases the interparticle velocity and therefore, the drag, with the result that the settling velocity decreases.

Let Vp = Settling velocity of an individual particle (unhindered);

Vs = Settling velocity of the suspension or floc, or the relative velocity of clear liquid above or below the suspension; and

Vd = Interparticle velocity

In any horizontal area, 1^2, the area of particles = f_1 (n^2 d^2) where f_1 is a function depending on particle shape.

Similarly in any volume 1 (3), the volume of particles = f_2 (n^3 d^3) where f_1 is a function depending on particle shape.

Hence, the concentration, s, of particles vol/vol is given by:

$$S = \frac{f_2 \; n^3 \; d^3}{1^3}$$

The concentration, s, is in other words the wet solids concentration in the slurry, being the ratio of wet solids settled in 24 hours in a cylinder to the original volume of the suspension.

Now, the rate of flow of liquid, say "q", passing any horizontal plane of area 1^2, fixed relative to the suspension will be constant. Hence,

$$q = V_S \; 1^2 = V_P \; (1^2 - f_1 \;\; n^2 \; d^2)$$

$$\text{Therefore,} \quad V_S = V_P \; (1 - \frac{f_1 \;\; n^2 \; d^2)}{1^2}$$

$$\text{But, from the above,} \quad \frac{n^2 \; d^2}{1^2} \equiv \frac{(s)}{f_2}^{3/2}$$

$$\text{Hence;} \quad V_S = V_P \; (1 - f . s^{2/3})$$

In this equation, Vs denotes the settling velocity of a suspension or floc, Vp is the unhindered settling velocity of the individual particles, f is a factor depending on particle shape, and S is the slurry concentration.

From the above equation, it can be seen that if the slurry concentration is very low, Vs is almost equal to Vp; whereas as the slurry concentration increases, the reduction in velocity is in direct proportion to the 2/3 power of the concentration. This equation is valid up to S = 0.164. In plain sedimentation, hindered settling commences at 1,000 to 45,000 mg/lit. of silt by weight.

At the top of a suspension or slurry pool, the interparticle velocity suddenly ceases and water above it is relatively still. Many small particles rise to the top of a suspension but then fail to leave it as the velocity suddenly reduces. The top of a suspension is thus sharply defined. Any particle whose velocity of fall is less than average will remain with it at the top and form a "trap" for even slower particles. The whole suspension thus settles as though it were composed of the fastest particles in it.

Now, velocity of settlement of particles or suspension in upflowing water will be exactly the same (relative to the water) as in still water. And, as before,

$$V = V_p \left(1 - f. S^{2/3}\right)$$

Where "V" is now = upflow velocity.

Transposing, one gets S =

$$\left(\frac{1}{f}\right)^{1.5} \left(1 - \frac{V}{V_p}\right)^{1.5}$$

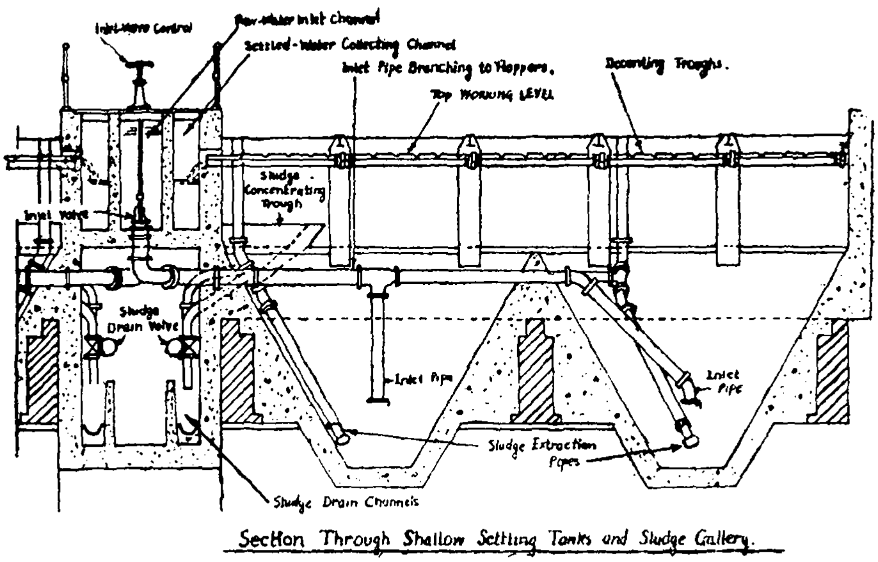
or $S = a \left(1 - \frac{V}{V_p}\right)^{1.5}$

Where "a" is a constant for the given type of suspension.

This is a very useful equation since it gives the expected slurry concentration for different values of upflow velocity V, and the settling velocity of the individual particles concerned. It will also be seen that the slurry concentration is a function of the ratio $\left(\frac{V}{V_p}\right)$ and the shape factor "a".

Upflow Velocity

An experimental unit has been set up at the VJTI, Bombay (Fig. 1) to first duplicate the work of Bond in this behalf and then see if the discrepancy reported by Bond (2) between the experimentally derived values of "a" and "f" can be resolved. His value of "f" was 2.78 for alum and lime flocs whereas the



Section Through Shallow Settling Tanks and Sludge Gallery.

Photo shows settling tanks of the inverted pyramid type. Coagulated water enters the settling tanks through pipes at the base of the pyramids and rises to flow out over the edges of the decanting troughs. In this process a blanket composed of coagulant and suspended matter from the water is built up, and the continuing process of building up the blanket during the passage of the water materially reduces the load on the filters themselves.

Fig. 1— Experimental unit at V.J.T.I, Bombay

value of the constant "a" was 0.17 for alum floc and 0.216 for lime floc. It is hoped that work will be possible to be done in the near future at VJTI on this experimental unit.

It can be demonstrated on such a unit that the top of the slurry pool is quite sharp as long as the upflow velocity $V = 0.5\ V_p$ The results are summarized in Table I.

All the floc is dispersed when the upflow velocity at the top of the slurry pool exceeds 0.30 to 0.40 ft/min, depending on the kind of floc and the water temperature. A velocity of 0.3 ft/min. is equivalent to 1.88 gal/min/sq ft or 2700 gal/day/sq ft.

Velocity at the top of the slurry pool must be such as to ensure satisfactory separation of the lightest kind of floc that will be produced at the lowest operating temperature. Table II gives the approximate range of values of V_p for various kinds of floc.

The settling velocity V_p of a particle decreases with a fall in temperature. But the ratio of the velocities V/V_p is independent of temperature. Hence the nominal upflow velocity, V, may be adjusted to suit the seasonal temperature. In other words in winter, the flow through the tank must be reduced so that reduction in V matches reduction in V_p Fortunately, the flow requirement from a plant is less in the winter season and hence the design can be based on the summer conditions of demand and temperature.

Alum floc tends to become heavier with age and it is, therefore, suggested that a new tank should be put into commission with a reduced inflow and gradually increased to the design value.

If a reasonably safe value of V_p equal to 0.24 to 0.28 ft/min is assumed, the upflow velocity V_p can be kept at about 0.13 ft/min equivalent to a surface loading of 1,200

Table I

Upflow Velocity	Result
V = 0.5 Vp	Top of slurry pool quite sharp
V = 0.55 Vp	Top of slurry pool practically satisfactory
V = 0.65 Vp	Top blurred and swirling

Table II—Settling velocity of various kinds of floc (After Bond)

Kind of floc	Settling of velocity Vp ft/min at 15°c
Fraggile floc, colour removed with alum	0.12 to 0.24
Medium floc, algae removal with alum	0.20 to 0.30
Strong floc, turbidity removal with alum	0.24 to 0.35
Strong floc, lime-soda softening	0.24 to 0.35

gal/day/sq ft (safe practice). This value can be suitably increased if the floc is more tough and of rapid settling type and if normal operating temperatures are quite warm. However, increasing the surface loading tends to make these units more sensitive to changes in floc formation and seasonal variations in raw water quality, temperature, etc. The purpose of the above discussion has been to show that the design of upflow tanks has to be done to suit specific conditions and not merely follow rules of thumb.

Quantity and Quality Fluctuations

From the equations given above, it is clear that if the inflow fluctuates, the velocity, V, through the tank also fluctuates and hence the slurry concentration, S, is disturbed. If the flow increases, the solids concentration decreases and if the flow decreases, the solids concentration increases. As soon as the value is disturbed from the optimum value, the clarification efficiency reduces until proper concentration is again reached by suitably adjusting the sludge withdrawal rate.

Upflow tanks are **not** suitable in the following situations:

(i) Rapid changes in quality or quantity of raw water. These tanks are sensitive to such changes and hence under such conditions more skilled attention is called for.

(ii) If turbidity is more than 1,000 mg/lit., plain sedimentation (without chemicals) may be necessary prior to upflow tanks. The late Mr. Rankine has made a useful suggestion that even the plain sedimentation tanks could be of the upflow type with surface loadings of 2,000 to 2,500 gal/day/sq ft, but provided with mechanical scraping equipment to remove the heavy silt deposits that may take place.

(iii) In summer, algal and other organic growths may cause septicity in the sludge blanket and pre-chlorination may be necessary.

Conclusions

Upflow solids contact tanks are being increasingly used in turbid water clarification. Their utility in lime-soda softening has been accepted without question. But their utility in turbid water clarification has not been yet accepted unreservedly. This is due to the fact that the concepts of crystallisation, hindered settling, etc., have not been widely appreciated by engineers and designs have been largely based on rule of thumb.

Equations, based on the analysis of Bond in particular, have been presented in this Paper to help engineers appreciate the various factors which affect design, such as the type of floc, the quality of raw water, the temperature, etc. The need for slurry bleeding to keep the optimum concentration is evident. Sensitivity of the tank to changes in quality and quantity of raw water also become more understandable by reference to the basic equations. An experimental tank set up at the V.J.T.I., Bombay,* has been described.

References

1. Bond, A.W., *J. Amer. Soc. Civ. Engrs*, *SED* **87**, 73 (Nov. 1961).
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DISCUSSION

SHRI K. R. BULUSU (Delhi): You have mentioned that alum is added in the zone where there is already settled floc. The settled floc is not absolutely devoid of any change even though most of the zeta potential is neutralised. When fresh alum is added in this zone, it again acquires positive charge and I am unable to understand whether it is possible in such circumstances to have a coating of alum on practically neutral floc. Kindly clarify my doubt.

PROF. S. J. ARCEIVALA: I think I have dealt with this question quite at length in the paper itself.

SHRI J. S. JAIN (Nagpur): I would like to know whetner Prof. Arceivala confirmed the empirical formula, $V = 0.5\ V\,p$ where Vp = settling velocity, V_o = Upflow velocity, in his laboratory studies which he has mentioned.

Upflow tanks in the opinion of the author, need very skilled operation. They do not work very well when there is algal problem or where there is rapid change in water supply. I wonder whether they can be recommended in India where skilled operators are very much in dearth.

I would like to know whether the author has some operational experience with this type of tanks in India.

I would feel obliged if the author can give a particular instance if any such tank in our country which is working better than other types of tanks.

PROF. ARCEIVALA: The relationships between V and $V\,p$ have not yet been confirmed by us at V.J.T.I., Bombay. We hope to be able to do so in the near future. These relationships are generally accepted by designers.

Whatever skill is called for in operating an upflow tank can be got with a little training and experience. India has poor capital sources and every effort should be made to reduce the capital outlay on treatment plants. On the other hand, India has a lot of young, capable men who if given proper training (as in a well conducted operators' course) can be pressed into service as skillful operators. As an analogy, we can take the example of motor cars. The fact that motor cars need more skilled attention than bullock carts has not held us back in promoting the motor car.

Yes, most certainly. And so do several others in India, where a large no. of these tanks exist, have the operational experience.

To be able to say whether these upflow tanks run better than other type of tanks for the same type of water and alum dose, it is necessary to have the good fortune to have these different types of tanks side by side in the same plant. Furthermore, one must be very careful to make sure that all other design criteria are equal before comparing their performances. Such a study will perhaps be possible soon at Vaitarna lake, Bombay where different types of tanks are being commissioned at one site.

SHRI K. D. MULEKAR (Bombay): Do V and Vp and the flocs of various sizes apply to different sections of the tank? Or, are they applicable only at the top zone i.e. above the sludge blanket?

Regarding desludging of the tank, I wish to know when desludging is to be done from top and to be done from bottom under the condition that the rate of flow of water and its quality are not varying. Please also let me know whether the desludging process is a continuous one.

Does the efficiency of the blanket formed change with the daily variation in temperature.

PROF. S. J. ARCEIVALA: The velocity V (0.5 V_p) applies to the top of the slurry blanket level, which is the critical position. Other particles of different sizes adjust themselves to the various sections at which the upflow velocity is able to keep them in suspension.

The excess sludge is to be removed through the slurry concentrator at the top. This assures that the top of the slurry blanket will be at a constant level. Sludge removal from the concentrator could either be continuous or periodic (actuated by time-switches, if desired). The size of the concentrator is provided accordingly. The choice between continuous or periodic desludging will depend upon the quantity of sludge expected.

The settling velocities of the flocs will be varying with the temperature of water and hence the diurnal variations in the temperature of water must be kept in view by the designer if the sludge blanket is to have a sharply defined top at all times and floc is not to swirl up with the upflowing water. This aspect has been covered in my Paper.

DR. S. AHMED (Sindri): Has the volume of sludge been taken into consideration while calculating the detention time? If not, additional volume will be required for detention time of 1½ to 2 hr, and thereby the cost will increase.

Usually these tanks are small in size and therefore they can be used for smaller plants only. If these are to be used for larger plants, then the number of units of such plants will be large and that may not be advisable because of both difficulties of construction and operation. Is it possible to suggest the maximum population or the quantity of water for which these units will be suitable?

PROF. S. J. ARCEIVALA: Yes. The volume of sludge is taken into account. The volume of the sludge or slurry zone is so kept as to give about 1 to 1½ hr "Solids-contact" time at the designed rate of flow. Additional volume is then provided so that the top of the sludge blanket is about 5 ft, below the top water level.

These tanks have to be kept small if mechanical equipment is not to be provided for keeping the slurry in suspension. Where mechanical equipment is provided, the tanks can be quite large. Single units up to 35 mill gal/day have been constructed abroad

SHRI J. M. DAVE (Nagpur): I wish to comment that the units described by the author are of two different types. One is the Accelator type and the other is the Dortmund type. The former has mechanical flocculation while the latter has hydraulic flocculation and both of them function differently.

Why is the plant factor for coagulants very high for these units?

PROF. S. J. ARCEIVALA: In the smaller, hopper-bottomed tanks, no mechanical equipment is necessary to keep the slurry in suspension. For larger tanks (where hoppers would be uneconomical to provide), some suitable mechanical equipment has to be provided to keep the slurry in suspension. Somehow or other, the slurry has to be kept in suspension, either by causing sufficient head loss of the main flow as in hoppered tanks, or by mechanical equipment in the larger Accelator type tanks. There is, however, no difference whatsoever in the theoretical concept behind either type. Both imply the same principles.

This question of plant factor is strange. Earlier also Shri Dave has given some plant scale-up factors when applying the results of alum dosage jar tests to actual plants. Nowhere in literature have I come across such specific scale-up factors like 1.5 or 2.5 times the jar test dose being required in actual plants. While Shri Dave states that these are common "scale-up" factors; in practice, I find that a most recent and up to-date publication of W.H.O. gives quite contrary information.

I am referring to the latest book **Operation and Control of Water Treatment Processes** by Charles R. Cox published in 1964 by W.H.O. and prepared in consultation with 24 specialists in various countries. The book says clearly on page 76: "Usually, chemical doses effective in the plant are somewhat lower than with laboratory scale equipment". In the absence of irrefutable data from Shri Dave, it will be difficult to accept idea implied in his question.

SHRI S. R. KSHIRSAGAR (Bombay): It is said that the capacity of the vertical flow tanks and their cost of construction will be half of those for the conventional type. The cost of the tank is not a linear function of the capacity. The perimeter, shape and the depth are important criteria. Vertical flow tanks with hopper bottom require more surface area of construction and deeper depths and they are difficult to construct. The difficulties are more when the ground water level is high and the soil is poor.

The subject matter of the Paper is not new. These tanks are being used for softening hard water in industries. The question is whether they should be employed for treating municipal water supplies. The operation in such plants is normally poor and hence it is risky to use such tanks since they require careful and continuous supervision and attention.

PROF. S. J. ARCEIVALA: Shri Kshirsagar observes that if the size of a tank is halved, its cost will not be halved in direct proportion. This is too obvious to need any comment.

Shri Kshirsagar observes that the operation of upflow tanks for Municipal water supplies is normally poor and hence they are "risky to use". This is a strange observation, since there is over-whelming evidence to the contrary.

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High-Rate Upflow Filters For Treatment Of Low-Turbidity Waters

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Introduction

When impounded reservoirs located in protected highland catchments are used as sources of domestic water supply, it often happens that the quality of the natural water does not warrant anything more than marginal treatment. Consequently, many communities both large and small, even in the most advanced countries of the world, do not treat their drinking water supplies beyond administering chlorine as a measure of precaution. New York is the largest of such cities.

Where marginal treatment is practised, it can be of various types and degrees depending upon the characteristics of the water. In San Francisco, for instance, the soft and clear mountain water of the Hetch-Hetchy Reservoir is treated with lime to reduce its corrosivity and the Calaveris Reservoir water is aerated, whereas the Crystal Springs and San Andreas Reservoirs, where excessive turbidities sometimes occur, have an alum plant and settling facilities. None of these waters are filtered.

Such low turbidity waters, however, suffer at times from algal blooms and other microscopic life, to combat which copper sulphate treatment is usually employed. Fish culture as a measure of biological control is also done in lieu of copper sulphate and has advantages over the other method, if done scientifically.

In addition, recently developed processes like micro-straining are often used now-a-days to improve the quality of water before it is delivered to the consumer.

The present paper describes an alternative method developed in Bombay for treating the low turbidity waters of the type obtaining at the Vihar and Tansa lakes which at present receive no treatment at all except sterilization with chlorine.

Theory of Upflow Filtration

During 1959-60, studies made on a model filter of 4 sq ft area composed of a layer of coarse anthra-filt overlying a bed of quartz sand, had demonstrated the advantage of 'capping.' The anthra-filt used in the experiments had been obtained specially from Wales, and the subsequent search for an equivalent variety of coal of Indian origin had proved fruitless. It was, therefore, sought to simulate the same conditions by reversing the direction of flow in an ordinary sand bed, and forcing the coarser media in the lower portion thereof to take on the function of the anthra-filt lattice.

The Metropolitan Water Board in London had by then carried out some experiments on the Thames River water wherein aluminium sulphate with or without a small dose of activated silica was added to a rapid sand filter bed just at the point of entry and without taking the help of any pre-treatment processes. The results had been reported to be very encouraging (1).

The fuller utilisation of filter beds obtained by the adoption of higher rates of filtration resulting in deeper penetration of suspended solids had also been generally recognised.

By adopting a higher than conventional rate of filtration and adding a small dose of coagulant at the point of entry of a reverse flow unit, it was therefore hoped to form a sticky film on the sand grains over the entire vertical section of the media and thus achieve interception of suspended material at all levels. As the water to be treated would have to pass through the coarser media in the lower layers before it reached the finer media higher up, it was also expected that the capacity to hold suspended solids would be increased and longer filter runs would result.

Literature Survey

A study of the literature on the subject revealed that the idea of upward flow filtration had already been investigated since the 18th Century (2). The main difficulty even in the more recent models developed during the early years of the 20th Century had been with regard to the washing of the filter bed. The wrong notion that the direction of flow should necessarily be reversed during the washing operation had resulted in improper cleaning. Cleaning by downward flow techniques tended to make the bed cake up. What had not been realized was that the filter could be washed by merely increasing the upward flow rate suitably to loosen up the bed and release the intercepted material.

This aspect was discussed in a joint paper (3) presented by one of the authors at the Fourth Conference of Public Health Engineers in Delhi in November, 1960 at the Symposium held during the session. Experiments carried out in Bombay during 1950-60 on a model upflow filter were described therein.

An upflow and contact type coagulation-filtration unit developed in the U.S.S.R. had in meantime been mentioned in a review which appeared in March 1960 (4).

In November 1960, Hill (5) had reported his experiences with upflow filters at Singapore. These filters were used together with conventional pre-treatment units unlike the type envisaged in Bombay.

A more detailed report 'Contact Clarifiers' using the upflow principle was published by Mintz (6), in 1962, in which work done on the subject in the U.S.S.R. since 1953 was described, and the advantages of system over conventional treatment methods for treating low turbidity waters were explained.

Commissioning of Pilot Unit

In the meantimes, much before most of the literature mentioned above came to hand, a pilot plant of 108 sq ft bed area with a nominal capacity of 1/4 mill gal/day when running at a rate of 100 gal/sq ft/hr, had been put into commission in Bombay in November 1961.

In the next few months, considerable experience was gained in carrying out field trials during which a number of minor difficulties were ironed out. Some of the main obstacles encountered at the time are described in what follows.

Initial Difficulties

The pilot unit was situated within a mile from the Vihar head-works and fish had often been found at the inlet to another pilot plant located nearby, namely the 1 mill gal/day micro-strainer unit installed in 1960. In order to prevent fish, fish-bones, scales, etc. from entering the under-drain system of the pilot upflow filter plant, an intercepting device had, therefore, been provided on the inlet to this unit.

During the operation of checking and cleaning this device periodically, air used to get into the under-drain system which created a back pressure during washing operations, not only resulting in an uneven wash, displacement of gravel, and cratering action at the surface but also in damaging the under-drain system, which consisted of 2 in dia laterals of asbestos cement piping. This condition was remedied by suitably re-locating the strainer box so as to prevent the entry of air.

During this period, doubts were expressed by certain observers about the advisability of adding alum at the inlet of the unit. It was contended that there would not be sufficient time for reaction and that flocculation which requires slow stirring over a fairly long period would not take place.

The type of floc required to be produced in a unit of this kind is, however, very different from that normally aimed at in conventional pre-treatment units. The necessity of a large sized and heavy floc with good settling characteristics did not really exist. It was only necessary initially to form what Mintz has described as 'micro-aggregates' to coat the media and enable 'contact coagulation' to proceed thereafter within the bed.

The 'Micro Floc' process as described by Miehe (7) is also being employed in the U.S.A. to obtain the maximum advantage of double-layer or capped filters of the downflow type.

In order to study the function of the lower supporting layers of an upflow filter in setting up velocity gradients, such as to accelerate the formation of 'floccules,' experiments were carried out with different flow rates and alum doses after removing the upper sand layer altogether and retaining only the supporting media comprising of the following sizes arranged with the smaller sizes overlying the larger ones:

Size	Depth, in
1/4 in to 10 mesh	4
1/2 in to 1/4 in	3
3/4 in to 1/2 in	7
1½ in to 3/4 in	5½
2½ in to 1½ in	9½
	Total depth 29 inches

A rate of about 250 gal/sq ft/hr with an alum dose of about 1 gr/gal gave best results yielding a dense tough floc of a size such that on transfer to a beaker was observed to settle rapidly. At this time, the raw water had a turbidity of 15 to 18 mg/lit. and a pH of 7.5. From this experiment, it was apparent that the supporting media had an important role to play in a plant of this type. The doubt about whether floc would ever form in such a short time, was also cleared.

The problem thus narrowed down to that of determining the depth and grading of sand needed to intercept the floc particles effectively on the remaining portion of their upward journey through the filter.

Performance of Pilot Plant

When the re-constituted filter bed was put into commission in September 1962, a layer of 31 in of quartz sand of 10-20 mesh size was used above 29 in of supporting material ranging from 10 mesh size to 2½ in. With a rate of 200 gal/sq ft/hr and a dose of only 1/8 gr/gal of alum, it was able to yield an attractive clear filtrate having a turbidity value well within the 5 mg/lit. standard adopted by the U.S.P.H.S. in 1960.

The main problem in the case of the Vihar lake waters used for these studies was, however, not that of excessive turbidities, but of biological invasions of the distribution system.

Among the larger nuisance organisms, cyclops had been most frequently found in the raw waters. Sponge epicules which apparently emanated from a sponge growth in the pipe-line between the head-works and the treatment plant were also observed in fairly large numbers during the period under study. Other zoo-planktons such as the protozoa, **cerratium** and **paramaecium** were found to be comparatively of rare occurence whereas rotifiers and nematodes were almost entirely absent. Among the phtyo-planktons, microcystis was the most predominant species.

The upflow unit when running initially without the aid of pre-chlorination was able to restrict the planktons to a fairly large extent.

When a dose of chlorine of 1 to 2 mg/lit. in the form of bleaching powder was introduced along with alum from Jan. 19 to March 18, 1963, there was a further improvement in the removals. The percentage reduction of **Microcystis** which had previously been about 70 rose to 100. Similarly cyclops removal efficiency shot up from 75 to 100 per cent. However, there was no marked difference in the reduction of **Oscillatoria**, the efficiency of removal being in either case of the order of 55 to 60 per cent.

The other planktons such as **Ulothrix, Pediastrum**, etc. were too few to be of significance, their count in raw water being on an average less than 10/ml. In fact, the total count of planktons in the raw water itself was never very high, ranging from about 50 to 350/ml.

Although the plant was run for most of the time at 200 gal/sq ft/hr, with alum dose of 1/8 gr/gal, various other conditions were also tried out, the maximum alum dose administered being 3/4 gr/gal, and the lowest filtration rate, 150 gal/sq ft/hr.

Other aspects investigated

(i) *After – precipitation :* Whereas it had been demonstrated that inline clarification with the application of alum at the inlet to the plant was quite feasible, the question still remained as to whether some of the coagulant passed through in an unreacted form and might result in after-precipitation. Samples, from the filtrate, were therefore, collected and subjected to slow stirring in the laboratory flocculator. On no occasion was any tendency for floc formation noticed even in samples kept overnight for observation.

On the other hand, the wash water was always found to contain floc in abundance even with the nominal alum dose of 1/8 gr/gal thereby confirming that, for this system of treatment, even a marginal dose can suffice to give the desired conditions for ideal operation.

(ii) *Condition of Body Water :* During November 1962, and up to the middle of December 1962, an intensive study was made of samples taken out from the under-drain system, just before and after washing operations by operating a scour-valve.

The samples taken prior to washing some times contained large number of cyclops or showed high concentrations of algae and were always markedly turbid. This was only natural as the filter was intended to intercept all such impurities. Wash water turbidities taken from the wash-water collecting trough above the sand bed also used to record initial values ranging from about 1,000 to 2,000 mg/lit. indicating that the unit was functioning as it should.

What is significant is that the scour-samples taken after washing operations were invariably clear (their turbidity never exceeding 5.1 mg/lit., even though unfiltered Tansa water was utilized for washing purposes), and with low algal and cyclops counts except on very few occasions.

These tests were carried out prior to the application of chlorine upstream of the unit. In order to ensure that the bed is always in a healthy condition, it is desirable to provide pre-chlorination facilities in such types of filters. As mentioned earlier, the application of chlorine along with the coagulant also resulted in better plankton removals.

(iii) *Iron Removal :* Although primarily not intended to deal with the problem of iron in water, the pilot unit was able to reduce the total iron from an average value of 0.31 mg/lit. obtained from 32 observations to an average of 0.16 mg/lit.

Fifteen tests on the content of dissolved and suspended iron showed that dissolved iron with an average value of 0.18 mg/lit. before treatment was reduced to 0.08 mg/lit.; whereas; a value of 0.13 mg/lit. of suspended iron was brought down to 0.08 mg/lit.

Some other features of the Plant

In this type of unit, rate-of-flow controllers are not necessary. As in the case of Singapore, no control modules were used at the pilot-plant. Operators in the U.S.A. have also of late been experimenting with filters running without these devices and have obtained very satisfactory results. By allowing a filter to run at a diminishing rate as it gets clogged up and forcing other units alongside to carry a larger share in proportion to their individual capacities at any given moment of time, the system is protected against undue strain. Not only have filter runs been reported to have increased, but even the quality of the filtrate is said to have improved.

The pilot plant in Bombay was built open to the sky unlike any other filters in the country but in keeping with modern trends in many other countries.

The wash-water consumption was maintained at 4 per cent of the quantity treated and the unit was washed once a day. However, experience gained on a similar unit to which no coagulants were added indicated that, during the major part of the year, it should be possible to do away even with a nominal alum dose, and step up filter runs very substantially. More requires to be done on this aspect.

The future of the Upflow Filters

More and more workers are studying the various aspects of upward flow filtration. Work done by Diaper at the University College, London, using two types of diatomite as suspended solids (5 and 40 microns average sizes) at concentrations of 100 and 500 mg/lit. and two flow narates, 100 and 200 gal/sq ft/hr, with both upwards and downward flow directions was reported upon in November 1962. It was reported that "penetration of turbid material takes place to a greater extent with upflow filtration, and because more layers of sand are employed in the filtration process, it is possible to obtain longer filter runs and lower head-losses."

In the U.S.S.R., the research stage has already given way to full-scale implementation. A number of plants have been already built and functioning. The one at Leningrad, having a capacity of 52.8 mill gal/day was visited by Shri R. S. Mehta, Director of the Central Public Health Engineering Research Institute during 1962 with a view to obtain first-hand information about the system being investigated by authors in Bombay. The Leningrad plant was very favourably reported upon by him. This plant has many features almost identical with those of the plant developed by the authors independently in Bombay, and confirms their line of approach and work.

The economics of the system both in capital and running costs are too obvious to need comment. At places where communities are forced by circumstances to draw their raw waters from river sources which can carry pollution down from upstream users, even the most elaborate and expensive of conventional plants laid out with ample provisions against hazards and high factors of safety are some times inadequate in practice.

But to apply the same logic to well protected catchment where the natural quality of the water is beyond question and where no real danger of pollution from domestic or industrial wastes exists, would be an unrealistic approach. At such places, treatment plants of the type described in this paper would provide more logical and much cheaper solutions.

Acknowledgement

The authors are grateful to Shri N. V. Modak, the former Director of CPHERI for the guidance given by him in this study and particularly for his encouragement in the initial stages when hardly anything was known about this system of treatment in the country and few were prepared to give credence to the idea.

The authors are thankful to Shri R. V. Abreu, ex-Hydraulic Engineer, Municipal Corporation of Greater Bombay, for his keen interest, as well as to all the personnel at the plant site who were responsible for the day-to-day operations there, and assisted in the collection of plant—performance data round the clock.

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DISCUSSION

PROF. M. V. BOPARDIKAR (Nagpur) : As regards the filters in Russia, I had the good opportunity to see the particular work done by Prof. Mintz of U.S.S.R. One factor which we should not lose sight of is that I never saw any raw water both in the Continent and USSR which had a turbidity of more than 40 mg/lit. Higher turbidities are something abnormal in those towns. This is because of the geographical conditions prevailing there. Hence the quality of raw water has got much to do with the design of filtration. From the discussion, I had with Prof. Mintz who is working on some polysaccharides and polyelectrolytes also, I understand that they have no experience of these filters with waters of high turbidity, but only for those waters which do not contain more than 40 to 50 mg/lit. of turbidity all the year round.

SHRI K. G. VEERARAGHAVAN (Madras) : Shri Pandit should be congratulated on his presenting a very thought-provoking paper on a new method of filtration. It is suggested that the upflow method, may be considered as an extension of the process of pre-treatment by trickling filter followed by sand filter.

This new method deserves to be tried out on a fairly large scale in different parts of India.

SHRI R. K. PANDIT : The upflow filtration system has been described as a filter in which filtration proceeds in the direction of declining size of the media. The filter bed is more fully utilised. The gravel, however, mainly helps in providing a zone wherein suitable velocities are created for the formation of micro-floc particles. The action of a trickling filter is rather different, its function being to provide suitable conditions for biological oxidation of organic matter. The upflow filter may be better visualised as a combination of roughing filter and polishing filter.

SHRI J. M. DAVE (Nagpur) : We are going to follow up this filtration by constructing a filter of vertical flow and AKX type biflow units in CPHERI for further work.

SHRI S. AHMED (Sindri) : How long can these filters be run without back-wash, and how do they compare with the conventional type ?

SHRI R. K. PANDIT : The pilot upflow filter plant described in the paper was run arbitrarily for 24 hours during the test runs reported. The loss of head and flow characteristics, however, indicated that during the fair season, it would be possible to run it for a much longer time. This has been corroborated by the observations made on a similar unit which was run without any coagulants and did not require washing after continuous operation over a week. In view of the larger volume of interestitial space available for storage of suspended material, the upflow arrangement is expected to result in runs longer than what would be expected from the down flow type.

From the actual data obtained at the 53 mill gal/day upflow filter at Leningrad, it may be said that such plants are ordinarily washed once a day and that the wash-water consumption is about 4 per cent, which is about the same as the quantity lost in conventional treatment plant including water for filter backwashes and desludging of pretreatment units.

SHRI A. D. PATWARDHAN (Bombay) : How is the upflow filter back-washed ? What is the quantity of wash water required ?

R. K. PANDIT: Back-washing is done as in conventional filters and the quantity of wash water is about 3 to 4 per cent.

SHRI T. S. BHAKUNI (Nagpur): I feel that the sand grains in upflow filters might be encircled with flocs of gelatinous nature and that sand should need washing very often. Please comment.

SHRI A. R. KANGA : There was no evidence during the tests made on the upflow filter pilot plant to support your apprehension that the washing of the bed was not effective enough and that the sand would require washing very frequently. Neither has any such difficulty been reported upon in other filters of the same type elsewhere.

SHRI T. S. BHAKUNI : The change of filter bed media may be required much oftener than in the case of other down-flow filters. Also the cost of sand changed must be much more in this case. Are these true ?

SHRI A. R. KANGA : The tests reported upon in the paper were not of a sufficiently long duration to warrant any comment on this issue. However, there was no indication that the washing was not effective enough as already explained. No difficulty of this type has been reported elsewhere. The depth of sand in the filter was about the same as in most conventional filters and the question of cost on replacement being more than it would otherwise be does not arise.

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Rational Analysis of Rapid Sand Filter Behaviour

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Water engineers are aware in fact, of what to expect from rapid sand filters. About 2,000 B. C., it was known that "impure water ...... may be purified by filtration through sand and coarse gravel". Approximately after 4,000 years, such treatment yet is considered to be an art rather than a science.

The main purpose of filtration of water is to remove suspended matters from the water. The amount of suspended matters removed from the water will be deposited in the bed. During the last ten years, Ornatskii **et al** (1), Mackrle (2), Mints (3) and Ives (4) have done considerable work in this field. It is very difficult to formulate the filter behaviour accommodating all the variables involved in filtration operation. So the help of some parameters, dependent on characteristics of fluid, suspension and filter media, is necessary to obtain the expression of the concentration changes in the flow and the associated head losses for any depth of filter at any time of run.

Iwaski (5) in Japan followed by Stein (6) in the U.S.A., attempted first to find a rational analysis relating the suspended solid concentration in suspension with depth of bed and time of run. Ornatskii **et al** (1) suggested that the removal of suspended solids through the depth is an exponential function and is expressed mathematically as :

$$C = C_o e^{-\lambda L} \quad \dots \quad (I)$$

where C_o = concentration of suspended matter in the influent (volume/volume ratio);

C = concentration of suspended matter at any depth of filter;

L = depth below filter surface; and

λ = filter coefficient

Equation I may be restated as :

$$-\delta C / \delta L = \lambda C \quad \dots \quad (I\ a)$$

Filter coefficient λ represents the rate of removal of suspended matters along the depth and depends on the characteristics of suspension, the rate of filtration, water viscosity and the internal geometry of porous filter. During the filter run, suspended matter is removed from the flow and is deposited in the bed and thus pore shape and size varies. Due to the above facts, λ varies with depth of filter and time of run. At surface, concentration of suspension in flow is C_0 and at the beginning of the run, filter media is clean and so $\lambda = \lambda_o$ where λ_o is initial filter coefficient, or value of λ at zero time. At time t = O, equation (I) becomes:

$$C = C_0 e^{\lambda_0 - L} \qquad .. \text{ (II)}$$

If the volume of material deposited per unit filter volume is termed as specific deposit σ, many workers found experimentally that λ is a function of specific deposit σ. Ives (4) stated that towards the beginning of the run, the deposits will be localised to form domes on the filter grain surfaces and thus the surface area for deposition will be increased. The value of λ will also be increased in the following form:

$$\lambda = \lambda_0 + c\,\sigma \qquad \ldots \text{ (III)}$$

where c = a rate factor parameter.

As the deposition increases, pores become constricted tending to increase the interstitial velocity and reduce the interstitial surface area for deposition. These actions will reduce the rate of deposition, thus λ reduces and the equation III is modified by Ives to:

$$\lambda = \lambda_0 + c\,\sigma - \phi\,\sigma^2 / (f_0 - \sigma) \qquad \ldots \text{ (IV)}$$

where f_o = initial porosity of the clean bed; and

ϕ = rate factor parameter

Filter parameters c, ϕ and λ are dependent on density and viscosity of fluid; size, distribution and specific gravity of suspension; and size, shape, and porosity of filter media. At a certain stage, the accumulated deposits can so constrict the pore size that interstitial velocity will reach its critical value and no further deposition will take place in that layer. The value of λ then becomes zero and all the particles will be carried from that layer to the next layer. The ultimate value of σ, i.e. σ_u can be obtained from equation I as follows.

$$\lambda_0 + c\sigma_u - \phi\sigma_u^2 / (f_0 - \sigma_u) = O \qquad \text{(V)}$$

$$\sigma_u = \frac{cf_0 - \lambda_0 \pm \sqrt{(\lambda_0 - cf_0)^2 + 4\,\lambda_0 f_0 (c+\phi)}}{2\,(\phi + c)} \qquad \text{(VI)}$$

If the filtration parameters λ_o, f_o, c, and ϕ, are determined experimentally, the ultimate value of specific deposit σ_u, may be calculated. Combining equations Ia and IV one gets

$$-\delta c/\delta L = \left(\lambda_0 + c\,\sigma - \frac{\phi\sigma^2}{f_0 - \sigma}\right) C \qquad \text{(VII)}$$

The above equations were developed by Ives (4) for homogenous suspension, being applied at a constant rate under laminar flow conditions to an isotropic homogeneous porous filter medium.

