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DRINKING WATER

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น้ำดื่มสะอาด

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ABSTRACT

Water for drinking remains essentially most important for every household especially in the rural everywhere. The most important source of reasonably clean water for drinking is rain-water of which Thailand is most fortunate to be such a climateric monsoon country. The large container or jar is used to store the rain-water enough for drinking throughout the whole year.

Agriculturally, Thailand has a rich network of tributaries of rivers. The population is dense near the sources of water. The surface water then could be treated to give accepted water for drinking and utilization. This communication describes the treatment of raw water by simple, low cost but effective, slow sand filtration.

The raw water from rivers or canals could be lifted to a gravity feed reservoir by means of a piston pump driven by power from a used bicycle. All these three devices: jumbo jars, filtering units and bicycle pumps are simple, cheap and effective.

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บทคัดย่อ

น้ำดื่มสะอาดที่หาได้ง่ายคือ น้ำฝน เพราะประเทศไทยมีปริมาณน้ำฝนตกมากเพียงพอในฤดูมรสุม จึงเหมาะสมที่จะเก็บกักน้ำฝนไว้ เพื่อบริโภคในหน้าแล้ง โดยการจัดทำภาชนะ ได้แก่ ตุ่มขนาดใหญ่ หรือโอ่งยักษ์

ประเทศไทยเป็นประเทศที่มีแม่น้ำ ลำธารไหลผ่านหลายสาย ตลอดจนห้วย หนอง คลอง บึงต่าง ๆ มากมาย ประชากรซึ่งอยู่กันหนาแน่นตามแหล่งน้ำเหล่านั้น สามารถนำน้ำผิวดินดังกล่าวมาทำให้สะอาด เหมาะสำหรับใช้บริโภคและอุปโภคได้ ด้วยเครื่องกรองที่สามารถสร้างขึ้นได้ด้วยตนเอง โดยใช้หลักของการกรองอย่างช้าด้วยทราย

นอกจากนั้น น้ำจากแม่น้ำลำคลองต่าง ๆ สามารถนำขึ้นมาเก็บไว้ในที่พักน้ำซึ่งอยู่ในระดับสูงได้ ด้วยการใช้เครื่องสูบชนิดสูบ-ชัก ซึ่งใช้แรงขับจากจักรยานธรรมดา โดยไม่ต้องใช้ไฟฟ้า อุปกรณ์ทั้งสามประเภท คือ โอ่งยักษ์ เครื่องกรองน้ำ และจักรยานสูบน้ำ ต่างก็มีราคาถูก ทำเองได้โดยง่าย และมีประสิทธิภาพดี

INTRODUCTION

Many villages and small towns in Thailand and many other regions in South East Asia do not have treated piped water supplies. They usually use springs where possible, wells or various surface sources. The dry season often causes springs to cease and wells to dry and consequently more people need to use surface water. It is known that much of the surface water in rivers and ponds in the region is highly turbid and contain many pollutants that are injurious to health.

The objective of this project was to build a low cost filtering device and carry out tests to show the extent of water quality improvement that can be achieved.

The water chosen for testing was the Chao Phya river which is a very heavily polluted raw water. Many people consume this water but treatment applied usually requires coagulants, settlement, filtration and disinfection before a clean and safe water can be produced. Processes of this complexity are too costly for generally used in villages. The use of sand filtration alone is investigated.

Quality of the Chao Phya river water

Analyses were carried out on samples drawn at a point 24 m from the river bank at the site of Siriraj Hospital. At no time in the period of all the experiments was clear water obtainable. The water frequently had an unpleasant smell. Detailed periodical analyses of the raw water are shown in Table 1, Figure 1 and Figure 2. Organic pollution was measured using the P.V. test conducted for 15 min at 100° C. and bacteriological tests were made using the following procedure.

