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FLOC BLANKET CLARIFICATION

An explanation of the mechanism of floc blanket sedimentation intended as an aid to plant design and operation

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SUMMARY

About 20% of the water treated for potable use in the United Kingdom involves sedimentation and the preferred process is floc blanket clarification. The mechanism of this process lacks an adequate scientific explanation and consequently the design and operation of floc blanket clarification plant remains very much an art.

This report aims to provide an explanation of floc blanket clarification as a system embodying chemical dosing and mixing; flow into, through and out of the floc blanket tank; and removal of excess floc from the tank. The importance of each aspect of the process is considered together with flow into the floc blanket zone, raw water quality and its seasonal variations, and other factors affecting performance of the system.

Guidelines are given for the use of pilot plant, uprating of existing plant, and design and commissioning of new plant. Field work is strongly recommended as the only reliable method currently available for assessing the effect of varying operating conditions on clarified water quality. Theory has still to be developed to predict settled water quality from the minimum of experimental work.

CONTENTS

1. INTRODUCTION

1.1. GENERAL

The design and operation of floc blanket clarification plant, embodying coagulation, flocculation and floc blanket sedimentation, is still very much an art, mainly because there has been no adequate scientific explanation of the mechanism of the floc blanket sedimentation process. This report aims to provide an explanation based upon work by the author(1) and others.

The term 'sedimentation' as used in water treatment can mean settling of particles from the water in horizontal or upward flow. In horizontal-flow sedimentation, the particles are allowed to settle to the bottom of the sedimentation tank essentially unhindered by the presence of other particles. For potable water treatment in the United Kingdom, upward-flow sedimentation is mostly used when sedimentation is required to help remove the particles or flocs formed as a result of chemical clarification*. This uses the principle of the floc blanket, which is a fluidised bed formed by the accumulation of flocs. Therefore the sedimentation that occurs in a floc blanket does so mostly under hindered flow conditions although relatively unhindered sedimentation can occur above a floc blanket. The concentrations of solids in the blanket are not as great as occur in sludge thickening†.

About 70 per cent of the potable water supplied in the United Kingdom is surface water and the remainder is groundwater. Since a number of large northern conurbations have well-preserved upland rock catchments and most groundwaters do not require chemical treatment other than disinfection, only about 40 per cent of all potable waters receive chemical clarification. Moreover, in chemical clarification sedimentation is not always necessary, and only about 20 per cent of all potable waters involve treatment by sedimentation. In the majority of cases floc blanket sedimentation is the preferred process in the United Kingdom. In typical treatment by sedimentation and filtration the capital cost of the sedimentation can be less than 15 per cent of the whole treatment works capital cost, and approximately equal to the capital cost of filtration (exclusive of chemical plant and sludge disposal costs(2)).

The above is not meant to imply that sedimentation is unimportant. On the contrary, when it is used it must be used efficiently to ensure that a suitable quality of water reaches the filters, and that treatment of the resulting sludge is kept to the minimum.

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*For definitions see Section 1.3.1.

†The term 'sludge' is reserved to describe concentrations of floc greater than in 'floc' blankets in water clarification. Thus, floc can be thickened to create sludge and in doing so be subjected to compressive forces, unlike floc suspended in a fluidised bed or floc blanket.

The properties of floc are difficult to measure, and little is widely known about how a floc blanket system works. This report is intended to improve the situation and to enable questions such as the following to be answered:

(i) What is the maximum upflow velocity that can be used?
(ii) What is the best design of tank?

1.2. PREVIOUS STATE OF THE ART

It has been well demonstrated, if not often remembered, that the nature of the product of coagulation - the floc - is dependent on the raw water quality and choice of chemical treatment. That the ease of separation of the floc from the water is related to the nature or quality of the floc has been demonstrated, for example, by Miller *et al.*(3), Yadav(4) and Vostrcil(5). Depending on the circumstances one might need also to consider such chemical factors as pH (Packham(6,7,8)), alkalinity (Elenin *et al.*(9)), and inorganic phosphates (McCarty *et al.*(10)).

Temperature also tends to have an effect on coagulation and flocculation* (Rao(11)), but the dependence of floc blanket performance on temperature has hitherto only been demonstrated to a limited extent (Bond(12,13)).

Miller *et al.*(3,14), Miller and West(15), Yadav(4), West and Yadav(16) showed the qualitative effects on floc blanket clarification of such factors as the time between the addition of the coagulant and entry to the blanket, delay time, blanket depth, supernatant depth, upflow velocity, injection velocity and choice of polyelectrolyte. In contrast, Ives(17) has proposed the only well known theory for floc blanket tank design, but it is one which is limited in application: contrasting and less developed theories have been proposed by Shogo(18) and Cretu(19).

Little detailed experimental work on design features appears to have been carried out and reported. Only Hale(20) has provided practical information of the hydraulic stability of large-scale floc blanket tanks and how it might be improved. Burdych(21) produced conclusions similar to Hale although he had not progressed as far in his investigations. Gould(22,23,), Bond(13), and Tesarik(24) were also interested in blanket behaviour and made various suggestions, which remain mainly unproven, as to the reason for unsatisfactory behaviour or how it might be improved.

Miller *et al.* and Yadav in their extensive work did not examine in detail the importance of floc concentration in the blanket. In contrast Vostrcil(5) has noted the dependence of blanket performance (in terms of settled water quality) on floc concentration. Accepting certain relationships between floc concentration and upflow velocity within the blanket zone, Bond(13) and Tambo(25) have also made a similar observation. They considered that satisfactory clarification is limited to an upflow velocity approximately equal to 0.7 times the floc terminal settling velocities as determined by them.

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* For definitions see Section 1.3.1.

However, previously published work on floc blanket clarification has not explained:

(i) the fundamental mechanism of floc blanket clarification, nor

(ii) the most important features of operation of large-scale designs, both of which are necessary for

(iii) a viable theory for the design of floc blankets.

This report attempts to remedy these omissions in the literature by referring to a great extent to work done by the Water Research Centre (WRC), much of which has not been published before. A major part is concerned with showing that the principal mechanism in clarification by a floc blanket is mechanical entrapment of the smaller particles as they try to pass upwards through the suspension of larger floc particles that form the bulk of the blanket.

1.3. CLARIFICATION USING A FLOC BLANKET

1.3.1. Coagulation and flocculation

Chemical clarification using floc blanket sedimentation involves the processes of coagulation and flocculation. The precise definitions of coagulation and flocculation are dependent upon the particular field of chemistry concerned, but can be conveniently defined in the context of water treatment for public supply. It is recognised, however, that there is no distinct boundary between the two processes.

(a) 'Coagulation' is the process involving the addition of a coagulant, usually aluminium, ferrous or ferric sulphates, under conditions which will lead to the formation of a 'floc' consisting of insoluble hydrolysis products of the coagulant together with the impurities. The mechanism of this process is complex: chemical precipitation is involved in the removal of humic substances, while removal of the particulates involves co-precipitation and chemical destabilisation. The definition includes only that mechanism of floc growth which is brought about by what is termed perikinetic transport whereby particle collisions are effected by diffusion through micro-dimensions. The factors involved in the stages of coagulation influence the resultant floc quality.

(b) 'Flocculation' is the process of floc growth whereby the products of coagulation are agglomerated under conditions in which particle diffusion is brought about by either or both hydraulic and mechanical mixing, otherwise known as orthokinetic flocculation. The resultant size and shape of floc created by this process influences the efficiency of the subsequent separation process. Flocculation is thus mostly influenced by the engineering of the process and can be considerably time-dependent.

The controlling factors of coagulation are the selection of the chemical conditions and the efficiency of mixing the coagulant into the water. The mixing should be accomplished within a small fraction of a minute to ensure all undesirable impurities are in contact with the coagulant as it hydrolyses and precipitates.

There are reasons to suggest that after the initial mixing an additional mixing time of a few minutes is useful to assist perikinetic flocculation (the formation of primary flocs) which results in improved orthokinetic flocculation.

Flocculation, besides being time-dependent, is also greatly influenced by the volumetric concentration of the particles and the velocity gradient of the liquid at the particle surface. In practice, the velocity gradient is measured in terms of the energy input to the bulk of the liquid. With the high concentrations of particles associated with floc blankets, the importance of time and velocity gradient are substantially reduced.

Floc properties, such as size, shape, density and structural strength, cannot be measured easily or accurately. Structural strength governs the size the particles are likely to reach. The process of flocculation involves both floc growth and break-up, so that even under equilibrium conditions there will be a range of floc sizes. The theoretical analysis of such floc systems is therefore difficult. In real systems the feed water quality will fluctuate in an indeterminate manner in addition to diurnal and seasonal variations: such variations can make it difficult to assess the chemical requirements and can also cause changes in the quality of the floc and the ease with which it can be removed.

1.3.2. Floc blanket sedimentation

A simple floc blanket tank has a vertical parallel-walled upper section with a flat or hopper-shaped base. The water which has undergone suitable chemical coagulation is fed downwards into the base. The resultant expanding upward flow allows flocculation to occur and large floc particles to remain in suspension within the tank. The initially slow accumulation of particles improves flocculation until the suspension reaches a maximum concentration related to the floc quality and the upflow velocity of the water. A floc blanket can then be said to exist. As the floc accumulates the volume of the blanket increases and its upper surface rises. The floc blanket surface level is controlled by removing solids from the blanket.

The mechanism of clarification within a floc blanket tank is complex, involving flocculation, entrapment and sedimentation. In practice, the mean contact time of the water within the floc blanket is usually greater than one hour, which is well in excess of the requirements for floc growth to control the efficiency of the process. A process of physical entrapment by flocculation and agglomeration, akin to surface capture in deep-bed filtration, occurs throughout the floc blanket; but more importantly, as will be shown, a process of mechanical entrapment and straining occurs in which rising small particles cannot pass through the voids between the larger particles which comprise the bulk of the floc blanket. The efficiency of entrapment is affected by the spacing of the suspended particles, which is related in turn to floc quality and water velocity, and to the particle size range and distribution. Above and at the surface of the floc blanket, sedimentation and elutriation occur, such that clarification efficiency is ultimately dependent on the rate of elutriation. The rate of elutriation is, however, dependent on the efficiency of entrapment by the floc blanket, particularly of the smallest particles.

1.3.3. The floc blanket clarification system

Fig. 1 shows the elements of the floc blanket clarification system in which sedimentation is only part. The efficiency of the system is influenced by many factors some of which are considered in greater detail in Section 2. All of the following affect the quality and concentration of the floc in the blanket and hence the resulting clarification:

(i) Raw water - it is necessary to know and understand its quality variations in the annual cycle.

(ii) Coagulation - efficient coagulation depends on good flow measurement and control; a good choice and control of chemical treatment; effective flash mixing and appropriate order of, and delay time between, addition of chemicals.

(iii) Flow distribution - inlet pipes and ducts should be designed to avoid unnecessary headlosses. The basic design of the tank should be simple, and the inlet to the blanket zone should be dimensioned appropriately with special features that might be necessary to ensure good flow distribution to the blanket to encourage its stability.

(iv) Blanket control - good settled water quality depends on effective and efficient blanket level control by removal of excess floc. Special blanket stability control and concentrating devices may be necessary to provide the desired blanket depth and floc concentration to enhance separation mainly by mechanical entrapment.

(v) Settled water removal - the outlet pipes and ducts should cause no unnecessary headlosses or biased flow patterns. In some cases features might be necessary to minimise wind-generated surface movement passing down to the blanket surface.

1.4. EXPERIMENTAL

This report refers extensively to both published and unpublished work.

Most of the previously unpublished work was carried out at Medmenham using three different upflow hopper-bottomed tanks. The tanks were 0.3 m diameter, 1.2 m square, and 3.5 m diameter. A comparison of their dimensions is given in Table 1. These tanks were operated in parallel using directly abstracted River Thames water, with aluminium sulphate coagulation and pH adjustment.

The evaluation and comparison of their performances was largely based on the statistical evaluation of extensive experimental data generally by the fitting of quadratic relationships. The resulting quadratic curves are used widely in this report and each curve typically represents 50 to 100 data points. The most important relationships are between settled water quality and upflow velocity; settled water quality and blanket floc concentration; and blanket floc concentration and upflow velocity. The general approach to experiment design is outlined in Appendix C. The blanket floc concentration was measured by taking a 100-ml sample of blanket in a 100-ml measuring cylinder. The concentration is defined as the proportion of the sample volume occupied by the settled floc after 30 minutes of quiescent settlement.

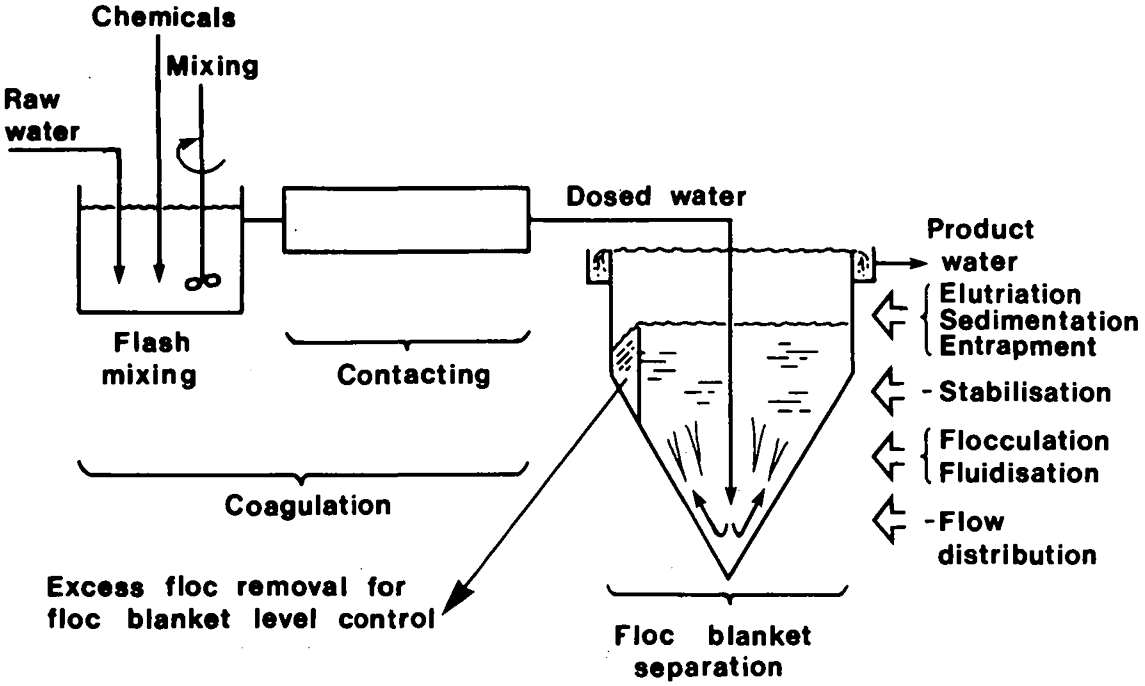


Fig. 1. Elements of floc blanket clarification system

Table 1. Comparison of tank dimensions

Tank	A	B	C
Size	0.31 m diam.	1.22 m sq.	3.51 m diam.
Maximum plan area	0.073 m^2	1.49 m^2	9.66 m^2
Relative area (to A)	1.00	20.4	132
Parallel depth	2.75 m	4.58 m	2.44 m
Hopper depth	0.46 m	1.07 m	2.74 m
Angle of hopper	22°	60°	60°
Supernatant depth	0.90 m	2.75 to 3.05 m	1.25 m
Hopper volume	0.0126 m^3	0.525 m^3	9.75 m^3
Parallel volume	0.1225 m^3	2.73 m^3	8.98 m^3
Total blanket volume	0.1351 m^3	3.26 m^3	18.73 m^3
Specific blanket volume	1.85 m^3/m^2	2.19 m^3/m^2	1.94 m^3/m^2
Hopper blanket	9.3%	16.1%	52.0%

Where it has been necessary to distinguish the results from the tanks in various figures and tables in this report, the experiment number is prefixed by A, B or C, as per Table 1, respectively. For some experiments it was found more appropriate to subdivide the data into two with the result that the experiment number is distinguished by the suffix a or b.