Equation of Continuity

Considering a small depth of filter layer δL, change of concentration of suspension in inflow and outflow from this layer in time δt is δC. The amount of suspension removed from flow in time δt, is $\delta t.\ Q.\ \delta C$; and the amount deposited in the bed during the same period is $A\ \delta L.\ \delta\sigma$ As suspended particles are removed from the flow, they accumulate in the filter pores and hence

$$-Q.\ \delta C.\ \delta t = A.\ L.\ \delta \sigma \quad \ldots \quad \text{(VIII)}$$

$$-v\ \delta C.\ \delta t = \delta L.\ \delta \sigma \quad \ldots \quad \text{(VIII a)}$$

In partial form, this equation may be restated as :

$$-v\ \delta C / \delta L = \delta \sigma / \delta t \quad \ldots \quad \text{(XI)}$$

Equation IX may be called as equation of continuity.

Head-Loss Curve Analysis

As the water is passing through the filter media, there will be a loss of head along the depth of the bed which depends on the nature of clogging of the bed. Head-losses at different points along the depth of the bed may be measured by differential water manometer. Fig. 1 shows the loss of head, H, in cm of water at various depths in the sand bed. It is evident from the head-loss curves that most of the head-losses occurred in the upper layers of the bed. Head-loss per unit depth or hydraulic gradient (h) in the upper layers are more than that in the lower layers.

For clean filter bed of uniform media, head-loss per unit depth h, is constant throughout the depth. As the run proceeds, the slopes of head-loss curves of Fig. 1, at various depths will increase, which is due to the change of characteristics of deposition of suspended materials in the pores of the bed. If there was no suspended matter in the influent water, there would have been no

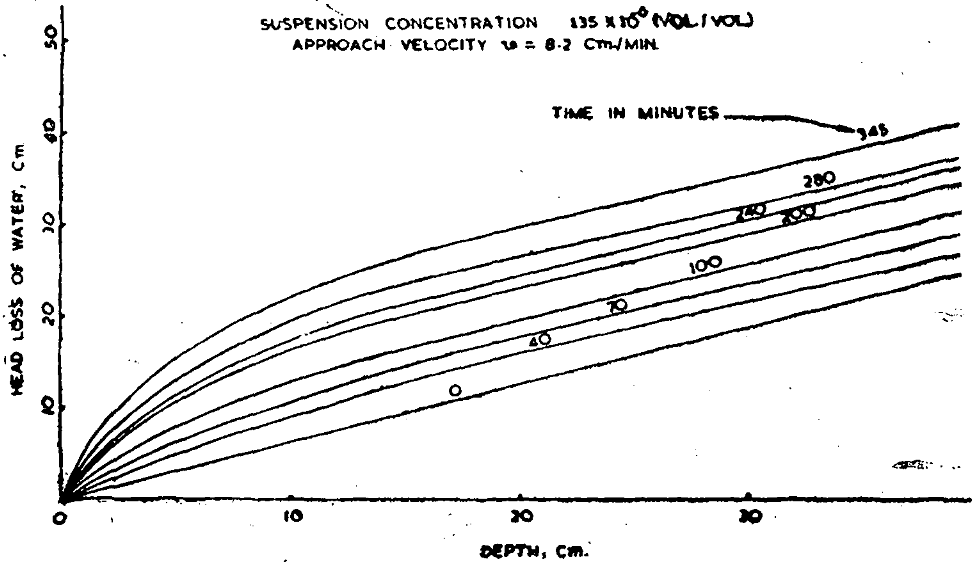

Fig. 1—Head loss through filter depth

change of initial head-loss per unit depth h_o during the length of filter run. Therefore, the increment of hydraulic gradient values (h) during the length of run has certain relationship with the accumulated deposits in the bed.

The difference between head loss per unit depth (h) at any time and initial head loss per unit depth (h_o) was plotted against time from Fig. 1 and is shown in Fig. 2. These curves are similar to specific deposit σ vs. time curves as given by Ives (7). Ives' curve showing the relationship of head-loss per unit depth (h) versus specific deposit (σ), is almost a straight line intersecting the former ordinate at a value of initial head-loss per unit depth at zero specific deposit (σ). Deb (8) pointed out that ($h-h_o$) is approximately proportional to specific deposit (σ), and may be expressed in the following form:

$$h - h_o = k\sigma \qquad \text{... (X)}$$

where k is a dimensionless head-loss coefficient, which is dependent on the characteristic of suspension and filter media. The above relationship may be utilized in evaluating the filtration parameters and in simplifying the filtration equations and for this the value of "k" is to be evaluated before.

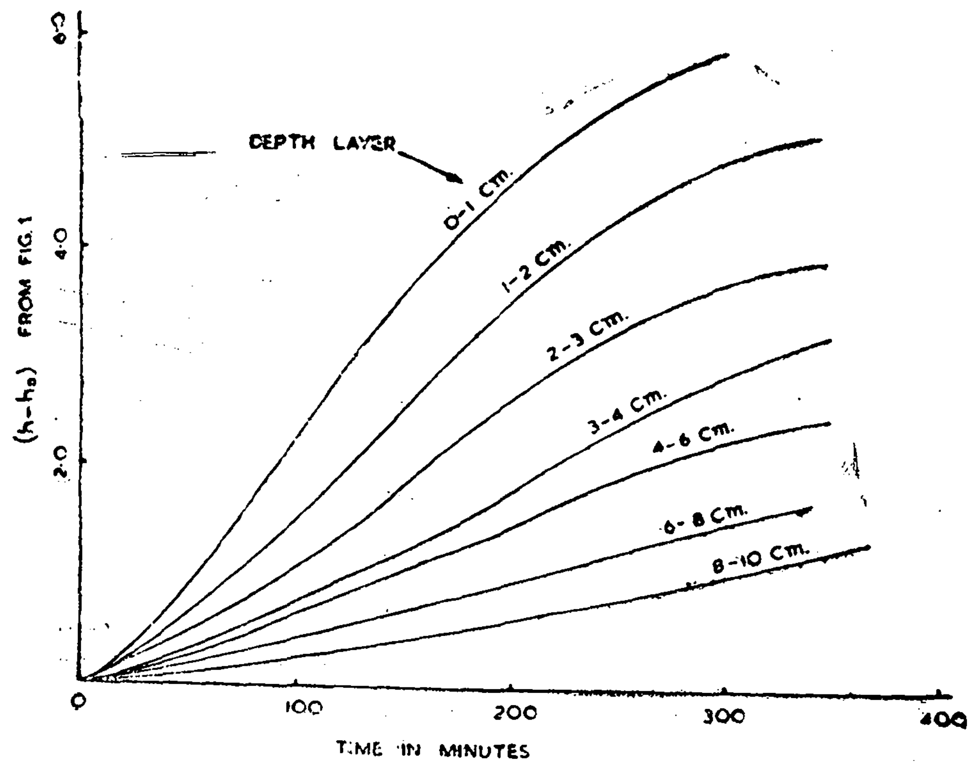

Fig. 2— Hydraulic gradient minus initial hydraulic gradient with time

Deb (9) developed the following method for the evaluation of k value. In any small layer of filter media between depths L_1 and L_2, head-loss across the layer may be written from equation X as

$$H_1 = \int_{L_1}^{L_2} h\, dl$$
$$= \int_{L_1}^{L_2} H_o\, dl + \int_{L_1}^{L_2} k\, \sigma\, dl$$
$$= H_{o1} + \int_{L_1}^{L_2} k\, \sigma\, dl \qquad (XI)$$

For uniform bed, k may be assumed to be constant for all depths.

$$\int_{L_1}^{L_2} \sigma\, dl = \frac{H_1 - H_{o1}}{k} \qquad (XIa)$$

where H_1 and H_{O_1} are total and initial head-losses in that layer. For uniform filter, k is assumed to be constant at all depths. The left hand side of the equation XI a represents the volume of deposit in the unit area of that filter layer bounded by depths L_1 and L_2 From equation VIIIa, $v\int_0^t \delta$ C. dt represents removal of suspension from flow in time t and equal to the deposit in unit area of filter bed of that layer. Therefore, the volume of deposit in the unit area of the same layer of filter bed may be equated to produce the relationship.

$$\int_{L_1}^{L_2} \sigma\, dl = v\int_0^t \delta C.\, dt. \qquad (XII)$$

combining equations XI a and XII.

$$k = \frac{H_1 - Ho_1}{v\int_0^t \delta C\ dt} \qquad \ldots (XIII)$$

Equation XIII may be written in the summation from as:

$$k = \frac{H_1 - Ho_1}{v\ \Sigma_0^t\ (C_1 - C_2)\ \delta\, t} \qquad \ldots (XIV)$$

If the initial and total head-losses and influent particle concentration C_1 and effluent particle concentration C_2, in any layer of uniform media could be measured at different intervals during test run, k for any layer may be computed from equation XIV. This equation may also be applied in stratified bed considering each small layer to be uniform.

Considering the full filter depth, for uniform bed the equation XIV becomes ;

$$k = \frac{H_1 - H_o}{v\ \Sigma_0^t\ (Co - Ce)\ \delta\, t} \qquad \ldots (XV)$$

Keeping influent suspension concentration to be constant throughout the run, equation XV becomes :

$$K = \frac{H - H_o}{vC_o t - v\Sigma_0^t\ Ce\ \delta\, t} \qquad (XVa)$$

where Ce is the effluent particle concentration. Measuring initial head-loss H_o and total head-loss H, for full filter depth and influent particle concentration C_o and effluent particle concentration Ce at different time intervals, the value of k for uniform bed can be computed from equation XVa.

Neglecting effluent particle concentration Ce which will be negligible for full filter depth, equation XVa can be approximated as :

$$k = \frac{H - H_o}{vC_o t} \qquad \ldots (XVI)$$

Equation XVI can be used for calculating the k value of uniform media.

The total head-loss in the actual filter at different times may be computed from equation XVI as follows:

$$H = H_o + k\,v\,C_o t \quad \cdots \quad (XVIa)$$

The values of k and H_o shall be obtained from experimental filter run. For the value of initial head-loss (H_o), well established formula of Kozeny may also be applied.

$$H_o = \frac{K_1 \mu v}{g} \cdot \frac{D^2}{\rho \psi^2} \frac{(1-f_o)^2 L}{f_o^3}$$

where K = Kozeny coefficient;

μ/ρ = kinemetic viscosity;

D = sand diameter;

f_o = initial porosity of the filter bed;

L = depth of bed; and

ψ = shape factor of sand

Equaluation of Filtration Parameters

The values of different filtration parameters and k can be obtained for particular raw water and filter media to be used in prototype, before designing a plant, by using a small portable filter kit in which tests must be conducted keeping water temperature and porosity same as to be expected on the full scale filter. Head-losses at different points along the depth are required to be measured and concentration of suspension in the influent will be kept constant. Approach velocity v will be calculated from rate of filtration. A set of head-loss vs depth curves at different points and at different times have been shown in the Fig. 1 (7).

Using equation XVI, the value of k can thus be determined. Initial head-loss per unit depth h_o and head-loss per unit depth h at any time are determined from slopes of head-loss curves for various depths and times from Fig. 1.

The value of $(h-h_o)/k$ at any point on the curves gives the value of specific deposit σ at that time and depth. The change of hydraulic gradient due to deposits in the bed vs time curves are prepared by plotting the values of $(h-h_o)$ for each depth against time as shown in Fig. 2

The slope of the curves of Fig. 2, for a given depth gives dh/dt. Combining equations I and IX,

$$\delta\sigma/\delta t = v\,\lambda\,C \quad \cdots \quad (XVII)$$

$$\lambda = \frac{1}{v\,c}\,\delta\sigma/\delta t \quad \cdots \quad (XVII\ a)$$

From equation X, $\delta\sigma/\delta t = 1/k.\ \sigma h/\ \delta t$, and therefore equation XVIIa may be rewritten as:

$$\lambda = \frac{1}{k\,v\,c}\,\frac{\delta h}{\delta t} \quad \cdots \quad (XVIII)$$

$\delta\sigma/\delta t$, i.e. $\frac{1}{k} \cdot \frac{\delta h}{\delta t}$

values of top layer at different times with different $(h-h_o)/k$, i.e. σ values are computed from Fig. 2. For the top layer $C=C_o$, and with v and $\delta h/\delta t$ known, the values of λ can be found for different values of specific deposit σ. A graph now can be plotted λ against σ as shown in Fig. 3. From equation IV, the intercept of this curve at σ = O gives the value of λ_o. Differentiating equation IV with σ, results:

$$\frac{d\lambda}{d\sigma} = c - \frac{2\phi\sigma(f_o-\sigma) + \phi\sigma^2}{(f_o-\sigma)^2} \quad (XIX)$$

From equation XIX, the slope of the curve of Fig. 3, at $\sigma = 0$, gives the value of c. Equation IV may be rewritten in the following form to calculate the value of ϕ.

$$\phi = \frac{(\lambda_\circ + c\sigma - \lambda)\,(f_\circ - \sigma)}{\sigma^2} \quad \ldots \quad \text{(VI a)}$$

Solution of Equations

Equations VII and IX are non-linear linked partial differential equations and can not be solved analytically for values of concentration of suspension C at different depths and times of filter run. Ives (4) suggested that these equations may be solved for C values numerically by electronic digital computers. However, the concentration of suspension (C), at any time and depth of filter may also be obtained without the help of digital computer from continuity equation IX. The empirical values of $\frac{\delta\sigma}{\delta t}$, ie. $\frac{1}{k}\,\frac{\delta h}{\delta t}$, from Fig. 2, may be put in equation IX.

$$-v\,\delta C/\delta L = \delta\sigma/\delta t \quad \ldots \quad \text{(IX)}$$

At any layer δL,

$$(C_1 - C_2) = \frac{\delta L}{v}\,\delta\sigma/\delta t \quad \text{(XX)}$$

For the curve of first layer δL $C_1 = C_\circ$, v = approach velocity, (obtained from filtration rate), C_2 may be caluclated for the values of $\delta\sigma/\delta t$ (which may be obtained from Fig. 2) at various times. For next layer, replacing C_1 by C_2, C_3 may be calculated. This procedure may be repeated in next subsequent layers, and thus concentra-

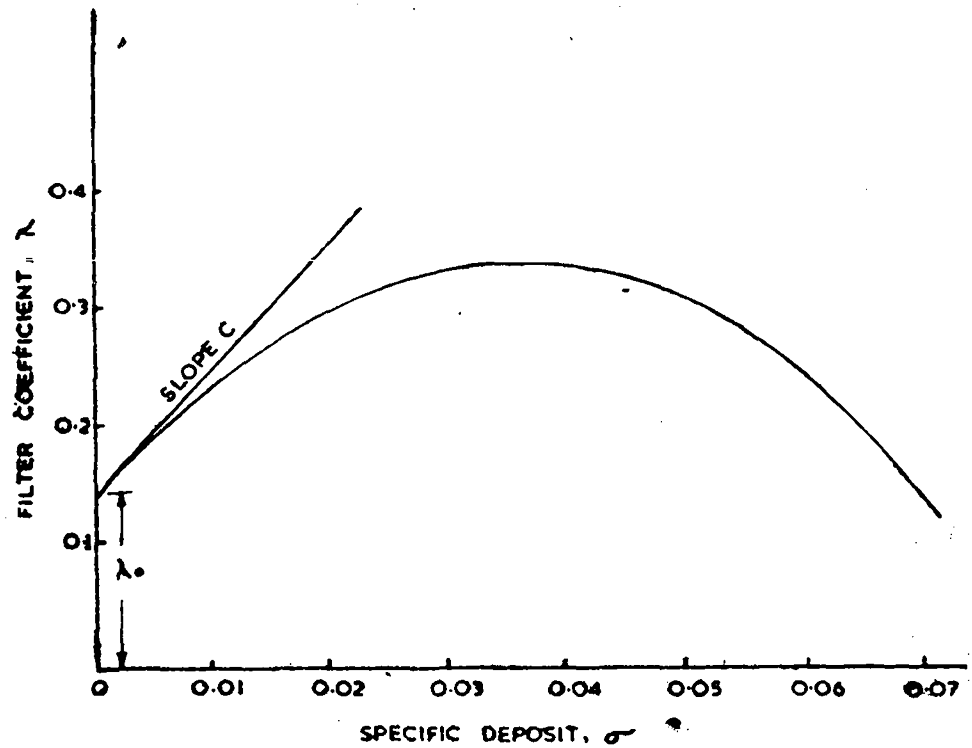

Fig. 3—Filter coeff. vs. specific deposit
(Ref. No. 7)

tion of suspension variation along the depth of bed for various times of filter run may be obtained.

The main disadvantage of this procedure of computation is that the value of concentration of suspension beyond the experimental filter depth and operation time will not be obtained. These formulae are applicable for uniform filter media only.

Approximate Method

The solutions of the above equations are quite complicated. A simplified procedure was obtained as follows. The slopes of the curves ($h-h_o$) vs time in Fig. 2 for a particular depth are determined and plotted against time as shown in Fig. 4. The empirical equation of each of these curves, at a particular depth may be given by,

$$\delta h / \delta t = \alpha + \beta t - \upsilon t^2 \quad \text{(XXII)}$$

α, β, υ, are filtration parameters for a particular depth of filter layer.

At zero time, the value of $\delta h / \delta t = \alpha$, and the slope of this curve at t=O, gives the value of β. The value of ν may be calculated from equation XXI. These values of α, β ν, are valid for the particular depth only. Different $\delta h / \delta t$ vs time curves are to be plotted for different filter layers. Values of filtration parameters α, β, ν are to be determined separately for different depth layers. Combining equatoins Ia, XVIII and XXI

$$-\delta C / \delta L = \frac{1}{v\,k} (\alpha + \beta t - \nu t^2) \quad \text{(XXII)}$$

$$(C_2 - C_1) = 1 / v\,k(\alpha + \beta t - \upsilon t)\,\delta L. \quad \text{(XXII a)}$$

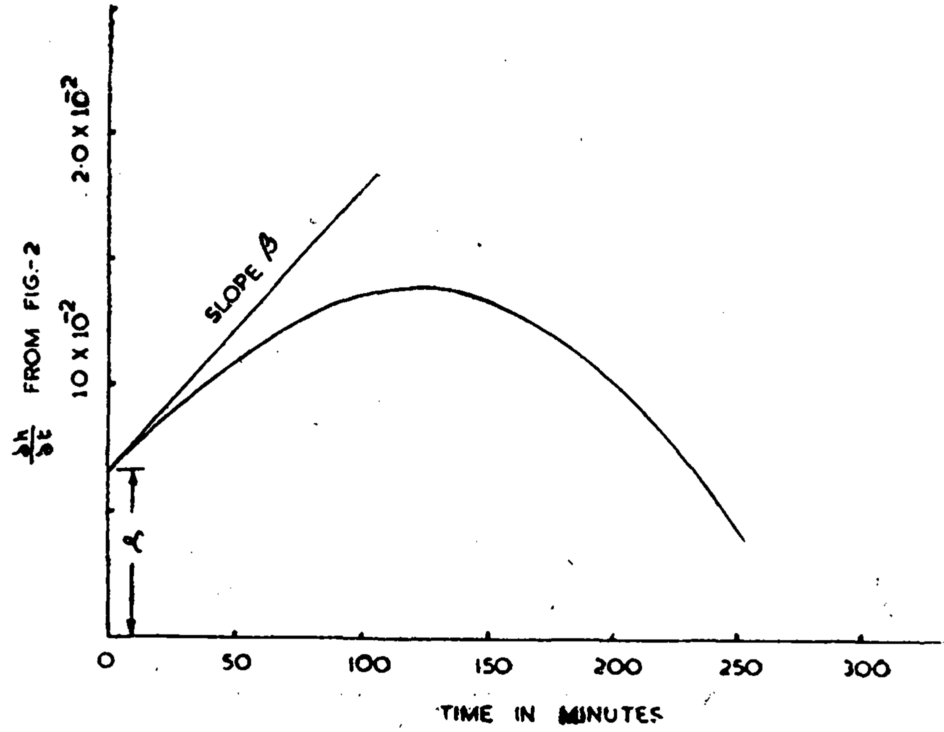

Fig. 4—$\frac{\delta h}{\delta t}$ vs. time (for 0-1 cm. layer

Values of concentration of suspension at different layers at different times may be obtained from equation XXII a, putting appropriate values of parameters.

By this method, concentration of suspension C at different depths of bed at times beyond the experimental operation time may also be obtained. The limitation of this simplified procedure is that the influent particle concentration in the experimental filter should be kept same as may be expected in actual filter. But equations VII and IX are independent of influent particle concentration and by solving these equations by digital computers, concentration C of suspension at any depth layer at any time beyond operation time of experimental filter run may be obtained.

Conclusions

From the above analysis, a clear picture of filtration of water may be viewed, which will help in designing filters. The proposed filter media may be put into a simple portable experimental filter in which head-loss at various depths are to be measured when raw water (as expected in actual filter) at a constant rate is passed through it. From head-loss data, filtration parameters may be calculated as mentioned in the paper.

The experimental filter should be run at different filtration rates, to choose a rate that results in a water of acceptable clarity with maximum production per run and thus minimising the back-wash water requirements. Total head-loss development in the test run should be noted carefully in selecting the optimum filtration rate. Head-loss (10) may develop at an increasing rate as the filter run progresses, greater water production per run can be expected as rates are increased. "An optimum rate can be reached, however, beyond which further rate increases result in decreased production. The optimum rate can be identified as the lowest rate at which the head-loss development curve becomes most linear".

The objective of the design engineer is to know the concentration of suspension in the filter at various depths and times of run. If this is known, depth of filter may be fixed for a particular filtrate quality requirement. Obtaining optimum filtration rate and filtration parameters, from head-loss data of the experimental filter run, filter depths may be calculated for required degree of purification. The head-loss at this depth and time may be obtained from equation XVI a. If the result is not practicable, different filter media may be tried. It should be noted that conditions of experimental filter run should be identical with actual filter conditions as far as practicable.

The above analysis is yet to be verified by plant data. So, the accumulation of much data on the operation of filters using different raw waters, at different flow rates and at different bed characteristics, together with the interpretation of these data is necessary before these may be applied directly by designing engineers.

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Appendix—Notation

Symbol	Definition	Dimensions
A	Area of filter perpendicular to di-tion of flow	L^2
C	Concentration of suspension in the flow (Volume/Volume)	
C_o	Concentration of suspension in the influent water	
C_e	Concentration of suspension in the effluent water	
c	Filtration parameter	L^{-1}
D	Sand grain diameter	L
f_o	Porosity of clean filter bed	
H	Total loss of head	L
H_o	Initial total loss of head	L
h	Head loss per unit depth	
k	Head loss coefficient	
L	Depth below filter surface	L
Q	Flow through filter per unit time	L^3T^{-1}
t	Time of operation of filter	T
v	Approach velocity of water	
α, β, ν	Filtration parameters	
λ	Filter coefficient	L^{-1}
μ	Dynamic viscosity of water	$ML^{-1}T^{-1}$
ρ	Density of water	ML^{-3}
σ	Specific deposit (Volume of deposit per unit volume of filter)	
ϕ	Filtration parameter	L^{-1}
ψ	Shape factor of sand	

DISCUSSION

SHRI J. S. JAIN (Nagpur) : Shri Deb has thrown lots of mathematical equations in order to find design parameters for a rapid sand filter. For theoretical refinement we may perhaps draw some satisfaction but for a designer, I am afraid, there is hardly any relief from the approach suggested by Shri Deb based on existing filter formulae.

SHRI DEB : The equation can be solved with the help of digital computers. An approximate solution is also possible.

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Diatomite Filtration and its Economics

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Diatomite filtration is one of the most significant developments in water clarification field in the last 50 years. It can be used to clarify any type of water, raw, pre-treated, potable or industrial, the choice being dictated by economics. In the early work with diatomite filters, more stress was placed on their applications where they had **marked technical advantages** over the older techniques of water clarification. During the World War II, for example, the portable water treatment plants used by Armed Forces weighed tons and were found to be too cumbersome. Moreover, certain chlorine resistant pathogens, including viruses present in polluted waters, were not removed by conventional pre-treatment and sand filtration and chlorination. Portable units using diatomite filters were thus developed under a "Crash Program" and used successfully by the troops. Continuing research has since been carried on by the private enterprise, and the Engineering and Development Laboratory of the Corps of Engineers both directly and through contracts with various universities. This effort has resulted in the development of greatly improved units, now in daily service, which use any one type of several filter aids, diatomite being foremost. Because of **much smaller space requirements, economics and potentially higher Quality of water produced by diatomite filters**, this means of water purification has resulted in its adoption for industrial, municipal and swimming pool filtration. The demand for more and better water is continually increasing. This very serious challenge is brought about by the tremendous increase in population and industrial growth as well as by the ever increasing per capita water consumption. The required expansion of present water supply systems and conservation in the form of reconditioning and re-using are problems, primarily economic which must be solved rapidly. **Diatomite filtration is a new and powerful tool which will help to solve these problems**. Filtration with Celite Filter Aids makes possible a very economical water treatment system which can be tailored easily to the condition of raw water source and to the desired quality of finished water. For the relatively unpolluted and low turbidity water of most of our municipal water suppliers, diatomite filtration makes conventional pre-treatment unnecessary and at the same time produces a high supply. Waters containing a high proportion of colloidal turbidity, colour, colloidal suspensions and iron can frequently be filtered using carefully selected and controlled amounts of coagulant coated filter aid body feed. This can eliminate the necessity for the use of costly **pre-treatment equipment.** Using such a system, it is possible to **remove up to 100 per cent turbidity and a substantial proportion of color, radioactive particles, iron, bacteria, viruses, and iron consuming and sulphate reducing organisms present in some water supplies.** Since 1946, there have been 92 diatomaceous earth filter plants, applied to water supplies for potable use throughout the United States, of which 64 are for surface supplies. Some of these have been abandoned, mainly because the filters were improperly designed or were improperly applied to the water system. In California, there are now **12 diatomaceous filter plants operating on surface waters, of which 9 are automatic.** The author personally visited 5 of these automatic plants amongst which is the Saratoga 5 mill gal/day plant.

What is Diatomite ? Diatomite is composed of fossil like skeletons of microscopic water plants called Diatoms, ranging in dimensions from **under 5 to over 100 microns.** Under favourable conditions of light, temperature and nutrition, such plants grow in profusion and during geological past, many deposits of these plant skeletons were built up in different areas of the earth. Each skeleton is **an extremely porous framework of nearly pure silica.** Characteristics of diatoms is the diversity of shapes in which they occur. More than 10,000 kinds of diatoms have been identified and catalogued, not all of these being found in every deposit. The World's largest and purest commercially operated "D'CALITE" deposits are at LOMPOC, California and considerable deposits are also available in Belgium, Italy, and Mexico City. Also JOHNS MANVILLE's modern processing facilities manufacture many grades of finished "Celite" products, among them being filter aids for water and other liquids. Ample supplies of crude diatomite are available for many years to come at the present rate of production. In India, deposits are located in : Andhra Pradesh at Panchgaon, Kattarala, Bhutramal, Adilabad District—sizeable deposits analysed as SiO 30.2; $Al_2 O_3$, 25.8 and Fe_2O_3, 1.3 per cent —Anantpur District at Balapuram; Kurnol District at Ramallakota, Amalapuram praema, Pigalla in Nellore, Mahabubnagar, Nalgonda, East Godavari District, West Godavari District, Vishkhapatnam District, and Assam, Bihar, Gujarat, Madhya Pradesh, Madras, Mysore and Orissa States. Deposits of diatomaceous earth (KIESSELGUHR) in India have been reported to occur at the following places.

(i) Low grade diatomaceous earths are known to occur on Camorta and Trinicutte islands of the Nicobar groups;

(ii) Recent marine muds from the banks off the Kerala coast near Nirakkal and Allepey are rich in remains of diatoms;

(iii) Diatom bearing clays of Kerewa near Gulmarg, Kashmir;

(iv) Diaton bearing silicified earths in the Santhal Paraganas of Bihar and the Birbhum district of West Bengal; and

(v) Diatomaceous earth near the village—Tummalpalem in the Vinukonda Taluk of the Guntur district of Andhra Pradesh.

Why Diatom Filtration Works ? The basic difference between a Rapid Sand Filter and a Diatomite Filter is the difference in the materials themselves. Although filter sand is referred to as "FINE", it is extremely coarse when compared with Celite 545, the coarsest grade of diatomite. Celite can remove much finer particles of turbidity which would pass right through a bed of filter sand. This is the reason that a diatomite filter plant using Celite can cost so much less than sand filter plant. The pre-treatment facilities required to make a sand filter work are not required in many cases for a diatomite filter plant.

Where can Diatomite Filtration be used ? A diatomite filtration system, when properly designed and operated on an applicable or suitable supply, can economically and efficiently filter the following :

i) Municipal potable water;

ii) Privately owned water utilities;

iii) Oil field injection water for secondary recovery, brine disposal or pressure maintenance;

iv) Industrial potable water;

v) Industrial process water;

vi) Boiler feed water;

vii) Waste Water;

viii) Recirculating water;

ix) Laundry wash water; and

x) Swimming pool water.

The Diatomite Filter Cycle

The diatomite filtration cycle consists of the following steps :

i) pre-coat;

ii) Filtration and body feed addition; and

iii) Removal of the filter cake

(i) *Pre-coat :* In pre-coating, filtered liquid is used to deposit a thin layer of filter aid on a filter Septum. The amount of pre-coat should be about 10 lb per 100 sq ft of filter area.

This corresponds to a thickness of about 1/16 in. The filter aid particles bridge the opening of the SEPTUM and form a microscopically fine sieve, much finer than the SEPTUM itself could provide. Consequently, the filter aid cake is now the filter medium and the Septum only serves as a support for the filter aid. Before the bridge is formed, however, a slight amount of filter aid may bleed through the septum. For this reason, flow during pre-coating operation is either re-circulated or run to waste. The pre-coat serves two purposes :

i) It forms the actual filter media; and

ii) It prevents the filter Septum from being clogged by solid impurities in water and thus materially decreases the need for expensive chemical cleaning or replacement of septa. The flow rate during the pre-coating operations should be at least equal to the filtering rate, but not less than 1 gal/min.

(ii) *Filtration and Body Feed Addition:* The filtering characteristics of a particular water depend upon :

(a) Amount of turbidity; and

(b) Nature of turbidity.

It is, therefore, quite possible to plug or slime over the minute openings in a pre-coat if much fine colloidal turbidity is present. To reduce the tendency to plug the pre-coat, additional filter aid called the BODY FEED is added to the water to be filtered. The body feed maintains cake porosity by providing a continuously fresh supply of microscopic flow channels so that the plugging tendency of the suspended solids is overcome, allowing long economical filter cycles. Adequate Body Feed is usually essential for long economic cycles on raw water. The nature and amount of solids govern the ratio of body feed to turbidity. Low suspended solids usually require higher filter aid ratios than to waters of higher suspended solids where some of the latter may themselves act as filter aid. **As a convenient starting point, a body feed ratio of two parts of Celite per one part of turbidity has been found to be satisfactory.**

(iii) *Removal of Filter Cake :* The filtration is continued until the resistance of the filter cake has increased to a point when, depending upon the mode of control, either the pressure drop, the filtration rate, or a combination of the two has reached the economic limit. The filtration is then stopped and the filter cake is removed by one of the variety of means depending on the filter design. It must be stressed that complete removal of the dirty cake is of paramount importance to successful and economical operation, since it is one of the major factors determining the cycle lengths and Septum life.

The Diatomite Filtration System

The basic component of a diatomite filtration system is a simplified pressure filter installation commonly used in water filtration. Several modifications such as an open slurry tank for pre-coating, or using the body feed tank for pre-coat and body feed are also common. In this set-up, dry filter aid is put in the pre-coat pot, and the pre-coat is then formed by passing filtered water through the pot which picks up the filter aid and then deposits on the elements.

(i) *Filter Types :* Generally, these fall into two classifications:

(a) Pressure; and

(b) Vacuum.

Cylindrical Element : The cylindrical element filter consists of vertical cylinders usually fastened to a tube sheet at the top. The commonest method of back-washing is simple reversal of flow using clean filtered water and the "Air Bump" or "Multiple Air Bump" in which air is trapped also on the raw water side of the filter Septum. At the end of the cycle, the air on the raw water side is suddenly released forming a pocket into which the back-wash can surge before draining out. This results in the most effective method of back-washing tubular elements developed up-to-date. The vacuum filter is very similar to the pressure filter, the principal difference being that with a vacuum filter, filtration is performed in an open tank where the element can be seen at all times. The pump of a vacuum filter is located on the discharge side, and thus is used to pump water away from the filter after being filtered. The element of a vacuum filter can be either cylindrical or tube or the vertical leaf type. Whereas vacuum filters are operated to low pressure differentials of 5-7 psi, similar to sand filters, pressure filters are normally operated to a pressure differential of 20-30 psi. The higher available pressure differential may result in longer filter runs and more efficient equipment use due to less frequent breakdown time for cake removal and pre-coating. Another characteristic of pressure filter is that full advantage can be taken of any available hydrostatic head which might eliminate need for filter supply pumps for transporting the treated water to the storage. On the other hand, vacuum filters are of simpler construction, since no pressure has to be taken into consideration in shell construction. The open tank allows completely visual operation and easy access to filter elements. One disadvantage of vacuum filter is the tendency to degasify, which may upset or blind a cake. Whether pressure or vacuum filters are selected, the filters should have the following characteristics.

The hydraulics must provide a uniform and sufficient flow pattern through the filter, i.e., not less than a vertical flow of 4.5 ft/min when the filter contains only the pre-coat. This will ensure even deposit of precoat and total use of the available filter area. Whenever filter cake removal is done by scraping or hosing or air-pump back-washing, the design must accomplish cleaning the total filter area, cleaning must be maximum possible, cake discharge system must be of sufficient size to allow rapid removal of the filter cake, at a back-wash rate of 20-30 gal/min/sq ft of filter area for 15 sec. The total back-wash water requirement is 1 per cent of which 75 per cent can be reclaimed.

(ii) *Septum Types :* Several types of septa are available. They can be classified as:

(a) Cloth—orlon, nylon, etc.

(b) Metal—wire, screen, plastic screens

(c) Stone—sintered

The selection of septim material depends upon the nature of the contaminants of water to be filtered. In all cases, a good septum is characterised by:

(a) ability to take an even precoat;

(b) minimum tendency to allow binding;

(c) ease of complete removal of filter cake upon cleaning; and

(d) proper opening dimensions.

Since the pre-coating function is to bridge the openings in the septum, it is obvious that the maximum opening size depends upon the particle size of the filter aid used. For higher flow rate filter aids most commonly used in water filtration, the maximum safe spacing is 5/1000 in, stability under most severe operating conditions which would be encounted in the system. The diameter of septa is usually 6 in, maximum permissible length 4-5 ft.

(iii) *Feeders :* Whether the body feed and pre-coat is added dry or slurry, it must be remembered that a uniform mixing of the slurry and good control of addition rate is important, not only in the single filter but also in multiple filter installation. The feeding device must have the following characteristics:

(a) Dependable constant delivery at each setting;

(b) Easily changed rate setting;

(c) Resistance to abrasion;

(d) Ability to overcome bridging tendency; and

(e) Prevention of degradation of delicate filter aid particle structure

For slurry feeders, positive displacement diaphargm type of plunger pumps have been found satisfactory. Five per cent slurry is used in most cases. Controllers and recorders can be from completely manual to fully automatic, the only direct labour required in the latter case is to maintain the pre-coat and body feed supply. The extent of automation is a question of economics.

Diatomite filtration has numerous optima. The different factors which may be optimized must be clearly understood before the proper body feed, filtration rate, terminal head-loss can be selected. To obtain the maximum quality of potable filtrate per pound of diatomite, one must use it at optimum economy body feed. For a given water and filter, this body feed is a function of the amount of pre-coat used and the terminal head-loss. In general, the optimum body feed decreases with the decreasing amount of pre-coat and increasing terminal head-losses. To obtain maximum quantity of filtrate per run to some terminal head-loss, the head-loss optimum body feed would be used. It is a function of the filter cake composition. The optimum occurs at much higher body feeds than the diatomite economy optimum. Lower rate of filtration produces more filtrate per run at a given terminal head-loss This rate is more pronounced at higher body feed rates. The overall optimum body feed, optimum filtration rate and optimum terminal head loss combine to produce potable water at the minimum cost per gallon. These optima are influenced by four factors—**labour, power, diatomite and equipment.**

Johns Mansville offers a wide range of filter aid grades. Properties of these grades are mainly the result of differences of particle size distribution. The one exception is Sorbo-Cel which has been developed especially for removal of emulsified oil from water. Particle size distribution of Celite Filter Aids builds up filter cakes of varying porosities. Celite-545 causes the formation of the filter cake of largest pores and Filter Cel-1 of the smallest. The differences in pore sizes are very small but greatly influence the rate of flow and degree of clarity.