2. FACTORS AFFECTING PERFORMANCE

2.1. RAW WATER QUALITY AND CHEMICAL TREATMENT

2.1.1. Raw water quality

Early work with the laboratory tanks using directly abstracted river water showed the problems of adopting statistical designs of experiments although a satisfactory general experiment design was eventually developed. This early statistical evaluation of the experimental data also demonstrated the relative importance of those raw water and environmental quality parameters whose effect on clarification performance could be easily measured although not controlled.

In one of the early experiments, the 3.5 m diam. laboratory tank C was operated under constant controllable conditions, with upflow velocity kept constant, for three weeks with about four sets of samples taken each day: the experiment was repeated 2 years later with the three tanks in parallel. Analysis of the results by regression confirmed that high levels of variability, due to uncontrollable and unmeasured variables, were possible in the settled water quality, since tank performance can be greatly affected by variables outside the operator's control. For example, the temperature difference between water and laboratory had a marked effect on settled water turbidity, accounting for 48% of the total variance due to uncontrolled and unmeasured variables. By bringing other measured variables, which included raw water colour and turbidity, coagulant dose, air temperature and the water temperature, into the picture the portion of total variance that could be accounted for only rose to 60%. In a similar set of results the laboratory air temperature accounted for 71% of the total variance, as compared to 81% by including the other measured variables.

The difference between air and water temperatures may thus be regarded as one of the major environmental factors acting upon the functioning of the tanks. This was especially noted with the 0.3 m tank. Other factors of definite if lesser importance are water temperature, coagulant dose, raw water colour and turbidity. Since all these parameters are seasonally dependent, their effects on tank performance will fluctuate similarly.

2.1.2. Seasonal effects

As a result of the extensive investigations with the three laboratory upflow tanks a considerable quantity of data was accumulated, covering the period from May 1971 to October 1972. It was, therefore, possible to examine the effect of seasonal variations in raw water quality on clarification performance, in terms of the quadratic relationships between settled water quality, blanket floc concentration, and upflow velocity. Fig. 2 gives the results for the 0.3 m diameter tank. The results for the other two laboratory tanks were similar, see Section 2.3. A conclusion from Fig. 2 is that if a tank is expected to perform satisfactorily throughout the year then it must be rated for the worst situation.

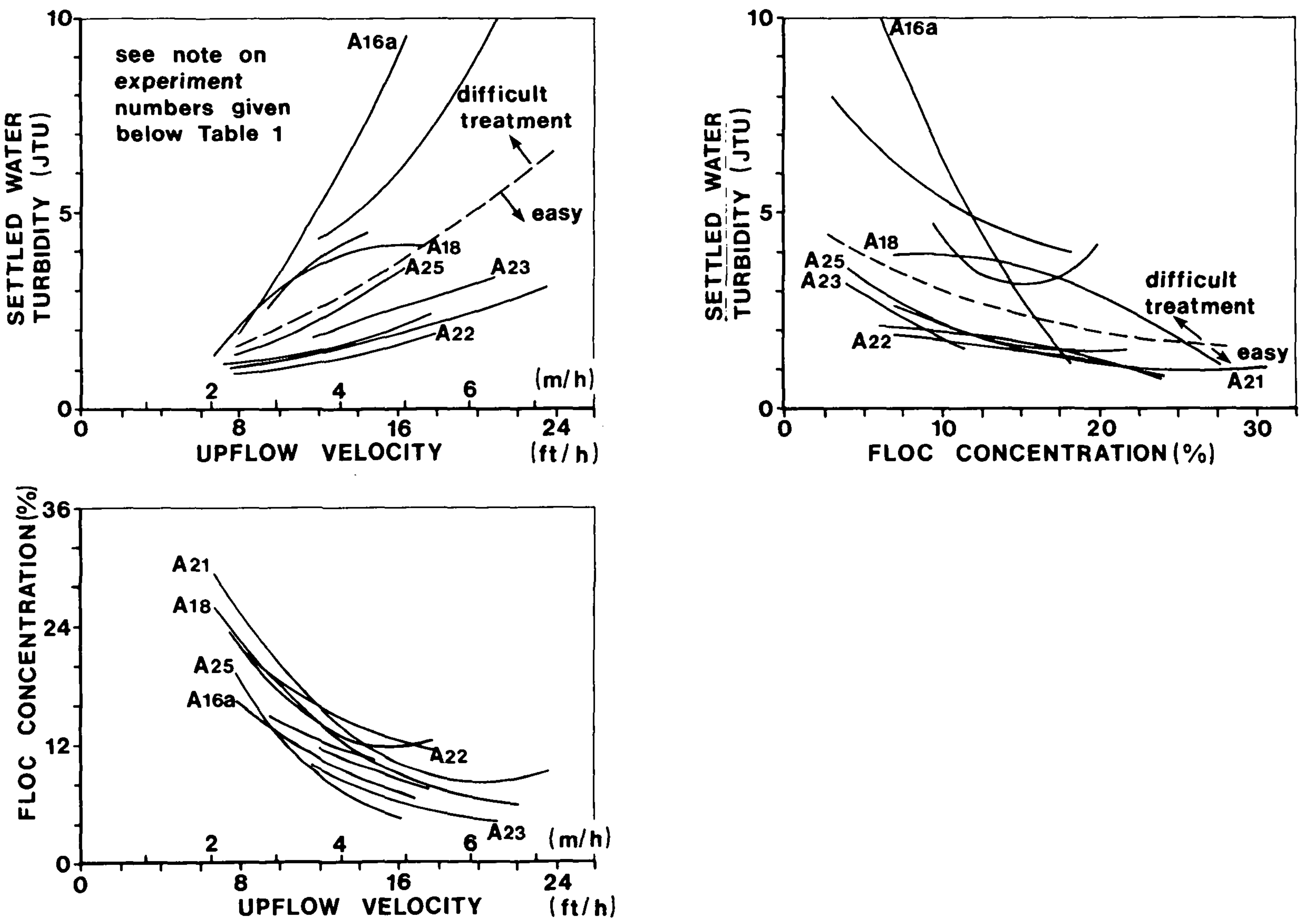


Fig. 2. Typical correlations of clarification data (0.3 m diam. tank)

Annual variation in raw water temperature is to a great extent synchronous with annual changes in the general quality of raw water. The influence of temperature on sedimentation rates in real systems will therefore be difficult to identify. However, various authors(11,12,26-30) have concluded that clarification is hindered by low temperatures affecting both the settling rate and the coagulation reactions.

Adjustment of the floc terminal velocity values, obtained in the regression analysis of the floc concentration-velocity data (see Section 3), to a standard viscosity of 0.01 poise to allow for temperature differences, was found to make the distribution of the results less acceptable. However, in Fig. 3, the terminal velocity, calculated from equation 9, Appendix A, has been plotted with respect to the viscosity of water at the temperature estimated as the average for the various experiments. In addition the curves A $\underline{X}$ B and A' $\underline{X}$ B' have been constructed. The point $\underline{X}$ was selected as mid-range for the viscosity and velocity. Points A and B were then determined as the end-of-range viscosities, and velocity at $\underline{X}$ referred to these viscosities. Because changes in water density, due to change in water temperature, are also of a similar order of magnitude as the density for the quality of floc encountered, the points A' and B' represent A and B respectively for the effect of a change in water density on floc density of about 0.006 kg per litre. It would appear that, particularly in the 0.3 m tank, the terminal velocity was closely related to the viscosity, and hence temperature, of the water. Changes in water density seem less important. It might be that floc, like water, naturally becomes less dense with increase in temperature.

For the conditions encountered during the investigations, easy and difficult treatment situations could be distinguished (regardless of which tank). In difficult conditions the lowest upflow velocity necessary to sustain settled water quality was about 2 to 2.5 m per hour; but for easy-treatment conditions the upflow velocity could be about 1.5 to 2 times as great. Similar values of upflow velocity can be selected by examination of maximum flux conditions. The ratio of these rates is approximately that of the viscosity range. For the temperature range of 4 °C to 20 °C the relative change in viscosity is about 1.6. This implies that if design upflow velocity is determined for easy treatment conditions, substantial difficulties might arise when difficult treatment conditions are encountered.

2.1.3. Chemical treatment

Performance of a floc blanket system is affected by any necessary pH adjustment, the selection and control of the coagulant and the polyelectrolyte(3,14,15).

The work reported for the three different sizes of upflow floc blanket tank involved aluminium sulphate as coagulant with pH adjustment using sulphuric acid. The use of polyelectrolytes was not investigated. Subsequent work with ferric sulphate without pH adjustment has not shown any differences in the general nature of the results reported, although there are differences in the actual values of the relationships involved. However, Miller and West(3) have provided some comparison between using aluminium sulphate or ferric chloride as coagulant. They showed that ferric chloride coagulation was less dependent on pH than aluminium sulphate; also that there was a noticeable difference between the performance of the iron and aluminium floc blankets for changes in the coagulant dose. This behaviour contrasted with the similarity of the results for the two coagulants with various blanket depths and upflow velocities.

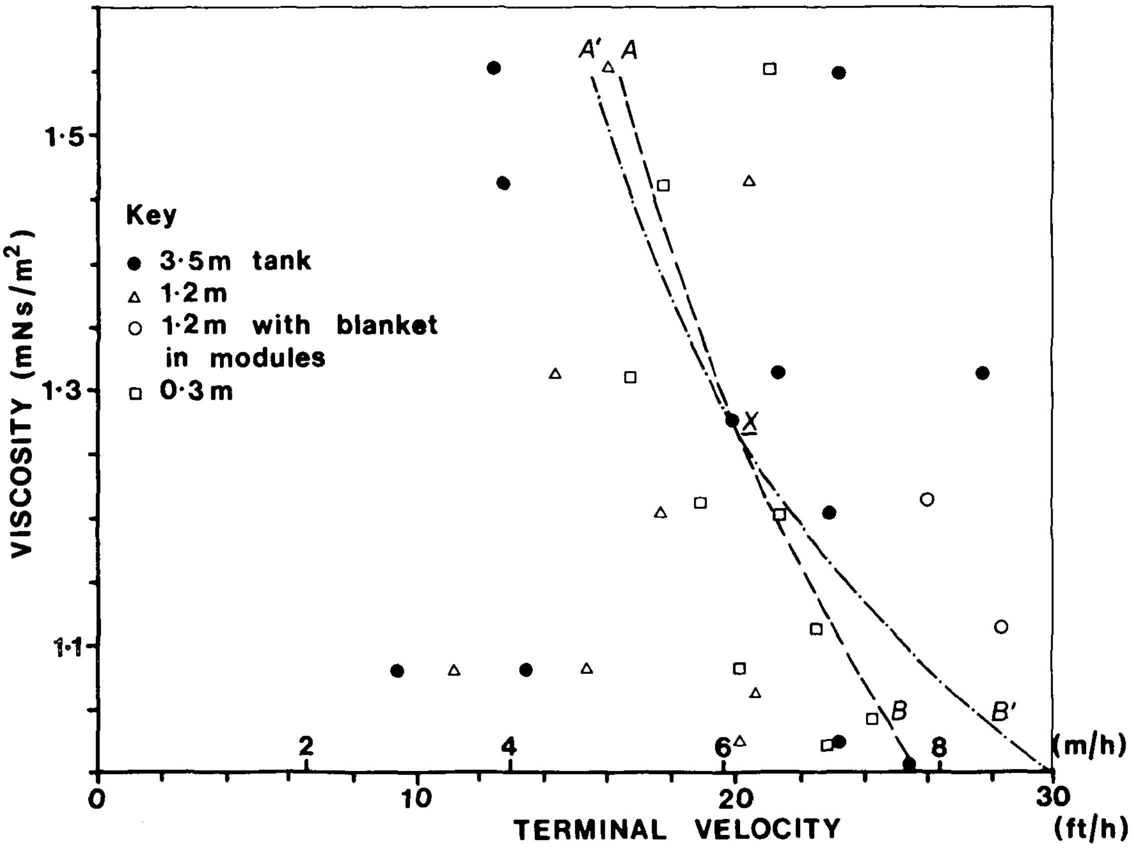


Fig. 3. Examination of settling data for effect of water temperature

The behaviour of a floc blanket with coincident precipitation softening is not known to have been investigated in detail. The choice of chemical treatment itself is determined by availability and cost of coagulants; while raw water quality and, in turn, the quality of the floc produced by the choice of coagulation governs the upflow velocity for the design of the sedimentation tanks. Some modification of floc quality by chemical means is possible in order to improve sedimentation performance in terms of either upflow velocity or settled water quality. This is usually achieved with polyelectrolytes and other flocculating aids which produce larger flocs and a range of floc sizes. However, weighting agents have also been tried. The principle of the Hungarian process used in the Simtafier at Amlaird, Kilmarnock, is to recycle fine sand in conjunction with suitable polyelectrolytes(31). At Amlaird a loading of greater than 5 m/h is normal for the upland coloured water.

Yadav(4) and Vostrcil(5) have examined the effect of different polyelectrolytes and of varying polyelectrolyte dose on floc blanket performance. They showed that there is a limit to improvement in floc quality as dose is increased.

2.2. TANK SHAPE

Most designs of floc blanket tanks include, if not all, certainly most of the engineering features of the floc blanket clarification system. Experience is that providing the following are equivalent,

(i) chemical treatment and control,
(ii) chemical mixing and delay time,
(iii) contact time in the blanket, and
(iv) blanket concentration at the same upflow velocity,

then there should be no difference in clarification performance between tanks. In practice different designs are not equivalent for all these at once and therefore performances differ.

Points (i) to (iii) influence the quality of the floc which in turn affects the relationship between floc concentration and upflow velocity as will the hydraulic conditions in the blanket zone. Point (i) has already been considered in Section 2.1.

2.2.1. Flash mixing and delay time

Just as the initial mixing-in of the coagulation chemicals is important in jar test analysis, so it is in full-scale operation. It is therefore important that:

(i) the chemicals are added in the appropriate order for their optimum use and maximum precipitation, and
(ii) they are mixed into the raw water quickly and efficiently to ensure that undesirable materials have equal chances for removal by coagulation.

A good floc growth environment, i.e. for orthokinetic flocculation, is not necessary before coagulated water enters a floc blanket. However, delay time between the addition of either coagulant or polyelectrolyte or both, and entry into the floc blanket has been shown by Miller and Yadav(4,15,16) to have significant effect on clarification efficiency, although there is a limiting return on improved clarification with increase in delay time. Rott(32) has also shown that improvements in clarification are possible with suitable mixing and delay time conditions. Miller and Yadav found that the gain could not be ascribed to improvement in the initial mixing of the coagulant but they demonstrated that it was dependent on the type of flow conditions as shown by residence time distribution measurement, even during delay times of a few minutes. The reason for the improvement is not obvious because a far greater delay exists within the floc blanket. It can only be assumed that improved primary floc formation, perikinetic flocculation, prior to orthokinetic flocculation (floc growth in the blanket), caused the improvement.

2.2.2. Inlet flow conditions

The nature of inlet flow to the base of the floc blanket affects conditions there and elsewhere in the tank, influencing the hydraulic stability and contact or residence time distribution of flow through the floc blanket, and hence settled water quality. The conditions of inlet flow are therefore important and have received some attention(20-24,26).

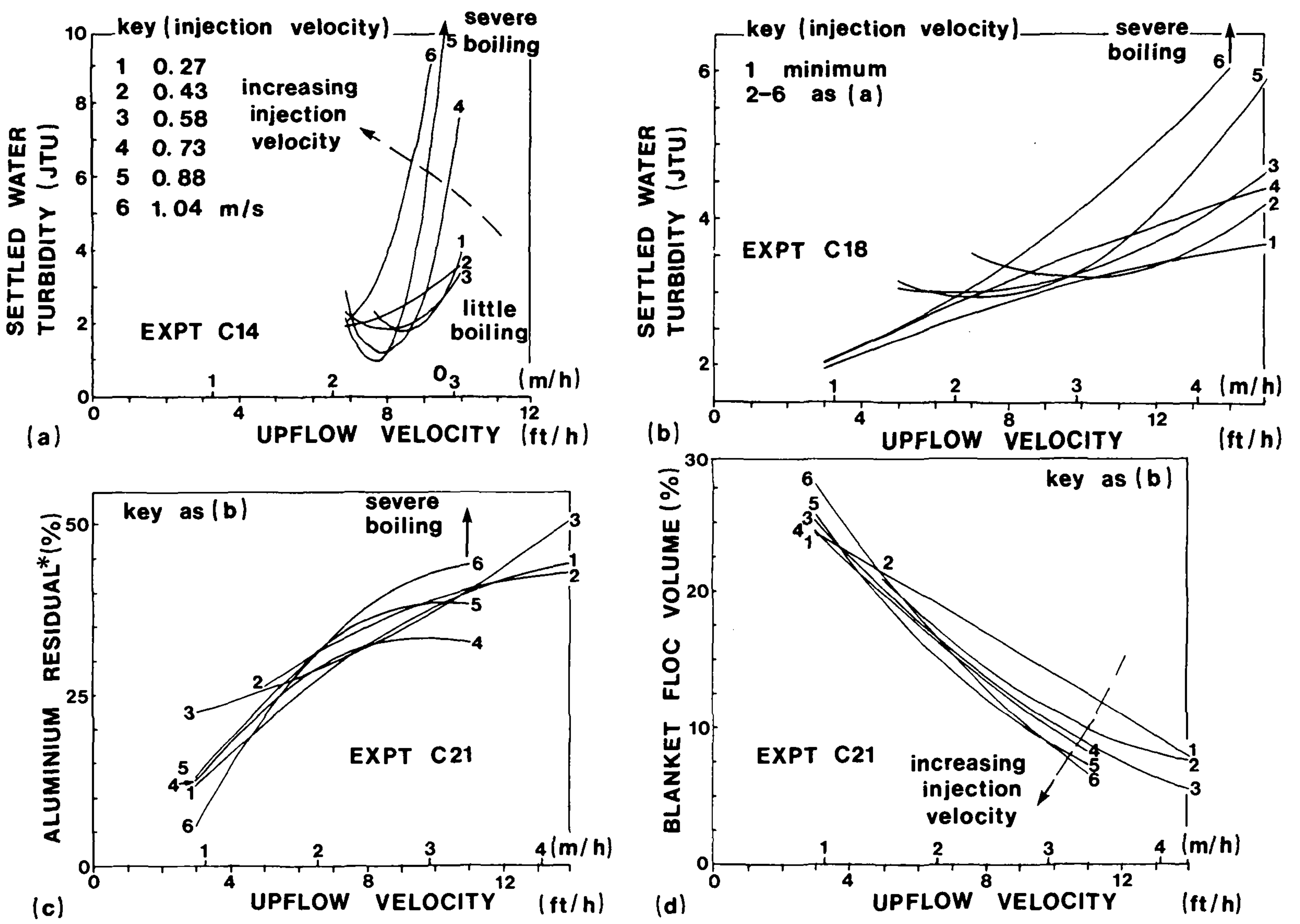
Poor inlet flow is eventually identified by the phenomenon known as 'boiling'. Only Larson(33) has considered mathematically the seriousness of eruptions from the surface of a floc blanket.

In a single hopper tank the verticality and centering of the inlet can easily be shown in the laboratory greatly to influence the stability of the floc blanket and thereby settled water quality. In a square hopper the flow bias would be up the corner furthest from the inlet. The level of the inlet, providing it is neither too close to the base of the tank nor to the surface of the floc blanket, is probably of least importance.

Injection velocity does affect settled water quality. It has been shown by Miller *et al.*(3) for 0.3 m diameter tanks with full bore orifices that increasing injection velocity, the velocity through the orifice, does not indefinitely improve settled water quality but the degree of improvement is greater with higher upflow velocity. In this case it can be assumed that injection velocity assisted inlet flow distribution to the blanket. However, a variable injection velocity cone-valve (creating an annular orifice) fitted to the experimental 3.5 m diameter tank and allowing injection velocity to be varied independently of throughput, showed that high injection velocities caused by such a device could also cause deterioration in settled water quality. A wide range of injection velocity and upflow velocity was investigated.

The results show, Fig. 4, that the settled water quality was dependent on injection velocity and upflow velocity. This can be illustrated by referring to aluminium residual (c) and blanket floc concentrations (d) as well as settled water turbidity (a) (b). It was noticed that the injection velocity setting greatly influenced the tank stability as identified from the amount and intensity of boiling and settled water quality. So much so that, within 10 minutes of an increase in injection velocity, there would be a greater intensity of boiling.

Experiment C21 (Fig. 4c) substantially demonstrated that high upflow velocities can be obtained at low injection velocities but not necessarily at high injection velocities. For the three highest injection velocities severe 'boiling' prevented operation at the highest upflow velocities achieved with the three lowest injection velocities. It was thought that the effect observed was perhaps related to flow conditions in the annular inlet orifice. Headloss measurements were therefore made, and it was found that at some particular injection velocity any further increase would cause a marked increase in the rate of headloss development. This onset of flow degeneration occurred at an injection velocity of about 1.2 m per second



*Settled water aluminium concentration expressed as a percentage of the dosed raw water aluminium concentration

Fig. 4. Effect of injection velocity on clarification

with water of 6 °C. Flow degeneration was probably also due to the width of the annulus varying irregularly as it was closed.

WRC observations on full scale, pilot scale, and model plants indicate that premature deterioration of floc blanket stability occurs because of the poor distribution of the inlet flow. The fault can be due both to the design of the inlet and to the general tank geometry and this has also been illustrated by Hale(20) and Burdych(21). If suitable diffusion flow conditions can be provided, after reversal and before the streaming flow enters and penetrates the blanket, then the inadequacies of the injection and flow reversal conditions can be compensated for. With this idea in mind diffusion grids were conceived and double layer grid systems were constructed and tested in the 3.5 m and 1.2 m tanks. Some effect in improved tank performance could be associated with the use of the grids, but it was not possible to be certain that the improvements were due to the grids alone. However, there was some evidence that stability related to injection velocity may be closely related to the viscosity of the water, and hence dependent on temperature. At lower temperatures the more viscous water causes better stability for high injection velocities; but less viscous warmer water allows a higher absolute upflow velocity. At these high temperatures it may be easier to discern the effects of increasing the injection velocity.

2.2.3. Control of the blanket surface

It can be concluded from the preceding section that, if the blanket surface is 'boiling', initial attention should be given to the inlet flow conditions. Only after this has been done should the probably more expensive remedy of controlling stability at the blanket surface itself be considered. (The Superpulsator proprietary design already includes a system that acts upon the blanket surface.)

(i) Use of inclined tube modules

One of the developments in sedimentation has been the use of multilayer inclined structures. These structures are in the form of a bank of plates or a nest of tubes, all inclined in one direction or with each vertical plane of tubes in alternate directions (see Fig. 5). The aim of these inclined structures is to decrease the settling depth and therefore the time necessary for sedimentation. Such structures were conceived primarily for discrete settling systems in contrast to the hindered settling conditions in a floc blanket. However, an application proposed for such structures is to place them above the blanket to act as a secondary settling or de-entrainment device.

The principle of inclined tube settling for water and waste water treatment was developed by Neptune Microfloc Inc., USA (34,35,36). However, little has been published about the use of inclined surface systems with floc blanket sedimentation having a constant upper blanket surface. Neptune Microfloc type tube modules supplied by Clarke Chapman - John Thompson Ltd., were installed in the 1.2 m tank and evaluated concurrently with investigations on the 0.3 m and 3.5 m tanks. It must be emphasised that the evaluation reported was the application of tube modules in upflow floc blanket sedimentation as distinct from unhindered settling in radial and horizontal flow designed tanks. However, some of the observations made will be relevant to these other applications.

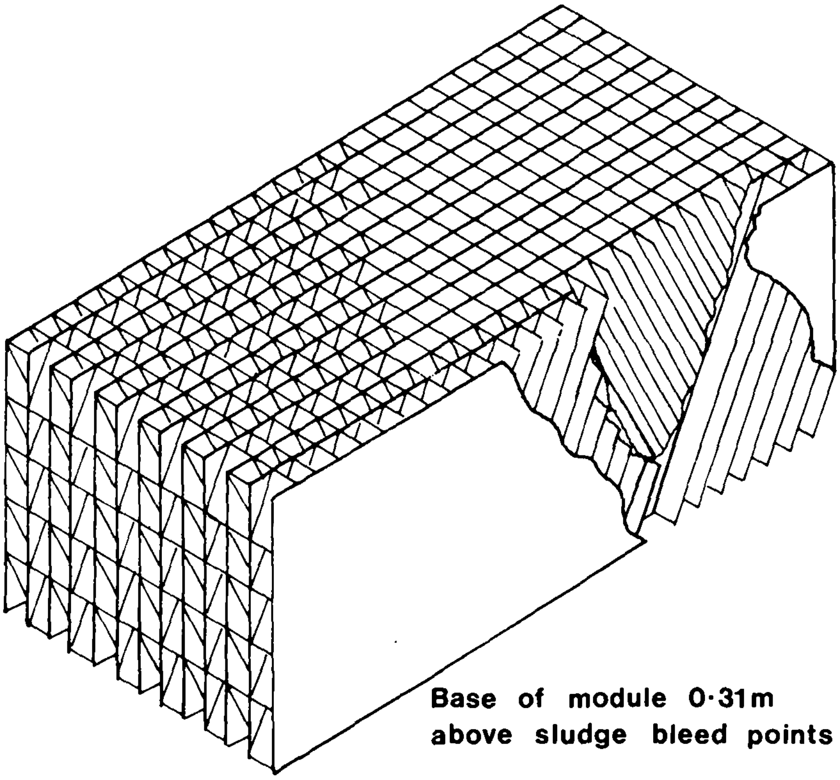


Fig. 5. Module of inclined tubes as used in the 1.2 m tank

The general conclusion was that tube modules are unlikely to be of economic value in floc blanket clarification although they can have beneficial hydraulic and hydrodynamic effects on floc blanket behaviour.

(a) Application in 1.2 m tank:

The modules had been constructed from plastic sheeting to form multi-lamella structures of tubes, the direction of inclination of the tubes alternating with adjacent vertical lamellae. Each tube was 51.0 mm square to its axis and inclined 60^o to the horizontal (Fig. 5). The height of a module was 0.53 m and originally constructed to give a length of 1.22 m. The 1.2 m tank was installed with a total of 23 lamellae with the alternating inclination maintained. The bottom of the modules was 0.31 m above the sludge bleed points to give 2.14 m parallel flow depth below the modules.

The results of operating the tank with and without the tube modules installed are presented in Figs 6a and 6b. The overall comparison of tank performances (Section 2.3) should also be referred to for operation of the tank without tube modules.

When operating with the blanket level below the modules no basic difference in performance could be established compared with the performance of the tank when

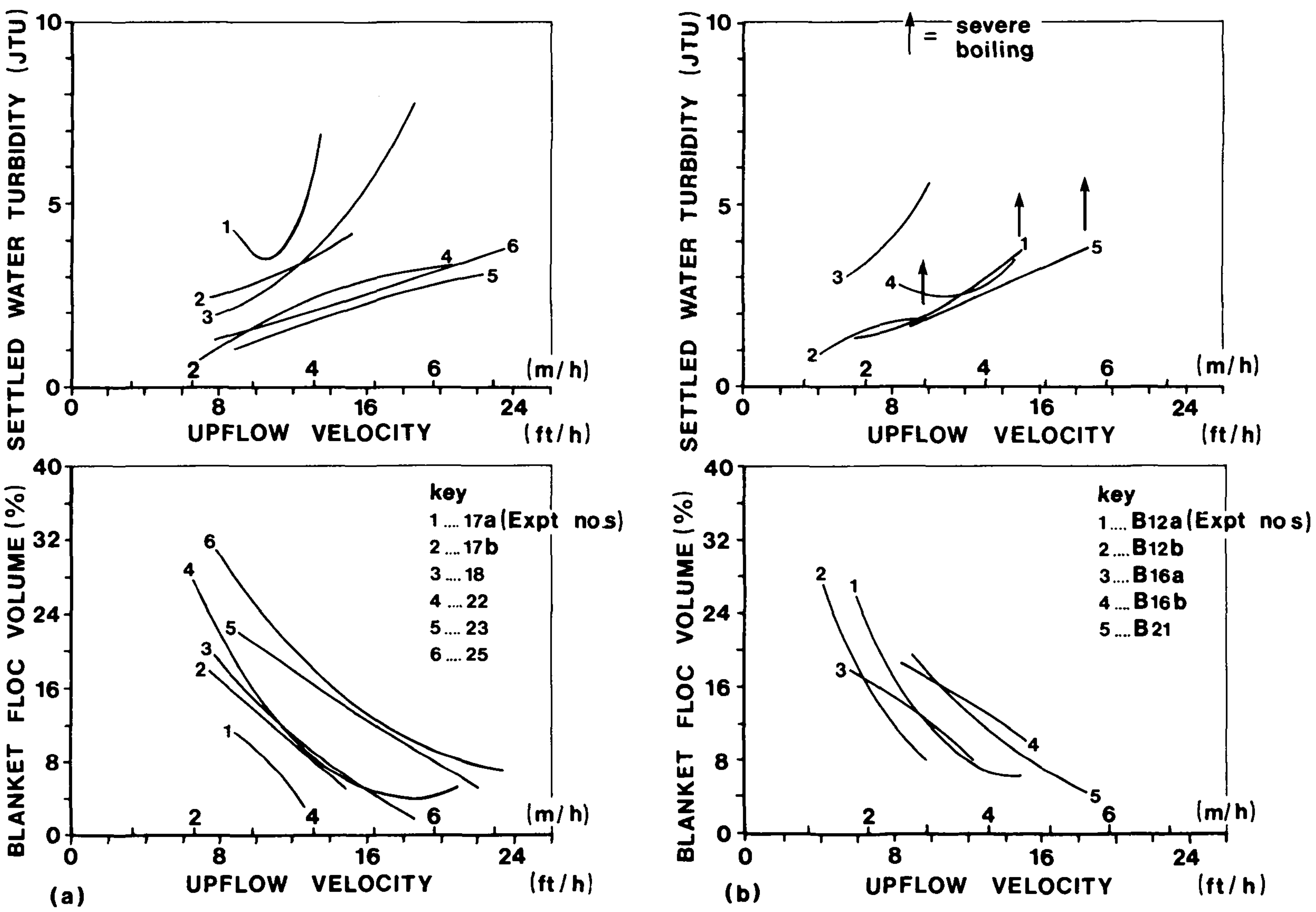


Fig. 6. Comparison of product quality/treatment rate relationships, 1.2 m tank; (a) with tube modules, (b) without tube modules

stable and not fitted with tube modules. When the tank was unstable, such as when the inlet was accidentally or purposely off-centre, some improvement was evident due to the modules acting as baffles, with the mechanism of shallow layer inclined settling very much secondary to the mechanism of flow stability control.