Thus a pre-coat of Filter-Cel which has the smallest size pore spaces will remove slime or colloidal type material of less than 0.2 microns. Viruses fall in the range of 10-300 $m\mu$ Entero-viruses, viz., Coxsackie, Polio, Echo are generally 28 $m\mu$ particle size. To give a general idea of pore sizes used in Microbiology, one can take the example of Millipore Filter range manufactured:

No.	Type Code	MF Pore Size mμ	
1	VF	10	
2	VM	50	
3	VC	100	
4	PH	300	
5	HA	450	usually used for Bacteriological examination of water and sewage.
6	DA	650	
7	AA	800	
8	RA	1200	(or 1.2μ)
9	SS	3000	(or 3.0μ)
10	SM	5000	(or 5.0μ)

Due to varying cake porosities, a Celite filter aid can be chosen which will give maximum rate of flow consistent with desired clarification. The primary function of the filter is to retain enough suspended solids to meet the clarity requirements imposed on the effluent and to prevent the suspended solids from plugging the filter septum. The choice of grade therefore entirely depends upon the size and type of particles to be removed and upon the clarity required. Thus, a maximum allowable turbidity of 1 to 2 mg/lit. may require relatively fine grade, if the particle to be removed is very fine or colloidal in nature; whereas a coarse grade may be satisfactory, if the particles are relatively coarse. Generally, most economical operations result from the use of coarsest grades which will give acceptable quality.

The efficiency of bacterial removal is 96 per cent. Break-down may occur above a head-loss of 10 lb/sq in. So, chemical disinfection is essential as it removes cercariae of **Schistosoma mansoni**, and of blood and anerobic cysts which are not removed by sand filters, the former being even resistant to chlorine also.

(iv) *Selection of Flow Rate :* Whereas the grade of filter aid selected and the filtrability of the water inherently impose a range limit on the cycle length, the optimum economic cycle length is further controlled by the flow rate selected. In general, it is true that the higher the flow rate the shorter the cycle. The relationship between these variables is not linear. High rates can be obtained only at the expense of increased power consumption and very short cycles. Cycle length increases disproportionately with decreased flow rates so that decreased power and labour costs also result from decreased flow rates. The same pattern is seen in a group of filter cycles obtained using Celite 503 filter aid which has about twice the permeability of Hyflo Super-Cel. The slope of these curves is almost identical with those of Hyflo Super-Cel, but the whole group of curves has been displaced down the head-loss axis. Coarser filter aids produce still more displacement down the axis. This is another way to lower power costs and extend the cycle length, but as mentioned earlier, use of coarse filter aids usually results in decreased clarification and may not be feasible to use due to effluent clarity considerations. Another significant point that can be made by comparing the pressure and cycle length curves at a flow rate of 4 gal/sq ft min with

2 gal/sq ft/min is that the cycle length and throughput both increase in the latter case. Thus by halving the flow rate, cycle length and volume throughout increase considerably. Many operations require long cycle because their treatment plants receive attention once a day or even in two or three days. A low design flow rate is an answer to this problem—flow rates as low as 0.2 gal/sq ft/min with cycles upto a full week have been reported using **Hyflo Super-Cel.** However, generally 0.5-0.7 gal/sq ft/min is more usually accepted as a minimum design flow rate. There are two practical considerations which limit the lowest flow rate through a filter. The first is the minimum velocity required to keep the filter aid and other solids in suspension until they can be deposited uniformly on the filter cake. This varies with the grade of filter aid. more velocity required for coarse filter aids. The minimum overall flow rate required to maintain the coarse filter aid in suspension varies with filter design and configuration. For design purposes, net superficial vertical velocity in the filter shell should not be less than 4.5 ft/min. under the worst conditions, i.e., when there is the least cake since cake accumulation increases velocity at constant flow rates. But balance between output per sq ft and relative investment when labor and power are considered appears to be in the range of 1.0 to 2.0 gal/sq ft/min. When filtering other types of water. the most economic rate may be lower or higher.

A diatomaceous filter can continuously remove suspended solids in concentrations as high as 1.500 mg/lit. However, filtering costs will determine the maximum turbidity and the length of time such operation can continue economically on waters containing up to 80 mg/lit. turbidity. Proper considerations must be given to turbidity as well as the flow in the selection of filter size Operating costs include diatomaceous earth, labor, maintenance, back-wash water and power. Some costs vary with the filtrability of the solids in water.

Economics of Celite Filtration : Filter aid filtration is a low cost high quality filtration method. Due to compact design of the filter aid and water filtration plant, a saving in capital cost of up to 45 per cent compared to the filtration is possible. This factor is not only important for new installations, but often makes possible for additional filter capacity with no increase in present plant area. For example, a tank of 58 in dia. and 100 in length provides 40 sq ft area for a sand filter but 500 sq ft area for a diatomite filter. The John Mansville General Engineering Dept. prepared an estimate of a sand filtration plant with pre-treatment and a diatomite filtration plant without pre-treatment for a rated capacity of 12 mill gal/day with a peak capacity of 18 mill gal/day. The preliminary estimates of both these plants based on 12 mill gal/day, are :

The installation cost of diatomite plant in this particular case was 47.5 per cent of the sand filtration cost or a saving of 52.5 per cent. Through the use of filter aids, waters containing a high proportion of colloidal turbidity, colour. and colloidal suspensions can be filtered using carefully selected and controlled

Item	Sand with Pre-treatment	Diatomite Filtration Plant without Pre-treatment
	$	$
Buildings	115,000	40,200
Concrete structures	569,600	...
Mechanical (Pumps, piping Feeders, Valves)	353,200	438,900
Facilities-power, light, air, etc.	65,900	47,000
Total	1,104,400	526.000

amounts of coagulant coated filter aid body feed. Using such a system. it is possible to remove 100 per cent turbidity, colour. radioactive particles, iron, coliform, and iron consuming and sulphate reducing organisms in some water supplies. Sand filters require 10 times the space, weigh 15-20 times more, initial cost is twice, and require 4 per cent waste water against 1 per cent.

Factors in the design and application of diatomaceous earth filters. These factors can be grouped as follows:

(i) Quality of raw water and type of treatment required:

(ii) System requirements;

(iii) Selections of filtration equipment: and

(iv) Economics

Each application must be considered individually.

(i) *Quality of Raw water and the Type of Treatment Required:* The type of treatment required can be determined from a raw water analysis. Diatomaceous earth filtration is being successfully applied with and without pre-treatment or post-treatment to remove turbidity, iron, taste, odour, and colour.

(a) *Turbidity:* Most applications of diatomaceous earth filters to date have been for removal of turbidity. In most cases, they have been applied without pre-treatment except chlorination. Turbidities have been ranging from 1 to 1,600 mg/lit. Of course, it is not economical to filter waters of high turbidity continuously when compared with other types of treatment. But the fact is that acceptable potable water can be produced from highly turbid sources. The type and amount of turbidity affects Filtrability. This in turn has a bearing on the operating costs which determines whether a diatomaceous earth filtration can do the required treatment economically. Turbidities consisting of heavy algae, bacteria, silt and other contaminants usually found in surface waters are being removed successfully. The quality of the effluent is generally of less than 0.5 mg/lit. turbidity.

(b) *Iron:* Iron is being successfully removed by using a newly developed pre-treatment process followed by diatomaceous earth filtration. This process has successfully reduced iron from surface and well water supplies from 12 mg/lit. to less than 0.1 mg/lit. The reaction pre-treatment consists of a 5 to 10 minute raw water detention tank equipped with a suitable mixer for agitation. Raw water is fed into the detention tank along with magnesite and diatomaceous earth. The reaction between magnesite and dissolved iron in the water forms precipitate which is easily filtered out with diatomaceous earth. The diatomaceous filter takes suction from the detention tank and filters out precipitate. The incoming water is fed to a 10 minute detention tank with slow speed agitation. To this is added diatomaceous earth and calcined magnesite. After this pre-conditioning, the water containing filter aid and magnesite is pumped to a diatomite filter which has been pre-coated with diatomaceous earth and magnesite. The process is most economical. It would cost 12 to 15 $ per mill gal to reduce 8 mg/lit. of iron to an acceptable standard. This cost includes magnesite, diatomaceous earth, labor and power. Generally, no H adjustment is required.

(c) *Taste and Odour :* For the removal of taste and odour, diatomaceous earth filters are followed by post-treatment consisting of an activated carbon column. The diatomaceous earth filter removes the turbidity from water including the organic material which casues tastes and odour. By filtering out the material, the organic load to be handled by carbon bed is halved thus extending its life. The fouling of the carbon by suspended solids is also eliminated. This process is more efficient than the conventional method of feeding powdered carbon into raw water contact tank and then flocculating, settling and filtering. New activated carbon has greater adsorptive power than partly spent one.

(d) *Colour :* Dissolved organic color may also be removed through the diatomaceous earth filtration followed by carbon column. Color may also be removed by alum treated filter aid.

(ii) *System Requirements :* Systems requirements must be thoroughly investigated for the proper selection and application of a diatomaceous earth filter. The following factors must be known to design a filtration plant properly:

(a) Average flow;

(b) Peak flows and duration of peak flows;

(c) Average and maximum turbidity;

(d) When peak turbidity and flows occur;

(e) Reservoir capacity;

(f) Alternate source;

(g) How much natural static head will be available;

(h) Will a filter plant be required to boost into the distribution system for back-wash?

(i) Will filtered water be available from the distribution system for back-wash?

(j) Pilot plant test data on water to be treated; and

(k) Selection of filtration equipment.

From the pilot plant test data, the following can be established:

(a) Filtration rates;

(b) Quality of the finished water;

(c) Approximate operating costs; and

(d) Type and size of equipment.

It is also necessary to conduct a pilot plant test on each application. A particular type of treatment that works quite well on one source of raw water may not give satisfactory results on another source of water. This applies to all types of applications. The filtration equipment selected to do a dependable job must be designed to the highest water works standards. An automatic diatomaceous earth filter plant can be designed for lowest total cost of labor, diatomaceous, power, capital charges.

Economics

Knowing the factors outlined previously as to the type of treatment, the systems requirement, size and type of filtration equipment, and approximate operating costs, an economic study can be made of a diatomaceous earth filtration system compared with treatment processes. The following factors must be considered to make an economic comparison:

(1) Capital cost of equipment;

(2) Land cost;

(3) Building cost;

(4) Bond interest and depreciation;

(5) Cost of any other sources of water; and

(6) Operating cost consisting of

(a) Diatomaceous earth and chemicals,

(b) Power,

(c) Labour,

(d) Back-wash water; and

(e) Maintenance.

It is difficult to discuss methods of making an economic study without referring to a specific case. As an example, M. Carleton Yoder, Consulting Engineer, Berkely, California, made an economic study for the city of Vacaville, on a conventional rapid sand filtration plant versus an Automatic Diatomaceous Earth Treatment Plant. The basic design of the plant is for 20 mill gal/day. The first phase of the construction was to build 5 mill gal/day plant with all intakes, etc. to be designed for the ultimate. The estimated cost of the first phase was $1,198,000 for the conventional rapid sand treatment plant and $429,000 for the automatic diatomaceous earth plant. The actual contract price of the diatomaceous earth plant was $469,000. The building as also the pump, the piping and controls, except the filter controls, are so installed as to increase the plant capacity to 10 mill gal/day. It is also estimated that it will cost $150,000 to instal the 5 mill gal/day additional filter capacity. This would make the total cost $619,00 for a 10 mill gal/day plant. No estimate was made on what it would cost to increase the rapid sand treatment plant to 10 mill gal/day, but it would be considerably more than the diatomaceous earth plant. The estimated annual operating cost including interest, depreciation, operation and maintenance for the rapid sand filtration plant is

$136,000 or $75 per mill gal and for the automatic diatomaceous earth treatment plant, it is $69,100 or $39 per mill gal. The treatment plant was expected to handle turbidities ranging from 7 to 50 mg/lit. with an average turbidity of 10 mg/lit. The treatment plant at Vacaville was put into operation in April 1963 and the above figures have been borne out. The plant is completely automatic and has operated very satisfactorily.

Conclusion

1. Diatomaceous earth filtration is a very effective form of water treatment for many water supplies.

2. Diatomaceous earth filtration is not limited to turbidity removal but can be used for iron, colour, taste and odour removal with various types of pre-treatment and post-treatment.

3. Large savings both in capital and recurring expenditure can be made when diatomaceous earth filtration plant is used.

4. Small communities which can not afford conventional treatment plants can get effective treatment by using diatomaceous earth filtration.

5. Automatic diatomaceous earth filtration plant operating costs are favourable to other treatment processes.

6. Automatic diatomaceous earth filtration plants, properly applied and designed will operate very dependably.

APPENDIX

Optimum Economical Design for Municipal Diatomite Filter.

The rate of body feed; Terminal loss of head; and Rate of filtration which combine to produce potable water for a specific city at a minimum cost per 1000 gal are referred to as:

(1) Overall body feed;

(2) Optimum terminal head loss; and

(3) Optimum rate of filtration respectively.

Data for Optimum Calculations.

Several data are needed to calculate the minimum cost combinations for determining the above optima. Basically needed are (1) Series of Head-loss Vs. Time of Filtration or Volume of Filtrate Curves.

Filtration of water under normal conditions of body feed and rate of filtration can be expressed by the equation:

$$H = K_3 \, Q W_1 \, K_4 \, C_D \, Q_2 \, t \quad \ldots (I)$$

K_3 constant depending on grades of diatomite and water to be filtered respectively—filter aid manufacture

K_4 Filtering characteristics of the suspended solids to be removed and related to ratio of suspended solids to body feed diatomite and can be verified in laboratory

Equqtion I is modified to

$$H = \frac{6.26 \times 10^{-9} \times u.Q}{gd} \left| a_1 \; w_2 \; a_2 \; \frac{C_D \;\; Q.t.d.}{10^6} \right| \quad .II$$

Where u is viscosity of filtrate; t, period of run in minutes; Q, gal/sq ft/min; C_D, body feed; a_1, specific resistance of body of pre-coat; a2, specific resistance of body feed, and suspended solids.

Cost of filtration includes (a) labour; (b) Power; (c) Diatomite; and (d) Equipment costs.

Rate gal/sq ft/min	Cost Automatic equipment us cents/100 gal
1	0.059
2	0.039
30	0.029

The procedure for working out the above design criteria can best be exemplified by an example

(1) Choose a filtrate rate—say 1 gal/sq ft/min

(2) Choose a body feed rate—say 40 mg/lit.

(3) Choose a head-loss—say 50 ft.

(4) Determine length of filter run from equation II—say 767 min.

(5) Multiply filter run × filtrate gal/sq ft. 767×1=767 gal/sq ft.

(6) Multiply (5) × body feed × 8.345 × 10—6 0.256 lb/sq ft diatomite

(7) Add pre-coat body feed—0.15 o.256=0.406 lbs/sft.

(8) Divide (5) by (7) 767 gal/sq ft=1889 gal/lb.

(9) Diatomite cost in Us cent/lb × 1000

(8)

=7/lb × 1000 3,706 U.S. cents per 1000 gals.

1889

(10) Length of filter run—767 minutes Labor cost—2.9 cents per 1000 gals ... A

(11) Find power cost using—0.71 cents per 1000 gallons ... B

(12) Total cost—labor + power + diatomite + equipment = 0.71 + 2.90 = 3.706 Total

(13) Repeat total cost in (12) for other head-losses

(14) Select minimum head-loss cost in (13) i.e., say 5.949 Us cents/ 1000 gal at 100 ft head-loss

(15) Add equipment cost at 10 to 14--5.949 0.059 6.008 Us cents/ 1000 gal total cost

(16) Plot total cost at 15 against mg/lit. of body feed —20, 40, 60, 80, 100 . 160 mg/lit.

(17) Repeat 1 to 16 for other filter rates.

The operating cost for a raw water turbidity of 30 mg/lit is $12 per mill gal and for 60 mg/lit turbidity, the operating costs are $40 per mill gal. The above items have to be calculated for a particular quality of water and the optimum cost is value for that quality alone and none else. If the quality changes, the optimum cost varies. In India, for non-monsoon period which extends for over 8-9 months in an year, the raw water turbidity in most of the reservoir drawn waters like those at Bombay, Poona, Calcutta, Hyderabad, etc. hardly exceeds about 60 mg/lit. Even river intake waters like Nagpur do not show a turbidity higher than this for this period.

The diatomaceous earth filtration which costs half as much as a conventional water treatment plant both in capital and recurring costs and requires less than 1/2nd the space required for conventional treatment plant can be made foolproof after certain training and in the Author's opinion is the best for Indian conditions and most economical. Further, the time required for erection of huge masonry and concrete tanks with the Bridge and other units can also be reduced to a great extent. Though at the moment, there are technical difficulties of developing Filter Aids from the available raw materials (in huge quantities) in India and technical know-how for the manufacture of the septa and other parts—yet in view of the huge benefit that is likely to be had in the shape of the financial savings which would go a long way to meet the potable water requirement, practically for double the population, compared to the conventional plants of specialised firms, it is the Author's firm belief that Diatomaceous Filtration plants are ideally suited to the needs of India. In view of the huge savings anticipated, both in Capital and Recurring expenditure, every attempt should be made to get immediate foreign collaboration for manufacture of such units which could in course of time be operated by Indian Technical personnel. This is the quickest way to do and will pay heavy dividents as maximum number of people would be provided with a potable water supply required in the **National Water Supply and Sanitation Programme;** and, at the same time, the Nation would save a huge sum both in capital and recurring expenditures. Industries do need these units also on a very large scale.

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Treatment Of Brackish Waters By Electrodialysis

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One of the facts of life, or perhaps I should say natural phenomenon, which I have learned since my arrival in India is that, even in monsoon-swept India, there are brackish waters. It is surprising to find that there are sources of water, particularly ground water, which are not fresh and not completely acceptable because of the dissolved salt content. The term BRACKISH WATER as used in this paper denotes water *containing total* dissolved solids, or salts in the range 1,500 to 10,000 mg/lit. In the Calcutta area of West Bengal, 37 tube-wells out of 490 sampled yield brackish water. In the Dudhai area, eastern Kutch, Gujarat, 44 wells out of 115 sampled in 1945, showed chlorides, exceeding 1,000 mg/lit. In the Purna Valley, Vidarbha, a considerable area is underlain by brackish ground water containing 2,000 to 5,000 mg/lit. of chlorides. Reports published by Geological Survey of India (GSI) record sources of brackish groundwater in and around Bikaner City in Rajasthan and in the Gurgaon district of Punjab. In GSI Bulletin No. 11 "Ground-water Resources of the Andhra State with Special Reference to Rayalaseema Districts," the summary states in part "Brackishness seems to be a general feature, ..."

Desalting of a municipal or industrial water supply may seem to be a remote possibility or in the distant future for India, but the problem does exist here in your country just as in many other countries of the world. A recently published United Nations Report entitled **Water Desalination in Developing Countries"** discusses water problems in India and concludes in part: "It is apparent that shortage of fresh water in India is creating serious problems in certain areas, especially in densely populated or commercial centres such as Madras or Kandla, Gujarat State. In sparsely populated areas, on the other hand, such as the greater portions of the Kathiawar and Kutch peninsulas in Gujarat State, shortage of water appears to be a major obstacle to settlement and development." The electrodialysis process is a relatively new and strikingly different process of water treatment which is finding widespread application to brackish waters.

The first commercial electrodialysis plant designed and installed by **Ionics Inc.** began operation in the

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Arabian Desert in 1954. In ten years time, the aggregate capacity of demineralizers, manufactured and installed by Ionics, has increased to more than 3 million gallons per day. Some 100 plants are located in North Africa, the Middle-East and United States. Ionics indicates Ionics Incorporated, Cambridge, Massachusetts, U.S.A. The reference to this Firm is quite natural since they pioneered research on, and development of, the process and membranes; they are the only fully integrated suppliers of electrodialysis equipment; they have built and installed 90 per cent of the world's commercial electrodialysis demineralizers, and they provided most of the data for this paper.

The Electrodialysis Process

The electric membrane process removes ionized salts and minerals from water by the migration of ions through ion-transfer membranes in a direct current electrical field. When most salts and minerals are dissolved in water, they break down into atomic or molecular-size particles which carry positive or negative electrical charges and are called "ions." If one immerses two metal electrodes in water containing ions and passes a direct electrical current between them, all of the negative ions (anions) will move toward the positive electrode and all of the positive ions (cations) toward the negative electrode.

Now if we interpose alternating cation and anion membranes between the electrodes, forming compartments for the ion-containing water between each pair of membranes, the movement of the ions induced by the direct current field is profoundly affected. Half of all the ions will be able to move through one membrane barrier, and half will not. No ion will be able to move through more than one barrier.

In Fig. 1, the negative electrode is on the left. Cations (Positively charged ions like Na) from compartments whose left boundary is a cation membrane (compartments 2, 4, 6, 8, 10, etc.) will be able to move one compartment to the left, but must then stop because the second membrane they encounter will be an anion membrane. However, cations from compartments whose left boundary is an anion membrane (compartments 3, 5, 7, 9 etc.) will not be able to move at all.

Conversely, the positive electrode on the right will attract all anions (negatively charged ions like chloride-Cl) toward the right. Anions from compartments whose right boundary is an anion membrane (compartments 2, 4, 6, 8, 10, etc.) will be able to move one compartment to the right, but must then stop because the second membrane they encounter will be a cation membrane.

However, anions from compartments whose right boundary is a cation membrane (compartments 3, 5, 7, 9, etc.) will not be able to move at all.

The net result of these ion transfers is that compartments 2, 4, 6, 8, 10, will lose ions and compartments 3, 5, 7, 9, gain ions.

Brackish or saline water can be fed into compartments 2, 4, 6, 8, 10 and will lose ions while in these compartments. The effluents from these compartments will be partially demineralised. The extent of de-

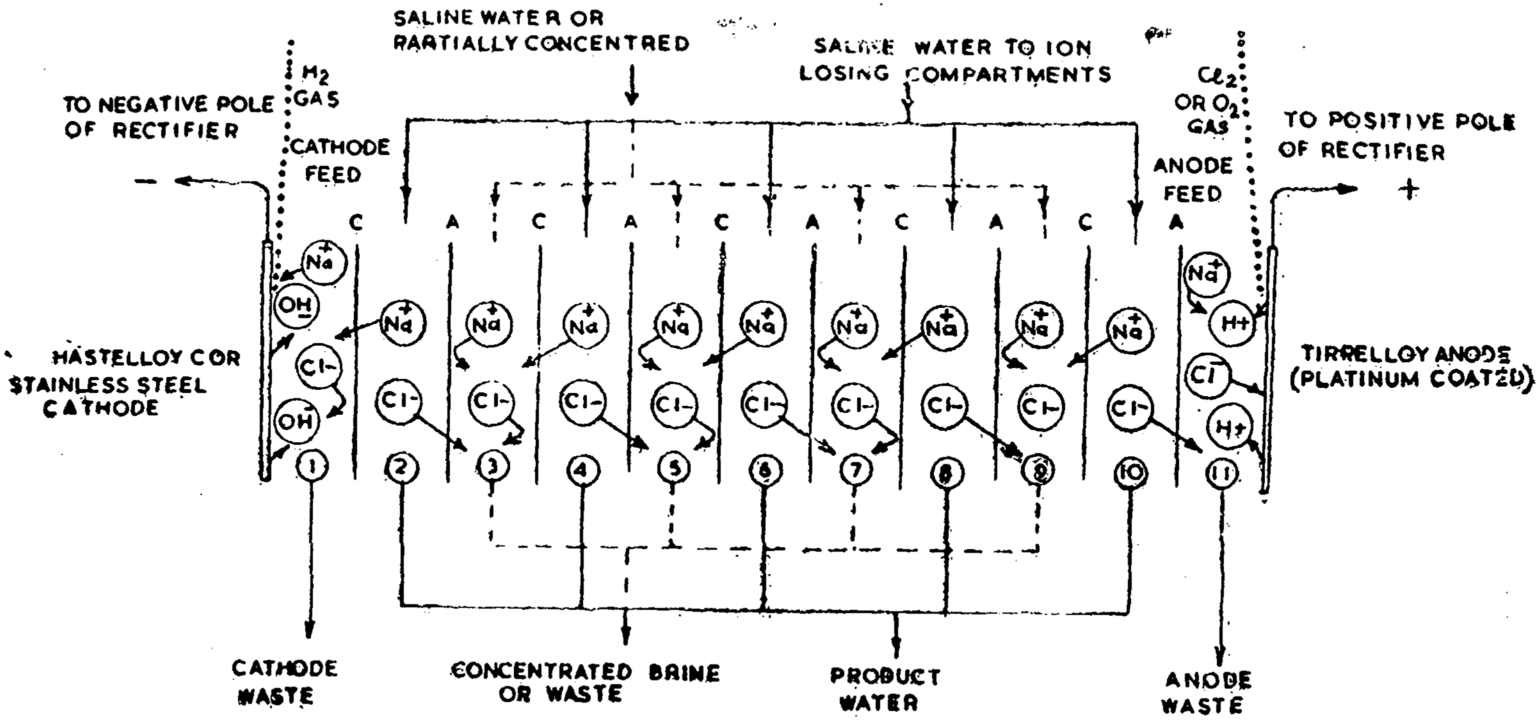

Fig. 1—Basic ion and water flow in electric membrane stack.

(Note: Top left hand arrow indicates saline water or partially concentrated brine to ion gaining compartments).

mineralization will depend on the amount of current passed, the amount of ions present in the feed solution, and the rate at which the feed solution passes through the equipment.

Brackish water fed into compartments 3, 5, 7 and 9, will gain ions while in these compartments and will emerge more concentrated than before. In water demineralization units, this brine or "blow-down" stream is a waste product and must be disposed of. However, in some situations, it may be a valuable concentrate of ionized substances. For example, much interest is currently being shown in Japan in the use of electric membrane units to concentrate sea water into salt brine for industrial brine uses.

In compartments 1 and 11, electrode reactions take place. Hydrogen gas and alkali (OH) are produced at the cathode or negative electrode (compartment 1). Oxygen or chlorine gas and acid (H) are produced at the anode or positive electrode (compartment 11).

These electrode streams require separate handling. Usually the gas is separated and vented and then the combined streams are mixed with the blow-down stream for disposal. However, in some situations, the electrode streams might be useful for chemical operations being respectively acid and alkaline. Even the gases may be utilized for disinfection or energy.

The Equipment

The physical structure in which electric membrane operations are carried out is called a membrane "stack." A membrane stack consists of alternating anion and cation membranes, spacers, electrodes, and blocks for making inlet and outlet connections, heavy steel end plates, and the rods to provide uniform sealing pressure. The spacers play an important role in this process. These (i) contain the water or other liquid between the membranes, (ii) hold the thin and flexible membranes at a constant distance from each other; and (iii) direct the flow of the liquids across the face of the membrane. A good spacer achieves an even distribution of flow and promotes enough turbulence to provide a scrubbing action at the membrane-liquid interface and prevent the formation of polarization films.

Ion Transfer Membranes (sometimes called ion exchange, electrodialysis, or permselective membranes) are thin sheets of ion exchange material (commonly 4 to 40 thousandths of an inch thick) containing ionic active groups, and, when in use, a substantial amount of water by weight. The membranes are composed of an inert cross-linked, plastic polymer such as styrene-divinyl-benzene to which ionisable radicals such as sulphonic acids or amines are attached by a chemical bond. The entire structure contains from 15 to 50 per cent by weight of water distributed in millions of very fine capillary pores which honeycomb the structure. The pore size is in the range of 10 to 100 Angstroms. The ion transfer membrane is virtually impermeable to water at normal pressures.

Ion transfer membranes are of two types—anion and cation. Anion membranes contain ionic amine groups e.g., $—N(CH_3)_4$ with a fixed positive charge—and thus are capable of repelling other positive ions (cations) such as sodium, potassium, calcium or magnesium. The fixed positive charges of an anion membrane require negative counter-ions (anions) such as chloride, sulphate, nitrate, or bicarbonate to preserve electrical neutrality. Thus anions are allowed to enter into the fine capillary pores of an anion membrane and travel through the membrane under the influence of a direct current, while the positive cations are repelled and can not enter or pass through the membrane at all.

Conversely, cation membranes contain ionic sulphonic acid groups ($—SO_3H^-$) with a fixed negative charge; and are thus capable of repelling other negative ions (anions) such as chloride, sulphate, or bicarbonate. The fixed negative charges of a cation membrane require positive counter-ions (cations) such as sodium, calcium, or magnesium to preserve electrical neutrality. Thus cations are allowed to enter into the fine capillary pores of a cation membrane and travel through the membrane under the influence of a direct current, while the negative anions are repelled and can not enter or pass through the membrane at all.

The spaces in the stack are fabricated from sheets of electrically insulating, plastic material with good gasketing properties such as plasticized polyvinyl chloride, polyethylene, or rubber-styrene compounds. A flow path for the liquid is die cut into these spacers as well as manifold holes for the main liquid manifolds and appropriate connections between the manifold hole and the flow path.

The electrodes are thin metal sheets—stainless steel or Hastelloy C are typical materials for the cathode. Anodes are usually made from coated sheets of platinum on tantalum or platinum on titanium.

A typical stack has 150 pairs of cation and anion membranes—18 in by 20 in by about 30 thousandths thick—and 150 pairs of spacers—18 in by 20 in by about 40 thousandths thick. It has a hydraulic capacity of twenty gal/min through its 150 "dilute" or ion-losing compartments and twenty gal/min through its 150 "concentrated" or ion-gaining compartments. These flow rates are achieved at a pressure drop (through the stack and its normal associated piping and controls) of 25 to 35 psi 30 psi being a good average figure.

The electrical demand of an individual membrane stack and the resulting demineralization depends on flow rate of the water through the stack, total dissolved solids in the entering water, type of solids present, and temperature of the water. At a flow rate of 20 gal/min, a typical stack will accomplish removal of approximately 40 per cent of the entering solids for waters up to 5,000 mg/lit. at 70°F and for a predominately chloride water. Lower temperatures or other anions will reduce the allowable per cent demineralization per pass. If greater demineralisation is desired, at least two arrangements are possible (i) additional stacks may be put in series to re-process the partially demineralized water (forming a "continuous" unit or (ii) the water may be recirculated through the same stack a number of times before being discharged to service (forming a recirculating batch unit).

The Continuous Unit

Fig. 2 is a flow-sheet of a typical continuous electric membrane unit, in this case a 4 stage series unit. The water flows through filter F, a replaceable cellulose cartridge type, to remove any traces of particulate matter and prevent dirt from fouling the membrane stack. Downstream of the filter, a pressure regulating valve (PRV) opens as the pressure drop through the filter increases, maintaining a nearly constant pressure of 10 psi downstream.

Beyond the pressure regulating valve, the filtered feed water branches into the streams—one of which, called the dilute will become the demineralized product; the other called the concentrate will become the concentrated brine blow-down.

The water to be demineralized is pumped by booster pump D_1 through the 150 ion-losing compartments of Stack 1, where approximately 40 per cent of the entering mineral content is removed. This partially treated water with 60 per cent of its original mineral content remaining is then re-pumped successively by booster pumps D_2, D_3 and D_4 through Stacks 2, 3, and 4 In each of these subsequent stacks, approximately 40 per cent of the remaining mineral content is removed, so that the final product has about 13 per cent (60 per cent raised to the 4th power) of the original mineral content remaining. The dilute product is pumped continuously to a product storage tank at the same rate that the four booster pumps are pumping through the stacks.

The ions transferred out of the dilute or product stream in each of the four stacks are continuously absorbed in the recirculating concentrated loop. In a typical continuous unit, the concentrated recirculating streams for each of these four stacks will be in parallel and fed from a concentrate manifold. The concentrate pump C recirculates at four times the rate for any given stack. The blow-down rate is controlled by control valve CV and rotameter R on the makeup of feed water to the concentrated loop. The blow-down approximately equals the makeup.

In a continuous unit, the conductivity of the water in each stack stays approximately constant with time; hence there is no variation of the direct current required from the

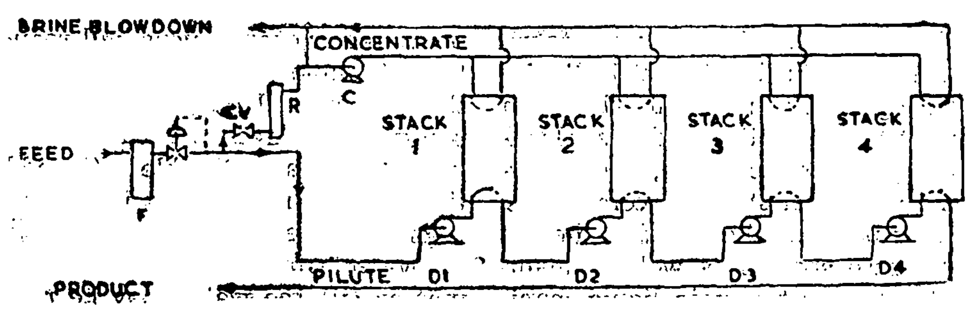

Fig. 2—Schematic flow-sheet of four-stage continuous unit

rectifier—as in the batch unit. However, the proper voltage differs for each stack, and the resulting currents also vary, due to the difference of voltage and the different resistance in the stack. The first stage has the highest voltage and by far the highest current. The last stage has the lowest voltage and by far the lowest current. The second and third stages have intermediate voltages and currents.

Electrodialysis Plants in the United States

In the United States, commercial water treatment plants utilizing the electrodialysis process have increased in number from 2 in 1958 to more than 14 today. These plants, having an aggregate capacity of 1½ million gallons a day, serve people in nine States. Two of the municipal plants deserve special mention. One is the plant at Coalinga, California, which is the first municipal electric membrane demineralizer to be installed in the United States. The other is the Buckeye, Arizona, plant which is, I believe, the largest and probably the most efficient plant installed in the U.S. to date.

Decisions to install electrodialysis plants to demineralize brackish waters were made largely on the basis of economics. Generally one or more of the following conditions must be present to make demineralization by electrodialysis worthwhile :

i) A reasonable demand for fresh water on a continuous basis;

ii) Absence of a suitable fresh water supply or a fresh water supply at such distance that development and delivery costs would be excessive;

iii) A convenient and reliable source of brackish water;

iv) A source of electric power.

In 1958 at Coalinga, California, all of the above conditions were present. The local ground water, although adequate in quantity, was excessively hard and not palatable. Fresh potable water was being hauled by railway tank car to Coalinga, pumped to an elevated tank and piped separately into homes. The householder had three taps, one hot and one cold with hard water, and one with fresh potable water for drinking and cooking. **Ionics** studied the problem and concluded that the brackish well water supply could be demineralized at much lower cost than the cost of hauling fresh water by tank-car. So, in 1959, Coalinga became the first U.S. city to install an electrodialysis plant. During the past 5 years, the plant has given good service, and although it is of small capacity, it has saved money for the people who still have their third tap for fresh water. The plant treats 28,000 gallons per day and reduces the dissolved salt content from 2,000 to 300 mg/lit.

Another city in Southwestern U.S., Buckeye, Arizona, had water problems, in fact, all of the conditions mentioned above were present The well water supply contained 2,200 mg/lit. of total dissolved solids, 1,1000 mg/lit. chlorides and 280 mg/lit. total hardness as $CaCO_3$. After numerous unsuccessful attempts to find better water by drilling deep wells, the city looked to **Ionics.** A special committee made a detailed study of the cost of water including those hidden costs incurred by water users to rectify or avoid the effects of the higher mineralized water. These latter included the costs of (i) bottled water, (ii) home water softeners and water conditioning agents, (iii) soap and detergent wasted, and (iv) premature replacement of appliances and plumbing fixtures due to excessive corrosion. Analysis of all the water costs showed that the average water customer spent $5 per month (Rs. 25) for his hard water supply and $ 10 per month (Rs. 50) for the hidden costs. It was also recognised that central treatment to improve water quality would be much more convenient for the consumer. **Ionics Incorporated** installed a portable demonstration plant and further offered to guarantee performance of the proposed city plant. It is no wonder the people voted a $ 305,000 bond issue to finance the plant.

One year after approving the bonds, the plant was completed and in operation, and it has now been in service for 2 years. The capacity of the plant is 650,000 gallons per day. At this capacity, the raw water supply containing 2,200 mg/lit. of dissolved salt is reduced to the acceptable limit of 500 mg/lit. Detailed mineral analyses of the raw water and the product water are shown in Table I.

A breakdown of the several components of water treatment costs at Buckeye is presented in Table II. It

Table I—Feed and Product water analys's at Buckeys, Arizona

	Well 8 Feed Water		Product Water	
	Specs*	Test+	Specs*	Test +
Sodium plus Potassium as Na	630	598	—	142
Calcium as Ca	116	100	—	17.6
Magnesium as Mg	15	7	—	1.7
Total Hardness as $CaCO_3$	354	279	85	51
Chloride as Cl	1,054	1,100	250	220
Sulfate as SO_3	155	169	75	60
Bicarbonate as HCO3	78	71	—	27
Nitrates as NO3	9	—	—	—
Fluorides as F	2	—	—	—
TDS	2,076	2,140	500	484
*p*H	8.1	7.6	7-8	7.1
Silica as SiO_2	17			
Iron as Fe	0.0	0.4	—	0.2
Manganese	Nil	—	—	—

Values in mg/lit. except pH

1) * From "Contract Documents, Water Treatment Plant, Town of Buckeye, Arizona"—January, 1962 and Ionice Performance Guarantee, Attachment 4, January, 1962.