When operating with the blanket level within the modules (experiments 23 and 25) blanket floc volume concentration was substantially increased, but the improvement in settled water quality as indicated in Fig. 6a was very small.

(b) Application in a scale model:

As part of the investigations a hydraulic model, scale 1 : 6, was constructed of the 1.2 m tank (Fig. 7). Scaled tube modules were also constructed.

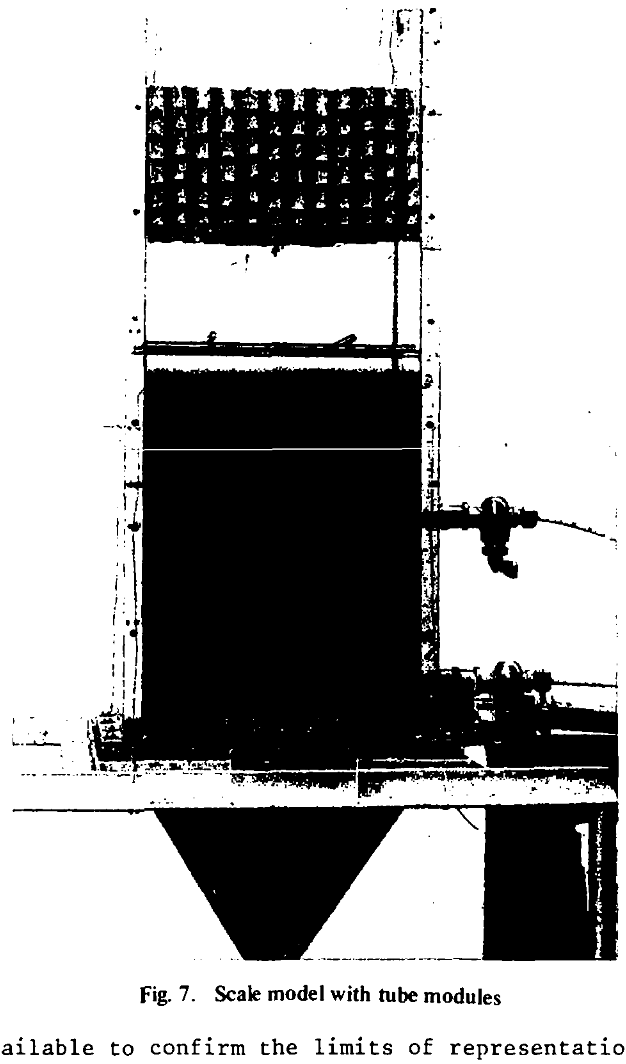


Fig. 7. Scale model with tube modules

Time was not available to confirm the limits of representation of the prototype by the model, but limited investigations made with the model strongly indicated the equivalence of operation and performance between the model and the prototype. Anthracite sieved 0.212 to 0.300 mm was selected and used as a suitable model sediment.

It was observed that the distribution of flow from the point of injection through reversal and diffusion up the hopper was dependent on upflow velocity. At low rates the solids against the hopper walls were stationary or almost stationary. At the middle of the range most of the solids would be sliding down into the apex with injected flow jetting a short way up the corners of the hopper. At high rates all sediment would be in full suspension and the jetting up the corners would project up into the parallel flow section. The quality of flow distribution, particularly once jetting up the corners became substantial, was dependent on the orientation of the inlet.

The interrelationship of bed depth, upflow velocity and solids concentration, and the effect of the scaled tube modules on their interrelationships were investigated. Fig. 8a shows the interrelationships for solids sampled at a point above the hopper section.

The scaled tube modules were constructed with respect to tube size but not material thickness. Comparison of Figs 8a and 8b demonstrates the effect of the tube modules on increasing the concentration once the surface of the bed enters them. The greatest part of the increased concentration was attained before the bed surface passed through more than 40 per cent of the module depth. It was also noted that the greatest relative increase in concentration was obtained at the higher treatment rates. The effect of the modules on elutriation was not examined with the model due to lack of time.

The effect of the modules on the concentration of the fluidised bed below the modules in the model is similar to that on the floc blanket in the 1.2 m tank. The mechanism proposed by Prandtl(37) can help to explain this effect(1).

(ii) Use of vertical baffles

Moderately spaced 1.2 m wide 2 m deep vertical baffle systems placed across the blanket-supernatant interface have been shown(38) to be capable of improving floc blanket sedimentation performance.

The purpose of such a baffle system is to contain and control the large scale motion often present in floc blankets. The improved stability results in a better settled water quality which permits the tank to be operated at higher rates. In the WRC trials(38) the baffles were positioned in that part of the tank where it was believed they would have the greatest effect on the settled water quality. Since a stable blanket-supernatant interface was required the baffles were placed in the upper part of the blanket to project into the supernatant.

The over-all conclusion from the baffle investigations was that, under conditions similar to those prevailing during the experiments, the use of baffles could improve settled water quality to the extent of twenty to thirty per cent better than settled water quality from a similar tank without baffles.

The general experience of all the investigations suggests that the experiments on the baffled tanks were real. The general experience also suggests that at low

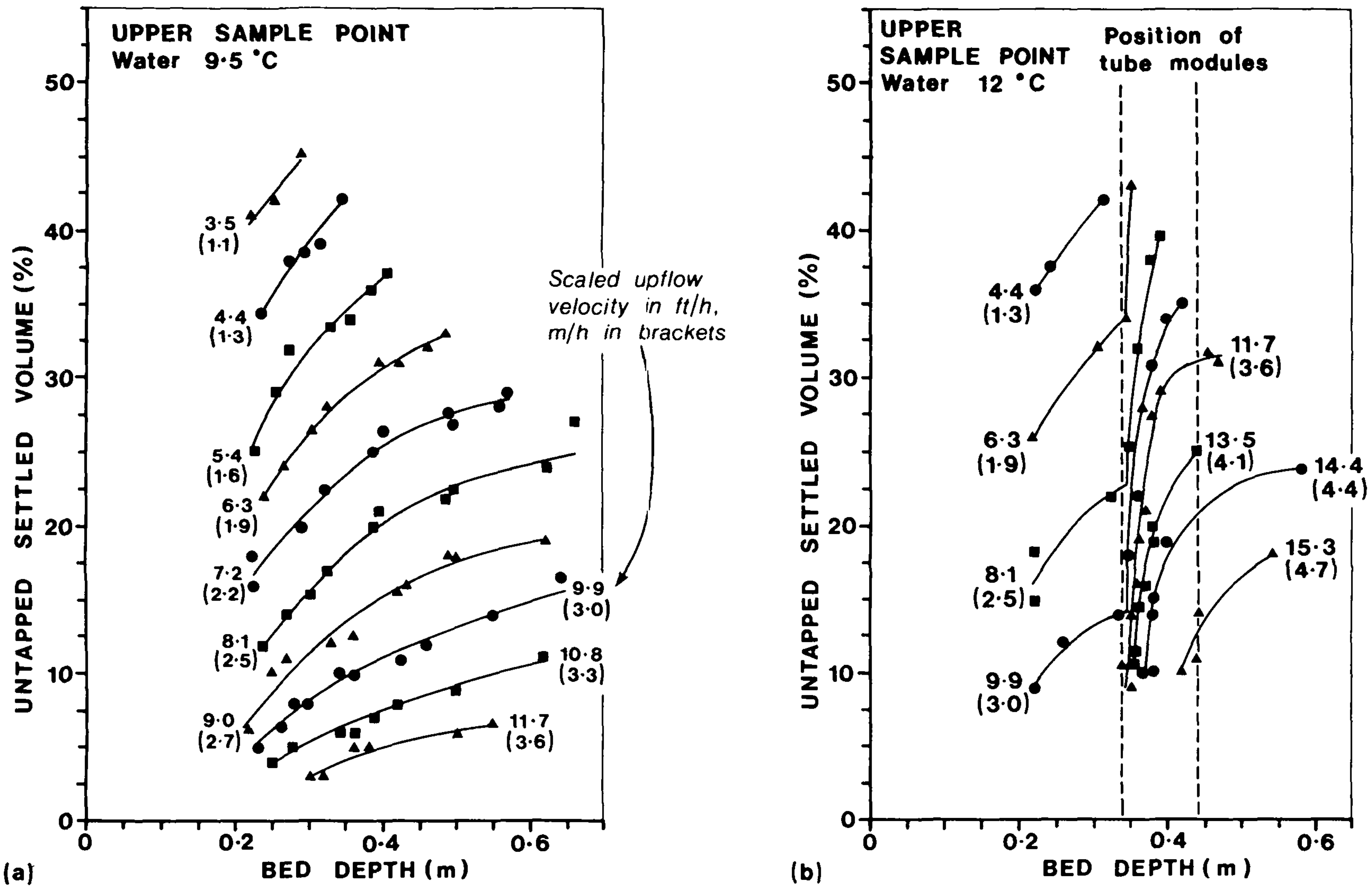


Fig. 8. Effect of bed depth on solids concentration: (a) without modules, (b) with modules

treatment rates, when the blanket is naturally stable, there will be no benefit from using baffles. The results from the trials might have been more substantial if higher upflow velocities could have been examined. However, the other investigations indicate that if at high treatment rates a tank can be stable then there is unlikely to be any benefit from installing such baffles.

(iii) Wind effect protection

Various ideas for providing protection from wind effects have been put forward, but it is difficult to assess whether the cost would be offset by the benefits. Such ideas include:

(a) Construction of a roof over individual tanks or total enclosure of all the sedimentation tanks
(b) Installation of 'scum boards' at the water surface between the off-take channels
(c) Installation of more and cheaper off-takes instead of 'scum boards': off-takes could be constructed with fins extending down into the supernatant
(d) Installation of vertical baffle systems.

(iv) Blanket level control

Blanket level control is primarily a matter of removing the incoming floc that is entrapped by the blanket and is excess to the required depth of blanket. The difficulty is to remove the excess floc efficiently so as to incur minimal subsequent thickening.

A continuous or frequent intermittent bleed directly from the blanket, although inefficient, is common. Occasional blow-down from the base of hopper tanks is good practice, but inefficient when carried out frequently for normal excess floc removal except in the case of such inlet arrangements as installed by Webster(26).

The most effective method is to ensure that at the desired level for the upper surface of the blanket there shall be sufficient cross-sectional area not subject to upflow where the floc can accumulate. This might be in the form of a distinct hopper or large flexible cone such as the proprietary Gravilectric device. The dimension of the area can be estimated from a simple mass balance. The emptying of these hoppers can easily be automated, based on an empirical operating rule or some form of sensor or monitor.

2.3. TANK SIZE

From Table 1 it can be seen there is, very approximately, a factor of ten difference in cross-sectional area between the three experimental tanks. One might, therefore, expect to distinguish a difference in performance between the tanks if a scale factor exists. It is important to note that at the normal blanket level in each tank all three had approximately equal relative blanket volumes, i.e. total volume of blanket per unit maximum cross-sectional area. This means that for these blanket levels at equivalent throughputs the mean residence times of the flow within the blankets were equal. However, the relative proportions of the blanket contained by the hopper and parallel section for each tank were substantially different.

It was generally observed that the performances of the three tanks were associated with their hydraulic stabilities as indicated by 'boiling'. 'Boiling' was not associated with the 0.3 m tank, but, on the other hand, for the 3.5 m tank, treatment performance was not usually reported at higher upflow velocities because of the extreme instability associated with the 'boiling' that developed over the whole tank area. The ultimate criterion of stability was whether a definable blanket would remain overnight or be washed out by the 'boiling'.

In the evaluation of the effects of uncontrollable variables (Section 2.1.1) it was found that the 3.5 m tank tended to be the most stable and the 0.3 m tank the most unstable, as shown by the comparison of the standard deviation of the performance parameter with its mean value. Worth noting is that the blanket floc volume and settled water turbidity were the most sensitive measurements of tank performance.

The overall comparison of tank performance is given by Figs 2, 6 and 9 presenting each tank individually and distinguishing the 1.2 m tank fitted with and without inclined tube modules (see Section 2.2.3). The results for the 3.5 m tank represent the lowest injection velocity examined. Close comparison of these figures produces a number of observations of possible importance for up-rating floc blanket clarification.

The relationships between blanket floc volume concentration and treatment rate for the 0.3 m tank were, in most cases, similar to those for the other two tanks. Exceptions were for the 1.2 m tank when operated with the blanket within the tube modules, when higher concentrations occurred, and for the 3.5 m tank for experiments 6, 12 and 16a when lower concentrations occurred.

The 0.3 m tank was also equivalent in general performance to the other two tanks as measured by the relationships between settled water turbidity and blanket floc volume concentrations, and the settled water turbidity and upflow velocity. However, these two relationships were obviously substantially affected by the chemical treatment conditions. When treatment was easy there was no substantial difference between the tanks: only when treatment was difficult did differences between the tanks become obvious. For example, these two relationships for the 0.3 m tank (experiments 12, 21, 22, 23 and 25) were indistinguishable from each other during 'summer' water conditions, but are obviously distinguished in experiments 16a, 16b, 17 and 18 with 'winter' water conditions. Thus to some extent 'easy' and 'difficult' treatment conditions are identified.

Although the evidence on the importance of blanket depth is not complete, it is possible to conclude from the results of Miller *et al.*, and the investigations with the scale model, that the benefit of depth is related to blanket concentration. Greater depth provides a greater mass of blanket solids. This assists better inlet flow distribution and hence blanket stability, which in turn will enhance blanket concentration, thereby increasing further the mass of blanket solids and improving clarification by entrapment. Increased depth will also increase contact time of the water with the floc blanket, no doubt enhancing any chemical and physical reactions. However, there is a diminishing return in settled water quality with increase in blanket depth: effective blanket depths of 2 to 3 m are usual; shallower blankets are possible but clarification efficiency and blanket stability can be problems.

For the size range represented by the three laboratory tanks there is no conclusive evidence over a prolonged period that different tank dimensions cause distinctive differences in clarification performance, providing the specific blanket volumes of the tanks are equal. However, comparison of tanks over the short period of one experiment can show differences between tanks, and the investigations did indicate that the larger a tank is, especially if hopper shaped, the more important it is to give careful attention to inlet flow distribution to the blanket.

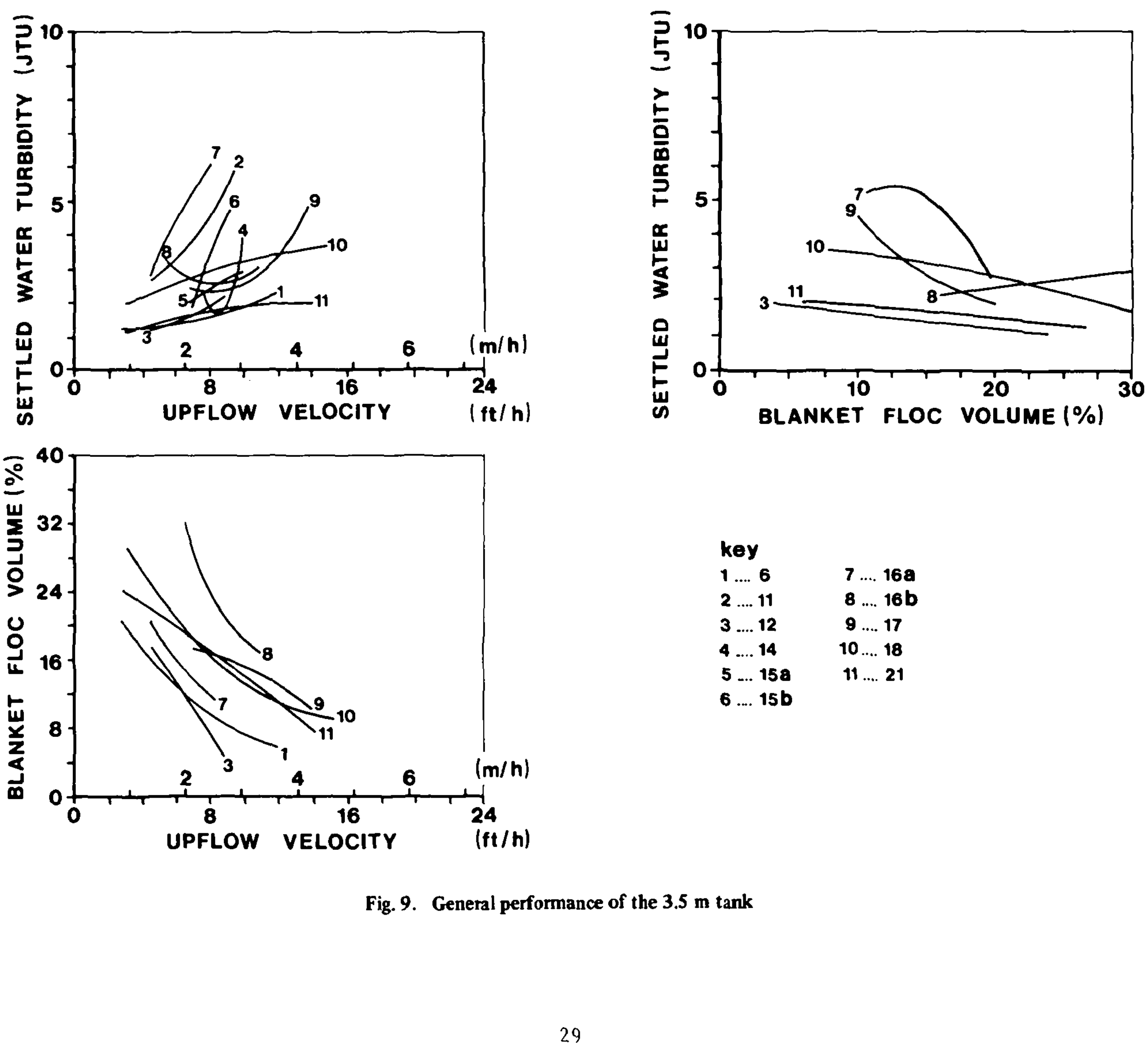


Fig. 9. General performance of the 3.5 m tank

3. IMPORTANCE OF FLOC CONCENTRATION

3.1. INVESTIGATIONS

3.1.1. Previous Work

Miller *et al.*(3,14), Miller and West(15) and Yadav(4) showed the qualitative effects on floc blanket clarification of changing certain variables excepting, unfortunately, blanket floc concentration. They showed that clarification deteriorated with increase in upflow velocity and reduction of supernatant depth and that clarification improved, although with diminishing return, with increase in blanket depth and increase in polyelectrolyte dose. However, Vostrcil(5) has noted that, by decreasing treatment rate to increase the blanket solids concentration, there is a value of that concentration beyond which further increase tends not to yield much further improvement in settled water quality. This value was not substantially affected by the use of polyelectrolytes which suggests that clarification is dependent on floc concentration.

WRC data can be used to demonstrate that when raw water quality, coagulant dose and upflow velocity are all constant, one polyelectrolyte only differs from another in its effect on blanket density and settled water quality by its relative effectiveness in improving floc properties. The ultimate effects of different polyelectrolytes in floc blanket sedimentation are the same: Fig. 10, in which the upper figure affirms the comparability of the data, simply shows a limiting return on improved clarification with increasing blanket concentration. (The effects on subsequent filtration would have been different.)

A number of authors have examined the relationship between floc concentration and velocity in hindered settling and fluidisation. Since the work published by Richardson *et al.*(39) on suspensions of solid particles, most authors have done little more than show how their data obtained from work with floc compare with the results of Richardson *et al.* (Table 2). There has been virtually no comment on how change in settled water quality might be related to the relationship between floc concentration and velocity of the suspension.

3.1.2. Recent work

The extensive operation of the WRC floc blanket clarification pilot plant to examine the factors affecting performance already outlined (Section 2) resulted in a substantial quantity of data, not only of settled water quality and upflow velocity, but also blanket quality.

In the first instance it was found that, by the use of quadratic regression analysis, settled water quality could be correlated with blanket floc concentration; and blanket floc concentration could be similarly correlated with upflow velocity. Thus, instead of saying settled water quality depends on upflow velocity, it became more acceptable to regard settled water quality as being dependent on blanket floc concentration, which in turn is dependent on upflow velocity (Fig. 2).

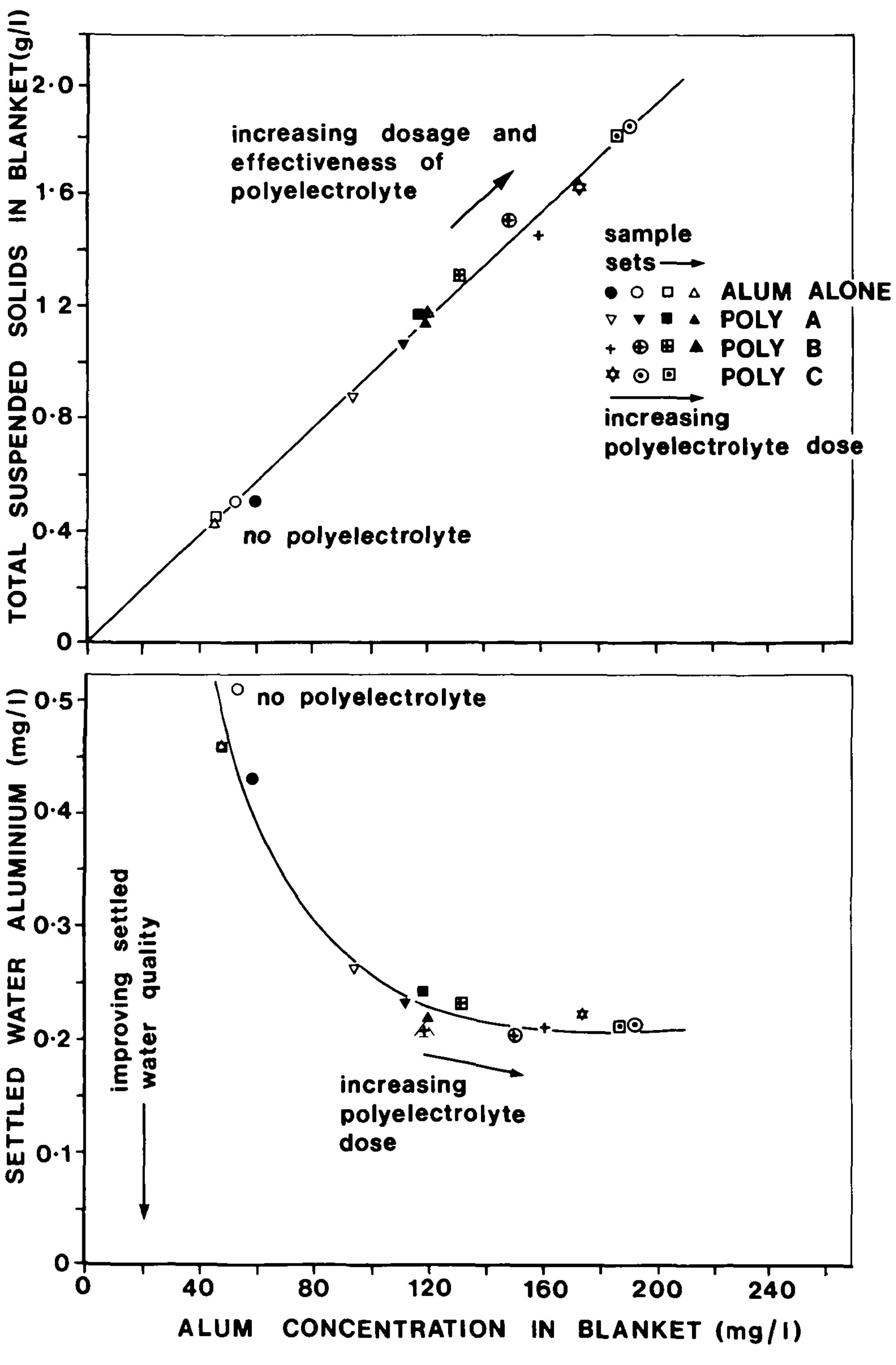


Fig. 10. Effect of polyelectrolyte on blanket density and on settled water quality

Table 2. Summary of earlier work

Reference		System	Concentration measurement	Values found for q and k (Appendix A)
Maude and Whitmore	(40)	settling: various non-flocculated	-	k_3= 4.15 to 9.35
Bond	(12)	settling: alum, lime fluidisation; alum, lime	24 h occasionally stirred settled vol.	f = 2.78 3.25 2.4
Thomas	(41)	settling; various solids size 0.4 to 17.0 μm	-	q_1 = 5.9
Tesarik	(24)	fluidisation; alum + silica, alum, iron flocs	2 h settled vol.	k_3 = 4
Edeline *et al.*	(42)	fluidisation; $FeCl_3$ + polyelectrolyte, activated sludge	2 h settled vol.	k_3 = 3.3 12 to 27
Brown and La Motta	(43a,43b)	fluidisation; alum, alum + polyelectrolyte, iron.	?	k_3 = 1.75 to 6.40

Table 2. Continued

Reference		System	Concentration measurement	Values found for q and k (Appendix A)
Merkel	(44)	settling	30 min settled vol. activated sludge	$q_4 = 1.7$; $k_5 = 4.8$
C < thickening		fluidisation		1.7 7.7
C < thickening		settling		1.2 1.4
		fluidisation		2.2 0.7
Hale	(20)	settling and fluidisation alum and silica	3 h settled vol.	f = 1.6 to 2.5
Vostrcil	(5)	settling: fluidisation	?	f = 1.4 to 2.8
		$FeCl_3$ + various polyelectrolytes		k = 3.0 to 10.8
Sen	(45)	settling: iron alum	60 min settled vol.	$q_1 = 7.44$ 2.94
Stevenson	(46)	Bond's data		$q_1 = 10$

Further analysis of blanket floc concentration and upflow velocity data was carried out using a variety of relationships in addition to the general quadratic to establish whether one relationship was more suitable than the remainder, and to compare with other published results of such analyses made elsewhere. These two parameters were also considered in terms of flux calculated as the product of the two. The relationships examined are described in more detail in Appendix A, while the symbols used are defined in the Nomenclature section.

In general terms, the results of the analyses were similar to other published information on floc suspensions. Any differences tend to reflect the different chemical situations and the method of measuring the floc concentration.

The data could be well represented by most of the expressions examined, especially the Richardson and Zaki relationship:

$$U = U_p\ (1 - c)^{k_2} \qquad \text{Equation 3, Appendix A}$$

However, it is found that over the range of velocity and concentration of interest, their product U.c, blanket flux, has a maximum value giving the special condition of equation 3:

when: $c = c_{mf}$, and $U_{mf}\ c_{mf}$ = maximum value of U.c

such that: $c_{mf} = \dfrac{1}{k_2 + 1}$ or $k_2 = \dfrac{1 - c_{mf}}{c_{mf}}$

The data could be represented better still by a modification of equation 3:

$$U = U_q\ (1 - q_4 c)^{k_3} \qquad \text{Equation 4, Appendix A}$$

(q_4 was estimated beforehand, see Appendix A, to be equal to 2.5)

The condition of maximum flux, $U_{mf}\ c_{mf}$, can be closely associated with the onset of deterioration of the settled water quality, Fig. 11 (see also next Section).

The value of terminal, or maximum, upflow velocity determined from these correlations can only be interpreted as the velocity of the suspension extrapolated to zero solids concentration and not as the terminal settling velocity of a single floc particle. The distribution of the values for the terminal upflow velocity U_p for the correlation of (1 - s) is shown in Fig. 12a, where s is the measured floc volume concentration. It is considered that the terminal upflow velocity defines the limit of operation of floc blanket sedimentation more suitably than Stokes's settling velocity.

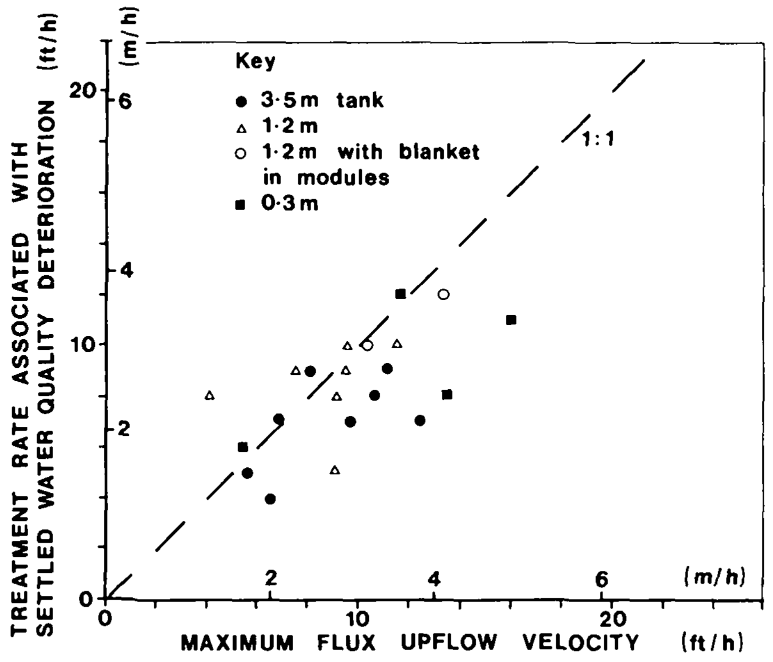


Fig. 11. Association of maximum flux treatment rate with product quality deterioration

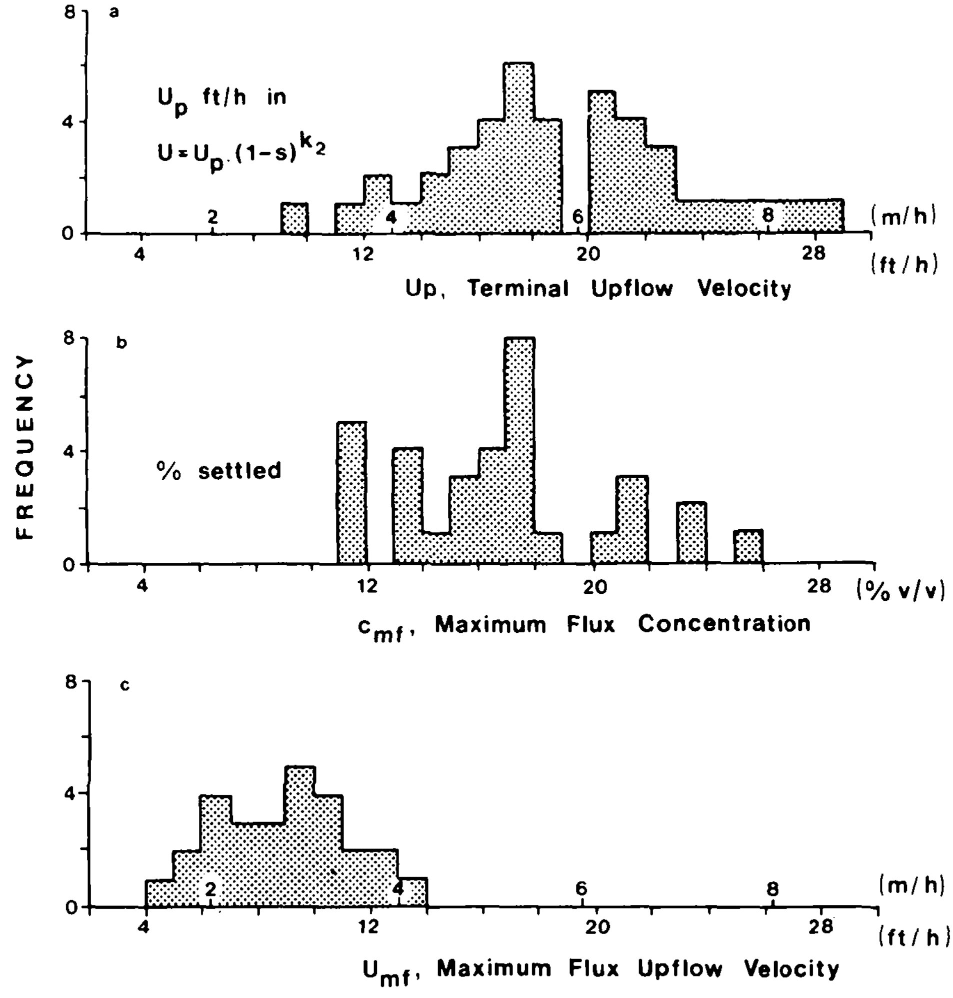


Fig. 12. Distributions of various velocity-concentration regression values

Bond(12) noted that the blanket surface remained clearly defined up to an upflow rate of about half his terminal settling rate, U_p, that slight boiling occurred above 0.55 U_p; and clarification deteriorated noticeably at about 0.65 U_p. Tambo *et al.*(25) found that a floc blanket is stable at upflow velocities less than about 0.7 U_p. At rates greater than 0.8 U_p they found the blanket very unstable with the coefficient of diffusion becoming exceedingly large. The results of these investigations indicate that treatment rates greater than obout 0.75 U_p should be avoided.