2) +From analyses of samples taken during Full Load Acceptance Test —October, 1962.

is interesting to note that 63 cents, the total cost of treatment per 1,000 gal. at 34 per cent load factor, is double the unit cost of treatment at full load capacity.

Future of the Electrodialysis Process

Although still in its infancy, the electric membrane process holds great promise. With further research on membrane efficiency and improvement in cell design, we may expect that larger and more effective units will be designed which will show significant reduction in cost. It is interesting to note that research on the development of membrane is being conducted by the National Chemical Laboratory at Poona.

Everett Howe, Professor of Mechanical Engineering at the University of California, stated in February, 1959: "Electrodialysis has a great advantage over distillation in that

Table II—Water treatment cost at Buckeye, Arizona

(Basis: Actual 1963 Load—80,182,000 gallons annual production—Load factor 34.4 per cent

Full Load Capacity—233,000 000 gallons annual production—Load factor 100.00 per cent)

	Actual Load[a] 1963		Full Load[b] Test	
	Cents/1000 gal	$/year	Cents/1000 gal	$/year
Electrical Energy[c]	12.9	10,300	11.2	26,100
Acid	0.6	475	0.7	1,630
Filters	3.2	2,560	2.7	6,270
Membrance Replacement	7.5	6,000	4.2	9.900
Other Replacements	5.0	4,037	1.8	4,200
Labour	6.9	5.490	2.2	5,100
Miscellaneous[d]	1 4	1.137	—	--
Bond Amortization & interest[e]	25.5	20,500	8.8	20.500
Total costs	63.0	50,499	31.6	73.700

(a) —Based upon 1963 calendar year fiures.

(b) —Based upon 14-day full load test, October 8, 1962 to October 22, 1962.

(c) —Cost of electrical power from Arizona Public Service Company depends upon amount used per month and peak demand during the month. The full load test averaged 1.09 cents/kwh; 1963 (34.4%) load averaged 1.71 cents/Kwh.

(d) —Service and materials purchased directly by the town not included elsewhere.

(e) —Even payments to amortize the 25-year, 41/2%, $305,000 bonds issue—calculated at 6.72% annually.

the energy required is in proportion to the salts removed rather than to the water produced. For this reason, it should meet the need of purification of saline (up to say 5,000 mg/lit.) water. If it can be operated at a high efficiency of separation, it could make the demineralizaztion of such saline waters competitive with natural supplies. This probably could come about only in very large plants."

Fred G. Aandahl, Assistant Secretary of the Interior, reported on Saline Water Conversion to the Select Committee on National Water Resources, United States Senate on October 19, 1959, as follows: "Since 1952, electrodialysis has developed from a laboratory phenomenon to the point where it is now one of the leading processes for demineralization of brackish water. One of the limiting factors in the use of electrodialysis has been the membranes themselves. During the last few years, improved membranes have been developed by a number of organizations in several countries. If the cost of membranes and equipment can be sufficiently reduced, an electrodialysis process may also become economically feasible for demineralization of sea water."

In the same Report to the Senate Select Committee, the Assistant Se-

Table III—Estimated costs for Producing 2.000.000 gal/day fresh water from three brackish waters by Ionics Mark III Equipment

(Design Basis:
Feedwater temperature, 85°F;
Electrical energy cost, 1.00c/kwh;
Sulfuric acid, 65° Be commercial, 1.25c/lb;
Membrance replacement—average 1/5th per year;
Amortization basis 25 years, 5 jer cent (7.1 per cent per year);
Maintenance costs other than membrances—1.5 per cent per year of capital;
Labour allowance—2hr per day plus 100 man-hours per stack-year at $4/hr including overhead; and
Anions predominantly chloride)

	Location I		Location II		Location III	
Feedwater TDS, mg/lit.	1000		2000		4000	
No. of stacks	8		16		24	
No. of stages	1		2		3	
Total capital cost, $	450,000		850,000		1,250,000	
Operating cost, cents						
1. Electrical energy	6.2		17.0		33.2	
2. Chemicals	2.5		2.5		2.5	
3. Pre-filtration	3.0		3.0		3.0	
sub-total		11.7		22.5		38.7
Maintenance cost, cents						
1. Membranes	2.4		3.6		5.4	
2. Other maintenance	0.9		1.8		2.6	
3. Labour	0.8		1.3		1.7	
sub-total		4.1		6.7		9.7
Amortization		4.4		8.3		12.2
Total water cost c/1,000 gal.		20.2		37.5		60.0

cretary estimates that, based upon future developments a projected large plant (75,000,000 gallons a day production) might reduce the mineral content from 4,000 to 250 mg/lit. for 40 cents per thousand or from 2,000 to 250 mg/lit. for 25 cents.

Ionics have also been looking into the future, and by using their new Mark III equipment they estimate that water demineralization costs may be cut even lower within the next few years. Table III shows their cost estimate for a 2 million gallon per day plant for three different cases. Note that for Case 1, which assumes a raw water of 1,000 mg/lit. and product water of 500 mg/lit. the estimated cost is only 20.2 cents per 1,000 gal.

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DISCUSSION

SHRI S. R. AGARWAL (Kanpur) : Is it that some electrolysis also takes place along with electrodialysis ? If so, what happens to the alkalinity developed ?

SHRI D. B. WILLETS : Alkalinity is developed in the electrode compartments from which the water passes into the brine discharge.

SHRI K. G. VEERARAGHAVAN (Madras) : May I enquire what is the normal quantity of waste water discharged from one of the electrodialysis plants in operation and how this is disposed of without polluting ground water ?

SHRI D. B. WILLETS : The waste water is disposed back into the raw water source or into municipal sewers. Quantity of raw water treated in one of the plants is about 867,000 gal/day. Product is 650,000 gal/day and waste water is 217,000 gal/day, which is about 25 per cent of the feed water.

SHRI P. R. MEHTA (Bhavnagar) : Is it possible to get fresh water from sea water by electrodialysis ? If so what will be the cost per 1000 gal, if the sea water contains 30,000 mg/lit. of solids ?

SHRI D. B. WILLETS : It is possible to produce fresh water from sea water by electrodialysis. However, the process is more generally recommended for brackish waters, since cost is roughly proportionate to the mineral concentration of the raw water. The actual cost of demineralisation of sea water by electrodialysis would depend in part, upon the size of the plant, temperature of the water and cost of electricity. I have no good figures on such cost but I would guess that it would exceed Rs. 15 per 1000 gal.

SHRI P. R. MEHTA : If it is economical, 50 per cent of tube well waters, river waters, or any other fresh water may be added to reduce the total solids. If this is done, kindly tell the cost per 100 gallons.

SHRI D. B. WILLETS : This question is not clear to me. It would appear that if fresh water is available for dilution it should be used for that purpose and there would be no need for demineralisation of the brackish water.

SHRI P. R. MEHTA : How is the cost reduced from Rs. 7/- to Rs. 2/- per 1000 gal. Please throw some light on this.

SHRI D. B. WILLETS : The cost of Rs. 7/- per 1000 gal applies to the municipal plant at Coalinga, California. It is a small plant which treats only 28 thousand gallons per day. The cost of Rs. 2.00 for 1000 gallons pertains to the Buckeye, Arizona plant which is a much larger and more efficient plant. It treats 650,000 gallons per day and the lowest value of cost applies when the plant is operated at full load. The product water from this plant contains 500 mg/lit. of dissolved salts.

SHRI P. R. MEHTA : Kindly throw some light on desalination of sea water to get drinking water as organised by WHO and work carried out in foreign countries.

SHRI D. B. WILLETS : Small plants have been installed to produce fresh water from sea water in Saudi Arabia and North Africa. For specific information on this subject, I would refer to **Ionics, Inc.** at 152 Sixth St., Cambridge, Massachusetts, 02142, U.S.A. The World Health Organisation has published a report entitled "Water Desalination in the Developing Countries" in 1964. I believe this publication and further information o nthe subject could be obtained by writing to the United Nations at Palais de Nations, Geneva, Switzerland.

SHRI T. S. BHAKUNI (Nagpur) : Do you feel that electrodialysis technique of demineralisation of brackish water is in any way a feasible proposition in brackish tracts in Delhi ? Most of the villages do not possess electric power and do not have proper mode of transport.

SHRI D. B. WILLETS : The feasibility of utilising the electrodialysis technique of demineralisation of brackish water is dependent in large measure upon the cost of supplying good water. It will also be noted that the cost of demineralisation by this process must be evaluated for each specific case. It depends upon the salinity of the brackish water, type of salt present, temperature of the water, allowable concentration of salt in the product and the cost of power. This process would of course not be applicable in any community where there is no electric power.

SHRI T. S. BHAKUNI : How does it *compare with ion-exchange de*ionisation.

SHRI D. B. WILLETS : The cost of demineralisation by electrodialysis must be estimated for each case. The cost estimates given in the paper are considered to be honest and realistic. I have no data regarding the cost of ion-exchange demineralisation. The latter process is generally used for water softening or for complete ion removal.

SHRI S. K. GAJENDRAGADKAR (Bombay) : Have any plants been installed in India ? What are the results in terms of efficiency ? I think it will be costlier than the figure Rs. 2/- per 1000 gal as quoted. What is the recurring cost ?

SHRI D. B. WILLETS : To my knowledge, no electrodialysis demineralization plants have been installed in India. With regard to the questioner's comments about cost I would refer to Table II in the paper which gives the actual cost of operation at the Buckeye Plant. This plant has met the performance guaranted by the manufacturer during the first two years of operation.

SHRI A. G. BHOLE (Nagpur) : I will be glad to know some details, on desalinisation of brackish water by solar distillation. The solar energy in India is quite ample. As such, an economical method of desalination by solar energy will be of practical utility.

SHRI D. B. WILLETS : This is a general question concerning application of solar distillation. In my opinion, it might well be applied to the problem of providing good water in India. If further information is desired on this subject, I suggest correspondence with Prof. E. D. Howe, University of California, Berkeley, California, U.S.A.

Proc. Symp. Problems in Water Treatment,
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Chlorination of Unfiltered Water Supply as an Interim Measure for Control Of Cholera in Calcutta

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Introduction

The city of Calcutta has been provided with a dual water supply—filtered and unfiltered. The filtered supply which is adequately purified and bacteriologically safe is used for drinking and other domestic purposes. The unfiltered supply is directly pumped from river Hooghly into the city. This supply, which is heavily polluted, is used for flushing water closets, washing roads, fire-fighting and such other purposes for which a bacteriologically safe water is not very essential.

There are two pumping stations one at Mullick Ghat and the other at Watgunge to pump the river water into the city distribution system. The Mullick Ghat pumping station is located near Howrah Bridge and pumps about 35 mill gal per day. The Watgunge pumping station is about 3 miles down-stream of Mullick Ghat Intake and is located about 200 feet below the point of discharge of Tolly's **nullah** (drain) into the river. The **nullah** carries sullage from one of the highly insanitary areas in the city.

Examination of samples of river water collected near the pumping stations during the period 1950-59 by the Micro-biology section of the All India Institute of Hygiene and Public Health showed that 36 out of 811 samples collected from Mullick Ghat and neighbourhood, and 18 out of 273 samples from Tolly's **nullah,** corresponding to 4.5 and 6.6 per cent of samples respectively, showed the presence of cholera vibrios, **inaba** and **ogava** types. The occurrence of cholera vibrio in river water provides evidence that cholera germs gain entry into different parts of the city through the unfiltered water supply.

Although the unfiltered supply is designed for purposes other than domestic use, it is widely used for washing utensils and other domestic purposes, being readily available at the tap in many homes. When there is scarcity of filtered supply during the summer months, the unfiltered supply is used for various domestic purposes in many residential localities and particularly in **bustees.** During this period, it is not uncommon to see street urchine drinking water directly from the stagnant pools and street hydrants (Figs. 1-3).

Figs. 1 —3 —Indiscriminate use of unfiltered supply

Fig. 1

Fig. 2

Fig. 3

The role of unfiltered water supply in the spread of cholera is obvious.

Several Expert Committees, who have examined this problem from time to time, have recommended the elimination of unfiltered supply as an important measure in the control of cholera. Replacement of unfiltered supply by a filtered purified supply involves heavy capital expenditure for which funds may not be available in the near future. In the meanwhile, the problem has to be tackled. Several interim measures have been considered to combat the problem. The engineering aspects of the chlorination of unfiltered supply have been discussed by Shetty (1). Although there was general agreement that chlorination of unfiltered supply would be useful, no serious attempt was made to implement this measure, because it was felt that the dose of chlorine required for effective disinfection of the river water would be high and uneconomical.

Chlorine dose for effective destruction of cholera vibrios present in unfiltered water

Laboratory experiments were carried out to determine the efficacy of chlorine in killing cholera vibrios in samples of water collected from the river. Samples collected from the pumping station during the months of March and April, 1962 were used for the experiments. The turbidity of the river water samples used for the experiments ranged from 600 to 1,000 mg/lit. The samples were treated with different doses of chlorine using freshly prepared chlorine solutions for the purpose. An untreated sample was kept as control.

A culture of cholera vibrio was added to all the samples so as to have a concentration of the order of 50,000 organisms per ml. After varying periods of contact, the samples were tested for residual chlorine and also cultured for the presence of cholera vibrios. The results of the experiments showed that a dose of chlorine sufficient to leave a residual of 0.5 mg/lit. after 10 min contract would be adequate to destroy all cholera vibrios present in the experimental samples.

Chlorine demand of river water to leave adequate residuals

Seth and Bhaskaran (2) and Radhakrishnan and Chakravarty (3) have shown that the 20°C 5-day BOD of Hooghly river water never exceeded 2 mg/lit. during the different seasons in the year. The low BOD indicates that the chlorine demand of the water, to leave residuals of 0.5 mg/lit. at the end of 10 min contact may not be high. Experiments were therefore carried out in March-April 1962 to determine the dose of chlorine required to be added in the river water to leave a residual of 0.5 mg/lit. at the end of 10 min contact. The results of these experiments indicated that a chlorine dose of the order of 0.2 mg/lit. may be adequate to provide satisfactory residuals at the end of 10 min. contact.

Installation of chlorinators and their operation

On the basis of the foregoing results, an Expert Committee of the Metropolitan Planning Organisation at its Meeting held on April 24, 1963 recommended chlorination of the unfiltered water supply of Calcutta as an interim measure for controlling Cholera in the city.

Five chlorinators were installed by the Calcutta Corporation—3 at Mullick Ghat Pumping Station and 2 at Watgunge Pumping Station on May 21, 1964. CE 'NH' type vacuum type chlorinatiors with a capacity up to 18.2 kg (40 lb) of chlorine gas per hour a capacity by the **Chlorine Equipment Co. Ltd.,** London, were used. The chlorinators were installed and operated by **Messrs Patterson Engineering Co.,** Calcutta

The chlorine gas was dissolved in a small quantity of water and the chlorine solution was then added under gravity into the bell mouth at the foot of the suction pipes. Chlorine demand tests on the river water samples were carried out to determine the dose of chlorine required from time to time. The dose used during the period of investigation is presented in Table I.

Table I—Chlorine demand of river water

Period	Chlorine dose*, mg/lit.	
	Mullick Ghat Sample	Watgunge Sample
21-5-63 to 28-5-63	2.0	2.0
29-5-63 to 31-7-63	2.3	3.0
1-8-63 to 31-8-63	2.0	2.5

* To leave a residual of 0.5 mg/lit. at the end of 10 min. contact time.

In the earlier period of operation of the chlorinators, samples of water collected from the pumps and different sections of the distribution near the suction were examined for chlorine to ensure that the chlorine added was getting into the distribution system. A log book was also maintained in pumping stations to maintain hourly record of chlorine added. The records showed that adequate amounts of chlorine were put into the distribution system through out the period.

Sampling and examination of water samples from the river and distribution system

After chlorination was in continuous operation for a fort-night, samples of water were examined from the river at the pumping stations and from 10 selected points spread over the entire distribution system once a week for a period of 2 months in order to determine the effect of chlorination on the quality of unfiltered supply. The samples were examined for: (i) residual chlorine, and (ii) bacteriological quality. The bacteriological examination of samples included culturing of samples for the presence of salmonella group of organisms. In addition to these samples. 30 other points in the distribution system were also sampled periodically for residual chlorine.

Samples for bacteriological examinations were collected from the hydrants by inserting a sterile glass tube up to a depth of 6 inches in the open hydrant as shown in Fig. 4.

Residual chlorine was estimated at site immediately after the collection of samples, using 500 ml of the samples. Since the samples were turbid, starch iodide method was used for determination of residual chlorine. (Fig. 5)

Fig. 4— Sampling for bacteriological test

Residual chlorine in distribution system

The results of examination of samples for residual chlorine are presented in Table II and Fig. 6.

Of the 130 samples tested during the period, only 10 samples from 3 sampling points showed the absence of chlorine. But on subsequent examination, 6 of the 8 sampling points recorded significant chlorine residuals. Taken on the whole, the residual chlorine data provide conclusive evidence that chlorination of the unfiltered supply has been effective in maintaining adequate residuals throughout the distribution system.

Effect of chlorination on vibrios and salmonella group of organisms

The results of bacteriological tests carried out in this connection are summarised in Table III.

Fig. 5— Field test for residual chlorine

Table II—Residual Chlorine in water samples collected from different points in the distribution system

(Period of observation June 3, to July 26, 1963)

Watgunge Zone			Mullickghat Zone		
Sampling point Number	Sample examined No.	Residual chlorine mg/lit. (Range)	Sampling point Number	Samples examined No.	Residual chlorine mg/lit. (Range)
1	7	0.53—5.00	14	2	0.57—0.92
2	2	0.85—1.34	16	1	0.78
3	2	0.71—1.17	17	1	1.56
4	2	0.85—1.24	18	1	1.42
5	1	1.63	19	1	0.69
6	1	0.57	20	1	1.06
7	2	0.49—0.57	21	1	2.06
8	8**	nil —1.49	22	1	1.42
9	2	0.67—0.85	23	1	0.64
10	3*	nil —1.13	24	1	1.00
11	1	0.75	25	1	1.45
12	2	0.31	26	1	0.75
13	1	0.92	27	2	0.35—0.85
15	8	nil —0.92	28	1	0.53
41	1	0.78	29	8	0.31—1.77
42	1	0.92	30	1	0.84
43	8*	nil —1.13	31	8*	nil —1.38
44	1	0.82	32	1*	nil
45	1	0.71	33	1	0.68
46	8	0.28—0.96	34	1	0.50
47	1	0.36	35	1	0.64
48	2	nil —0.96	36	8	0.21—1.14
			37	1	nil
			38	1	0.53
			39	1	0.36
			40	8**	nil —0.99
			49	1	nil
			50	1	0.41—2.44

* One sample showed absence of chlorine

** Two samples showed absence of chlorine

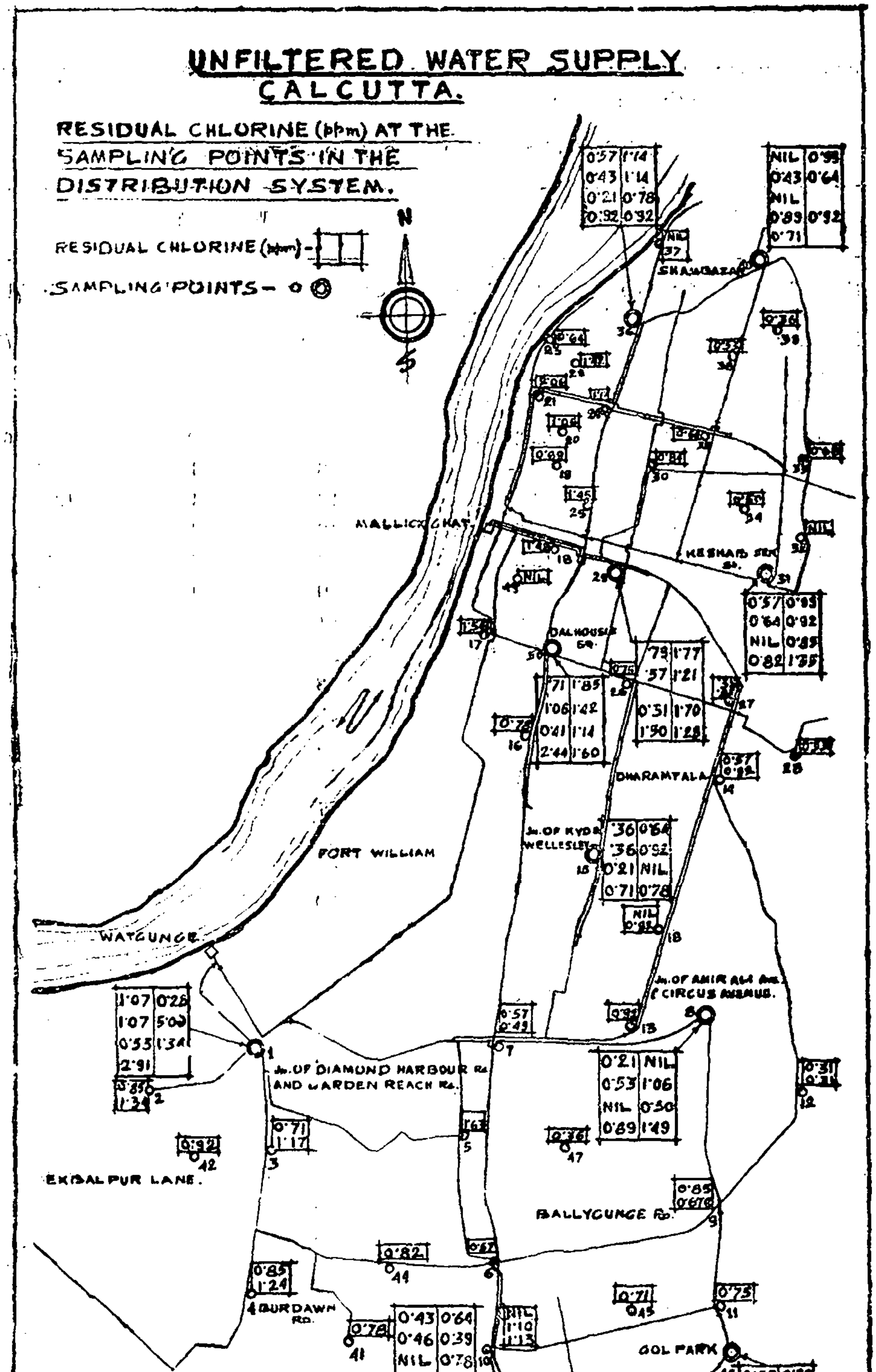
UNFILTERED WATER SUPPLY
CALCUTTA.
RESIDUAL CHLORINE (ppm) AT THE SAMPLING POINTS IN THE DISTRIBUTION SYSTEM.
RESIDUAL CHLORINE (ppm)
SAMPLING POINTS
N
S
SHAMBAZAR
MALLICK GHAT
KESHAB SEN ST.
DALHOUSIE SQ.
DHARAMTALA
FORT WILLIAM
Jn. OF KYD & WELLESLEY
WATGUNGE
Jn. OF AMIR ALI AVE. & CIRCUS AVENUE.
Jn. OF DIAMOND HARBOUR Rd. AND GARDEN REACH Rd.
EKBALPUR LANE.
BALLYGUNGE Rd.
BURDAWN Rd.
GOL PARK
CHETLA ROAD.

Fig. 6

The results showed that of the 15 samples of river water tested during the period, 11 samples showed the presence of vibrios, including one AG cholera vibrio; whereas only 1 of the 53 samples examined from the distribution system showed the presence of NAG vibrios. Salmonella group of organisms were isolated only from 2 river samples

The foregoing results indicate that chlorination has been effective in destroying all vibrios including cholera vibrios and the salmonella group of organisms that are likely to come into the city through the unfiltered water supply.

Effect of chlorination on coliform organisms in the river water

The data obtained in this connection are presented in Table IV and Figs 7 and 8.

It was also observed that many samples collected from the distribution system during the latter half of the sampling period showed less than *10 coliform organisms per 100 ml.* The average percentage reduction of coliform organisms due to chlorination was of order of 99 per cent. The foregoing data shows that chlorination brings about a marked impro-

Table III—Occurrence of Vibrios and Salmonella group in Water Samples

(Period of Sampling June 3, to July 26, 1963)

Nature of Sample	Samples examined No.	No. of samples positive vibrios		for salmonella group
		NAG vibrio	A.G. vibrio (cholera)	
River water near the pumping stations	15	10	1 (Inaba)	2
Distribution system	53	1	nil	nil

Table IV

Zone	Mullick Ghat		Watgunge	
Nature of sample	River	Distribution system	River	Distribution system
No of samples examined	8	40	7	33
MPN of coliforms (Range/ml)	240-15,000	0.03-240	240-9,300	0.03-430
Percentage Reduction		99.5		98.9

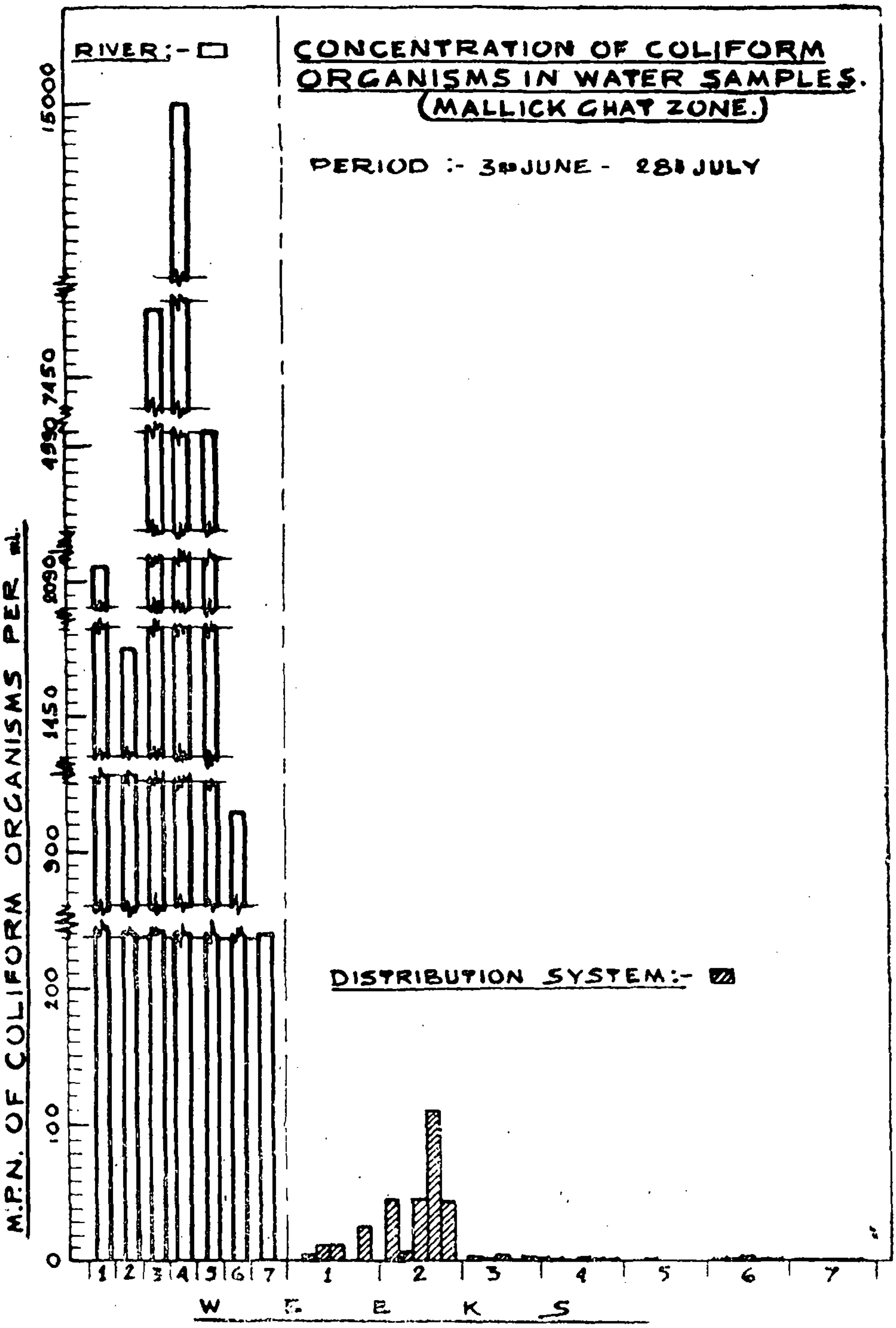
RIVER:-
CONCENTRATION OF COLIFORM ORGANISMS IN WATER SAMPLES.
(MALLICK GHAT ZONE.)
PERIOD :- 3rd JUNE - 28th JULY
DISTRIBUTION SYSTEM:-
M.P.N. OF COLIFORM ORGANISMS PER ml.
15000
7450
4990
2090
1450
900
200
100
0
1
2
3
4
5
6
7
W E E K S

Fig. 7

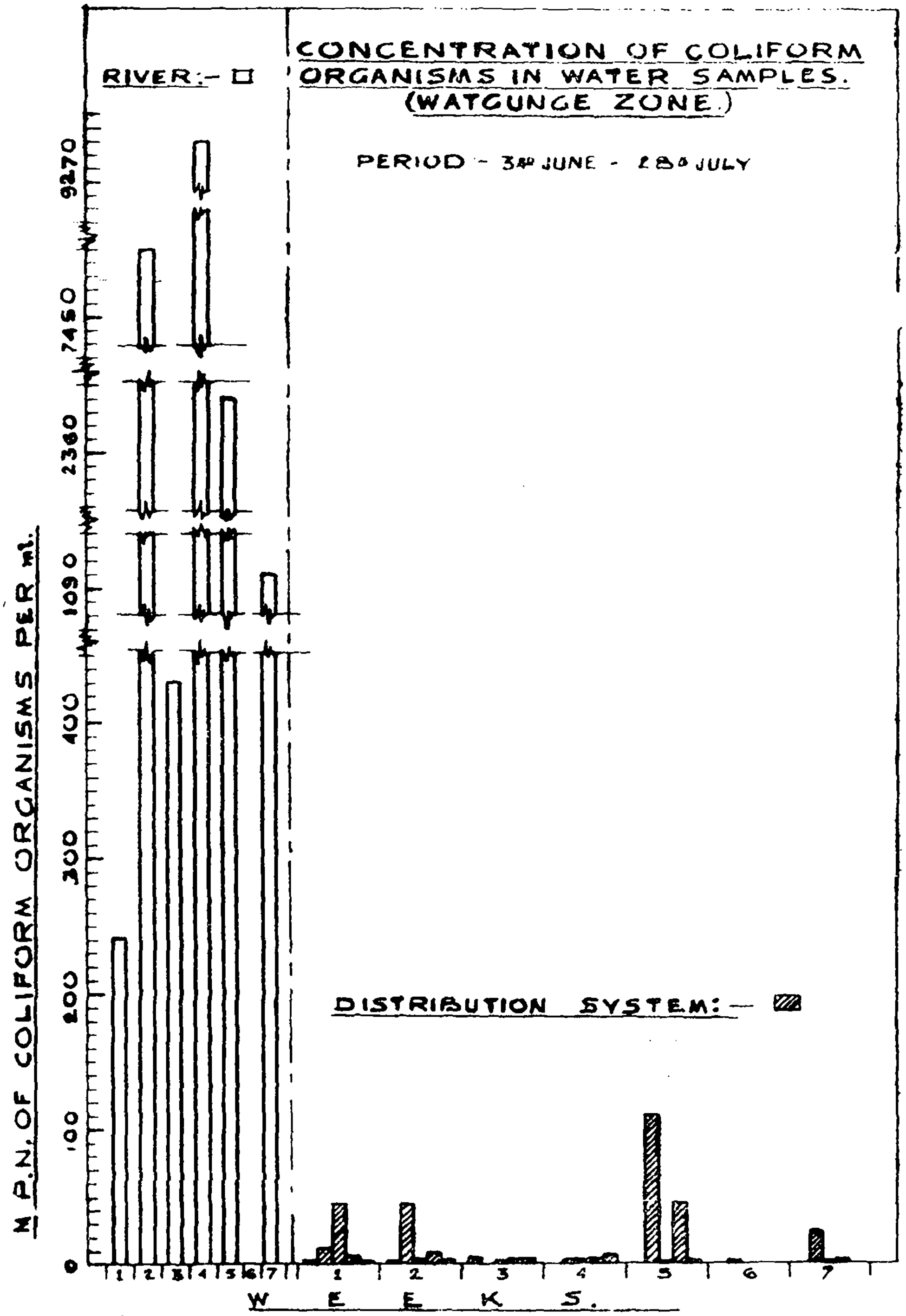
CONCENTRATION OF COLIFORM ORGANISMS IN WATER SAMPLES.
(WATGUNGE ZONE.)
RIVER:-
PERIOD - 3rd JUNE - 28th JULY
DISTRIBUTION SYSTEM:-
M.P.N. OF COLIFORM ORGANISMS PER ml.
9270
7450
2360
1090
400
300
200
100
0
1 2 3 4 5 6 7
1 2 3 4 5 6 7
WEEKS.

Fig 8

vement in the bacteriological quality of the unfiltered water supply.

Chlorine demand of river water during different seasons in the river

The stretch of the Hooghly river where the intakes for the unfiltered water supply are located is under tidal influence. The quality of water at the intakes is therefore subject to variation both diurnal and seasonal. Systematic sampling of the river water at the intakes was therefore carried out every 3 hr for 24 hr period, once a month, for 1 year to determine the diurnal and seasonal variations in the chlorine demand of the river water. The results obtained are presented in Table V and Fig. 9.

The results show that magnitude of the diurnal variation is of the order of 7 to 20 per cent. The average daily chlorine demand was lower in the months of September to Febru-

Table V—Dose of chlorine (mg/lit.) required to leave a residual of 0.5 mg/lit. after 10 min contact

Month & Year	May 1963	June 1963	July 1963	Sept. 1963	Oct. 1963	Nov. 1963	Dec. 1963	Feb. 1963	April 1964
				MULLICK GHAT PUMPING STATION					
Time									
11 a.m.	1.90	3.20	1.50	1.85	1.21	1.42	1.99	1.64	2.79
2 p.m.	2.27	3.00	1.50	0.78	1.92	1.46	1.49	1.64	1.70
5 p.m.	1.78	2.50	1.47	1.92	1.46	1.76	2.06	1.49	2.63
8 p.m.	2.20	2.80	2.39	1.85	1.64	1.49	1.64	1.92	2.49
11 p.m.	1.78	2.10	1.60	1.70	1.49	1.28	1.78	1.70	2.46
2 a.m.	2.06	2.60	2.02	1.64	1.28	1.07	1.64	1.85	2.91
5 a.m.	1.78	2.40	1.53	1.92	1.42	1.28	1.42	1.35	3.27
8 a.m.	2.06	3.30	1.64	1.45	1.78	1.28	1.85	1.71	3.13
Mean for the day	1.89	2.74	1.70	1.64	1.53	1.38	1.73	1.73	2.80
				WATGUNGE PUMPING STATION					
11 a.m.	2.85	2.80	1.49	1.39	1.64	1.71	1.71	2.41	—
2 p.m.	2.21	2.50	1.54	1.35	1.35	1.28	1.64	2.49	—
5 p.m.	2.42	1.60	1.78	1.71	1.42	1.85	1.64	2.20	—
8 p.m.	2.42	2.50	2.42	1.81	1.42	1.85	1.64	2.42	—
11 p.m.	2.56	2.30	1.74	1.49	1.28	1.28	1.84	1.99	—
2 a.m.	2.77	2.33	1.42	1.32	1.49	1.64	1.56	2.27	—
5 a.m.	2.56	1.50	1.62	1.46	1.21	1.21	1.49	2.20	—
8 a.m.	2.98	2.80	2.06	1.49	1.14	1.28	1.42	2.21	—
Mean for the day	2.60	2.41	1.76	1.50	1.37	1.51	1.53	2.27	—

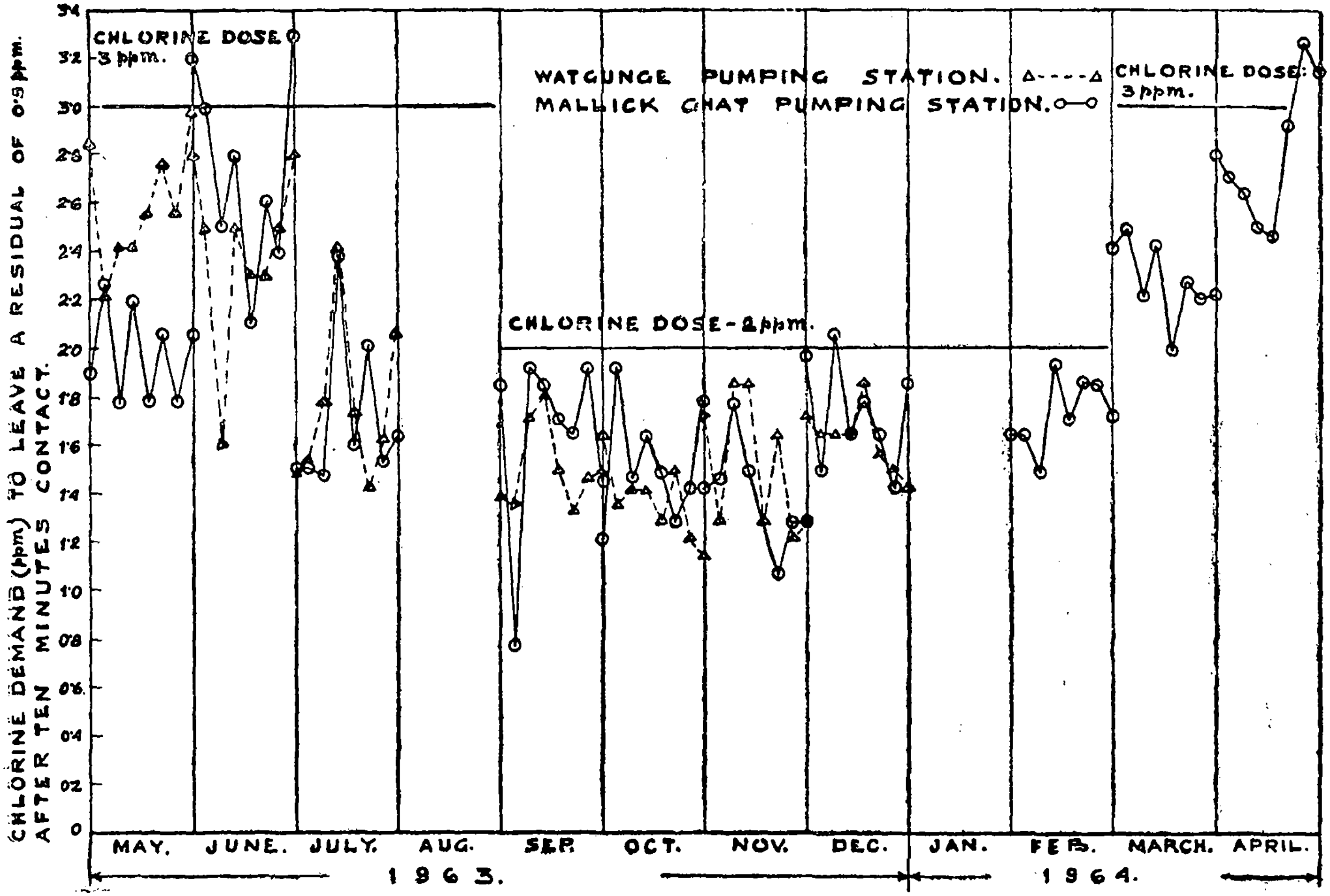

Fig. 9— Chlorine demand of river water

ary as compared to the period March to August. From the results obtained during 1963-64, it would appear that a chlorine dose of 2 mg/lit. for the period September to February and 3 mg/lit. for the period March to August would be sufficient to take care of the variations in the chlorine demand and provide adequate residual in the distribution system.