3.2. THE MAXIMUM FLUX CONDITION

Only Vostrcil(5) has noted that it is not worth increasing blanket floc concentration beyond a certain value because such increase tends to bring no further improvement in settled water quality. More recently, Davies *et al.*(47) have concluded that the state of maximum flux can provide useful indices of hindered sedimentation.

Davies and Kaye(48) found that the segregation in sedimentation of mixed particles is related to a critical concentration. They explained that the critical concentration is dependent on the inter-particle orientations and resultant mechanical interlocking of the smaller species. They found that, for spherical particles of equal density, the critical volumetric concentration is in the range 0.35 to 0.40, and for mixtures of cubes and cylinders about 0.17. The critical concentration is observed to represent the transition from the diffuse to the defined interface of a settling suspension of a multiple-size mixture. It was found at WRC that the packed point concentration could not be determined easily for a settled concentration of less than about 0.16 and that the concentration at maximum flux was in the range 0.13 to 0.18. It appears that the phenomena of maximum flux and defined interface transition and the critical concentration defined by Davies and Kaye are the same condition of a suspension of rigid or floc particles.

Figs 12b and 12c show the distributions in the values of concentration and velocity at maximum flux for conditions at Medmenham. From all the data, this maximum flux velocity was observed to equal approximately half the terminal upflow velocity deduced from the linear correlation with ln (1 - s), Fig. 12a.

Close examination of the general performance data of floc blanket tanks indicates that there is a strong relationship between the commencement of deterioration in settled water quality and the maximum flux conditions, Figs 2, 6 and 9. The practical interpretation of this maximum flux condition is that it represents conditions of operation likely to give the best tank performance with respect only to quantity and quality: the operational costs and the optimum relationship with subsequent processes are not taken into consideration.

Deterioration in settled water quality is associated with the relaxation of the entrapment, as concentrations become less than at maximum flux and inter-particle distances increase with upflow velocity, and with the development of a diffuse

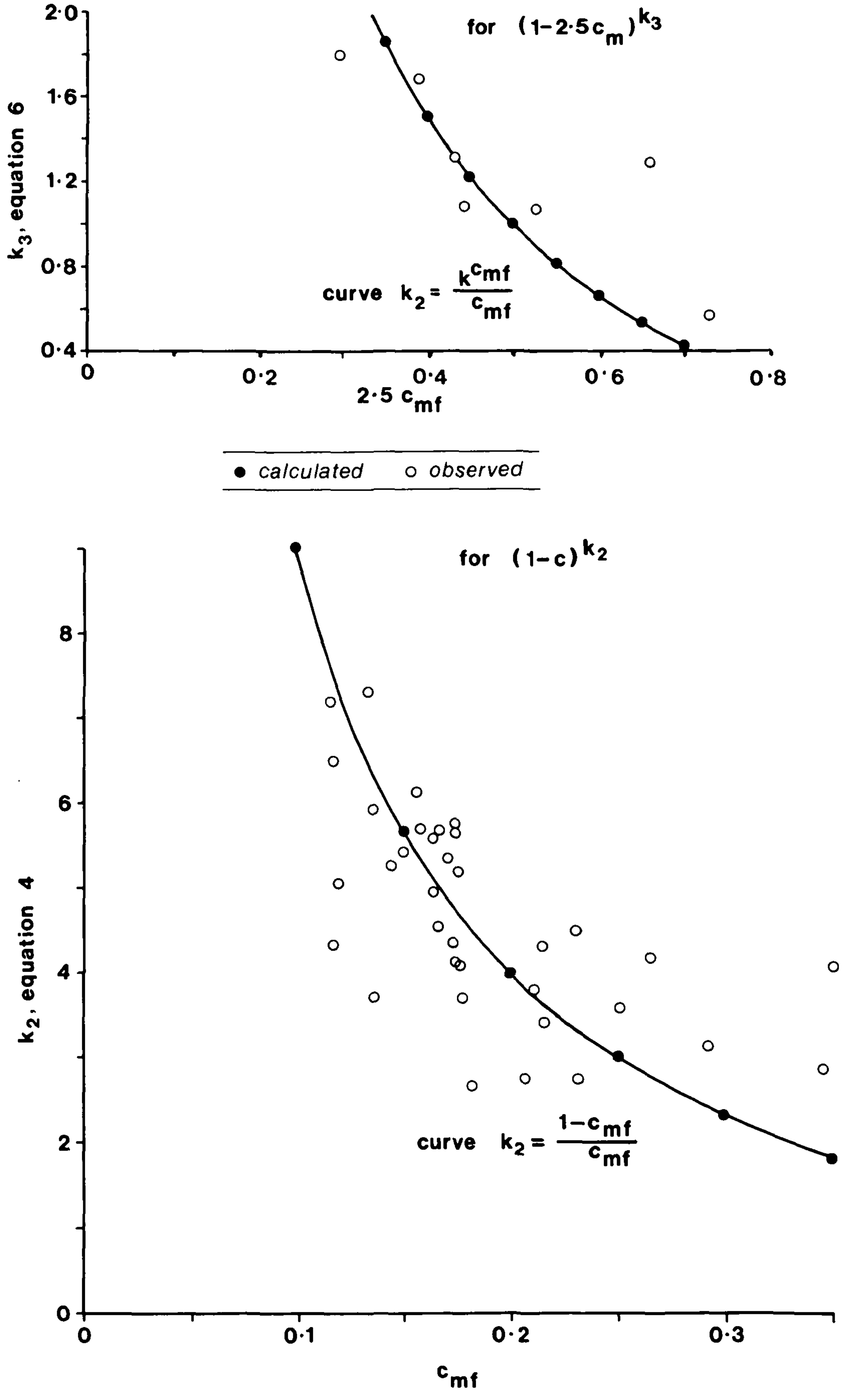


Fig. 13. Comparison of experimental results with the theory that k is related to c_{mf}

interface. For concentrations greater than at maximum flux this deterioration is primarily caused by material which, being neither successfully coagulated nor effectively flocculated, is thus still small enough to pass through the mechanical structure of the blanket.

If this explanation of the mechanism of clarification is valid then settled water quality data should be more appropriately separately correlated for conditions representing either greater or less than maximum flux. To examine this mechanism further, Fig. 11 was prepared. The upflow velocity associated with settled water quality deterioration has been estimated for the three tanks from their respective group presentations of settled water turbidity/upflow velocity relationships. This value is plotted against the maximum flux upflow velocity. The bias to one side of the equality line probably indicates that the estimate of settled water quality deterioration was conservative. The maximum flux upflow velocity otherwise appears to be closely related to deterioration in settled water quality.

Fig. 13 has been prepared to show how the present results compare with the theory that k_2 and k_3 are related to c_{mf}(equations 4 and 6 in Appendix A and Section 3.1.2.). Introducing q does not cause the results to depart from the theory.

Examination of the theories of Ives(17), Shogo(18) and Cretu(19), using the new data and conclusions, results in increased support for Ives's theory which can nevertheless be improved to give more acceptable answers, as outlined in Appendix B.

4. DESIGN OF FLOC BLANKET CLARIFICATION SYSTEMS

The investigations reported here illustrate that clarification is fundamentally dependent on the floc blanket and that clarification efficiency ought to be the same for any shape or form of tank providing certain equivalent conditions exist. Aspects of design that need consideration to ensure the best performance from the floc blanket have been identified. However, sedimentation must not be considered in isolation from the whole clarification system, and it must be remembered that the quality of the settled water will affect filter performance.

4.1. GENERAL CONCEPT

A floc blanket clarification system consists of the following stages:

(a) quality measurement and rate control of the water to be treated,
(b) fast, efficient mixing of the coagulation chemicals after selection of the preferred chemical treatment,
(c) conveyance of the coagulated water to the separation part of the system often providing a period of contact referred to as delay time,
(d) floc blanket separation involving distribution of flow into the blanket zone, flocculation, fluidisation, flow stabilisation, inter-particle mechanical entrapment, sedimentation and elutriation.

There are two aspects to the design of the floc blanket separation itself:

(i) the hydraulic nature of flow conditions within the blanket and at the blanket surface, and,
(ii) floc quality and its effect on the hydromechanical process of separation and accumulation of the floc from the water.

Some prediction of the correct method and the ease of treatment is possible by simple analysis of a new source and comparison with successfully exploited sources; and the available theory can be used to check, or perhaps guide, the design of the floc blanket tank itself. However, to minimise guesswork and avoid inefficient design, the range of raw water quality needs to be rigorously characterised, especially its influence on floc quality. This should preferably be done by operating a pilot plant over an adequate period of time to cover at least one, or preferably both, the periods of maximum treated water demand, and most 'difficult' treatment conditions as appropriate.

4.2. TREATMENT SELECTION

The following are recommended when using pilot plant, commissioning new plant, or uprating assessment of existing plant:

(a) Determine the most effective chemical treatment, taking into account the annual variation in raw and settled water quality using acceptable analytical methods. Plotting the data helps to show the most likely times of year when treatment could be difficult. Initial categorisation of raw water quality can usually be based on the periods of low, rising, high and falling water temperature.

(b) Continuously monitor either or both the untreated and settled water qualities where the raw water is subject to frequent rapid changes in quality.

(c) Ideally, in addition to jar test analyses, control the coagulation by continuous monitoring according to an operating rule.

(d) Relate the variation in settled water quality to upflow velocity.

(e) Define the upflow velocity limits for the maintenance of an acceptable settled water quality with due allowance for seasonal effects.

(f) Match the seasonal rating of the floc blanket clarification plant with the seasonal demand for treated water.

(g) Ideally, when examining new sources, operate pilot plant over as long a period as possible, and certainly for the most difficult treatment conditions likely with respect to raw water quality and treated water demand.

(h) The full-time use of polyelectrolytes should normally be avoided, even if economically attractive. They should be reserved for occasional use for overcoming otherwise difficult treatment situations, and for future uprating.

Further guidelines are given in Appendix C on the operation of pilot and operational plant to produce experimental data. The method of evaluating the resulting data is also described.

4.3. TREATMENT APPLICATION

A number of points needs to be considered for the successful application of the selected treatment.

(a) Ensure satisfactory rate control and measurement of the water. This is essential for correct chemical dosing and plant performance evaluation.

(b) Ensure fast efficient mixing of the coagulant chemicals in the correct order of addition with the appropriate times for mixing and contacting between each chemical. This may take place in either or both pipe and open channel flow. Improvement is usually possible on many older plants both in the control and addition of the coagulation chemicals. It is important that each chemical is added to the maximum benefit of the next, and to ensure that every particle of substance to be removed is subjected to equal chance of removal.

(c) Give adequate attention to the optimum delay time between coagulant addition and entry to the floc blanket when observing clarification. In spite of considerable study the mechanism is still not known but is clearly related to coagulation and flocculation kinetics. However, improvement in clarification diminishes with increase in delay time. The benefit of delay time depends greatly on raw water quality (including temperature), and the chosen chemical treatment. Each source therefore needs to be considered individually.

(d) Achieve a stable floc blanket/supernatant interface. Disparity in blanket floc concentration and upflow velocity data from pilot and operational plant is likely to be due to different hydraulic conditions for the floc blanket. Direct stability control of the interface, for example by vertical baffles, should not normally be necessary. If the blanket is unstable, then the inlet design and subsequent flow distribution should first be considered, this probably being the cheapest approach.

(e) Avoid excessive injection velocity which can cause blanket instability, as might any other input of kinetic energy. The efficiency of flow distribution is also dependent on flow geometry, and especially on the accuracy of construction, and hence tank geometry and proportions.

(f) Operate the blanket supernatant interface as high in the tank as possible to maximise blanket depth, thus improving stability and increasing blanket floc concentration, and thereby improving separation. The floc blanket itself contributes to the dissipation of turbulence and hence to its own stability. However, this stability is dependent on the quality of the floc, and its concentration and water temperature, as well as the quantity, or depth, of the blanket.

(g) Use an effective method of blanket level control which also provides efficient excess solids removal by preliminary thickening of the solids. The preliminary thickening requirements can be determined simply from a mass balance and allowance for increases in throughput and for coagulant dose variations.

(h) Make the ultimate choice of tank geometry, e.g. round or square, hoppered or flat bottomed, on a cost-effective basis, i.e. whether it can produce the required amount of water of the required quality for minimum cost. Fundamentally there is no reason to believe there is any difference in effectiveness between various types of tank providing (i) all the basic tank designs are operated with controlled blankets, (ii) all are equally flexible in operation and provide equivalent conditions of blanket contact time, (iii) all give equivalent values for upflow velocity at the blanket surface, and for blanket floc concentration, and (iv) equivalent conditions exist between the addition of chemicals and entry of water to the blanket. However, there has been a tendency for the cheaper concrete structures to involve greater mechanical and operating costs. The sensitivity of costs to design and operating parameters is not known.

4.4. TYPES OF TANK

There is a comprehensive range of proprietary and other designs of tanks used for floc blanket clarification some of which are perhaps, more suitable for the job than others. Some of the designs effectively provide features, such as flash mixing, delay time and blanket level control, which may render additional construction to provide these unnecessary.

No substantial comparisons of operational tanks are known to have been reported, although Holland(49) has reported some experience with operating both Pulsators (flat bottom) and Accentrifloc (premix-recirculation) tanks. Three different tanks, square hopper, circular hopper, and square flat-bottomed have been constructed at Burham(50), but results of their comparisons are not yet available.

The basic requirements of floc blanket clarification are satisfied by a simple upflow design, in which the inlet flow is dispersed uniformly over the inlet level cross-section and the collection at the outlet is uniform over the outlet level cross-section. A hopper shape in the base of the tank assists the flow distribution. It has been generally recognised that the square plan hopper tank deteriorates in performance at lower upflow rates than circular tanks. However, the square plan permits economies in construction.

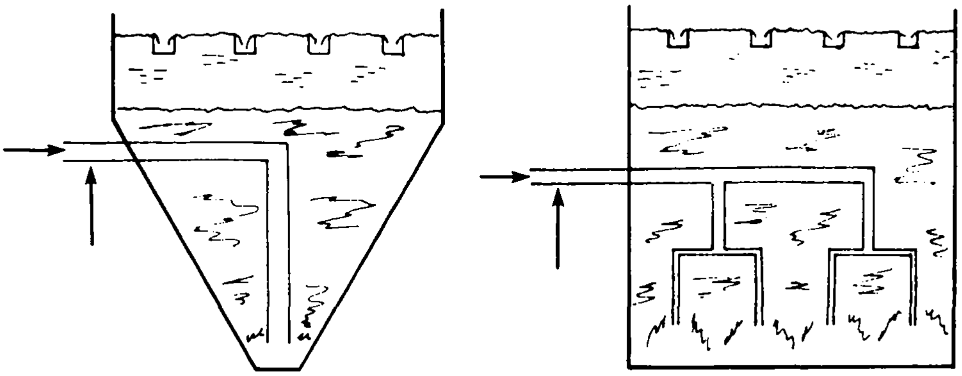
There can be economy in construction with the removal of the hopper section. As advances are made in producing tanks with flat bottoms, multi-hoppered tanks have been conceived and constructed. The problems in their design then become those of efficient multi-inlet flow distribution, the assurance of blanket stability and floc settlement, and excess floc removal.

Other designs, some quite complex, do exist. However, probably few of these were designed as floc blanket clarifiers but were conceived as solids-contact units, not only for clarification by coagulation, but also for softening and other processes. Barham *et al.*(51) have made an extensive patent review of clarification, sedimentation and thickening plant which traces the developments of such equipment. Prager(52) confined his review specifically to floc blanket clarifiers. Hartung(53) has presented a study of eight different designs of solids-contact units used in water treatment. Such contact designs can be sub-grouped into premix-recirculation tanks (see Fig. 14).

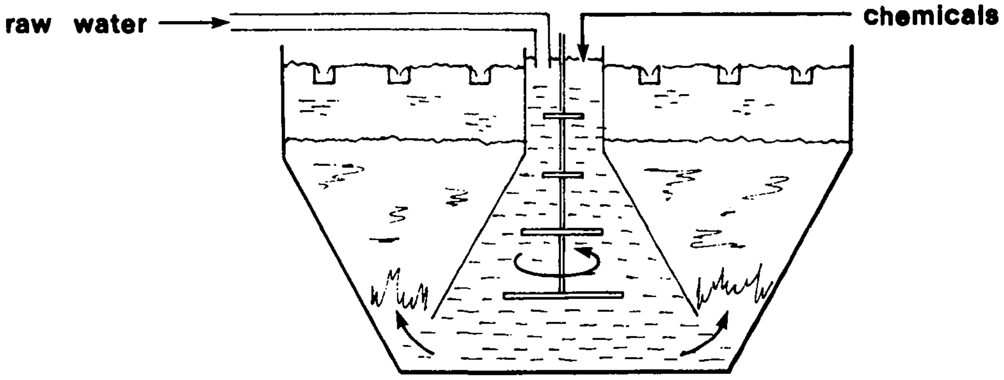
Essentially the simple premix tank, Fig. 14 (c) consists of a central inlet to a circular tank. The inlet feeds the central part of the tank which is mechanically agitated. The shroud of this premix zone acts as the inner containing wall of the annular, blanket region.

It might be possible to regard this design as an approach to a flat-bottomed tank, with the central premix zone acting as the flow distributor. It is recognised that too much stirring can cause the agitation to be carried into the blanket with resulting blanket hydraulic instability.

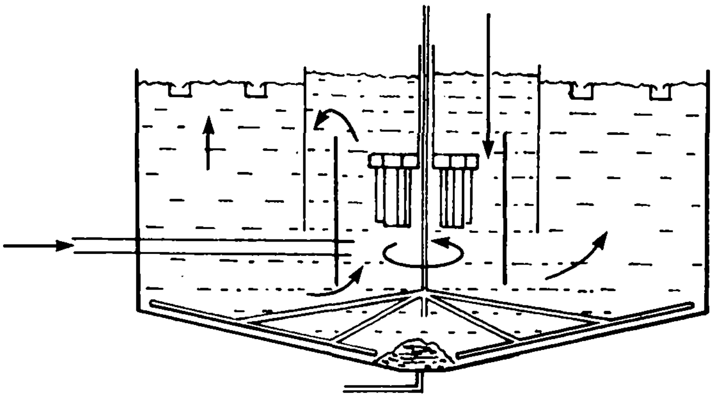
It is usually accepted that this design achieves better blanket performance due to improved floc quality. As indicated by delay time and flocculation investigations, any improvement is more likely to be a result of the delay time between the addition of coagulant and entry to the blanket than to orthokinetic floc growth. However, there does not appear to be any evidence that such a design of tank will operate better, or worse, than a single hopper tank provided with the same coagulation conditions. The mechanical and operational disadvantages of a simple premix tank must be offset by constructional advantages.



(a) Single hopper **(b) Flat bottom**



(c) Premix compartment and blanket



(d) Premix–recirculation and unhindered settling

Fig. 14. Solids-contact clarifiers

The premix-recirculation design, Fig. 14(d), employs the additional concept of recirculation of flocculated material to provide flocculation seeding and involves additional mechanical equipment. This concept can be extended to the accepted principle of concentration benefit to flocculation. The recirculation is achieved by drawing the flow from the premix zone upwards and then distributing it downwards under a second shroud. The rate of pumping from the premix zone must exceed the throughput to cause the circulation required. Flow in excess of the throughput is drawn under the inner shroud back into the premix zone, to provide the recirculation.

The concept of floc seeding may be valid to this design of tank in lime softening and other precipitation-crystallisation processes, but there is no known substantial evidence to support this in simple coagulation-flocculation. The concentration effect on flocculation is unlikely to be used to full advantage (especially in fluctuating-load plants other than when frequent shut-down occurs), because of the need to adjust the recirculation to suit.

Further, the contact provided by the blanket is likely to be much greater than that due to the premixing of recirculated solids. It is conceivable that recirculation of solids causes physical degeneration of the floc structure. This, although providing weighting and improved quality of the resultant floc, could create an additional coagulant requirement for its recoagulation. It is also conceivable that the recirculation could cause other difficulties in the control of coagulation such as with the use of polyelectrolytes.

A premix-recirculation tank cannot be considered as a floc blanket tank unless the recirculation shroud continues low enough into the tank for an effective blanket to be maintained well above the lower rim of the shroud.

It is possible to predict that the most economic and efficient tank would be rectangular, 3 to 4 m deep, flat-bottomed, with candelabra type flow distribution and a widely spaced inclined plate system across the floc blanket surface. Use of widely spaced inclined plates, as used in the Superpulsator type tanks, has yet to be reported in detail.

The Simtafier process involving sand recycling probably has potential but has yet to be reported in detail. Its use will depend on the gains relative to the additional operating costs such as occurs with dissolved air flotation and high rate lamella sedimentation (Gregory(54)).

5. CONCLUSIONS

1. The principal clarification mechanism of a floc blanket at normal concentrations of floc in the blanket is mechanical entrapment.
2. The onset of the failure of mechanical entrapment due to increasing upflow velocity through the blanket can be related to the blanket floc volume concentration at maximum flux of the blanket.
3. There is a range of blanket concentrations (which is 16 to 20 per cent for alum at Medmenham) beyond which settled water quality is relatively unaffected by the quality of chemical treatment, or by further increase in concentration or decrease in upflow velocity: it is coincident with the maximum flux condition.
4. The maximum flux condition represents the condition of operation likely to give the best tank performance with respect to quantity and quality only. It does not take into account the effects on operational cost, and optimum relationship with following processes. Operating conditions, especially upflow velocity, at maximum flux also represent the ease of treatment of the water for the chemical treatment applied, and hence can be used as a measurement of floc quality, raw water quality, and tank efficiency for the water temperature and the operational and environmental conditions prevailing.
5. Settled water quality is best related to blanket floc volume concentration which in turn is related to upflow velocity.
6. These relationships are not only dependent on the choice of chemical treatment but also very much on the raw water quality, and its seasonal changes (particularly in water temperature), such that annual variations in the ease of treatment can be distinguished.
7. Since floc blanket instability can diminish the blanket floc volume concentration, instability can cause poor clarification efficiency.
8. The design of the inlet to the floc blanket region can be important in order to ensure a stable floc blanket.
9. Floc blanket instability can be improved by placing large, widely-spaced vertical or inclined surfaces across the blanket surface.
10. Closely spaced inclined surfaces can increase the concentration of the blanket floc below the surface system but a substantial improvement in settled water quality does not occur. However, improved settled water quality might occur with widely spaced inclined surfaces to allow treatment rate increases of more than 50%.
11. The maximum flux velocity of a blanket is inversely proportional to the viscosity of the water and hence dependent upon the temperature.
12. Ives's theory of floc blanket clarification can be simplified to give more acceptable answers, but available theory cannot yet replace practical work to assess design requirements.
13. Hydraulic scale modelling of floc blankets with careful selection of the particulate material to represent floc is possible.
14. The stages in design and operation might include:
    (a) Determining the most effective chemical treatment

(b) Continuous monitoring of water quality where the raw water is subject to frequent rapid changes in quality

(c) Controlling coagulation by continuous quality monitoring according to an operating rule in addition to jar tests

(d) Relating the variation in settled water quality to upflow velocity and blanket quality

(e) Defining the upflow velocity limits to ensure an acceptable settled water quality

(f) Matching the rating of the floc blanket clarification plant with the annual demand cycle for treated water

(g) Use of pilot plant when examining new sources

(h) Ensuring satisfactory measurement and control of the water flowrate

(i) Ensuring fast and efficient mixing of chemicals dosed

(j) Giving adequate attention to the period between the fast mixing and entry to the floc blanket

(k) Ensuring tanks are designed and constructed for a stable and controllable blanket

(l) Giving adequate attention to efficient excess floc removal and blanket level control

(m) Selecting tank design on the basis of technical suitability and economics.

NOMENCLATURE

c	volumetric concentration, m^3/m^3
c_{mf}	volumetric concentration at maximum flux
c_m	maximum volumetric concentration (Equation 5)
C	mass concentration of particles or of coagulant cation, mg/litre
C_a	camp number (Vostrcil)
d	diameter of particle, orifice, m
f	particle shape constant (Bond)
g	gravitational constant, m/s^2
G	velocity gradient, s^{-1}
h	useful loss of head, expressed as metres head of water
k_1, etc.	power indices in velocity-concentration analysis
L	Total vertical depth of blanket, m
P	mechanical power, N.m/s
q_1, etc.	arithmetical constants in velocity-concentration analysis
Q	volumetric flow rate, m^3/s
s	settled volume concentration, floc, m^3/m^3
t	flocculation time, seconds
U	superficial upflow velocity, m/h
U_{mf}	superficial upflow velocity at maximum flux
U_o	terminal velocity of a single particle, m/h
U_p, U_q	modified terminal velocities determined by correlation, m/h
$\bar{V}$	volume, m^3

α	regression constant
β, γ	regression coefficients
δ	differential of
Δ	difference of
μ	viscosity, $N.s/m^2$
ρ	density, kg/m^3
σ	specific gravity

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APPENDIX A – SELECTION OF VELOCITY/CONCENTRATION RELATIONSHIPS

The following summarises the velocity/concentration relationships selected for the analysis of the experimental data obtained in the laboratory investigations.

Equation 1

Perhaps the most simple and viable empirical relationships between velocity, U, and concentration, c, is given by(41,45,46)

$$U = U_p \cdot \exp(-q_1 \cdot c) \qquad (1)$$

where U_p represents a terminal velocity and q_1 is a constant.

Equation 2

Many of the semi-empirical relationships for viscosity of suspensions can be expressed in the form of a power series. Thus, in the analysis of settling and fluidisation, the best general statement of the various relationships would appear to be the power series(55,56)

$$\frac{U}{U_p} = (q_2 \cdot c)^{k_1} \cdot (q_3 - c)^{k_2}$$

where q_2, q_3, k_1 and k_2 are constants dependent on the data set. The simple form of this relationship is(57)

$$U = U_p \cdot c^{k_1} \cdot (1 - c)^{k_2} \qquad (2)$$

Equation 3

For even simpler purposes the following expression is usually preferred(39,42,43)

$$U = U_p \cdot (1 - c)^{k_2} \qquad (3)$$

Equation 4

Substituting for viscosity (Landel *et al.*(55)) in the equation derived by Robinson(58) from Stokes's equation of settling gives

$$\frac{U}{U_o} = \left(1 - \frac{c}{c_m}\right)^{2.5}$$

where U_o is the terminal settling velocity of a single particle, and c_m is the maximum obtainable volumetric concentration.

This can be re-written(57) as

$$\frac{U}{U_q} = (1 - q_4 \cdot c)^{k_3} \qquad (4)$$

where U_q is equivalent to $U_o.q_5$ and must be distinguished from U_p in equation 1; q_4 is a constant representing the fluid mechanical effects related to the floc concentration at incipient fluidisation which needs to be established before equation 4 is easily used for regression analysis.

Equation 5 and 6

A further approach is to consider the flux of the suspension: this is defined as the product of velocity and concentration(59). In the concentration range of interest, the flux, U.c m^3/m^2h, has a maximum value with respect to both U and c, and can therefore be represented as the quadratic relationships

$$U.c = \alpha_u + \beta_u.U + \gamma_u.U^2 \tag{5}$$

and $$U._c = \alpha_c + \beta_c.c + \gamma_c.c^2 \tag{6}$$

where α, β and γ are constants.

For regression analysis, the above equations were all transposed to the following forms:

Equation 1: $$\ln U = \ln U'_p - q'_1.s \tag{7}$$

Equation 2: $$\ln U = \ln U'_p + k'_1.\ln(s) + k'_2 \ln(1 - s) \tag{8}$$

Equation 3: $$\ln U = \ln U'_p + k'_2.\ln(1 - s) \tag{9}$$

Equation 4: $$\ln U = \ln U'_q + k_3.\ln(1 - q'_4.s) \tag{10}$$

Equation 5: $$U.s = \alpha'_u + \beta'_u.U + \gamma'_u.U^2 \tag{11}$$

Equation 6: $$U.s = \alpha'_s + \beta'_s.s + \gamma'_s.\ s^2 \tag{12}$$

where s is the blanket floc volume concentration, i.e. the 30-minute settled volume of a blanket sample measured in a graduated measuring cylinder, as distinguished from c the actual or effective volume concentration; and where 'prime' (′) also denotes this difference. Equations 7, 9, and 10 were also examined as quadratics. A full comparison of the usefulness of these equations to correlate the data is given in reference (1).

To simplify the use of Equation 10 a value of q'_4 was estimated. Its value represents the difference between the measured concentration, s, and the hydrodynamically effective volume concentration, which can only be represented by c for non-flocculated spherical particles. An estimate of 2.5 for the value of q'_4 was made and is the ratio of the packed point volume to the blanket floc volume when using alum at Medmenham. The packed point is the estimated point of transition from the constant concentration settling rate period to the initial part of the falling rate period in the settling rate curve of a suspension, i.e. the start of thickening.

The values of the constants and coefficients derived in the regression analyses of the floc concentration/velocity data with the preceding equations can be related to and provide information on the character of the floc quality and general properties of the suspensions. Although these values represent settled volumes, s, they would be little altered if corrected for a more realistic volume concentration, c, since estimates indicate a porosity of approximately 0.10 for the settled volumes. Although a value of 2.5 for q'_4 was used, the value of q'_4 was found to vary occasionally beyond the range 1.8 to 3.5. This variation was usually associated with raw water quality changes and unsatisfactory coagulant doses.