Discussion

One of the important conclusions arising out of the present investigations is that chlorination of the unfiltered water supply of Calcutta is practicable and provides adequate residual chlorine at all points in the distribution system. Chlorination is effective in destroying all vibrios including cholera vibrios and the salmonella group of organisms that are likely to be present in the river water. It also brings about 99 per cent reduction of the MPN of coliform organisms present in the water thereby leading to a marked improvement in the bacteriological quality of the unfiltered water supply. The presence of significant residuals throughout the distribution at all times may also bring about destruction of other gastro-intestinal pathogens that are likely to come in the city through unfiltered supply. It is evident from the foregoing results that chlorination of the unfiltered supply is one of the very useful interim measures in reducing the incidence of cholera and other gastro-intestinal diseases amongst population in the city exposed to the unfiltered supply.

The results of chlorine demand test carried out during different seasons in the year show that 2 to 3 mg/lit. chlorine dose would be sufficient to provide adequate residuals. This dose can not be considered excessive or uneconomical. The annual cost of chlorine for proper chlorination of the entire supply of 90 mill gal will be Rs. 2.4 lakhs at the rate of Rs. 650/- per 1,000 kg. The total cost of chlorination of the entire unfiltered supply will not exceed Rs. 3 lakhs per annum inclusive of staff for efficient operation of the process and depreciation on the chlorinators. Considering the benefits accruing from such a measure, this expenditure is fully justified.

It may also be observed that chlorination is not a permanent solution to all the problems associated with the unfiltered supply in the city of Calcutta. This measure can only prevent the entry of cholera and other gastro-intestinal pathogens into the city through the unfiltered water supply and thereby reduce the incidence of these diseases. The chlorinated unfiltered supply, can not, however, be considered satisfactory for drinking and other domestic uses. Apart from the pathogens, the unfiltered supply carries considerable amounts of silt which creates serious difficulties in proper maintenance of city drainage system which is also equally important from the point of view of better sanitation in the city. Because of the adoption of chlorination of unfiltered supply as an interim measure for the control of cholera and other gastro-intestinal diseases, the authorities should not slacken their efforts to replace the unfiltered supply with a filtered and properly purified supply.

Summary

1. The role of unfiltered water supply in the spread of cholera in Calcutta is discussed.

2. Results of laboratory experiments showed that a dose of chlorine sufficient to leave a residual of 0.5 mg/lit. at the end of 10 min. contact is adequate to destroy cholera vibrios added to unfiltered water samples.

3. Chlorine demand tests of the samples of river water during April 1963 showed that dose of chlorine of the order of 2 mg/lit. may be sufficient to provide 0.5 mg/lit. residual after 10 min contact. Based on the foregoing findings, chlorinators were installed in May 1963 for chlorination of the unfiltered water supply of Calcutta.

4. After chlorination was in operation for some time, an investigation was carried out to determine the effect of chlorination on the quality of unfiltered water supply in the city.

5. Examinations of samples from representative sections of the distribution system showed that the disinfection procedure is effective in providing adequate chlorine residuals throughout the entire distribution system of the unfiltered water supply.

6. Bacteriological examination of samples of water from the river and distribution system showed that chlorination was effective in preventing the entry of virbrios including cholera vibrios and salmonella group of organisms into the city through unfiltered water. Chlorination brings about 99 per cent reduction in MPN of coliform organisms of river water thereby leading to marked improvement in the overall bacteriological quality of supply.

7. Chlorine demand tests of the river water samples, collected during different parts of the day and night and during different months in the year showed significant diurnal and seasonal variations in the chlorine demand. The results also showed that a dose of 2.0 mg/lit. during the months September to February and 3.0 mg/lit. during March to August would be adequate for the proper chlorination of the unfiltered water supply.

8. The cost of chlorination of unfiltered supply and its usefulness as an interim measure in control of cholera and other gastro-intestinal diseases are discussed.

Acknowledgement

The authors wish to express their thanks to Dr. (Smt.) M. Sen, Director and Shri N. Majumdar, Professor of Sanitary Engineering for the encouragement and support given to this work; to Dr. K. Bhaskaran, Professor of Microbiology, who kindly carried out the experiments to determine the chlorine dose for effective kill of cholera germs in samples of unfiltered water and his guidance in other aspects of bacteriological work; to the Chief Engineer, Calcutta Corporation for providing necessary facilities for collection of samples from the distribution system; and to Shri G. Majumder, Technician, Microbiology Section for his assistance in carrying out the bacteriological work.

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DISCUSSION

SHRI M. M. GHATPANDE (Nasik) : The author has stated that when residual chlorine was 0 5 mg/lit., even the bacteria of salmonella group were not noticed. Some of these groups form spores. Is it possible to destroy the spores with a low dose of chlorine to the extent of 3 mg/lit. ?

SHRI S. SUBBARAO (Singur) : Spores of all Salmonella group of organisms will be destroyed provided the residual of 0.5 mg/lit. is in free form within the stated contact time of 10 minutes.

Proc. Symp. Problems in Water Treatment, Oct. 29-30, 1964 (CPHERI, Nagpur) (1965).

Emergency Water Disinfection In The Field

M D. PATIL and N. U. RAO
Central Public Health Engineering Research Institute, Nagpur

In any modern supply of potable water, supply has to be kept as free as possible from contamination by chemicals and bacteria. Water should also be treated before consumption by measures such as coagulation, sedimentation, filtration, and disinfection to be doubly sure of its potability. In many cases, increasing concentrations of municipal wastes are being discharged to the only available potable water source. This naturally necessitates specific treatment measures to be sure of the potability of the water supply with respect to its bacteriological safety.

Disinfection of water by Chlorine

Race (1) stated that the occasion on which chlorine compounds were first used for the disinfection of water can not be definitely ascertained. Probably sodium hypochlorite solution was used for treating wells as early as 1850, though it is now obvious that these well waters were chlorinated before it was known that micro-organisms were the causative agents for disease. Records show that sodium hypochlorite and chloride of lime were employed by a number of investigators. During 1890's, many experiments on water chlorination demonstrated the effectiveness of chlorine as a water disinfectant.

Faber (2) stated that great improvements in the methodology and techniques of the practice of water chlorination have been made in recent years. The chlorine demand of waters was found to be highly variable and it was recognised that satisfactory chlorination could be obtained not by applying a specific dosage, but on the basis of the residual which was maintained.

Iodine as a Disinfectant

Though iodine is commonly known as a germicide for medical application, it was frequently recommended for the treatment of small quantities of water as an emergency method. There has been very scanty information in the literature on its efficacy in water treatment and the concentration required for this purpose.

In 1918, Hinman (3), in a paper describing water supply problems in the field, referred to the use of tincture of iodine for sterilizing small quantities. Later in 1922, Hitchens (4) described the usefulness of iodine for disinfecting waters in the field. However, neither of these authors gave any experimental evidence to substantiate their statements. A survey of the literature up to 1937 reveals no actual laboratory or field data to bear out the repeated claim of the effectiveness of iodine in water treatment. However, this lacuna was filled by the work of Pond and Willard (5), who, in 1937, introduced a technique for studying this problem. Their results showed that seven per cent tincture of iodine (USP) in a concentration of two drops per litre would ordinarily be adequate to make any potable water innocuous within fifteen minutes.

Chang and Morris (6) showed that iodine was an effective agent against all types of pathogenic organisms, that can be transmitted through water, within a reasonable time at a concentration of a few parts per million. It was recommended as suitable for emergency disinfection of water supplies. It was claimed to maintain a substantial germicidal efficiency in waters of high *p*H value, and in waters containing ammonia or other nitrogenous materials. It was found that a dosage of 8 mg/lit. iodine reduced enteric bacteria concentration of 10^6 /ml to then 500/ml within 10 min.

Morris **et al** (7) used several compounds of iodine in their studies and concluded that any of them was suitable for the emergency disinfection of water, when used in amounts sufficient to yield 8 mg/lit. of active iodine. Taking storage property, thermal stability and humidity resistance into consideration, they recommended the use of tablets containing about 20 mg of tetraglycine hydroperiodide, 19 mg of disodium dihydrogen pyrophosphate, and 5 mg of talc as a convenient and reliable method for the emergency treatment of drinking water supplies.

Backwith and Mosser (8) studied the comparative efficiencies of chlorine, bromine and iodine for killing **Escherichia coli** and soil bacteria added to water samples. They showed that bromine was the most effective halogen. The methods used for testing the germicidal activities of these three halogens are not suitable for determining the potability of the waters.

The disinfecting properties of both chlorine and iodine are studied on polluted waters and reported in this Paper. Disinfection of polluted water is generally considered to involve the destruction of those bacteria that cause disease. Waters are seldom examined for the presence or absence of pathogenic bacteria. But tests are usually made for the detection of coliform bacteria. Their absence is considered as sufficient evidence for disinfection. This assumption is probably safe with reference to common bacterial infections.

Materials and Methods

Raw settled sewage was added to water in different quantities to obtain desired sewage concentrations. After thorough mixing, coliforms were estimated by MPN method using 5 tubes for each aliquot of the sample. Lactose broth and BGLB broth were used in presumptive and confirmation tests respectively. Whenever **E. Coli** was estimated, it was done by using BGLB at 44°C for confirmation and by the indole test.

Table I — Disinfection of small quantities of water using Halazone tablets

Sl. No.	Sewage concn %	Tablets added no.	Intial coliform count no./100 ml	pH	Coliform MPN/100 ml			Residual chlorine, mg/lit.		
					10 min.	20 min.	60 min.	10 min.	20 min.	60 min.
1.	1	1	2.8×10^{5}	7.8	350	2	0	0.75	0.7	0.6
2.	1	2	5.4×10	7.8	2	2	2	1.00	0.75	0.7
3.	2	3	1.4×10^{6}		4.5	2	0			
4.	10	4	1.75×10^{6}	8.0	21	13	0	3.0	2.5	1.0
5.	10	6	2.8×10^{6}	8.1	12	2	0	4.0	9.9	1.5

The disinfectant in the tablet or liquid form was added and coliforms were estimated as above after different contact periods, after neutralising the disinfectant in the sample under examination with thio-sulphate. Halazone tablets that were used in the First World War for disinfecting small quantities of water were tried in the first set of experiments and the results are recorded in Table I. It is found that sixty min contact period was necessary to make the water safe in majority of the cases under the conditions of the test.

The next batch of experiments was carried out using iodine tablets containing tetraglycine hydroperiodide as source of iodine and results are recorded in Table II. It is found that one litre of water containing 10 per cent of sewage could be made safe for drinking with 3 tablets after a 30 min contact period. Two tablets were found adequate to successfully disinfect one lit. of water containing 6 per cent of sewage after 30 min contact period. Though these doses are successful for disinfection, they can not be recommended because of the high concentration of 24 mg and 16 mg of iodine respectively. Each iodine tablet liberates 8 mg of elemental iodine.

At this stage, it was decided that raw water containing 4 per cent settled sewage should be arbitrarily taken as a representative type of water one may have to drink often in the field, under adverse conditions. It was also considered that one can normally wait for about 20 min to drink water after the addi-

Table II — Disinfection of small quantities of water* using iodine tablets

Sl.No.	Sewage concn %	Tablets added no.	Coliform MPN/100 ml			
			10 min.	20 min.	30 min.	60 min.
1.	Raw water only	1	7.8	0	—	0
2.	1	1	17	2	—	0
3.	1	2	0	0	—	0
4.	2	2	2	0	2	0
5.	4	2	4.5	4.5	0	0
6.	6	2	23	13	0	0
7.	8	2	130	79	23	2
8.	10	3	0	2	0	0

*Quantity of water taken, One litre; Coli form count of sewage, 0.7×10^8 for 100 ml; Coliforms count of the water used in Expt. No. 1, 110 MPN/100 ml

Table III — Disinfection of small quantities of water using tincture iodine

S. No.	Sewage concn %	I_2 mg/lit.	pH	Initial coliform MPN/100 ml	Temp. C	Coliform MPN/100 ml				Residual Iodine mg/lit.			
						5 min.	10 min.	20 min.	40 min.	5 min.	10 min.	20 min.	40 min.
1.	4	4	8.1	3.3×10^6	28	49	49	7.8	4.5	Nil	Nil	Nil	Nil
2.	4	4	8.2	0.96×10^6	29.5	240	43	9.1	0	Nil	Nil	Nil	Nil
3.	4	3	8.2	0.92×10^6	30	23	9.1	0	3.6	5.5	4.57	3.8	2.55
4.	4	8	8.2	1.2×10^6	30	79	17	0	2	5.58	3.81	2.54	2.54

Table IV — Disinfection of small quantities of water using chlorine solution

Sl. No.	Sewage concn %	Chlorine mg/lit.	pH	Initial coliform MPN/100 ml	Temp. C	Coliform MPN/100 ml				Residual Chlorine mg/lit.			
						5 min.	10 min.	20 min.	40 min.	5 min	10 min.	20 min.	40 min.
1.	4	2	8.1	0.35×10^8	30	2400	22	2	2	1.5	1.5	1.5	1.5
2.	4	4	8.1	0.7×10^8	30	11	4.5	0	4	3.0	3.0	3.0	2.8
3.	4	8	8.1	0.7×10^8	30	0	2	0	0	(More than 5 —)			

(Note : Residual Chlorine measurements were done by using ortho-toluidine and Comparator-box, and a disc having maximum 2 mg/lit. colour index. Whenever necessary, the sample was diluted to bring it down in the disc range. The results of residual chlorine are rough index rather than accurate readings) tion of any disinfectant. Hence the contact period of 20 min was given in most of the experiments. Experiments were then carried to estimate dose of iodine or chlorine required to render 4 per cent sewage-polluted water safe for drinking after 20 min contact period. The results are recorded in Tables III & IV. It can be observed that a dose of 8 mg/lit. of iodine or 4 mg/lit. of chlorine is suitable for this purpose. It was also interesting to note that after a contact period of 40 min, there were some coliform counts below five, though there were none after twenty min.

Iodine is becoming increasingly popular as a disinfectant for small quantities of water in emergency conditions, as in the war front, because its activity is less affected by *p*H of water and the presence of nitrogenous compounds in it. Hence, a comparative study of the disinfecting abilities of iodine and chlorine was carried out at different *p*H values, viz., 8.1, 9.1 and 6.8. The test for **E. coli** was also carried out along with coliforms. The results are recorded in Table V.

Discussion and Conclusion

Disinfection of polluted water is considered satisfactory when coliform bacteria are absent from 100 ml quantity of water. Moreover, the killing of **E. coli** is considered as sufficient evidence for the destruction of enteric pathogens in water. Hence, in the experiments where the disinfecting abilities of chlorine and iodine, were studied at different *p*H, both coliforms and **E. coli** were estimated.

Since it could be dispended in tablet form, Halazone was used during First World War to disinfect small quantities of water. About 3.3 mg/lit. of Halazone was found adequate to treat normal water. Larger amounts were necessary for more polluted water. In the present study, this concentration was found adequate to reduce initial coliform count of 2.8×10^5 per 100 ml to 2 organisms per 100 ml in 20 min contact period and zero in 60 minutes. When sewage concentration is increased from 1 to 2 per cent, 10 mg/lit. of Halazone was required to produce the same results.

In experiments with iodine tablets, two tablets were found to be adequate to disinfect one litre of water containing 4 per cent sewage. Each tablet is supposed to contain 8 mg of elemental iodine. This shows that 16 mg of iodine per litre of contaminated water is necessary for disinfection. When tincture iodine was used in subsequent experiments, a dose of 8 mg/lit. was found to be adequate for disinfecting the same type of contaminated water. This may be due to loss of iodine from the tablets during storage.

In experiments with tincture iodine and chlorine (Tablets III & IV), it was observed that, in certain instances, coliforms less than 5/100 ml were found after a contact period of 40 min while no coliforms could be detected after 20 min exposure. This is an apparent discrepancy. Rationally, it is probable since it is not uncommon to come across this kind of discrepancies dealing with waters of low bacterial concentrations.

Table V — Comparative efficiency of chlorine and iodine at different *p*H values

(Concentration of sewage, 40%; Chlorine dose, 4 mg/lit.; Temperature, 30 C; Initial coliform and **E. Coli** count, 10 /100 ml)

*p*H	CHLORINE				IODINE			
	Coliform MPN/100 ml				Coliform MPN/100 ml			
	5 min.	10 min.	20 min	40 min	5 min	10 min	20 min	40 min
6.8	4	0	0	0	2	0	0	0
8.1	11	4.5	0	4	79	17	0	2
9.1	23	2	0		46	4.5	7.8	0
	E. Coli						**E. Coli**	
6.8	0	0	0	0	2	0	0	0
8.1	2	4.5	0	0	2	0	0	0
9.1	23	2	0	0	33	4.5	2	0

In the preliminary studies, it was found that 8 mg/lit. of iodine could make waters containing a maximum of 4 per cent sewage safe after 20 min contact period. The same type of contaminated water could be disinfected with 4 mg/lit. of chlorine. Hence studies on the comparative efficiencies of chlorine and iodine as disinfectants were carried out using the above concentrations at different pH, in the range of 6.8—9.1, since natural waters normally fall within this range.

Since water containing more than 8 mg/lit. of iodine can not be consumed regularly without adverse effect on the human health, it can not be recommended to disinfect water having more than 4 per cent of sewage pollution. However, with chlorine, higher doses than even 8 mg/lit. can be used to disinfect waters containing more than 4 per cent sewage. This can be done safely because regular consumption of water containing up to 30 mg/lit. of chlorine is shown to have no ill effects on health.

Studies are under progress to determine concentrations of chlorine necessary to disinfect waters of higher pollution than 4 per cent sewage concentration.

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Bacterial Reduction At Different Stages In Water Treatment

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Water intended for human consumption must be free from chemicals and micro-organisms that are harmful to health. In addition, water should be odourless and sparkling to make it aesthetically attractive. In spite of 17 years of Freedom, it has not been possible to provide this basic amenity, pure water, to a large proportion of Indian people. The urban population of India is about 73.83 million and is distributed over 2,690 towns and cities. Of these, 248 cities have a population of more than 50,000. Only 34 per cent of the total urban population can be said to enjoy water supply and sanitation facilities at a satisfactory level. This includes cities like Calcutta, Bombay and Madras which have water supplies that are outmoded and very insufficient in quantity for the increased population. Rs. 720 million have been spent during the 12½ years of the three Five-year plan periods. The work yet to be done to cover the urban areas with satisfactory water facilities is of very big magnitude. For the rural population, which is about 359 million, the picture with respect to water supply is very dismal (1).

It is generally believed that if the raw water does not contain more than 5,000 coliforms per 100 ml, the conventional water treatment with rapid sand filtration and post-chlorination will eliminate these bacteria to make the water safe (2).

Cox (3) stated that the removal of bacteria by filtration depends on the effectiveness of flocculation and sedimentation. He pointed out that the degree of removal of coliforms by the combination of flocculation, sedimentation, rapid sand filtration and post-chlorination should be 99.98 per cent.

The efficiency of water treatment is generally gauged by the removal of turbidity. Sedimentation and filtration, two vital steps in water treatment, are responsible for the final clear water. Since these two processes are also responsible for the removal of a large percentage of bacteria, it is worth-while to study their performance in this respect in a water treatment plant.

Not much data is available on the bacteriological performance of water treatment plants at different stages of water treatment. To assess this, a systematic study of the bacteriology of water at different stages in two treatment plants of Nagpur was carried out for a period of two years.

from January 1961 to December 1962 and has been reported in this paper.

Nagpur City, having a population of 7 lakhs (approx.) gets its water supply from Ambazari and Gorewada lakes and Kanhan river. The waters from Kanhan and Gorewara are treated by the conventional methods of coagulation, sedimentation, rapid sand filtration and chlorination, whereas the Ambazari water is straight-away chlorinated before distribution. In Kanhan and Gorewada treatment plants, bacteriological analysis was carried out on raw, settled, filtered and chlorinated waters. Since there is no conventional method of treatment at Ambazari lake, this water was not studied.

Gorewada lake is 4 miles away from the City with a catchment area of 28.8 sq km (11.2 sq miles) and its waterspread area is 1.9×10^6 sq m (20.5×10^6 sq ft). It has a maximum depth of 7.8 m (25.5 ft) in rainy season, with a capacity of 1944×10^6 gal (312×10^6 cu ft and the average quantity of water supplied from this source is 4.0 mill gal/day. Kanhan water works supplies 12 mill gal/day of treated water to Nagpur City.

Bacteriological Studies

Samples of raw, settled, filtered and chlorinated waters were collected every week during 1961 and 1962 from Kanhan and Gorewada water treatment plants. All the samples were analysed bacteriologically for the following groups of organisms.

i. *Coliforms* : These were estimated by multi-tube technique using five tubes for each dilution. Lactose broth and brilliant green bile lactose broth were used as presumptive and confirmatory media respectively.

ii. *Escherichia coli* : All the presumptive tubes that became positive at the end of 24 and 48 hr were subcultured into brilliant green bile lactose broth and incubated at 44°C for 24 hr. Positive brilliant green bile lactose broth tubes were further confirmed for **E. coli** by Indole test at 44°C.

iii. *Enterococci* : These were enumerated by MPN method using Hanny and Norton's sodium azide broth (4) in the presumptive test carried out at 44°C for 48 hr followed by confirmation by streaking a heavy inoculum from each positive tube onto MacConkey agar plates and incubating at 44°C.

For estimating coliforms and enterococci, the quantity of the sample and its dilutions were selected on the basis of their bacterial load. Ten ml and 1 ml portion and serial dilutions were planted in a series of 5 tubes each, using double strength media for 10 ml volumes and single strength media for the others.

Results

The method selected to report the mean values for bacterial counts in any month should have the property of giving an unbiased estimate. For variables that are normally distributed, the arithmetic mean has this property. The MPN counts of coliforms and other organisms in these waters are not normally distributed. Therefore the arithmetic mean for such data will not provide the central tendency. One or two extremely high or low values reported during a month will distort the arithmetic mean to such an extent that it does not truly represent the general condition for that period. The geomeric mean, on the other hand, gives a picture of central tendency and hence it is a truer estimate than the arithmetic mean.

Percentage removal of coliforms, **E. coli** and enterococci at different stages of water treatment, are recorded in Table Nos. I, II and III respectively. The average reduction for the 2 year period in coliform, **E. coli** and enterococci is given in Table IV.

Table I—Percentage Removal Of Coliforms

	GOREWARA WATER TREATMENT PLANT % Removal after				KANHAN WATER TREATMENT PLANT % Removal after			
Months and Years	Raw water MPN/ 100 ml.	I Coagulation & Sedimentation	II I+ Filtration	III II+ Chlorination	Raw water MPN/ 100 ml.	I Coagulation & Sedimentation	II I+ Filtration	III II+ Chlorination
1961								
Jan.	8.0	— 12.5	25.0	100.0	1104.0	97.6	95.9	99. 7
Feb.	10.0	—880.0	—190.0	100.0	1653.0	99.2	97.6	99. 9
Mar.	37.0	—165.0	21.6	100.0	439.0	47.4	66.5	100. 0
Apr.	9.0	— 22.2	—144.4	44.4	1460.0	— 19.5	98.4	100. 0
May	32.0	— 37.5	— 6.6	96.9	1358.0	61.9	94.0	99. 6
June	29.0	20.7	10.4	100.0	1460.0	23.7	89.0	100. 0
July	198.0	1.0	21.8	100.0	2400.0	55.8	89.7	99. 9
Aug.	647.0	77.1	95.1	100.0	2167.0	33.6	62.4	99.95
Sept.	271.0	51.7	87.8	100.0	5369.0	55.3	80.4	99.97
Oct.	55.0	20.0	45.5	100.0	2426.0	44.1	89.0	99. 8
Nov.	64.0	54.7	— 28.1	100.0	198.0	—371.7	76.8	99. 0
Dec.	5.0	—220.0	—320.0	100.0	538.3	88.5	93.7	99. 7
1962								
Jan.	4.0	Nil	25.0	100.0	100.0	69.0	89.3	100. 0
Feb.	3.0	—100 0	— 66.7	100.0	280.0	— 39.3	91.8	100. 0
Mar.	5.0	—260.0	Nil	100.0	372.0	— 71.8	88.5	99. 2
Apr.	2.0	—200.0	—500.0	100.0	264.0	49.6	93.2	96. 6
May	16.0	12.5	31.3	93.8	1470.0	— 2.6	79.9	99. 8
June	6.0	100.0	— 16.7	100.0	1141.0	— 14.0	90.2	100. 0
July	197.0	83.2	88.8	100.0	8527.0	94.8	98.3	99.97
Aug.	91.0	31.9	68.1	100.0	1880.0	89.6	95.1	99.95
Sept.	121.0	42.1	78.5	100.0	4112.0	80.4	74.8	100. 0
Oct.	15.0	6.7	33.3	100.0	683.0	— 5.6	95.5	100. 0
Nov.	14.0	28.6	42.9	100.0	206.0	92.7	90.8	99. 5
Dec.	20.0	— 75.0	55.0	95.0	1060.0	90.4	96.1	99. 6

Table II—Percentage Removal of Escherichia coli

Months and Years	GOREWARA WATER TREATMENT PLANT % Removal after				KANHAN WATER TREATMENT PLANT % Removal after			
	Raw Water MPN/ 100 ml.	I Coagulation & Sedimentation	II I + Filtration	III II + Chlorination	Raw Water MPN/ 100 ml.	I Coagulation & Sedimentation	II I + Filtration	III II + Chlorination
1961								
Jan.	2.0	Nil	50.0	100.0	72.0	77.8	97.2	98. 6
Feb.	2.0	Nil	50.0	100.0	366.0	99.2	98.1	100. 0
Mar.	2.0	—150.0	—100.0	100.0	186.0	83.3	89.8	100. 0
Apr.	2.0	— 50.0	—100.0	100.0	274.0	72.6	97.8	100. 0
May	3.0	—300.0	— 33.3	66.7	687.0	77.7	98.5	99. 6
June	10.0	50.0	80.0	100.0	155.0	72.9	70.3	100. 0
July	82.0	Nil	87.8	100.0	213.0	62.0	63.8	99. 1
Aug.	186.0	93.0	89.3	100.0	1284.0	66.6	76.5	99. 8
Sept.	64.0	17.2	82.8	100.0	365.0	—384.9	—16.4	100. 0
Oct.	14.0	— 28.6	— 28.6	100.0	8887.0	26.3	80.7	99. 5
Nov.	9.0	55.6	— 11.1	100.0	153.0	—107.8	89.5	100. 0
Dec.	1.0	—100.0	—200.0	100.0	167.0	91.1	98.2	100. 0
1962								
Jan.	1.0	100.0	Nil	100.0	49.0	87.8	91.8	100. 0
Feb.	2.0	100.0	Nil	100.0	45.0	— 62.2	75.6	100. 0
Mar.	2.0	— 50.0	Nil	100.0	33.0	— 24.2	63.6	93. 9
Apr.	1.0	—200.0	—300.0	100.0	23.3	13.1	82.6	91 .3
May	3.0	— 33.3	—166.7	100.0	693.0	33.5	92.8	99. 7
June	3.0	— 66.7	— 66.7	100.0	856.0	10.4	93.3	100. 0
July	65.0	83.1	90.8	100.0	1476.0	78.9	96.2	100. 0
Aug.	19.0	36.8	68.4	100.0	1095.0	90.4	92.8	100. 0
Sept.	14.0	— 64.3	57.1	100.0	2384.0	83.3	93.9	100. 0
Oct.	4.0	Nil	25.0	100.0	23.0	— 56.5	69.6	100. 0
Nov.	1.0	—100.0	Nil	100.0	21.0	90.5	90.5	100. 0
Dec.	3.0	— 33.3	33.3	100.0	255.0	91.4	97.7	99. 2

Table III—Percentage Removal of Enterococci

Months and Years	GOREWARA WATER TREATMENT PLANT Raw Water MPN/ 100 ml.	% Removal after I Coagulation & Sedimentation	II I + Filtration	III II + Chlorination	KANHAN WATER TREATMENT PLANT Raw Water MPN/ 100 ml.	% Removal after I Coagulation & Sedimentation	II I + Filtration	III II + Chlorination
1961								
Jan.	0.0	—	—	—	87.0	88.5	97.7	100.0
Feb.	0.0	—	—	—	93.3	93.5	100.0	100.0
Mar.	0.0	—	—	—	9.0	— 11.1	88.9	100.0
Apr.	0.0	—	—	—	19.0	— 57.9	100.0	100.0
May	2.0	Nil	— 50.0	100.0	18.0	55.6	77.9	88.9
June	3.0	— 66.7	— 66.7	100.0	133.0	24.8	84.2	100.0
July	26.0	53.8	84.7	100.0	1110.0	94.1	99.1	100.0
Aug.	26.0	69.2	88.5	100.0	811.0	89.8	96.3	100.0
Sept.	10.0	60.0	40.0	100.0	735.0	63.4	94.2	100.0
Oct.	7.0	42.9	42.9	100.0	159.0	19.5	85.5	97.0
Nov.	0.0	—	—	—	11.0	—509.1	72.7	100.0
Dec.	2.0	100.0	Nil	100.0	26.0	73.1	92.3	100.0
1962								
Jan.	0.0	—	—	—	32.0	87.5	93.8	100.0
Feb.	0.0	—	—	—	41.0	4.9	92.8	100.0
Mar.	0.0	—	—	—	13.0	— 7.7	84.6	100.0
Apr.	1.0	Nil	—500.0	100.0	109.0	90.8	98.2	96.3
May	5.0	20.0	60.0	100.0	72.0	47.2	84.7	97.2
June	2.0	—200.0	— 50.0	50.0	270.0	35.2	82.2	100.0
July	12.0	Nil	50.0	100.0	712.0	91.6	99.2	100.0
Aug.	8.0	— 87.5	75.0	100.0	1668.0	93.1	94.9	100.0
Sept.	11.0	18.2	72.7	100.0	633.0	72.4	93.0	100.0
Oct.	3.0	33.3	100.0	100.0	13.0	7.7	76.9	100.0
Nov.	2.0	50.0	100.0	100.0	10.0	70.0	80.0	100.0
Dec.	4.0	— 50.0	50.0	100.0	168.0	86.3	94.6	100.0

Table IV—Average percent reductions of organisms from raw water

(Jan. 1961 — Dec. 1962)

Treatment Processes	GOREWARA WATER TREATMENT PLANT			KANHAN WATER TREATMENT PLANT		
	Coliforms	E. Coli	Enterococci	Coliforms	E. Coli	Enterococci
I. Coagulation & Sedimentation	36.0	67.0	50.0	69.0	69.0	65.0
II. I+ Filtration	51.0	65.0	69.0	88.0	87.0	90.0
III. II+ Chlorination	97.1	98.6	96.9	99.7	99.2	99.1

COLIFORMS

Gorewara Water Treatment Plant : After coagulation and sedimentation, there was actually a negative reduction (increase) in quite a few months. This happened only when the monthly coliform MPN average was less than 40 per 100 ml. If the months showing an increase in coliforms after sedimentation are ignored, the average per cent reduction in coliforms after sedimentation is 36.0 (Table IV).

After coagulation, sedimentation and filtration, also, in 11 months out of 24, an increase in coliforms was noticed. This is rather surprising. Occasionally one expects larger number of bacteria in the filtered water than that in the raw water, particularly, after the rapid sand filters are backwashed. Even then, in 9 out of these 11 months, the finished waters were found to be potable. In the other two cases, only 5 and 1 coliforms per 100 ml were present. Considering the months during which there was actual reduction in coliforms after coagulation, sedimentation and filtration, the average per cent reduction from raw water was 51.0 (Table IV).

Out of the 24 months under study, there was 100 per cent reduction during 20 months after the complete treatment. Of the other 4 months, one coliform per 100 ml. was present in 3 months and 5 coliforms per 100 ml. during one month. The average monthly reduction was 97.1 per cent (Table IV).

Kanhan Water Treatment Plant : The raw waters were very highly contaminated with coliforms. In 7 out of 24 months, there was negative reduction in coliforms after coagulation and sedimentation. If the months during which there was actual reduction in numbers of these organisms are considered, the percentage reduction after sedimentation would be 69.0 (Table IV).

In contrast to the Gorewada Water Treatment Plant, where there was increase in coliforms after filtration, this Plant shows considerable reduction in these organisms during every month of this 2 year period. The average monthly reductions after coagulation, sedimentation and filtration is 88.0 per cent (Table IV).

During 21 out of 24 months under study, the reduction in coliforms after chlorination was above 99.5 per cent. The average reductions during the rest of 3 months being 96.6, 99.0 and 99.2 per cent. The final waters in these three months had 9, 2 and 3 coliform MPN per 100 ml. The water showing a 99.2 per cent reduction had 3 organisms per 100 ml while the one with 99 per cent reduction had only 2 organisms per 100 ml because the former had a much higher initial bacterial concentration.

During 14 out of these 24 months, the reduction was above 99.9 per cent. Out of these 14 months, there was 100 per cent reduction in 8 months. Taking all the 24 months into consideration, the monthly average reduction after chlorination was 99.7 per cent (Table IV).

ESCHERICHIA COLI

Gorewada Water Treatment Plant : During 12 months of the 24, there was an increase after coagulation and sedimentation. Out of these 12 months which showed a negative decrease, this organism was present in a concentration of 3 or less per 100 ml of water during 10 months. During the other 2 months, its concentration was 14 per 100 ml. Considering the months in which there was actual reduction after coagulation and sedimentation, the average was 67.0 per cent (Table IV).

After sedimentation and filtration, in 9 months out of 24, there was an increase in **E. coli** concentration. Here again, during 7 out of these 9 months, the **E. coli** concentration in the raw waters was less than 3 per 100 ml. During the other two months, it was 9 and 14 per 100 ml. The average monthly reduction of **E. coli** was 65.0 per cent, (Table IV), if the months with reductions are only consideration.

E. coli was reduced by 100 per cent after coagulation, sedimentation, filtration and chlorination in 23 out of 24 months. During that one month, raw water had 3 organisms per 100 ml, while the finished water had 1 per 100 ml.

Kanhan Water Treatment Plant : After coagulation and sedimentation, positive reduction of this organism occurred during 19 out of 24 months, giving an average of 69.0 per cent (Table IV). However, after sedimentation and filtration, 23 out of 24 months showed significant reductions with a monthly average amounting to 86.0 per cent (Table IV).

After the full treatment, the final chlorinated waters during 15 months out of 24 showed 100 per cent decrease in **E. coli** from raw water. The final monthly average **E. coli** reduction was 99.0 per cent (Table IV).