APPENDIX B – DEVELOPMENT OF THE IVES FLOC BLANKET THEORY

Ives(17,60,61) has produced the most comprehensive quantitative examination of floc blanket clarification known to exist. Ives(26) attempted to apply the theory of orthokinetic flocculation then available to the case of a conical-shaped upflow clarifier. His objective was to produce some design considerations which relate the clarifier dimensions to the rate of flow and the characteristics of the floc. He examined the clarifier for its individual functions as a flocculator, as a retention tank for floc, and as a balancing tank for the solids fed in. When these functions are put together they should specify the hydraulic requirements of the tank and lead to some design considerations. However, Ives had to make many simplifications which may not be justified in practice. These are discussed whilst reworking his design example:

Viz. Let us assume that we require a clarifier to treat

$$^{*}\ 2\ \text{mgd}\ (Q = 3.7\ \text{cu ft/s});\ \text{at } 50\ ^{o}\text{F},\ {}^{\mu}/_{\rho} = 1.41.10^{-5}\ \text{sq ft/s}.$$

(i) Although Argaman and Kaufman(62) have recognised that orthokinetic flocculation is a balance between floc growth and breakup, the term G.c.t. used by Ives is a much easier expression of flocculation to employ and has found some general acceptance. Ives took G.c.t. = 100 as a typical value. Vostrcil(5) and Fair *et al.*(63) have proposed that a modified form of G.t. can represent clarification conditions in a floc blanket, where:

$$(\text{G.t.})\ \text{modified} = C_a = \sqrt{\frac{P}{\mu\ .\ \bar{V}}}\ .\ \frac{\bar{V}}{Q} \qquad (13)$$

where $P = \rho_b . g . h_f . Q$, N.m/sec, (14a)

in which ρ_b = density of the blanket, kg/l,

h_f = useful loss of head = weight in water of the floc in the blanket,

$= L.c.\ \Delta\sigma$, m, (14b)

$\Delta\sigma$ = specific gravity difference between floc and water.

$$C_a = \left[\rho_b . g . \frac{L.c.}{\mu} \Delta\sigma . \frac{V}{Q}\right]^{\frac{1}{2}} \qquad (15)$$

but $\frac{V}{Q} = \frac{L}{U}$ hence $C_a = \left[\rho_b . g . \frac{L^2 . c.}{\mu\ . U}\ \Delta\sigma\right]^{\frac{1}{2}}$ (16)

---

* units as used in the original by Ives.

It is believed that the value of c should be taken as $q_4.s$, the hydrodynamically effective volume concentration. The value of this equation, at Medmenham in the experimental tanks at maximum flux conditions, when L = 2 m effective depth, $U = 3 m/h$, $s = 0.16$, $\Delta\sigma = 0.005$ is:

$$C_a = 8.6 \times 10^3$$

(which is of the same order of magnitude as found by Vostrcil)

hence $\underline{G.c.t. = 3550}$.

(ii) The assumption of a single particle size, shape and density throughout the blanket is justified providing they are regarded as their effective values. However, the work reported has shown that the use of Stokes's velocity as the terminal velocity in the velocity-concentration relationship is not acceptable. Using the apparent terminal velocity means the lower boundary of the blanket is unrealistically higher than calculated by Ives. From observation through a clear plastic column, the flow conditions at the lower boundary appear extremely turbulent. The terminal velocity in fully turbulent flow is given by:

$$U_o = \left[\frac{4}{3} . \frac{d.(\rho_f - \rho)}{0.44\ \rho} . g \right]^{\frac{1}{2}} \tag{17}$$

and

$$= \frac{4\ Q}{\pi . L_1^2}$$

For the example, $L_1 = 0.94$ m. This level at which the blanket actually starts is comparable with the levels found in practice.

(iii) From the investigations the velocity-concentration data is probably well approximated by:

$$U = U_q . (1 - q_4\ s)^{1.0} \tag{18}$$

where U refers to the upflow velocity at the blanket surface.

Therefore the power dissipated per unit volume is given by

$$P_D = \frac{4.\Delta\rho.g.Q}{\pi.L^2.q_4} . \left[1 - \frac{U_s}{U_q} \right] \tag{19}$$

This should be compared with Ives who proposed that a concentration gradient existed through the depth of the blanket, which in general can be assumed not to be significant.

Hence: $$G.c.\ \delta t = \left[\frac{\Delta\rho.g.\pi}{4Q.\mu}\right]^{\frac{1}{2}} c^{\frac{3}{2}} .L.\delta L \qquad (20)$$

Then integrating between $L = L_1$ and $L = L_s$

$$G.c.t. = \left[\frac{\Delta\rho.g.\pi}{4Q.\mu}\right]^{\frac{1}{2}} . \left[1 - \frac{4Q}{\pi.L_s^2 . U_q}\right]^{\frac{3}{2}} (L_s^2 - 0.9) . \tfrac{1}{2} \qquad (21)$$

hence: $$3550 = 542 \left[1 - \frac{66.7}{L_s^2}\right]^{\frac{3}{2}} (L_s^2 - 0.9) . \tfrac{1}{2}$$

and: $$13.1 = \left[1 - \frac{66.7}{L_s^2}\right]^{\frac{3}{2}} . (L_s^2 - 0.9) \qquad (22)$$

Solving by trial and error, for the R.H.S.:

if L_s	=	8.5	9.0	10.0	9.5	9.6
R.H.S.	=	1.37	6.0	18.8	11.6	13.2

The value of $L_s = 9.6$ m. This is about that found in practice; compared with 7.4 m calculated by Ives.

Check $U_s = \dfrac{4Q}{\pi.L_s^2} = 0.0014$, m/s

to give $s = 0.12$

Since the calculation was meant to arrive at maximum flux conditions, the method results in slight underdesign. However, the whole calculation is very sensitive to a small change in the value of L_s. Maximum flux is found at $L_s = 10.3$ m.

(iv) The maximum value of G will be at the lower boundary of the blanket:

$$G_1 = \left[\frac{c.\ \Delta\rho.g.Q.4}{\pi.\mu.L_1^2}\right]^{\frac{1}{2}} \qquad (23)$$

$$= 41\ s^{-1}$$

and $G_s = 4.1 s^{-1}$ at the blanket surface.

These values are clearly below most shearing values found for mechanical flocculation.

It appears that acceptable and simplifying changes can be made to Ives's theory that lead to more acceptable answers to the calculations in the theoretical design of floc-blanket clarification. However, what is also important is prediction of separation/clarification efficiency by the blanket. Ives did not achieve this. Prediction can be achieved if the settled water quality, blanket concentration, and upflow velocity relationships are known, as established by these investigations.

APPENDIX C – PERFORMANCE DATA COLLECTION AND ASSESSMENT

Consider each treatment situation separately. For any given treatment situation settled water quality is determined by the blanket floc concentration which in turn is determined by the upflow velocity at the blanket surface. Both relationships are affected by the physical properties of the floc and the hydraulic conditions of the blanket. The maximum rate of operation for an acceptable settled water quality is identified from these relationships. Obviously as the upflow velocity increases so the settled water quality deteriorates. However, there is a concentration of floc beyond which any further increase in concentration is unlikely to cause substantial improvement in settled water quality. Blanket floc concentration, as conveniently measured by the 30 min settled volume, is therefore a useful means of following blanket performance in addition to turbidity monitoring.

Addendum C1 is a typical data check list of parameters recommended to be monitored. The full extent of either or both pilot and operational plant work will depend on the assigned budget which will be related to the intended size of the new or uprated works and previously identified difficulties in treatment of the raw water. Addendum C2 is an extract from a typical recommendation for experiment design for evaluating the potential uprating of existing plant. The objective is to obtain as many results as possible for settled water quality with frequent yet practical changes in upflow velocity during selected periods of, hopefully, relatively constant raw water quality. The floc blanket data is correlated to produce the three principal performance spectra, and Addendum C3 illustrates how these might be used. For design, the worst settled water quality acceptable for filtration is selected, to lead to the respective blanket floc concentration and upflow velocity. However, this floc concentration should not be less than about 75 per cent of maximum flux conditions otherwise blanket stability problems are likely to be encountered. With this value of upflow velocity the total minimum area for upflow at the blanket surface is calculated. For new operational plant, pilot plant might have been used to determine optimum blanket depth, and can be compared with prediction from the modified Ives calculation. The cheapest floc blanket tank system for this area and depth is selected with respect to both capital and operating costs and operational flexibility.

ADDENDUM C1 – DATA CHECK LIST

Raw Water

- temperature
- colour (membrane filtered)
- *PV (if considered important)
- turbidity (preferably by light scatter)
- pH
- alkalinity
- orthophosphate
- algae and animals
- jar test analyses for coagulant dose and pH
- flow rate to treatment
- recycled water

Chemical Dosing

- coagulant
- polyelectrolyte
- chlorine
- carbon

Dosed Water

- total aluminium
- pH
- flow rates to sedimentation tanks
- sedimentation tanks in operation

Settled Water

- total Al, both streams and types A, B, C of each stream
- turbidity, both streams and types A, B, C of each stream
- algae and animals

Floc Blanket

- blanket levels, types A, B, C of each stream
- note of instability pattern of blanket surface
- 30 minute settled volume of in-depth sample
- (settling rate curves of 1 litre samples, occasional)
- total suspended solids dried to 105 °C
- desludging rate and frequency

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* PV – permanganate value

Filtered Water

total Al, both streams or total blended, each filter
turbidity, both streams or total blended, each filter
dissolved Al, total blended
colour, total blended
PV, total blended
algae and animals, selected filters
filtration rate
run length
head loss
core analyses

ADDENDUM C2 – TYPICAL PROPOSAL FOR EXPERIMENTAL DESIGN FOR A BANK OF EXISTING TANKS

Experimental Procedure - Sedimentation

Three-week sedimentation trials are envisaged. A new trial should commence every 6 or 7 weeks unless a change in raw water quality, represented for example by ± 3 °C, 0.4 pH or 20 mg/l alkalinity, occurs after the end of the preceding trial. If a trial is terminated prematurely then the next should be started as soon as is convenient. Trials should be avoided when a bank holiday will occur or short staffing is anticipated.

It is hoped that at least 6 complete sedimentation trials are carried out within an annual cycle with at least one trial in any one period. The annual cycle might be conveniently regarded as being from February to November.

Between trials sedimentation performance should be fully monitored 2 to 3 days per week, within a frequency of not more than 1 in 2 days or not less than 1 in 4 days.

It is preferred that trials start on a Monday and terminate on the third following Friday. The basic routine is to check that everything is as it should be first thing in the morning. Sampling and measurements might then be made at some convenient time during the morning after allowing sufficient time for stabilisation due to any changes made. The experimental changes are then made and the rest of the day is used to confirm the acceptance of the change from an operational point of view and to ensure 'equilibrium' will have been reached before the next morning. If time is available two sets of samples and measurements could be made for the same experimental plant conditions during a morning.

The daily procedure is to increase tank relative flow rate but to leave at a low rate over weekends. The resultant 3-week pattern might therefore look like:

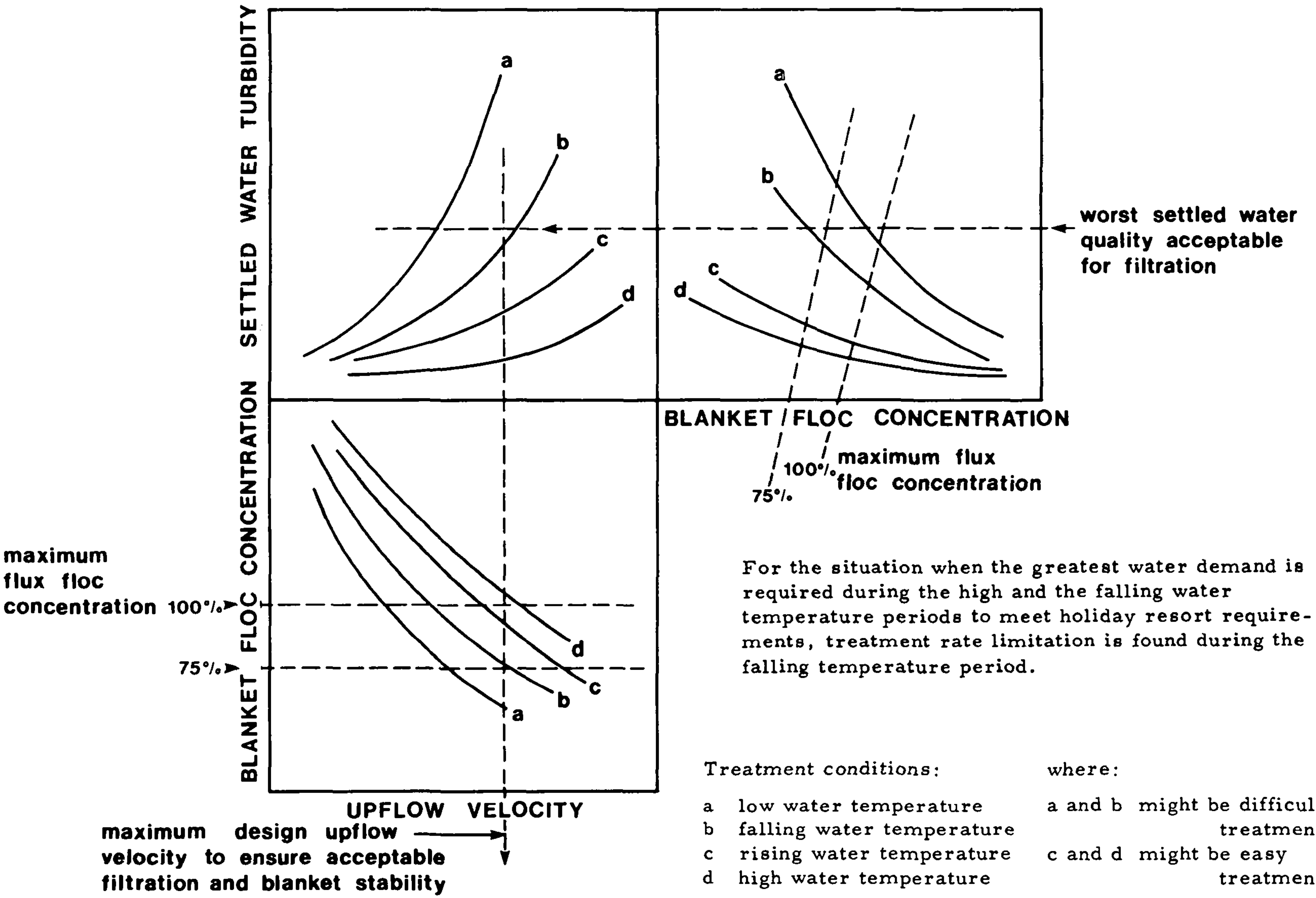
Week	Mon	Tue	Wed	Thur	Fri
1	1.0	1.22	1.42	1.50	1.56
2	1.15	1.42	1.56	1.86	1.95
3	1.22	1.42	1.56	1.22	1.0

Obviously the relative rate applied and maintained will depend on operational acceptance of the resultant water quality.

During the sedimentation trials consideration will need to be given to increasing filter backwashing frequency. Perhaps certain quality limits need to be set as permitted maxima not to be exceeded for more than, say, 24 hours,

e.g.	individual sedimentation tanks	1.5 mg Al/litre
	blended settled water	1.0 mg Al/litre
	individual filters	0.25 mg Al/litre
	blended filtrate	0.15 mg Al/litre

The major problem of the trials might be to ensure adequate but efficient excess floc removal from the sedimentation tanks.



For the situation when the greatest water demand is required during the high and the falling water temperature periods to meet holiday resort requirements, treatment rate limitation is found during the falling temperature period.

Treatment conditions:		where:	
a	low water temperature	a and b	might be difficult treatment
b	falling water temperature		
c	rising water temperature	c and d	might be easy treatment
d	high water temperature		