ENTEROCOCCI

Gorewada Water Treatment Plant : These organisms occurred in very low numbers, whenever they did. The average reduction after coagulation and sedimentation was 50 per cent. Coagulation, sedimentation and filtration resulted in a monthly average of 69 per cent reduction (Table IV). After post-chlorination, there was 100 per cent reduction during all but one month, in which the raw water showed 2 organisms per 100 ml and the finished water, 1 organism per 100 ml.

Kanhan Water Treatment Plant : There was an average monthly reduction of 65 per cent in enterococci after coagulation and sedimentation during the 20 month period showing reduction. After filtration the average reduction for the entire 24 months period was 90 per cent; while the finished water after chlorination showed a 100 per cent reduction during 20 of the 24 months. The average final reduction of enterococci was 99.1 per cent for the entire 24 month period (Table IV).

Discussion and Conclusions

In Gorewada lake and Kanhan river, the raw waters showed a definite seasonal variation in the numbers of these three groups of organisms; Coliforms, **E. coli** and Enterococci. They occurred in much larger numbers in the monsoon than the rest of the year. This obviously is due to the rains bringing in the contamination through the run-off waters. The Gorewada lake water showed much less bacteria than the Kanhan river water, because of the natural settling that occurs in lakes.

In both the treatment plants, considerable numbers of samples showed an increase in the bacterial numbers after coagulation and sedimentation. This increase in numbers was noticed only in samples of comparatively low bacterial density. This phenomenon is difficult to explain. It may be due to getting unsettled flocs, containing large concentrations of bacteria, in the sample collected. The other possibility may be sampling error, particularly in the case of waters containing 5 organisms or less per 100 ml. The average reduction after coagulation and sedimentation was calculated only taking the positive reduction into consideration. Sometimes, the percentage figures are misleading particularly when the raw water had very low bacterial density. This phenomenon is difficult to explain. It may be due to getting unsettled flocs. For example, when raw waters containing 10 and 2 organisms per 100 ml show a reduction of 50 per cent after coagulation and sedimentation, the settled water would contain 5 and 1 organisms per 100 ml respectively.

From Table IV, it can be seen that the reduction in all these three groups of organisms after sedimentation, and sedimentation and filtration, is lower in Gorewada Water Treatment Plant than in the Kanhan Water Treatment Plant. This may be because of the fact that Gorewada lake water had much lower bacterial density than Kanhan raw water. Another significant factor for this difference is that the turbidity of lake waters never exceeded 100 mg/lit., while that of the river water went up to 2,000 mg/lit. Hence, in waters of high turbidity, better removal of bacteria takes place after sedimentation and filtration.

The average per cent reduction after the complete treatment really does not give a clear cut idea about the performance of the water treatment plants. It is always better to look into the number of organisms in the final chlorinated effluent from the water treatment plants than the percentage reductions from the raw water. For example, from Table IV it can be seen that the average reduction of coliforms in Gorewada Water Treatment Plant, was only 97.1 per cent. One would get the impression from this figure that the plant performance was not satisfactory. But, from the data obtained, it is known that during 20 out of 24 months, there was 100 per cent reduction in coliforms. Of the other four months, there was 1 organism per 100 ml in 3 months and 5 organisms per 100 ml during the 4th month in the finished waters. In the case of enterococci, out of the 16 months during which they occurred in Gorewada raw water, there was 100 per cent reduction in the finished waters during 15 months. During the 16th month, the finished water had 1 organism per 100 ml indicating 50 per cent reduction. Because of this one month period during which there were only 2 organisms per 100 ml in raw water, the final average reduction in finished water dropped to 96.9 per cent. This final average per cent reduction obviously does not give the real picture about the performance of water treatment plant.

Because of these apparent discrepancies, the results were reported both in the form of monthly percentage reductions though the final average for the two year period was also given. The results obtained on the finished chlorinated water are as follows for these two water treatment plants.

i. *Coliforms :* Gorewada showed 100 per cent reduction during 20 out of 24 months. The effluent during three months showed 1 organism per 100 ml, and, and in the fourth month, there were 5 organisms per 100 ml.

In Kanhan, however, only 8 out of 24 months showed 100 per cent reduction. During the other 16 months, an MPN of less than 10 per 100 ml occurred.

ii. *Escherichia Coli :* There was 100 per cent reduction during 23 out of 24 months in case of Gorewada and, in one month, only 1 organism per 100 ml was present. However, in Kanhan only 15 out of 24 months showed 100 per cent reduction while the rest of the months showed an MPN of 5 or less per 100 ml.

iii. *Enterococci :* These organisms occurred in Gorewada raw water in 16 months out of 24 months. There was 100 per cent reduction in 15 months while the 16th month showed one organism per 100 ml. In Kanhan, the raw water contained these organisms during the entire 24 month period. There was 100 per cent reduction in 20 months, while the other four months had less than 5 organisms per 100 ml. in the final effluent.

These results clearly show that the performance of Gorewara Water Treatment Plant was much better than the Kanhan Water Treatment Plant. This may be due to lower bacterial density and low turbidities of the Gorewara raw waters.

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DISCUSSION

DR. M. G. GEORGE (Delhi) : The authors have discussed the reduction in coliform organisms at different stages in water treatment for three sources at Nagpur. Similar studies have been carried out at Delhi for one year at both the sources of water supply, Wazirabad and Okhla. The data are being analysed to compute the reduction in coliform, enterococcus and certain other organism at different stages. However, it is our observation that with proper prechlorination, coagulation, sedimentation, filtration and chlorination with more than 1 mg/lit. free residual chlorine and several hours contact time, a count upto several lakhs in raw water could be reduced to zero.

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Some Economic Aspects of "Pasterilizer" system

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Introduction

The flowing open stream has long been man's most common and readily available source of fresh water, as also the most convenient waste disposal system. The practice of using a stream or river for both water supply and waste disposal systems seems incredible but until this Earth became heavily populated, the process worked quite satisfactorily. The amount of waste was small, the nature of the waste, that of an agrarian economy, and the rivers and streams could accommodate such wastes by dilution and by aeration with little or no danger from pollution.

We no longer have an agrarian economy and our industrial wastes do not respond well to natural purification. Our population has recently increased by astronomical porportions. The number of people presently inhabiting this Earth exceeds the total of all humans who no longer live. The problems of waste disposal for populations of this magnitude are still unsolved and, as time goes on, will likely become more serious. The result at present, has been pollution of a great many of our lakes, streams and rivers affecting the quality of our potable water supplies. This has had a deleterious effect on many of our important natural resources.

Sources of fresh water which were once safe are now suspect and require extensive treatment before becoming suitable for human consumption. Shortage of water during draught has required the re-use of treated sewage effluents as potable water in some of the water starved areas of the United States, such as the classic case of the City of Chanute, Kansas. Less spectacular but nonetheless significant is the contamination of water supply wells from septic tank effluent. This problem, once minor and generally confined to farms, has become a major problem in many of our mushrooming housing developments.

One way to be assured of bacteria-free water without imparting an objectional taste and thereby limiting its usefulness is to sterilize it. This is perhaps the oldest and possibly the most effective way to destroy bacteria in water. It need not affect taste and if carried out at a sufficiently high temperature will destroy all known micro-organisms.

Whether sterilization of water for producing a potable water supply is feasible depends mainly on its economics. An understanding of the economic factors may be gained by comparing the costs for producing potable water from non-potable supplies by distillation, by "Pasterilization" and by pasteurization.

Processes Considered

To make such a comparison, it is reasonable to assume three conditions as follows:

1. Processing contaminated and filtered water for a drinking water supply.
2. Processing complete treatment sewage effluent for the re-charging of water wells by ground seepage.
3. Processing complete treatment sewage effluent for a drinking water supply.

In selecting equipment for the above cases, heat exchange apparatus for both sterilization and pasteurization of water were considered. Fig. 1 includes data relative to heat transfer surfaces for the heating/cooling process and for the heating process for both the sterilization and pasteurization systems. The maximum sterilization temperature was selected at 290°F., while the pasteurization process temperature selected at 170°F. The temperature scales in the figure for both the sterilization and pasteurization processes are the same but, because of the relative size of the counterflow heat exchangers in relation to the heaters, the scale showing square feet of surface for the heaters is ten times that for the heat exchangers. This extreme difference with respect to

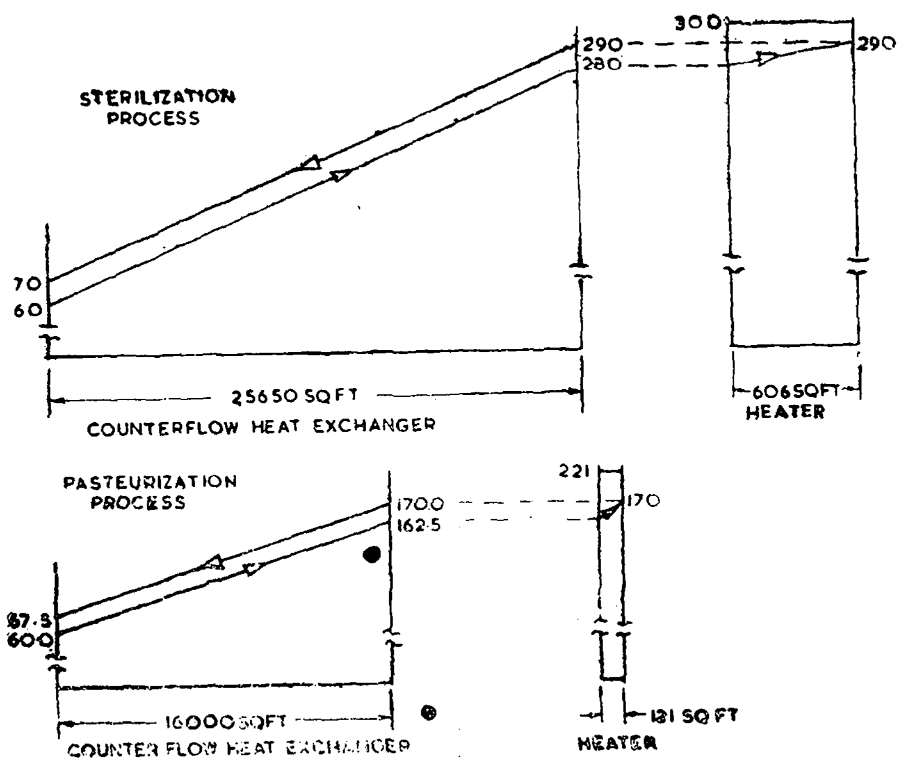

Fig. 1— Heat transfer relationships of 'Pasterilizer' process

surface requirements is an indication of the small amount of heat required to thermally treat the water. Actually, only 10 Btu/lb of water produced for the sterilization process and 7.5 Btu/lb for the pasteurization process is all the heat required for these two systems. The distillation process selected for comparison, and incidentally more efficient than any installed to date, requires 67 Btu/lb of water produced.

The selection of a terminal temperature difference of 10°F and 7.5°F for the "Pasterilizer" and the pasteurizer is based on an economic evaluation. Fig. 2 shows a plot of the data for the heat transfer equipment for the sterilization process and indicates that minimum fuel and capitalization costs occur at about a 10°F temperature difference. A similar plot of data showed that the minimum cost for the pasteurizer process occurs with a design temperature difference of 7.5°F. Both are based on heat supplied to the system at a cost of 50 cents per million Btu using current costs for the heat exchangers and heaters. The capitalization charges used were 15 per cent.

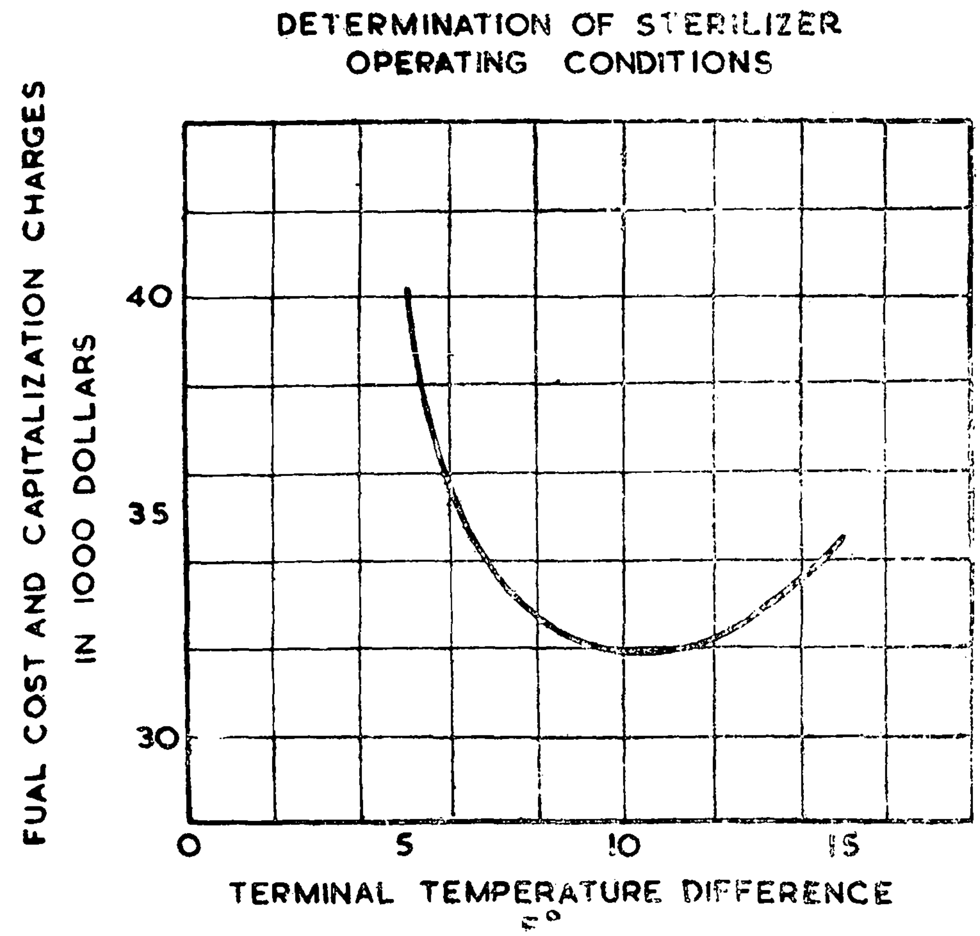

Fig. 2

Fig. 3 illustrates Condition 1, processing contaminated and filtered water for a drinking water supply. The system consists simply of a transfer pump, counterflow heat transfer apparatus for sterilization of the water, a steam actuated heater, a low pressure boiler (50 psig operating pressure) and its auxillaries. The same system would be used for pasteurization of the water but less heat transfer surface would be required and the boiler operating pressure would be reduced to about 3 psig.

Fig. 4 illustrates Condition 2, processing complete treatment sewage effluent for well re-charging by ground flooding and seepage. The system is the same as for Condition 1 except that pressure filters to clarify the treated sewage effluent are added along with backwash and service pumps. If a pasteurization system rather than a sterilization system is to be used for this process, the size of the counterflow heat exchanger, the heater and the boiler will be reduced as described previously.

Fig. 5 illustrates Condition 3, processing complete treatment sewage effluent for a drinking water supply. The system is the same as for Condition 1, except that activated carbon filters are added to remove color, odour, taste and to reduce the amount of refractories present in the water as well as to clarify it An aerator to provide maximum aeration for the processed water is included as well as service and backwash pumps. Since it is intended that this water be available for immediate use, a chlorine feed station is provided to maintain the sterility of the water in the distribution system in accordance with USPHS Standards. If it is elected to pasteurize the water rather than to sterilize it, modifications to the system as described under Conditions 1 and 2 apply.

Economic Study

The systems for the three conditions outlined for both the sterilization and pasteurization of water were evaluated in accordance with procedures recommended by the Of-

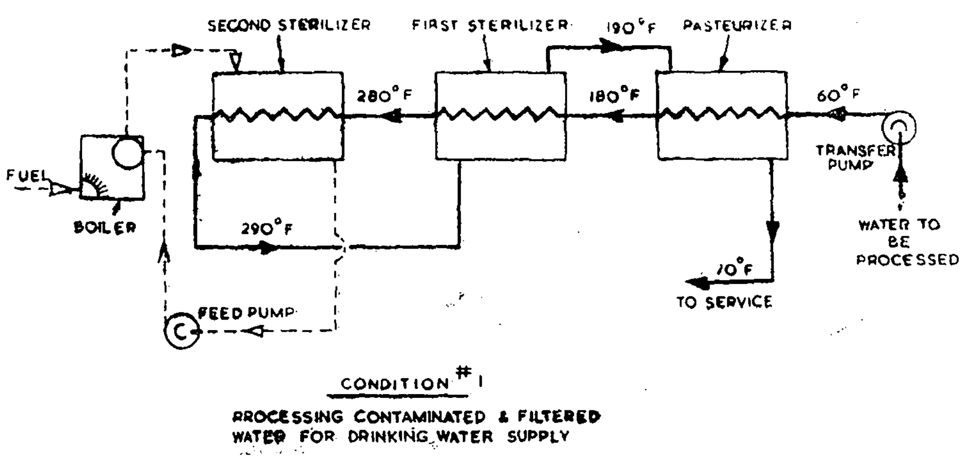

Fig. 3

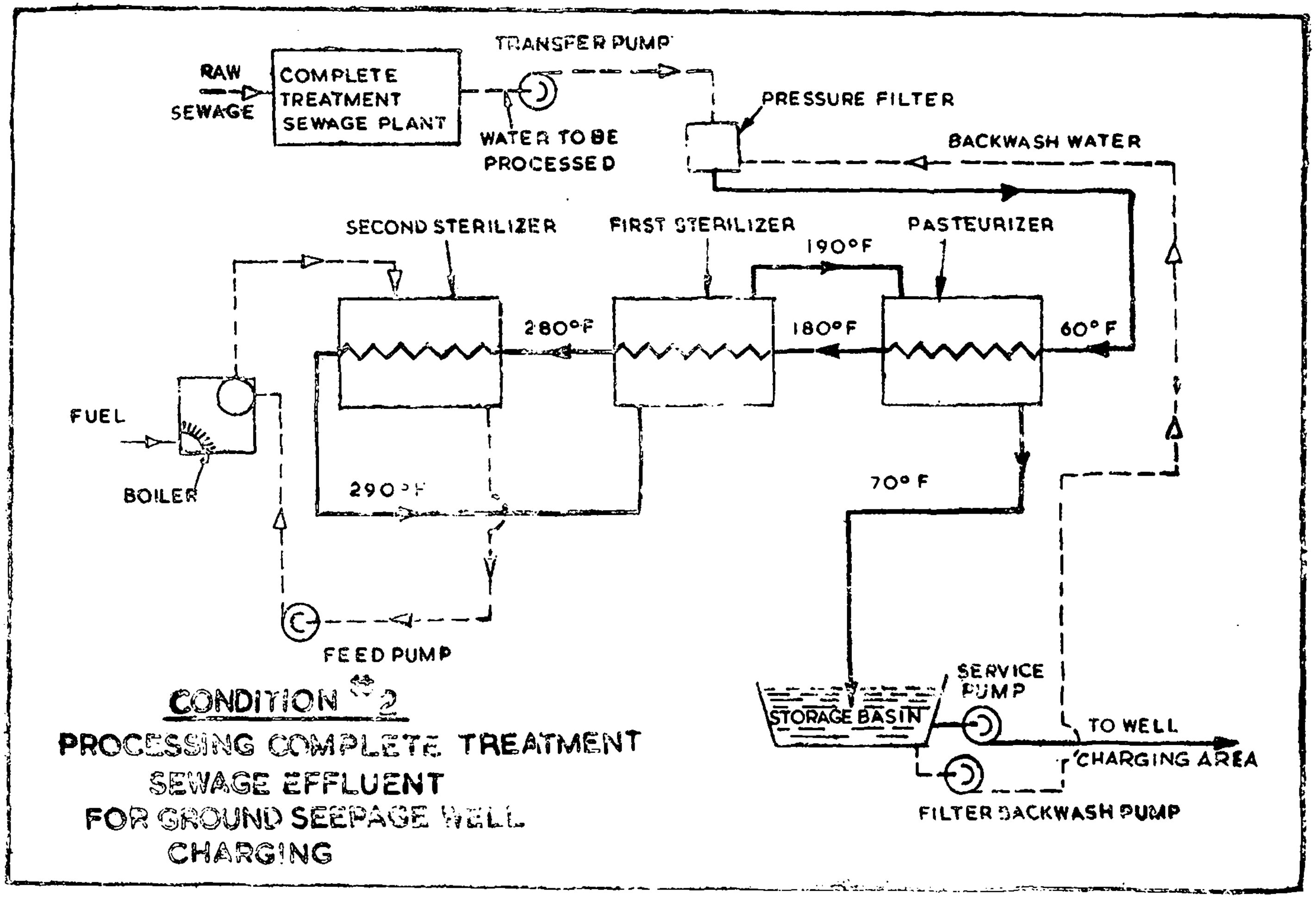
RAW SEWAGE
COMPLETE TREATMENT SEWAGE PLANT
TRANSFER PUMP
WATER TO BE PROCESSED
PRESSURE FILTER
BACKWASH WATER
SECOND STERILIZER
FIRST STERILIZER
PASTEURIZER
190°F
280°F
180°F
60° F
FUEL
BOILER
290°F
70° F
FEED PUMP
SERVICE PUMP
STORAGE BASIN
TO WELL CHARGING AREA
FILTER BACKWASH PUMP
CONDITION #2
PROCESSING COMPLETE TREATMENT SEWAGE EFFLUENT FOR GROUND SEEPAGE WELL CHARGING

Fig. 4

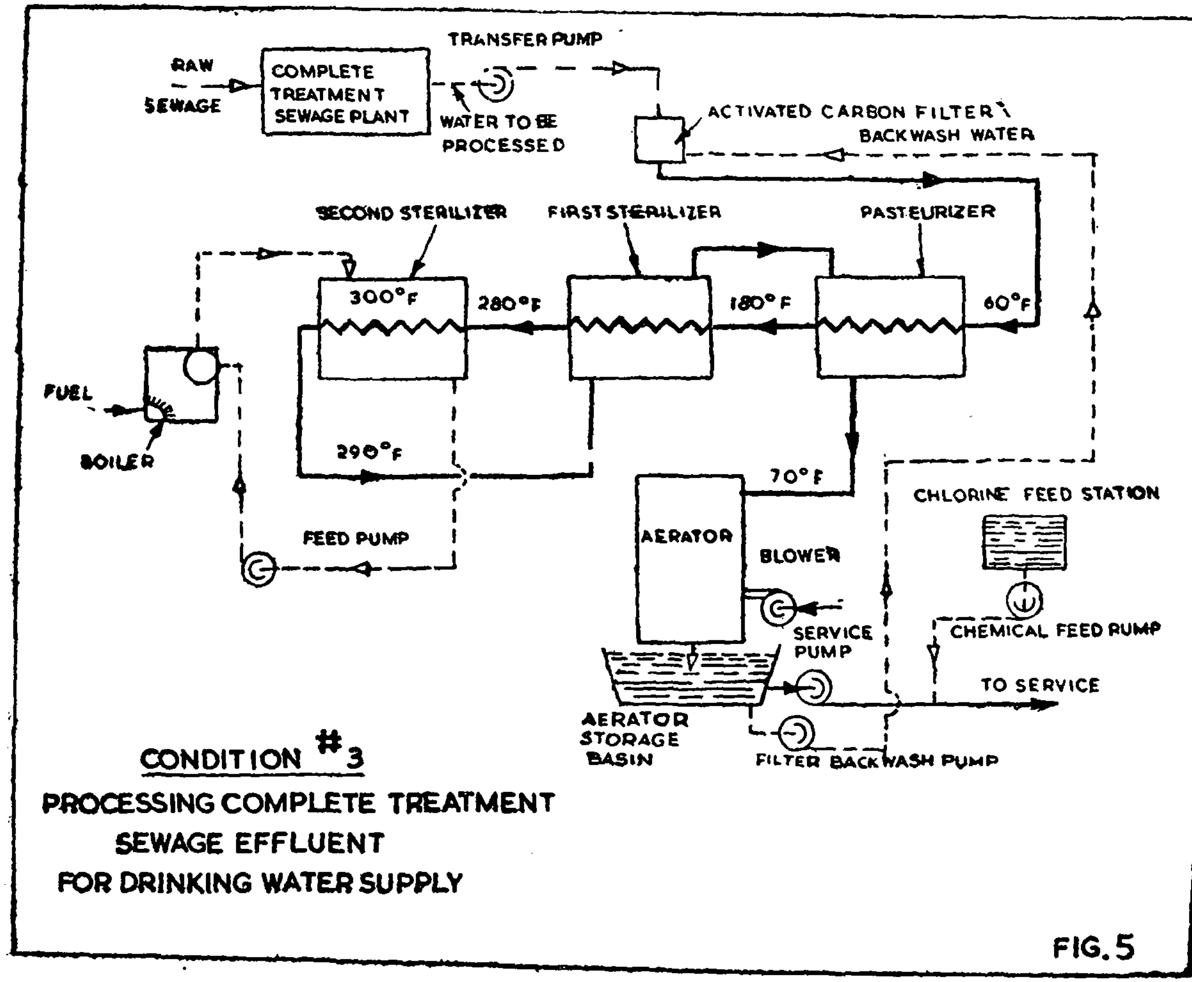
RAW SEWAGE
COMPLETE TREATMENT SEWAGE PLANT
TRANSFER PUMP
WATER TO BE PROCESSED
ACTIVATED CARBON FILTER
BACKWASH WATER
SECOND STERILIZER
FIRST STERILIZER
PASTEURIZER
300°F
280°F
180°F
60°F
FUEL
BOILER
290°F
FEED PUMP
70°F
AERATOR
BLOWER
SERVICE PUMP
AERATOR STORAGE BASIN
FILTER BACKWASH PUMP
CHLORINE FEED STATION
CHEMICAL FEED PUMP
TO SERVICE
CONDITION #3
PROCESSING COMPLETE TREATMENT
SEWAGE EFFLUENT
FOR DRINKING WATER SUPPLY
FIG. 5

Fig. 5

fice of Saline Water (OSW). To provide a basis for comparison, a similar evaluation was made for a highly efficient multi-stage flash type evaporator system such as those used for saline water conversion and considered as one of the applicable processes for purifying polluted waters. Table I is a listing of the factors involved in making such an evaluation for this evaporator plant Except for operating labour rates, all items listed are in accordance with OSW procedures.

Table II shows a similar evaluation for Condition 3 using the "Pasterilizer" system. Again all items listed are in compliance with OSW procedures except operating labour rates.

The same evaluation was carried out for all three conditions outlined previously for both the "Pasterilizer" system and pasteurization systems.

The comparison of equipment and installation costs are tabulated in Table III. Note that the installed costs of sterilization systems exceed pasteurization system costs by 24 to 48 per cent, depending on the application. The installed cost of the distillation plant remains constant and

Table I—Multi-stage flash evaporator economics suitable for conditions 1, 2 &3.

Distillation of contaminated water for drinking water purposes

Direct operating costs	Basis for estimate (OSW Except where noted) *	Daily cost $
Fuel	50 cents/10^6 BTU	280.00
Elect. Power	7 Mills/kwh (12,000 kwh)	84.00
Supp. & Main. Mtl.	.0015% of total investment (1,312,000)	19.68
Operating Labor	* Estimated at $2.50/hr (24 hr day)	60.00
Maintenance Labor	.0015% of total investment	19.68
Payroll Extras	15% of above 2 items	11.93
Subtotal	Direct operating cash costs	475.29
Fixed operating costs	**Basis for estimate (OSW Except where noted) ***	**Daily cost**
overhead & Admin.	30% of last 3 items above (91.61)	27.45
Taxes & Insurance	.006% of total investment (1,312,000)	78.72
Int. on working capital	.000725% of all other operating costs (277.48)	27.80
Subtotal	Fixed operating cash costs	133.97
Subtotal	Direct operating cash costs	475.29
Amortization	.224% of total investment (1,312,000)	294.00
Total operating cost (per M.G.D.)		903.26
Cost per 1000 gallons=	$ 0.903	

is independent of service requirements. It is 6.25 times greater than the highest priced sterilization system and 12.7 times greater than the lowest priced pasteurization system.

One of the most popular criteria for comparing the costs of water processing systems is on the basis of costs per 1000 gallons of water produced. Table IV gives cost data of this type, arranged for convenient economic comparison of each of the three basic treatment methods investigated.

It should be noted that it costs less than three cents per 1000 gallons to sterilize rather than pasteurize water. The cost of operating the distillation plant is approximately 3 to 5 times greater per 1000 gallons than the "Pasterilizer" systems.

Table II— Pasterilizer Economics condition 3

Complete Treatment sewage effluent— Drinking water supply— 1 mill gal/day

Direct operating costs	**Basic for estimate (OSW except where noted) ***	**Daily cost**
Fuel	50 cents/10^6 BTU	42.00
Electric Power	7 Mills/kwh (2300 kwh)	16.12
Activated Carbon	Soft Carbon-Regeneration at 2 week intervals	86.00
Supp. & Maint. Mtl.	.0015% of total investment (210,000)	3.15
Operating labor	*Estimated at $2.50/hr (24 hr day)	60.00
Maintenance labor	.0015% of maintenance and labor	3.15
Payroll extras	15% of maintenance and labor	9.45
Subtotal	Direct operating cash costs	219.87
Fixed operating costs	**Basis for estimated (OSW except where noted) ***	**Daily cost**
Overhead & Adm.	30% of last 3 items above	21.72
Taxes & Insurance	.006% of total investment (210,000)	12.60
Int. on working capital	.00725% of all other operating costs (147.27)	10.69
Subtotal	Fixed operating cash costs	45.01
Subtotal	Direct operating cash costs	219.87
Amortization	.0224% of total investment (210,000)	47.10
Total operating cost (per M.G.D.)		311.98

Cost per 1000 gallons= $0.312

Conclusions

There is no question that processing contaminated or polluted waters by distillation yields a superior product and one that is completely acceptable from a health viewpoint as well as from an aesthetic viewpoint. Water produced by this process is generally considered too pure for continued use and would benefit by the addition of dissolved solids to impart taste and to inhibit corrosion. To be used in city mains, chlorination is required but to the minimum acceptable levels only. The cost figures given are realistic in terms of the size of plant, although studies now in progress seem to indicate that costs of from 50 to 60 cents per 1000 gallons of water are possible with "giant size" plant, such as 50 to 100 mill gal/day. It is thought that these estimated costs may possibly be lowered to 40 or 50 cents per 1000 gallons of water if minimum fuel costs prevail in the installation area. Some engineers studying the problem at the Robert A. Taft Sanitary Engineering Centre of the U. S. Public Health Service seem to feel quite optimistic relative to the distillation process for reclaiming polluted waters.

The "Pasterilization" of water such as described under Condition 1 offers a considerable economic advantage over distillation, approximately 4.7 to 1 in production costs. Not only are the economics favourable but there can be little or no psychological objection in applications of this type. It is suggested for use only where the chemical contamination of the water supply is within acceptable limits.

The "Pasterilization" of water as described under Condition 2 also is

Table III—Comparison of equipment and installation costs* for three service conditions

Condition	Pasteurization	Sterilization	Distillation
1) Contaminated filtered water	103,000	154,000	312,000
2) Sewage effluent for well charging	153,000	194,000	312,000
3) Sewage effluent for Potable supply	169,000	210,000	312,000

* Value in U.S. dollars

Table IV—Comparison of process economics* for three service conditions

Condition	Pasteurization	Sterilization	Distillation
1) Contaminated filtered water	16.3	19.1	90.3
2) Sewage effluent for well charging	19.0	21.3	90.3
3) Sewage effluent for Potable supply	28.8	31.2	90.3

* Cost in U.S. cents/1000 gal

more feasible economically than processing sewage effluent by distillation. Interest has recently been shown in processes of this type. Objections to the employment of such a process for aesthetic or psychological reasons does not seem likely. In essence, it is no different in principle than "natural purification" in rivers to which we have become accustomed Ground seepage recharging of wells with "Pasterilized" water starts out with a bacteria free product. Our river and stream purification systems do not. With incremental increases in water supplies costing as much as 20 to 30 cents per 1000 gallons of new capacity, the economics of ground seepage well charging with heat sterilized water appears to be feasible.

The very thought of treating sewage effluent for immediate re-use is objectionable to most people. Even processing the effluent by distillation does not completely eliminate this attitude on the part of our general population. The systems shown as applicable to Condition 3 appear to become more acceptable when potable water is available by no other means. In specific instances, either "Pasterilization" or distillation would have been helpful to established populations in areas where the available supply of water is cyclically critical. Under conditions of this kind whether economics or aesthetic will dictate has yet to be learned, but with the differences in costs shown in Tables III and IV, it is more than likely that economics will be the determining factor.

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Vertical Flow Sedimentation Tank

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Water required for public supplies and many industrial uses generally receives its final clarification treatment by being passed through rapid sand filters. To use such filters in an efficient and economical way, it is frequently necessary to "condition" the water before it reaches them.

This "conditioning" is of two kinds:

(i) The addition of a coagulant to cause the colloids and finely divided particles in the water to coalesce into larger size particles; and

(ii) Where the concentration of the solids to be removed is appreciable (say 50 mg/lit. or more) providing facilities for the particles to settle out from the water by gravity.

The first part of the treatment therefore is concerned with converting all the matter to be removed from the water into a state where such removal is possible by settlement or rapid sand filtration, and the second with relieving the loading on the filters by removing the bulk of the matter in an economical manner and leaving only a relatively light duty to the more expensive filtration plant which as a result may be relatively small.

The basic principles of coagulation and flocculation are well known and may be summarised as follows:

The coagulant (most frequently sulphate of alumina or an iron salt) produces positively charged ions which neutralise the potential of the suspended colloids which bear a negative charge and repel each other, and also forms particles of hydroxide "floc" by reaction with the bicarbonate in the water. Following the formation of these floc particles, conditions are provided which cause them to collide with each other and build up in size with the object of increasing their settling velocity.

When the coagulant has been added and mixed with the water, the first stage of coagulation, that is the neutralisation of the colloidal particles and formation of the hydroxide particles, occurs almost instantaneously provided the dosage is adequate and the pH is suitable. and it is very important to understand that the control of coagulant dosage must be accurate irrespective of the type of equipment subsequently used, as whatever form this may take, it can not compensate for incorrect chemical treatment.

It is after the addition of the coagulant to the water that the design of the clarification tanks enters the picture, and the first concern of the clarification plant designer is with the flocculation process which precedes the separation of the solid particles from the water by gravitational means.

To achieve flocculation, it is necessary to cause the particles existing in the water following the addition of the coagulant to come into collision with each other and to coalesce so growing in size. The collisions must take place as frequently as possible in order to achieve the greatest number within a given time, but they must also take place gently or the floc particles formed will tend to break up again.

Collisions are caused by introducing velocity gradient either by mechanical means (i.e., by paddles or similar devices) or by hydraulic means (i.e., by a stream of water). There is a limiting value of the floc size which can be achieved in a given suspension at a given velocity gradient. It will be appreciated that, as particles in the suspension coalesce, their number becomes smaller and the chances of collision diminish. At the same time, it is not possible to increase the velocity gradient in order to increase the number of collisions without breaking up the floc particles which have already coalesced.

It is in order to overcome this state of affairs that preformed floc is introduced into the flocculation zone in a number of clarification tank designs. The presence of the pre-formed floc enables a far greater number of collisions between particles to take place at a given velocity gradient; and, conversely, it permits a lower velocity gradient to be used resulting in larger flocs being formed.

The object of introducing preformed floc into the flocculation zone is therefore essentially to improve the flocculation process and so to increase the size and settling velocity of the solid particles to be removed from the water.

Clarification tanks are basically of two types; those in which flocculation is effected by the movement of the fine floc particles in the water in which they have been formed only, and those in which the water and the fine particles are brought into contact with a mass of previously formed floc.

In the former, the flocculation compartments are separate units although they may be located within the body of the settlement tank. The floc, once it has left the flocculation chamber, does not return there and no further aggregation of the particles takes place.

In the second type of clarification plant, the water and fine floc are deliberatley brought into contact with the pre-formed floc in order to encourage further contact and so to increase the final size and settling velocity of the particles.

Clearly, the larger the particle size achieved and the higher its settling velocity, the smaller the clarification tank in which it may be settled out.

At this stage, it may be worthwhile re-stating that the capacity of a clarification tank for settlement is basically a function of its surface area and that this rather than "retention time" is the parameter used for designing such tanks at the present time.

This is because in the settling of flocculated particles in water, the main forces are gravitational pull on the particle and the viscous drag of the water acting against any movement of the particle relative to the water. Since the particles are small and the velocities are low, the frictional forces developed obey the laws relating to laminar flow. It is a necessary corollary of this that momentum forces are very small in relation to the frictional forces due to viscosity.

Changes in the direction of flow of the water carrying a suspension do not therefore exert any significant force tending to move the particle relative to the surrounding water. If changes of velcocities were introduced which did cause sufficiently large forces to develop, the flow would no longer be laminar and turbulent conditions would occur which would mix the water and inhibit the settling process.

The direction in which the water is flowing relative to the gravitational pull does not have a great effect on the elimination of suspended matter in a settling tank. This is shown by the following:

In a vertical flow tank, the frictional and gravitation forces are directly opposed. The limiting condition occurs when the settling velocity in still water equals the vertical velocity of the particle, i.e.

$$\frac{F}{A} = V$$

F = flow of water

A = area of tank

V = settling velocity

In a horizontal flow tank of length L, and width B in which the stream of moving water occupies a depth D, the limiting condition is when a particle drops to the bottom of this moving section in the same time as the water take to cross the tank.

$$\frac{D}{V_p} = \frac{L.\ B.\ D.}{F}$$

Then since L.B. = A,

$$F/A = V$$

This is the same limiting condition as for the vertical flow tank and it should be noted that it is independent of D.

Reverting to the clarification tanks in which pre-formed sludge is brought into contact with the water entering the tanks, two such designs are the Candy vertical flow tanks and the Paterson Accentrifloc tank.

The accentrifloc tank uses a power driven rotorimpeller to set up circulation in the reaction zone of the tank and the floc settling out in the clarification section of the tank is drawn into this reaction zone and brought into contact with the incoming water.

After reaction, the treated water discharges the solids at the surface in the sludge zone in the annular settling part of the tank, the clear water rising to be decanted from the troughs

In the Candy vertical flow tank, the pre-formed precipitate is maintained in suspension by the upward flow of water. In both cases, the *sludge mass is kept fluid* and the volume in the tank is controlled by allowing part of it to flow into a stilling compartment where it can concentrate before being discharged.

Although the Accentrifloc tank is not primarily the subject of this Paper, it is mentioned here because it makes use of what is essentially the same principle as the Candy vertical flow tank and a second illustration of the application of the principle may serve to make it clearer.

The Candy vertical flow tank is diagrammatically shown in Fig. 1. It has a conical or pyramidal bottom section in which the sides are sloped at 60° to the horizontal. Above this section is a vertical square or cylindrical section.

The slope of the lower section walls is made 60° to the horizontal because this is the minimum down which sludge will drop by gravity.

The water, after being dosed with coagulant, is introduced at a point near the bottom of the hopper section through a pipe pointing downwards and is withdrawn from the tank over decanting channels which in smaller sizes may be peripheral round the tank walls but in larger sizes traverse the surface area of the water. The velocity at the point of entry is usually about 3 ft/sec and the stream of water on entering the tank is immediately deflected upwards causing the necessary velocity gradient and random currents required for flocculation. The water rises in the hopper section at a decreasing velocity and the flow gradually becomes more uniform.

The floc is carried up the tank with the flow of water until the particle size has increased and a level is reached where the upward velocity of the water is equal to the settling velocity of the particle which then remains stationary. Finer floc particles moving up with the water

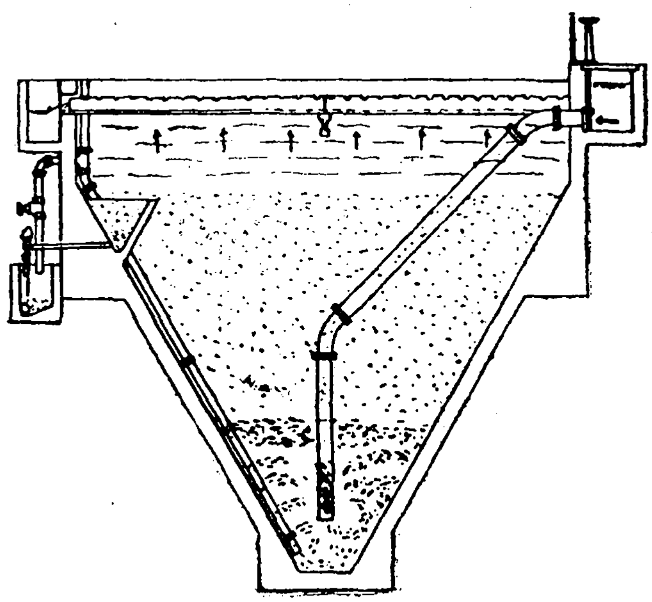

Fig. 1— Candy vertical flow tank

adhere to the stationary flocs which then owing to their increased size descend in the stream of water until they are once more balanced by the greater upward velocity. This process is continuous and a "sludge blanket" is built up throughout the hopper section of the tank, which ensures that the finer floc particles entering with the untreated water are aggregated with the pre-formed particles and the rate of flow of water through the tank does not therefore have to be low enough to permit the small incoming particles to settle on their own.

The flocculation process can therefore in a sense be said to continue through-out the whole volume of the sludge blanket

The top level of the blanket is usually maintained at 3 to 4 ft below the surface of the clear water being decanted from the tank and this level is maintained by withdrawing sludge from the stilling and concentrating compartment which is shown in the diagram. The sludge overflows into this compartment and is then removed either by continuous bleeding or intermittently.

Should the flow through the vertical flow tank be stopped, the sludge kept in suspension will fall towards the bottom of the hopper section and provision is made for draining it from this point when necessary.

The head-loss through the tank is made up of the head required to induce the inlet velocity, that required to cause the water to flow through the sludge blanket and that lost when the water discharges from the decanting channel weirs and into the outlet channel. The overall head-loss incurred in this way is approximately 12 in of water.

At this point, it should be noted that any floc which does leave the tanks with the settled water drops first into the decanting channel and later into the main outlet channel of the tank or tanks; and hence there is a tendency to break it into finer particles. Contrary to some previously expressed ideas on this subject, this is an advantage, in that fine floc will penetrate deeper into the filter sand bed with a result that the bed will offer greater storage capacity and the result will be longer filter runs than would be possible with comparatively large floc particles being retained near the sand surface.

The size and number of vertical flow tanks required in any installation is determined mainly by the flow of water to be treated and the settling velocity of the floc particles which may be expected to form when the sludge blanket or re-circulated flow principle is employed. This velocity varies widely depending on the nature of the impurities to be removed from the water, the chemical treatment applied, and the temperature of the water. Generally, the velocity is between 4-20 ft/hr and has to be determined in each individual case. However, it is always true that the settling velocity of the particles formed by the combination of the fresh particles and the pre-formed floc will always be substantially higher than that of the particles leaving direct through flocculation compartment. The velocity of settlement determines the area of the settling tank or tanks.

Usually the depth of water in the vertical section of the tank is 5 ft and the depth of the hopper section is of course determined by the 60° slope of the sides.

Where the flow of water to be treated is greater than can conveniently be dealt with in one tank, batteries can be built up, and the large number of small units may sometimes be used in preference to a small number of large ones so as to keep the overall depth down and to avoid excessive excavation. Tanks up to 36 ft square and tanks up to 45 ft dis have been used.

It is worthwhile considering some features of the vertical flow sludge blanket tank which make it an attractive proposition, apart from its efficiency as a clarification unit, such as;

i) It has been mentioned above that the overall head-loss through the tank which includes the head required for inducing flocculation, is only 12 in of water. In terms of energy, this is appreciably lower than the consumption of most power driven flocculators alone.

ii) The absence of power driven flocculators and also of sludge scrapers means an installation which is extremely simple and cheap to maintain.

iii) As the flocculating zone is in the base of the tank, no additional site area is occupied.

iv) True vertical flow distribution damps out thermal effects which can affect cross or mix flow systems.

v) With the favourable depth to area ratio, there is no difficulty in re-starting after intermittent shut-downs.

vi) The sludge level is not critical and considerable variations are permissible.

vii) The square plan shape means 20 per cent less site area than circular tanks.

viii) The multiple unit design provides all but the smallest installations for one or more to be shut off without significant detriment to the effluent quality.

ix) The multiple unit design also minimizes construction costs by re-use of formwork.

There are a very large number of vertical flow tanks throughout the world treating more than 630 mill gal/day.

Kanhan Water Works, Nagpur	13,500,000 gal/day
Quilon Water Supply, Kerala	4,000,000 " "
Kolhapur Water Works, Maharashtra	2,500,000 " "
Vaitarna Water Works, Bombay	1,000,000 " "
Birmingham Corporation, U. K.	18,000,000 " "
Sheffield Corporation, U. K.	25,000,000 " "
Kinta Water Works, Malaysia	20,000,000 " "
Navet Water Works, Trinidad	12,000,000 " "

DISCUSSION

SHRI J. M. DAVE (Nagpur) : First I would like to make a correction. The turbidity of the raw water was only 7,000 mg/lit. and not 17,000 mg/lit as mentioned by the author. Secondly, I would like to mention that the performance of the Kanhan filters was brought to excellent performance under the critical supervision of one Assistant Director from CPHERI, one man from Candy, some two other persons and one Assistant Engineer from the Corporation. Of course, I agree that there was some malmanagement of the plant. Otherwise the plant will function well as you had shown and I have quite a respect for that particular plant.

SHRI S. P. UNVALA : The figures as illustrated on the charts presented by me occur in the letter of 14-9-1964 addressed by the City Engineer, Nagpur Municipal Corporation to M/s. Candy Filters Ltd.

SHRI MULEKAR (Bombay) : I am in charge of Vaitarna filtration plant which is a model plant actually. As Mr. Unvala told you just now, we are not adding alum dose less than that is shown by jar tests. We add alum as per the results of the jar tests only. Secondly, sludge bleeding is not 1 per cent as mentioned by the author but it is 10 per cent; and thirdly, turbidity was not 0.25 mg/lit. but actually 2.5 mg/lit. When the turbidity was reported as 0.25 mg/lit., the turbidimeter was not working properly.

SHRI UNVALA : Regarding sludge bleed: The 2 inch sludge bleed pipe, attached to the 60 gal capacity sludge concentrator pocket, has a discharging capacity of 2100 gal/hr when opened fully. Therefore, at full open position, the pocket is desludged in 1½ min. For the pocket 3 ft deep, to be filled with floc (of settling velocity 0.12 ft./min.,) it takes 20 to 25 min. Hence the bleed at 2100 gal/hr occurs at interval of 25 minutes, for 1½ min, at a time. Hence the maximum bleed quantity per day works out to 58 x 60 gal = 3480 gallons = 1.65%. Actually at Vaitarna, to obviate the necessity of attending to sludge bleed valve 58 times a day, the operators have kept the 2 in valve only 1/4th open, so that there is a continuous bleed of sludge which works out to again 1½ to 2 per cent. It may be now mentioned that if the sludge bleed was as high as 10 per cent as pointed out by the delegate, these hopper bottom tanks would not continue to be in the market over the last 30 years, and would not find a ready acceptance by leading water works authorities all over the world.

Regarding turbidity: As explained by the participant delegate, the disparity in the figure of settled water turbidity was due to the fault in the departmental turbidimeters. It can come to be considered that the difference involving the same multiple factor also was recorded by the department on the corrected turbidimeter. Hence the resultant turbidity of 2.5 mg/lit. after treating a raw water of 20 to 120 mg/lit. turbidity is a commendable performance.

SHRI PUSHKAR NATH QAZI (Bhopal) : I want to ask Mr. Unvala about short-circuiting in this type of tanks and the methods of desludging. We find the general method offered by Candy is hydraulic desludging, where the sludge cone is not fully desludged. The sludge

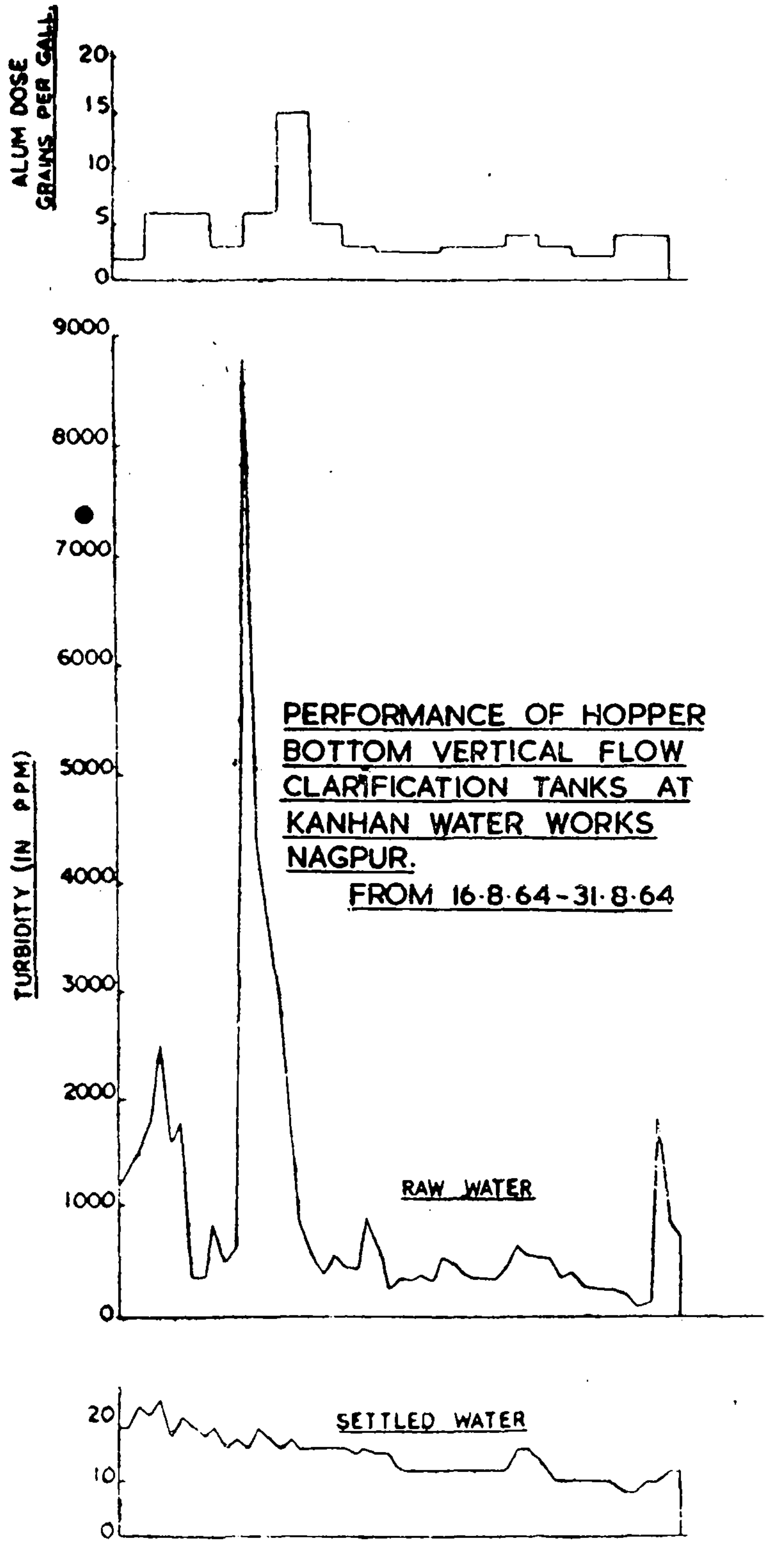
ALUM DOSE
GRAINS PER GALL.
20
15
10
5
0
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
TURBIDITY (IN PPM)
PERFORMANCE OF HOPPER BOTTOM VERTICAL FLOW CLARIFICATION TANKS AT KANHAN WATER WORKS NAGPUR.
FROM 16·8·64–31·8·64
RAW WATER
20
10
0
SETTLED WATER

Chart 1

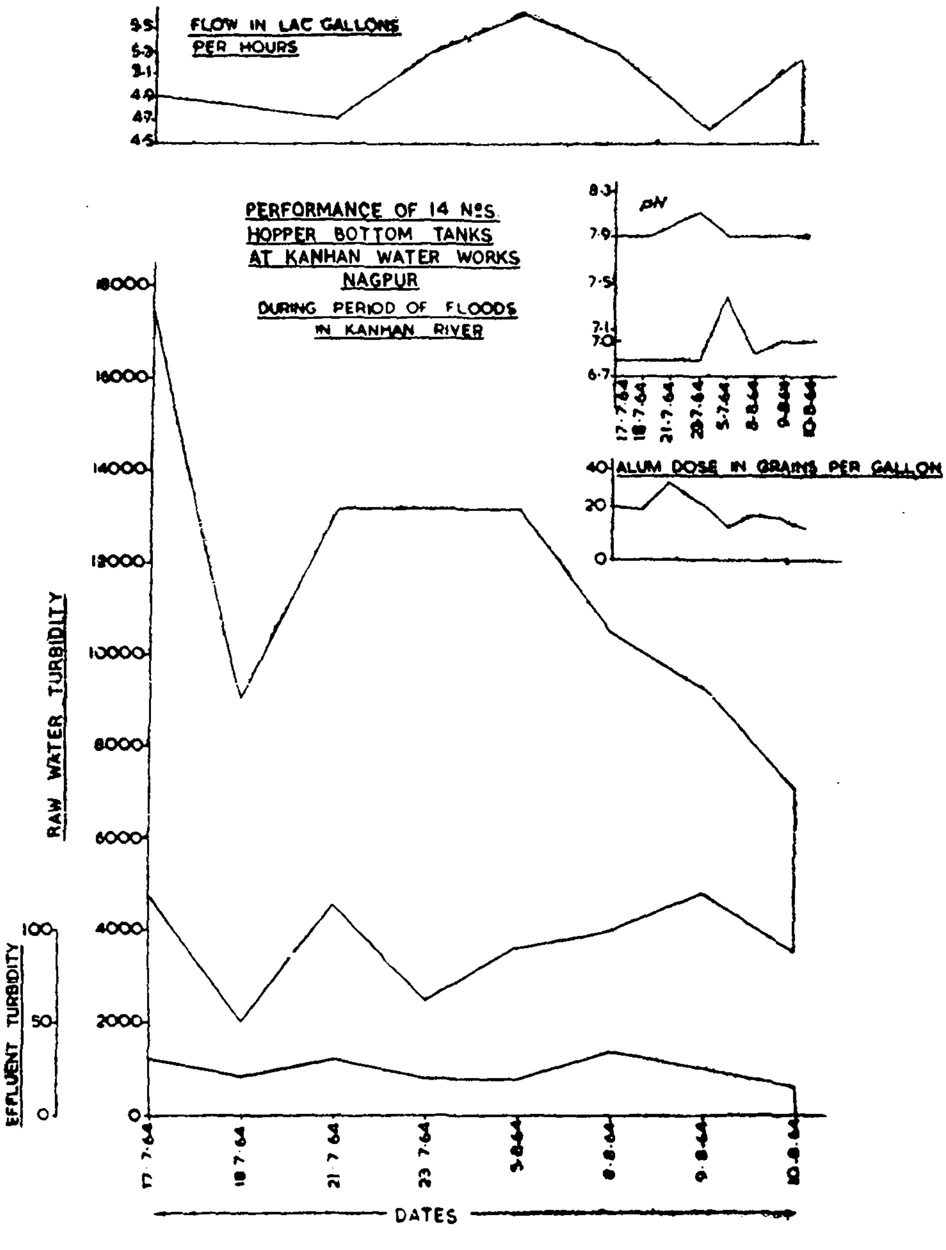
FLOW IN LAC GALLONS PER HOURS
PERFORMANCE OF 14 Nos. HOPPER BOTTOM TANKS AT KANHAN WATER WORKS NAGPUR
DURING PERIOD OF FLOODS IN KANHAN RIVER
pH
ALUM DOSE IN GRAINS PER GALLON
RAW WATER TURBIDITY
EFFLUENT TURBIDITY
DATES

Chart 2

forms another cone within the masonry cone and later on its removal becomes a problem. Has the author anything else to offer ?

SHRI S. P. UNVALA : As regards sludge removal, Prof Arceivala pointed out that there is a sludge concentrator pocket provided at the top. This sludge concentrator is actually a designed pocket and varies from water to water. Regarding this a reference is made to the article by Bonn in the ASCE Journal. The sludge concentrator pocket is actually drained by a pipe and there the sludge bleeding is really very efficient. To control sludge bleeding, solenoid valve can be used.

PROF. M. V. BOPARDIKAR: (Nagpur) : For the Kanhan works what were the design factors before remodelling and after remodelling ?

SHRI S. P. UNVALA : For the horizontal flow tanks, I do not remember the overflow rate exactly but in the case of hopper bottom tanks the figure is 750 gal/sq ft/day.

SHRI A. W. PUROHIT (Nagpur) : In vertical flow sedimentation tanks, in spite of continuous bleeding, flocs are coming up to the top, particularly near the inlet. What is the reason for this ? Secondly, is presedimentation necessary during times when turbidity is very high?

SHRI S. P. UNVALA : As the floc particles come up, they get broken into smaller particles, which are carried to the effluent weir and then to the filters. These fine particles get settled over the sand grains and help in effective filtration. A study as to how far this affects filter perform-

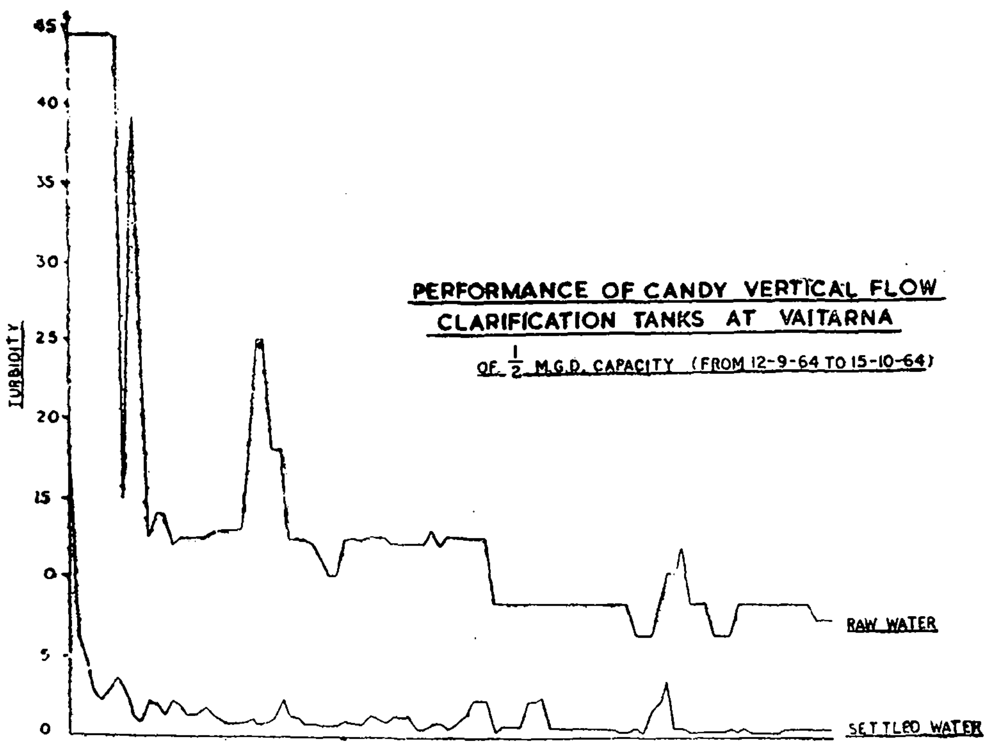

Chart 3

ance should be undertaken in the plant. Otherwise there should not be any objection Pre-sedimentation of raw water, during times of high turbidity is not necessary in view of the performance of the settling tanks.

SHRI S. K. GAJENDRAGADKAR (Bombay) : What is the slurry concentration in the tanks ? What is the upflow velocity ?

SHRI S. P. UNVALA : It is not understood from the question as to the location of the slurry concentration for which information is desired by the questioner. It can, however, be mentioned that the slurry concentration is dependent upon the ratio of the settling velocity and the upflow velocity and therefore it is dependent upon the type and the age of alum floc formed in the tank and on the surface rating of the tank. From the question, it is also not understood whether information is desired for the hopper bottom tanks at Kanhan, Nagpur or for the hopper bottom tank at Vaitarna. It may be mentioned here that the tanks at Kanhan are never subjected to a steady flow and the tanks at Vaitarna can be run at any upflow rate varying from 4 to 8 ft per hour.

SHRI S. K. GAJENDRAGADKAR: The alum dose is very high. What is proposed to reduce it ?

SHRI S. P. UNVALA: Once again, it is presumed that the question pertains to the performance of the tanks at Kanhan, Nagpur. It is not understood as to how the author of the question comes to consider the alum dose as high when the administered dose meets with the indicated requirement after carrying out suitable jar tests. Kanhan river waters are such, that is to say, that they are so alkaline that they require a large quantity of alum to form 'floc.' It is suggested that a presedimentation tank upstream of the hopper bottom tanks may help in reducing the tank load of silt during the periods of peak floods in Kanhan river. That may serve only to remove the silt and may not bring about an effective reduction in the alum dose.

SHRI S. K. GAJENDRAGADKAR: Is not the alum dosage high because *p*H is 9 ? Why not use other coagulants when it is known that alum is most effective only in the *p*H range of 6 to 8 ?

SHRI S. P. UNVALA : The question once again is presumably pertaining to the hopper bottom tanks at Kanhan, Nagpur. However, as far as the records available with the author of the paper are concerned, the *p*H does not seem to be as high as 9.0 for raw waters during periods of peak floods in Kanhan river. As for the suggestion for the use of any other coagulant, the Department can try out the use of ferrous sulphate in place of aluminium sulphate. Ferrous sulphate is now readily available in the country and is sold by **Hindustan Steel Ltd.** at Rs. 130.00 per metric ton F.O.R. Rourkela.

Proc. Symp. Problems in Water Treatment,
Oct. 29-30, 1964 (CPHERI, Nagpur) (1965).

Rational Approach to Filtration Theories

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Although every one is used to seeing clear and sparkling water coming out of wells or natural springs, one seldom stops and thinks how the nature provides such a water free from turbidity. The natural water percolating through the various strata of formation is filtered and most of the impurities are removed in this process to give clear water. The intensification of this natural process both in time and space is called the 'artificial filtration' and is an age-old method of purifying water.

Though the concept of filtration is very old, very little improvement is made in the process since the early years of 19th century. The purpose of this paper is to discuss to a certain detail the existing theories on filtration and their merits and demerits and the recent change in thinking of the workers in this field. A comparative study is made of all the up to date theories on filtration by various workers and a rational approach is suggested.

Types of Filters

1. Conventional Sand Filters—downward flow

2. Biflow Filters

   (i) AKX Filter—developed by the Academy of Municipal Economy in USSR (1)

   (ii) Immedium Filters—developed in Holland (2)

3. Contact Filters—vertical type, used in USSR (3)

Conventional sand filters can be divided broadly into two main groups, viz., slow sand filters and rapid sand filters or mechanical filters as they are sometime called. They both differ hydraulically and structurally. Hydraulic loading applied on slow sand filters varies from 2 to 3 gal/hr/sq ft while on rapid sand filters, the loading ranges from 90 to 200 gal/hr/sq ft. Structurally, they are different because penetration of suspended matter and its subsequent removal during cleaning operations are completely confined within few inches of the slow sand filters, while in rapid sand filters, almost full depth of the filtering medium helps purifying the water and hence also requires cleaning.

Theory of Conventional Filtration

An overall purification due to filtration is achieved by a combination of processes such as: (i) mechanical straining; (ii) sedimentation; (iii) flocculation; and (iv) biological activity. The biological activity is applicable to slow sand filters only which are now almost obsolete, because of their poor hydraulic loading and the large space required for their installation. The following discussion will therefore be restricted to rapid sand filters which are commonly used now-a-days.

An anology can be drawn between the flow through a pipe and a porous media. The resistance offered by the torturous path of the filter media is analogous to the resistance encountered to the flow in small pipes. Based on this analogy, Hazen's classical formula was developed which is :

$$v = c\, d^2 \frac{h}{L} \left(\frac{T + 10}{60} \right) \qquad (I)$$

where h = loss of head in depth L;

v = velocity of water moving down upon the sand bed;

d = size of the sand grain;

T = temperature of water, °F; and

c = coefficient

Though the Hazen's formula is basic, it does not give any specific design parameters for sand depth. The voids and porosity ratio do not appear in this formula.

American Society of Civil Engineers (4) reported another relationship, based on Hazen's approach for a constant hydraulic load of 2 U.S. gal/sq ft and formulated as :

$$L = k\, d^{1.67} \left(\frac{60}{T + 10} \right) = K\, d^{16.7} \frac{\upsilon_t}{\upsilon_{10}} \qquad (II)$$

where T = temperature of water in °F;

υ_t and υ_{10} are respectively Kinemetre viscosity of water at t° and 10°C;

K = constant, variable with water turbidity; and

L = depth required to give less than 0.2 mg/lit. turbidity at filtration rate of 2 U.S. gal/sq ft/min and terminal loss of head of 8 ft.

Stanley (5) suggested yet another relationship :

$$P = K.d^{2.46} \quad Q^{1.56} \qquad (III)$$

where P = floc penetration depth in inches at 77°F;

d = dia of sand grains, cm; and

Q = rate of filtration, gal/min/sq ft

Here if P > filter depth, the filter is satisfactory

On the same lines, Hudson suggested still another formula

where head-loss is not predetermined :

$$P = KQhd^3 \left(\frac{60}{T + 10} \right) \qquad (IV)$$

$$= K_1 \; Qhd^3$$

where h = maximum allowable head loss in ft. Other terminology the same as in III.

Declining Rate Filters

All the above four formulae discussed are not materially different from each other and hardly suggest any improvement in the approach. However , Hudson (6 & 7) after many years of careful study of the design and operation of rapid sand filters developed a measure of filter performance called the 'break-through index.'

$$B = \frac{Vd^3h}{L} \qquad \ldots \text{(V)}$$

where B = break-through index;

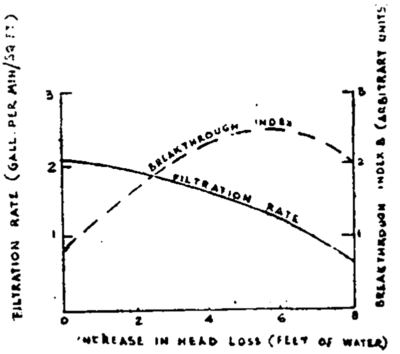
V = filtration rate;

d = sand grain dia.;

h = head loss; and

L = depth of filter

For any filter run, V is constant, the sand size d is constant and therefore, 'break-through index' depends on the hydraulic gradient h/L. Hudson, therefore, recommended use of high filtration rate when h/L is relatively low initially and to allow to diminish the filtration rate V as h/L increased. This 'break-through index' can be controlled so that it is always less than the critical value. This was named as declining rate filter as shown in Fig. 1.



DECLINING RATE FILTER RUN

FIG 1

Jackson (8) operated the declining rate filters from approximate 5 gal/min/sq ft initially to almost zero rate after runs of 100 hr. The head loss remained in the range of 3 to 7 ft in 100 hr run. This can therefore be said constant pressure filtration. But these filters proved uneconomical due to poor output.

Rational Approach

Neither of the formulae given above indicate the variation in the quality of filtrate or the head loss in relation to time, nor effect due to change in filter depth is considered so far. First attempts to correlate depth, time, and turbidity of filtrate were made by Iwasaki in Japan in 1937 (9), followed by Stein (10) and Hall (11) in USA in the year 1940 and 1957 respectively. Though the idea was excellent but studies did not lead to any concrete results.

Further attempts on these lines were made by Ornatskii and others (12) in USSR to explain the clogging process in sand. They expressed mathematically a relation between turbidity, depth and time.

$$C = Co\, e^{-\lambda L} \qquad \text{(VI)}$$

where Co = initial (surface) turbidity;

C = turbidity at any depth;

L = depth; and

λ = filter coefficient.

λ is a function of the nature of turbidity, the rate of filtration, water viscosity and the internal geometry of the filtering media. The turbid water while passing through the filtering media, deposits some turbidity in the pores and so the internal geometry of the media changes and consequently λ varies. Fig. 2 shows the variation of concentration with depth. The authors of equation VI further state that

$$\lambda = \lambda o - b\sigma \qquad \ldots \text{(VII)}$$

where b = constant; and σ = specific deposit-quantity of material deposited per unit filter volume.

Based on this principle of diminishing filter coefficient linearly with quantity of deposit, it can be said that

$$-\delta c\, Q\, \delta t = \delta\sigma\, A\, \delta L \qquad \text{(VIII)}$$

where δc = change in turbidity;

Q = flow rate through filter;

$\delta\sigma$ = change in specific deposit; and

A = plan area of the filter Lamina

Combination of equations VI, VII and VIII results in a differential equation; the solution of which will give specific deposit σ at any depth and time. The specific deposit causes the permeability of the sand to change in the form:

$$K = Ko\,(1-\sqrt{\sigma})^3 \qquad \text{(IX)}$$

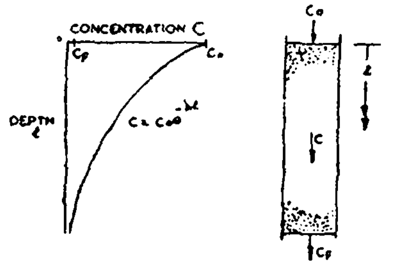
where Ko = initial (clean sand) permeability and therefore Darcey's equation becomes

$$V = Ko\,(1-\sqrt{\sigma})^3 \frac{dh}{dL} \quad \ldots \quad \text{(X)}$$

or

$$\frac{dh}{dL} = \frac{V}{Ko}\,(1-\sqrt{\sigma})^{-3} \quad \ldots \quad \text{(XI)}$$

In equation XI, $\frac{dh}{dL}$ is the hydraulic gradient across any lamina containing specific deposit. The total head-loss across the filter is therefore obtained by summing the elements δh across all the laminae δL, which contain the varying amounts of specific deposits. Thus, the head loss and the change in filter quality at any time can be found out.



INITIAL VARIATION OF CONCENTRATION WITH DEPTH

FIG. 2

Mackrle (13, 14) used the same question VI but λ was modified ussing filter porosity, water viscosity etc., and defined as

$$\lambda = \lambda_o\,(1 - \frac{\sigma}{fo})j \quad \ldots \quad \text{(XII)}$$

where λ_o = coefficient for a clean sand;

fo = porosity of clean filter;

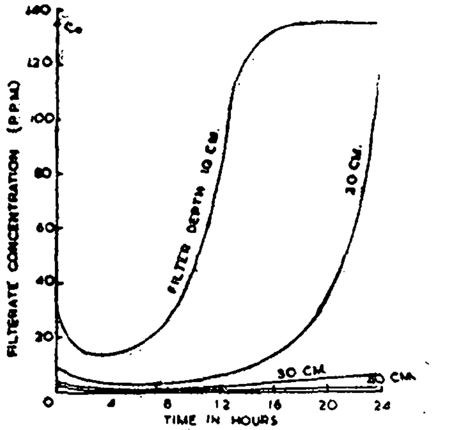
σ = specific deposit; and

j = complex exponent.

Using a form of Kozeny's well known equation, the head-loss can be figured out for a particular filter. Interpretation of both Mackrle and Ornatskii gives a diminishing value of λ as the pores become clogged. Figs. 3 and 4 represent the change in filtrate quality and head-loss respectively with time for various depths of filters. But complex nature of this equation makes the use difficult.

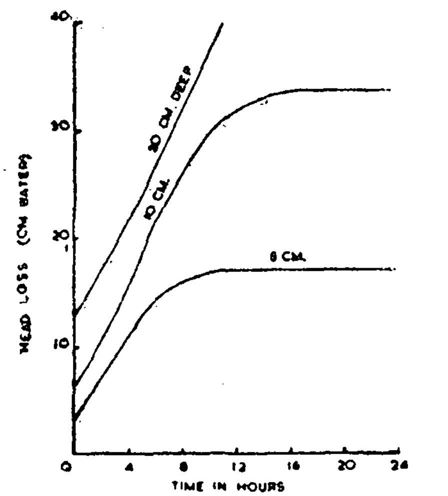
Ives (15, 16) agreed that there is period of improved or constant filtration before the filtrate quality begins to decline. In equation VI, the filter coefficient. λ was modified as

$$\lambda = \lambda_0 + c\sigma - \frac{\phi\sigma^2}{f_0-\sigma} \quad \ldots \quad \text{(XIII)}$$



VARIATION IN FILTERATE QUALITY WITH DEPTH & TIME

Fig. 3



TOTAL HEAD LOSS VARIATION WITH DEPTH & TIME

FIG.4

where $\lambda_{\circ}$ = clear filter coefficient; (c & ϕ are constant)

fo = clear filter porosity; and

σ = specific deposit

A combination of equations VI and XIII and continuity equation VIII leads to a complete solution.

The head-loss in any layer due to decrease in porosity can be obtained from the equation :

$$\frac{dh}{dL} = P\int_{0}^{\sigma} \lambda \, d\sigma \quad \ldots \text{(XIV)}$$

where P = head loss constant.

This takes into consideration that head-loss through a porous media is a function of velocity, grain size, porosity, Kinematic viscosity and grain surface characteristics. The filter coefficient is also dependant on the same parameters.

Non-Conventional Filters

The biflow filters are of recent development and are mainly used in USSR and Holland, where these as known as "AKX Filters" and "Immedium Filters" respectively. The arrangement of the piping and appurtenances of such filters are as shown in Fig. 6. The filtered water is collected in the central pipe and both the top and bottom layers of sand are used as filtering media. This arrangement permits the use of entire filter bed, compared to conventional filters where only a few inches of surface layers are active. The back washing is done in a conventional method (Fig. 6) with a usual rate of 12 to 15 gal/min/sq ft. The underdrain system is a standard one but generally patent porous plate or such fine hole type underdrain systems are not used as they tend to choke. Perforated pipes with graded gravel are most suitable. The flow rate is generally 2 to 3 gal/min/sq ft and can be increased up to 5 gal/min/sq ft under careful operation. The flow through biflow filter is of different nature from the regular gravity rapid sand filtration as the lower portion of water tries to expand the sand bed due to vertical flow while the upper one compresses it. Therefore, porosity and the frictional resistance in both will act differently. Also the mechanism of filtration in the upper layer will mostly be straining while in the lower, it will be combined action of straining and adsorption as water has to pass through an expanding bed with much higher porosity and longer bed length. The head-loss pattern in a biflow filter will be as shown in Fig. 6.

The upper part will have two components of the curve—one due to the surface film, an abrupt drop, and the other of the slowly clogging pores due to suspended matter which may be exponential as shown. The lower part will consist entirely of the exponential nature as full bed penetration will be expected. The filter rate and performance efficiency will be a composite result of the both. Considerable research needs to be done to arrive at a reasonable mathematical prediction on the behaviour of these filters.

The contact filters are radically different from the conventional rapid sand and the biflow filters in the sense that mechanical straining action becomes of secondary importance, as compared to other actions of contact and adsorption. The general construction of the unit is as shown in Fig. 7. The water is introduced at bottom through perforated distribution pipes without any pre-treatment and it rises through the vertical column of graded rock and gravel and eventually through the bed of sand placed on the top of them. The lower coarse medium helps flocculation. All the

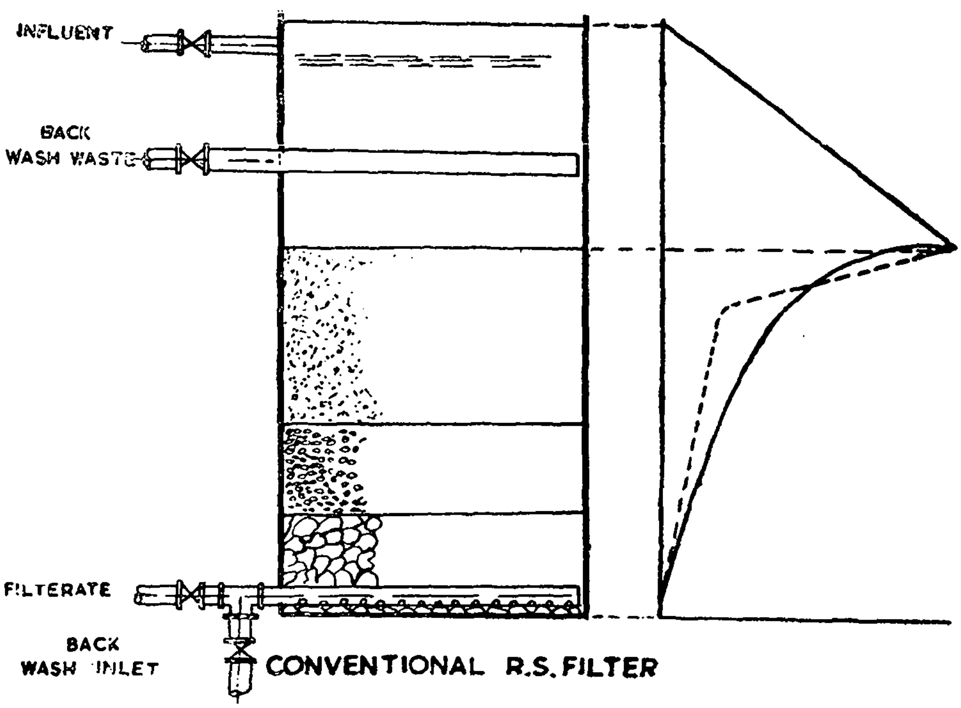


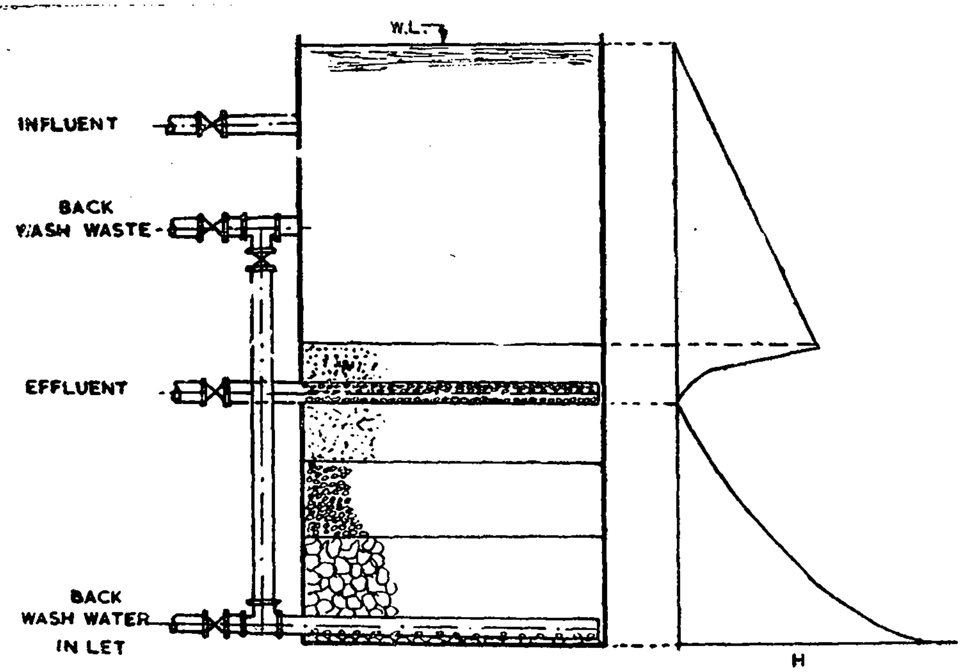
Fig. 5

suspended matter is removed by the sand by some mechanical straining and more by contact deposition on the sand particle. The name "Contact Filter" is derived from this process. The normal operation depth of these filters is generally 16 to 18 ft or even 20 ft some times; and the flow rate is generally 1.6 to 1.7 gal/min/sq ft. No overloading of these filters is permissible as the sand bed operates under vertical flow in a fluidised condition and the efficiency is considerably reduced with very slight increase in the flow rates.

The contact filters are the filters which are easily amenable to analytical approach by mathematical models. The entire bed is permeated with suspended matter and the corresponding porosity reduction will be exponential as originally proposed by Ornatskii. Actual experimental work to verify these propositions remains to be carried out. There are other aspects also in contact filters, of flocculation and some separation at the entry and their efficiency which may also effect the overall performance.

Discussion

Thus, it can be seen that since the inception of artificial filtration as water purification process, many attempts have been made by many workers in the field of Sanitary Engineering to arrive at a true picture of how the purification takes place by removal of suspended solids in a sand bed. The original concepts were of gravity deposits, mechanical straining to biological activity, adsorption phenomenon and electro-



BIFLOW SAND FILTER

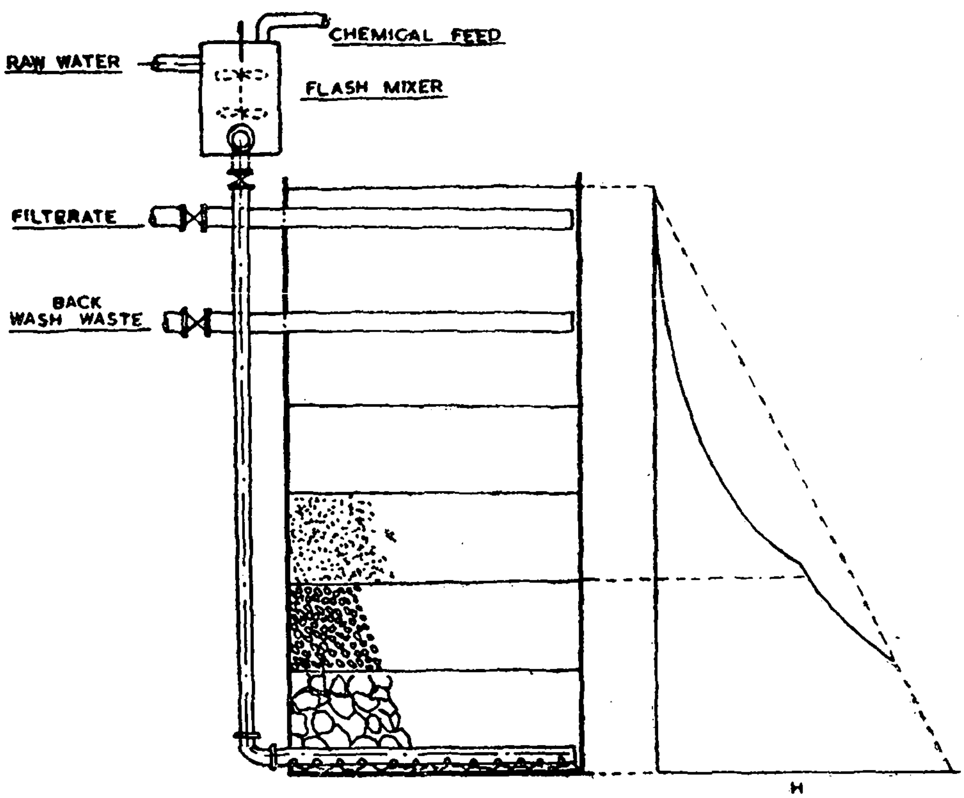
Fig. 6

motive force due to charged particles of suspended matter and they are still under dispute and no clear picture is available.

The workers like Ornatskii, Mackrle, Ives, etc. have recently tried to account for the various factors such as porosity, suspended matter, deposition, hydraulics, shape and size of the filter media and their internal geormetry in order to rationalise the interpretation of the behaviour of filters. But these approaches also do not account for the surface deposit and high head-losses due to them with better suspended solid removals.

All the equations mentioned in the foregoing pages are by far the most general and the complex mathematical expressions. Some simplification is required. Further, they do not cover the case when surface matter deposits on the filter bed.

The present approach is based on a single phenomenon of exponential head-loss as originally proposed by Iwasaki (9), but in actual practice, it is a combination of the two. Rational approach, therefore, should be made to this problem so as to incorporate both surface film resistance and the suspended matter penetration in filter media with decreasing



UP FLOW CONTACT FILTER

Fig. 7

porosity so that a mathematical model of the sand filter can be developed. A rational theory should provide for mechanical straining on surface which may be directly proportional to the porosity and length of the layer with a superimposed exponential loss. These factors should also be related to size or nature of turbidity in water by some relation with porosity and size of media.

Thus, filtration is not a simple straining mechanism but is a complicated phenomenon involving many factors which need evaluation by further research. The removal performance of rapid sand, biflow and contact filters is a function of composite mechanism taking place in the filter media. All factors responsible for purification and head-loss should be considered in this evaluation. Any good rational and workable theory of filtration developed from the above will go a long way to improvement in present filtration technique to give a better water at a cheaper cost.

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Boiler Blow-Down Water: Its Utilisation and Effects on Water Treatment

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As the name implies, the boiler blow-down water is a part of the boiler water blown off from the operating boilers in order to maintain a definite level of concentration of the various components of water inside the boiler. As the boilers operate under different conditions of temperature and pressure and evaporation capacity, the quality and quantity of the blow-down varies widely. The water fed to boiler gets concentrated inside the drum and gradually the concentration of the solids increases. Unless a part of it is taken out, the boiler water may develop undesirable characteristics and serious scales may from and stream purity may also be affected, even when internal treatment is practised.

In boilers of smaller capacity, this blow-down may be intermittent and recovery of flash steam might not be economical. In larger installations, when the quantity of blow-down is also very high, it is desirable to instal a continuous blow-down system with recovery of steam. The percentage of water to be blown down from a boiler is dependent on the nature of the feed water and operating pressure. In boiler plants where blow-down water is considerable, recovery of water as well as the chemicals contained in it might prove some times worth-while. Under the standard conditions of boiler operation, the allowable maximum solid concentration in the boiler water at different operating pressures is shown in Table I. This data is generalised and may vary under special circumstances.

The problems associated with the use of boiler blow-down water from Sindri Power Plant boilers in cold lime softening operation were investigated. In Sindri Power Plant, the evaporation capacity of the boilers is nearly 900,000 lb/hr at a pressure of 650 lb/sq in. Since large amount of steam is used in the various processes and not returned to the boiler as condensate, the make up water is very high. Make up water is supplied by conventional hot lime-soda-magnesia treatment. The percentage of blow-down is nearly 7 to 8 per cent of the total boiler feed. The total quantity of blow-down principally continuously operated is nearly 80-100 gal/min. Before putting this blow-down into the sewer, it is flashed in two stages to recover steam and then passed through heat exchangers to recover part of the sensible heat. The general characteristics of the blow-down water after recovery of steam and heat are indicated in Table II and show that quite large amounts of alkalis, phosphates and sulphites are wasted along with the water.

It was considered whether these chemicals present in the blow-down water could be utilised in some way or other in the water treatment processes at Sindri.

In Sindri, the process water treatment is carried out in two distrinct treatment system, namely : (i) Clarification in Dorr type concentric clari-flocculator; and (ii) Sludge blanket type rapid flow cold softeners (Accelators). As the clariflocculator is used mainly for clarification of raw water using filter alum

Table I—Allowable boiler saline concentrations (tentative) for various operating pressures (ABMA)

Operating pressure psig	Boiler Saline concentration as NaCl mg/lit.
300 or less	3.500
450	3,000
600	2,500
750	2,000
900	1.500
1,000	1,250
1.500	1,000

Table II—Chemical composition of boiler blow-down water before its discharge to sewer

Chemical	Concentration
*p*H	11.6
Hardness	Nil
Sodium hydroxide as NaOH	260
Sodium Carbonate as Na_2CO_3	200
Sodium sulphite as Na_2SO_3	58
Sodium sulphate as Na_2SO_4	432
Sodium chloride as NaCl	150
Sodium Silicate as Na_2SiO_3	44
TDS.	1310
Suspended solids	156

All values except pH are in mg/lit.

as a coagulant, the use of this blow-down water containing high concentration of alkali carbonate and hydroxides was not considered. The treated water from the Accelators is used partly for further treatment for boiler feed water make up and partly for use as process water. Normally, lime and sodium aluminate is used for cold softening and clarification. Experiments were conducted on the effect of the use of boiler blow-down water in the cold softeners.

During these studies, the accelators were operated at a load of 3,000 gal/min of raw water feed with about 45 gal/min of blow-down water. Cold softening was performed by dosage of lime and small addition of sodium aluminate. The increase in TDS in the treated water thus obtained was calculated to be about 25 mg/lit., half of it being due to sodium alkalinity and rest mainly due to sodium sulphate. This small increase in sodium salts is not expected to affect the quality of process water, as well as in subsequent hot softening process for boiler feed water. Moreover, it was considered that the presence of Na_2CO_3 and NaOH present in the boiler blow-down water will reduce the consumption of lime and soda in the subsequent softening operations. Experimental trial was conducted for about a week. It was observed that, instead of hardness being reduced, it actually increased during the cold softening operation and it was difficult to control the softening operation. Some typical data of the cold softener performance given in Table III shows that the alkalinity and hardness have increased appreciably when blow-down water was used in the cold softeners. Although magnesium hardness has remained the same as that of raw water, the calcium hardness has shown a definite increase. In the control experiment, when no blow-down water was used in the Accelator, the calcium hardness showed a value of 30 mg/lit. compared to 70 mg/lit. when blow-down water was used under the same conditions. From the results of the 'P' and 'M' values of alkalinity, it is seen that the cold softening, i.e., the conversion of bicarbonates to carbonates has been achieved, but the calcium carbonate content has increased instead of decreasing by precipitation. This is a very peculiar phenomenon in a softening operation and, at the outset, no definite reasons could be attributed for this abnormal performance. It seemed that some thing present in the system is inhibiting the precipitation of $CaCO_3$ and keeping it in solution much above its normal solubility limit. In order to locate the specific reasons for this peculiar phenomenon, an exhaustive study was made under standard laboratory conditions on the effects of various constituents present in the blow-down water. In the laboratory experiments, the cold lime softening of the raw water was performed with lime and sodium aluminate and presence of small amount of blow-down water in contact with preformed sludge. The effect of blow-down water on cold softening operation is shown in Fig. 1. It is seen that in absence of any blow-down water, the raw water hardness is reduced from 88 mg/lit. to 64 mg/lit., the reduction being entirely due to removal by precipitation of calcium hardness, magnesium hardness remaining unchanged. The residual calcium hardness of 30 mg/lit. was mainly due to solubility of calcium carbonate at the operating conditions. With the addition of blow-down water, the Ca-hardness and also the total hardness was increased. At a blow-down water concentration of 0.9 to 1.2 per cent, the calcium and total hardness values reached maximum values of 70 and 105 mg/lit. respectively. On further increase of blow-down water addition, there was very slight fall in the hardness. This laboratory result was identical to the performance obtained in the actual softening plant by the use of blow-down water. Of the different compounds present in blow-down water, the sulphate and chloride of sodium are not known to interfere in the cold lime softening in presence of preformed sludge (1). This was also verified by actual laboratory experiments. Sodium silicate and Na_2SO_3 were also found not to affect the lime softening process. Organic substances originating from sewage or other industrial waste contamination some times interfere in cold lime softening (2). But this was not considered in this case as no trace of organic substances was detected in the blow water. Phosphates, particularly polyphosphates present in very small quantity, were known to stabilise the Ca-hardness in water (3-6). In the boiler blow-down water, there is no possibility of having polyphosphate and no trace also could actually be detected by analysis. A thorough search for the reference to literature revealed that orthophosphate sometimes exhibits stabilisation of hardness in water although its effectiveness is much less than pyro and metaphosphate (7, 8).

The orthophosphate present in the blow-down water amounted to 136 mg/lit. as Na_3PO_4 and the ultimate concentration in the laboratory treatment process containing blow-down water (0 to 20 ml per lit.) amounted to 0 to 2.72 mg/lit of Na_3PO_7 (Fig. 1). Further experi-

Table III—Typical data on cold lime softener performance when blow-down was recirculated

Sample	pH	Alkalinity Phenolphthalein	Alkalinity Methyl Orange	Hardness Ca	Hardness Mg	Hardness Total
1. Raw water	8.2	Nil	84	54	34	88
2. Accelator outlet when blow-down was recirculated	10.1	48	100	70	34	104
3. Accelator outlet with no blow-down recirculation	9.8	27	60	30	34	64

All values except pH are in mg/lit.

ments were carried out in the laboratory particularly to study the effect of orthophosphate on cold lime softening. The concentration range of the orthophosphate was 0.5 to 20 mg/lit. as Na_3PO_4 The effect of orthophosphate on this cold lime softening is shown in Fig. 2. It was observed that even 0.5 mg/lit. of Na_3PO_4. also showed appreciable stablising effect on the precipitation of $CaCO_3$. With further increase in phosphate, the residual hardness of the water also increased, and beyond 5 mg/lit., there was practically no increase in residual hardness. Under normal conditions of cold lime softening without the presence of phosphates, the calcium hardness and total hardness were 30 and 61 mg/lit. respectively, whereas the Na_3PO_4 were 80 and 111 mg/lit. values reached with 5 mg/lit. respectively. This threshold action of orthophosphate for keeping $CaCO_3$ in solution beyond its normal solubility limit was similar to the threshold treatment obtained by polyphosphates. The comparative effects of threshhold action of the different phosphates are shown in Table IV. It is observed that inhibitory effect of the phosphates so far as the precipitation of $CaCO_3$ was concerned was least with orthophosphate. Thus the peculiar phenomenon observed in the cold softening with boiler blow-down water could be attributed to the presence of orthophosphate in it. It was also observed during the laboratory as well as plant scale trial in the cold softeners that there was indeed a saving of the chemicals, particularly lime and was thought worth while to extend the study further in order

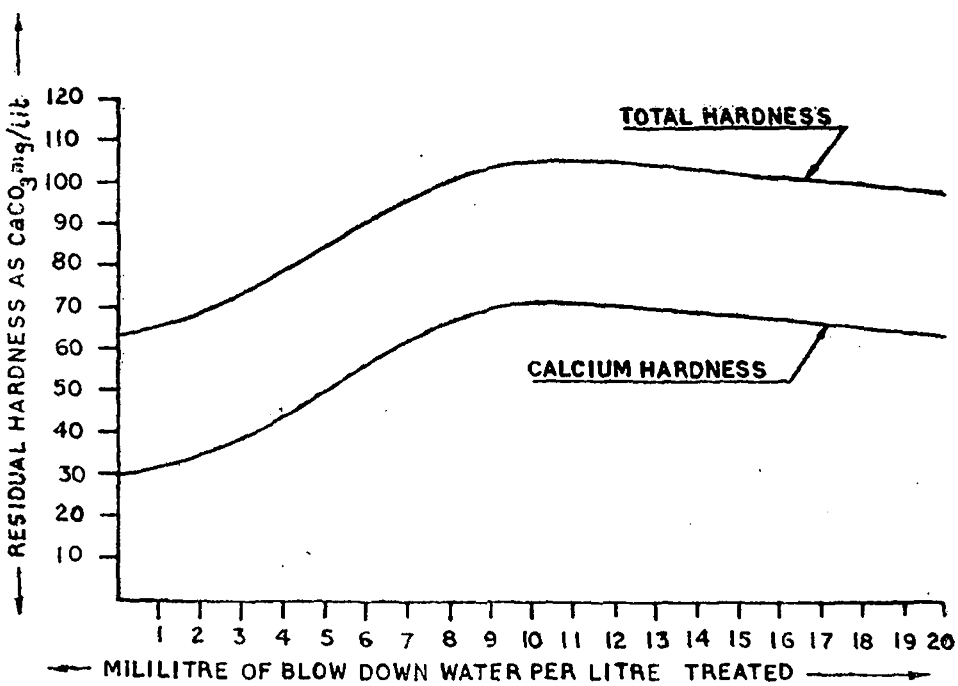

Fig. 1—Effect of blow-down water on cold lime softening Raw water characteristics (mg/lit.): Total Hardness, 88; Ca Hardness, 54; M.O. Alkalinity, nil.

to find out whether this water of increased hardness could be used in the process. The suitability of a water for process purpose is mainly guided by its scale deposition and corrosion tendencies. The most suitable process water is such that will neither dissolve any scale nor deposit any more in the cooling surfaces even when it is concentrated in the recirculatory cooling systems. The conventional marble test method of determining the stability of water (9), when applied to threshhold phosphate treated water may yield some-what misleading conclusions (3).

In the laboratory, the comparative stability of the various threshold phosphate treated waters was determined by allowing the water to stand in a well stoppered bottle for 24 hr in contact with preformed sludge. The deposition of the unstable hardness ($CaCO$) was measured by determining the reduction of alkalinity during this period. The comparative stability of the waters treated with ortho-, meta- and pyrophosphates are shown in Table V. It is evident that the waters treated with orthophosphate are much less stable than those treated with pyro and meta-phosphates. Thus the process water obtained by the addition of boiler blow-down water in the cold lime softening process seemed to be unsuitable due to its lesser stability.

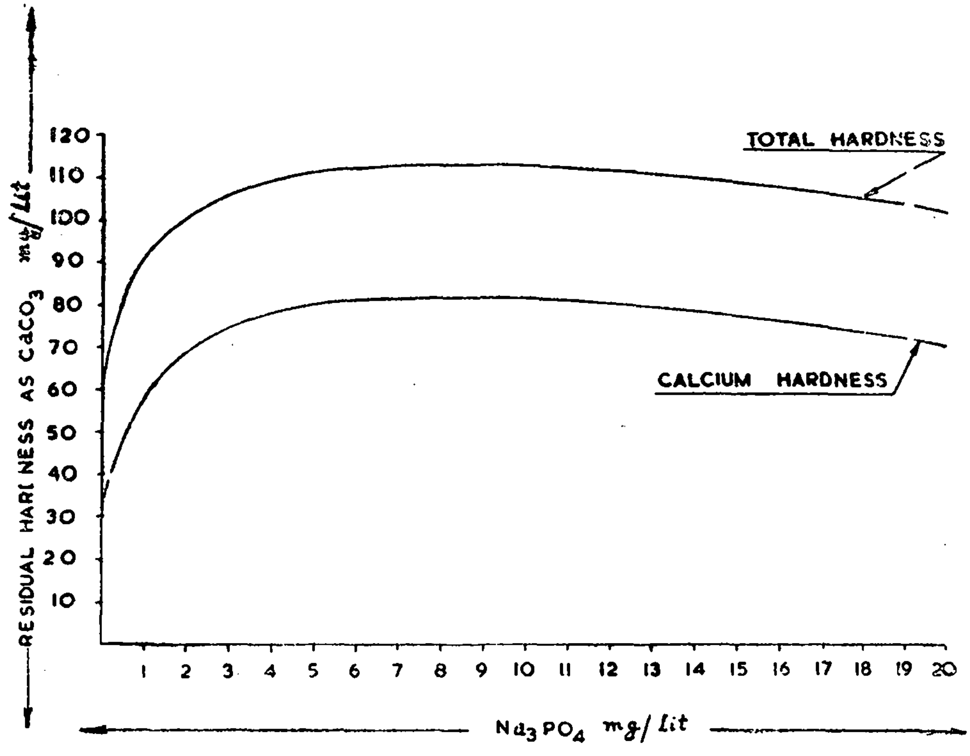

Fig. 2—Effect of orthophosphate on cold lime softening Raw water characteristics (mg/lit.); Total Hardness, 94; Ca Hardness, 55; M.O. Alkalinity, 78; Phth Alkalinity, nil.

As the cold softening water is also used as a feed to the hot lime soda softening plants for the treatment of boiler feed water, the suitability of blow-down treated water for this purpose was also considered. It was observed that under the operating conditions of the hot lime-soda process, the threshhold action of the orthophosphates was completely absent and the hot softening operation is not affected at all. But as the blow-down water contains high concentration of dissolved solids, its use in boiler feed water treatment plants could only be considered in restricted cases.

From all the experiments and observations carried out, it could be concluded that the blow-down water of boilers could not be recirculated in cold softeners for the treatment of process water as the phosphates always associated with this blow-down water may exhibit a threshold stabilisation of high calcium carbonate concentration in treated water which is not very stable. Its use in boiler feed water treatment processes is also very limited as the high concentration of solids present in it may offset the saving in chemicals by its use.

In view of the presence of orthophosphate in the blow-down water and its undesirable effect on water treatment processes, the contamination of raw water supply by blow-down water should be avoided under all circumstances. Although the

Table V — Stability of phosphate treated waters at different threshold concentration of phosphates

Phosphates used mg/lit.	Phosphates as PO_4	Initial total alkalinity M_I	Final total alkalinity M_F	Decrease in total alk. $M_I - M_F$
1. Na_3PO_4—0.5	.29	66	48	18
$(NaPO_3)_6$—"	.47	95	80	15
$(Na_4P_2O_7)$—"	.35	124	52	72
2. Na_3PO_4—1.0	.58	88	72	16
$(NaPo_3)_6$—"	.93	143	142	1
$Na_4P_2O_7)$—"	.70	152	150	2
3. Na_4Po_3—2	1.16	98	92	6
$NaPo_3)_6$—"	1.86	148	148	0
$(Na_4P_2O_7)$—"	1.40	156	154	2
4. Nil Phosphate		54	46	8

All values in mg/lit.

study was made with blow-down water, in fact, the same difficulties are likely to be encountered with any effluent containing any form of phosphate.

Acknowledgement

The authors are grateful to Dr. K. R. Chakrabarty, General Manager, Planning & Development Division, F.C.I., Sindri, for his keen interest and encouragement during the investigation.

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Concluding Remarks

R. S. MEHTA

Delegates and Colleagues,

We have come to the end of the Sessions. We discussed the problems and methods of the treatment of water and this Symposium was inaugurated by Air Vice Marshal O. P. Mehra. The first session was presided over by the Chief Engineer of U.P., Shri A. K. Roy; the second session by Mr. A. P. Mehta, Chief Engineer of Gujarat; the third session by the Chief Engineer of Goa, Mr. Balacrisna R. Naique; and then we had Prof. Arceivala for the last session. The discussions, I think, were very useful and the papers that were presented were of a very high order and I think that the final report that we will publish for this Symposium also will give very useful suggestions and data to the people who are working in this field of public health engineering. Unfortunately due to shortage of time, four papers could not be discussed and I am very sorry for that. We have to thank all those authors who have presented those papers. If any members have questions on these papers, let them send out those questions to us and we shall be able to reply to them. I may incidentally mention here that these papers that were dropped out of the Symposium yesterday were papers from my own scientific workers who very gladly agreed that due to the shortage of time their papers may be deleted.

We have come to the end of the Symposium and before I thank some of the people who have been very useful, I have to thank firstly, of course, the delegates who have come all the way from different parts of the country.

I would like to make an announcement here. M/s Associated Industrial Consultants, Bombay have donated an annual prize of Rs. 100 for the best paper published in the journal of the CPHERI, "Environmental Health" and also included in the Symposia held by the CPHERI. This is a small gesture by an organisation where Prof. Arceivala is taking keen interest. But on behalf of the CPHERI, we welcome it and thank the sponsors for this generous act.

Coming to the last item, I would ask, Dr. N. U. Rao, who is the Convener of the symposia, to thank all those people who have been helpful. I must say, however, that all the members of the staff who had been put on different jobs have been extremely co-operative and useful. I would, however, like to mention the Convener, Dr. N. U. Rao, who, I think, has done the work very creditably and I congratulate him.

Vote Of Thanks

N. U. RAO

Friends,

I am officially known as Convener but I can be called an Announcer because I come here often to make some announcements about transport, functions. etc. I thank all the delegates for their excellent co-operation with all the volunteers of this Institute by bearing the little inconveniences they were put to. I would be failing in my duty if I do not very sincerely thank all my colleagues of various Committees who actually worked very hard to make the symposia a success.

I thank the Press and the All India Radio, Nagpur for their co-operation with us. I thank the staff of Matru Sewa Sangh, Nagpur for helping us serve excellent lunches during all these sessions. Thanks are also due to Public Health Department of Maharashtra State for placing their Staff-Bus at our disposal for transporting delegates. I hope I will bc pardoned if I forget to thank any one who helped us in conducting these Symposia

Thank you all

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CONTROL OF WATER TREATMENT

COAGULANT DOSE

Depends on type and size of colloids. Dose is usually determined by JAR TEST

CHECK ALKALINITY

TOO LITTLE ALKALINITY

may need some supplementing by LIME OR SODA ASH.

Alkalinity is necessary for alum reaction and for prevention of corrosion.

TOO MUCH ALKALINITY

beyond the optimum for a given water may lead to wastage of alum used and hence, prior neutralisation with acid may be beneficial.

pH

Alum works best in the pH range of 7.0 to 8.0 whereas ferric-salts work over a much wider pH range

Colour removal is more efficient at lower pH values; **Hardness** or **iron** and Manganese is best removed at **high pH values.** Hence, in such cases, it may be advantageous to use iron salts instead of alum.

NO. OF PARTICLES & SIZE DISTRIBUTION

It is relatively easier to clarify more turbid waters than the relatively clearer lake waters

Better floc formation is obtained with higher concentration of turbidity particles.

Larger particles serve as nuclei for floc formation.

In the case of low-turbidity waters, addition of clays and bentonites may help. Lime and pulverised lime-stone may also be used. All this are primarily to increase settling rates.

(see co-agulant aids)

ION EXCHANGE CAPACITY

Waters with the same initial turbidity may yet require different doses of co-agulant because different days have different ion-exchange capacities. Montmorillonites (Black cotton soils) have high Exchange capacity and therefore need greater alum dose. Exch. capacity is mainly associated with particles of less than 2 micron diameter. Addition of clays, bentonites, increases Exchange capacity and hence the alum dose.

ZETA POTENTIAL

Initial Perikinetic co-agulation takes place when ZP is sufficiently reduced by alum or other co-agulant.

Colour colloids and fine turbidity *In such* cases, alum may have to be supplemented by co-agulant-aids, or else large doses of alum may be expensive and may also make the water corrosive.

COAGULANT AIDS

Use of congulant aids can only be seasonal (when raw waters are relatively clear and difficult to coagulate).

To make floc settle more rapidly in Sedimentation tanks

To increase floc strength so as to prevent filters break-through

PRE-TREATMENT EQUIPMENT

DOSING EQUIPMENT NOT ACCURATE

OVERDOSE

Wastage of chemical and yet may get poor co-agulation.

(Alum is amphoteric).

UNDERDOSE

Poor co-agulation.

FLASH-MIXING

Very important step. This is where initial PERIKINETIC co-agulation takes place. What is going to be removable later on is decided in this step.

FLOCCULATION

"G" VALUE

This depends on

(1) Speed of paddles

(2) Paddle area

(3) Temperature

INCREASE "G"

This will improve contact apportunity Increase speed or paddle area or both This will increase power input. Variation in speed may be desirable to compensate for change in water viscosity owing to temperature changes.

DECREASE "G"

This is necessary if movement is so great as to shear the floc formed. Floc, once broken up, will not re-coagulate and will tend to pass through, filters, broken floc can be as bad as no floc.

DETENTION TIME

Theoretical detention time is fixed by size of tank and rate of flow.

Avoid fluctuations in flow and short circuiting. Flocculation time not of much consequence in **up-flow tanks** since precipitation takes place directly on the surfaces presented by old floc particles in the sludge blanket.

SEDIMENTATION

ADEQUATE SURFACE AREA

This determines the size of particles that will be removed in tank.

SHORT CIRCUITING

INLETS

(1) Proper distribution of flow between two or more parallel tanks.

(2) Baffles to be placed judiciously.

OUTLETS

To maintain reasonable overflow rates.

THERMAL AND DENSITY CURRENTS

Absent in upflow tanks But can be substantial, at times, in rectangular and circular tanks, especially if their REYNOLD'S NO. is high and FROUDE'S NO. is low.

DETENTION TIME

Theoretical detention time is fixed by tank size and Flow rate.

Actual detention time in rectangular & circular tanks can be drastically reduced by short circuiting, so as to be 50% to 70% only of the theoretical value.

UPFLOW VELOCITY IN UPFLOW TANKS

Upflow velocity has to be kept half (or less) of the settling velocity of the floc suspention in order to ensure a sharp solids-liquid separation at top of slurry or sludge blanket.

Generally upflow velocity is kept 0.15 fpm. at slurry top when alum is used (1200 gpd/sft.)

FILTRATION

REDUCE SOLUBILITY

WEIGHT THE FLOCK WITH RELATIVELY INERT AGENTS

LIME STONE

BENTONITES

(Volcanic clays)

Also help to strengthen floc.

CLAYS

ACTIVATED SILICA

Helpful when floc formation is weak.

Especially helpful in high-rate filtration.

But, may lead to shortened filter runs.

Several methods of preparing Activated silica continuously at the water plant are now available.

POLYELECTROLYTES

Organic co-agulant aids Similar remarks apply as for activated silica.

FILTER RUNS TOO SHORT

LOSS OF HEAD THROUGH FILTER INCREASES RAPIDLY

This may be due to unusually tough floc. Hence, floc penetration into sand is small. Filter gives sharply curved loss of head graphs. Reduce dose of co-agulant aids, if used. It may help to increase rate of filtration which will increase floc penetration. Increase in sand size may be necessary.

EARLY FLOC BREAK THROUGH

Raw waters relatively clear, Insufficient removal of solids, Improve Sedimentation— use floc. weighting agents, or co-agutant aids such as Activated silica.

Reduction in filtration rate and/or reduction in sand size may be necessary.

BACKWASHING INADEQUATE

This will lead to accumulation of fines in sand top causing "mud-balls" and sand surface cracks. Low initial head loss will not be obtained after backwashing. Check for following possible reasons

- Insufficient quantity of back wash water.
- Rate of rise of back-wash water in inches per minute too slow to fully expand sand bed.
- Sand size larger than specified.
- Backwashing aids like air-scour, surface wash etc not properly designed
- Uniform distribution of wash water not obtained
  (1) Defective underdrains
  (2) Defective placement of troughs.

RELATIVELY LONGER RUNS

CLEAR EFFLUENT

FILTER EFFLUENT NOT PERFECTLY CLEAR

Small, but uniform, increase in loss of head indicates continuing penetration of floc into filter bed which may eventually break-through.

COLLOIDAL TURBIDITY

Unflocculated colloidal matter passes thru. in this case owing to insufficient flocculation. Turbidities less than 5 units can be detected by BAYLIS or ST. LOUIS or Hellige type turbidimeters which measure scattered light rather than penetrated light.

CAUSES AND REMEDIES

(i) Incorrect co-agulant dose
(ii) Incorrect alkalinity
(iii) Temperature very low
(iv) Relatively clear raw waters
(v) Flocculation equipment too slow or of inadequate capacity.

FLOCCULATED TURBIDITY

This is due to weakly-bound floc. It is very high in water content.

Does not impede transmission of light in the usual optical turbidimetric determination.

Hence it should be seen by reflected light as in "BAYLIS FLOC DETECTOR" or in a clear well illuminated by side-lighting, or by Cotton plug filter.

CAUSES AND REMEDIES

(i) Increase in speed of agitation may not help. It will perhaps break-up the floc still more. Reduced speed may help.
(ii) Use co-agulant aids, or floc weighting agents.
(iii) Check sedimentation tank design to ensure reduction in floc carry over to filters.
(iv) Wash filters at lower terminal head loss, so as to wash before break-through occurs.
(v) Check filter design for sand size, filtration rate etc.

CONTROL OF WATER TREATMENT

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