Series 1: Mar. 1982 – Nov. 1982, diluted $\frac{1}{2}$ to cover range <5 to >36 MPN/100 ml.
Dec. 1982 – Oct. 1983, diluted $\frac{1}{5}$ to cover range 9 to >160 MPN/100 ml.
Series 2: Jan. 1984 – Apr. 1984, diluted $\frac{1}{50}$ to cover range 0 to >1800 MPN/100 ml.

The MPN index of coliform counts using MacConkey broth was used in the bacteriological analysis. In series 1, coliforms were allowed to grow at 44° C for 24 h[7] In series 2, the incubation was performed at 37°C for 24 – 48 h[1]

other parameters were measured and shown in Figure 1.[3,4,8]

It is clear that many of the parameters measured, in particular the coliform MPN were considerably in excess of acceptable limits of drinking water and consequently the water must be considered as a risk to health.

Construction of pilot scale low cost filters

The principle materials used were a common builders sand which was sieved and the grades passing a 0.5 mm sieve amounting to about 80% of the raw sand were used after washing first with clean water and finally with raw water. Small gravel of 2-5 mm grade was obtained from the same sand using the fraction >0.5 mm. Villagers would obtain suitable sand locally but sieve and wash sand as required.

The vessels used for constructing the pilot scale filters were common earthenware water jars, the approximate cost of a 160 l jar is about 200 baht, and a 40 l jar about 60 baht. Vessels constructed from cement rings were also used but in a village situation, large cement jars would be as effective but cost less. A cement jar of 500 l capacity would cost about 135 baht. Construction of the systems also requires some 15-25 mm PVC tube and fittings. Tubes were fitted to the jars by cutting holes in the appropriate places with a hammer and a small chisel and cementing PVC tubing in place with conventional cement.

Four systems were built for pilot scale tests. The first system utilised continuous settlement and a combination of primary upward flow filtration followed by downward flow secondary filtration (Figure 3). The second system employed settlement followed by a number of upward flow filters connected in series as in Figure 4. The third system was a duplicate of the first unit and the fourth system employed downward flow filtration only.

Operation of pilot scale filters on the Chao Phya river water: Series 1

The first series of tests was commenced on system 1 and 2 in December 1982 during the cooling season when river flows are normally lower than average and dilution available to the gross pollution load is also lower than average.

A. Upward flow and downward flow filtration units

The flow rates used at the start of the operations were 0.3 l/min in one plant representing 8.3 h retention time in sedimentation tank, 3.44 $m^3/m^2/d$ flow rate in primary upward flow filtration and 0.86 $m^3/m^2/d$ in secondary downward flow filtration[2,6] The net output of the pilot plant at these rates were 432 l/d which would provide sufficient water for an average family of 7 people.

The duplicate plant was operated in the same way with a net rate of 0.7 l/min representing 3.6 h retention time in sedimentation tank, 8.02 $m^3/m^2/d$ flow rate in primary upward flow filtration, 2.00 $m^3/m^2/d$ flow rate in secondary downward flow filtration. The net output of the duplicate plant was 1008 l/d which would provide an adequate water supply for 17 people using a minimum of 60 l/h/d.

Analytical tests show that performance for the first 40 to 50 days was unstable and improving, indicating that the filters were establishing their biological activity. Samples of raw water and final water were analysed every few days of continuous operation and the results are presented in Figures 5a - 5e.

During the tests, the upward flow filters were backwashed by draining weekly and the downward flow filters were cleaned by scraping a thin layer of sand from the surface on day 118 and days 150 and 172. Prominent algae growths were observed on the surface of the downflow filter on a few occasions due to exposure to direct sunlight. The upward flow filters were all provided with covers and no algae growth occured in them.

Flow measurements were regularly made and are given in Figure 5e. On each occasion that the flow rate recorded was lower than the required rate, adjustments were made to return the flow to the correct rate.

Performance of the upward-downward flow filtration units

The turbidities of the raw water of the Chao Phya river range from 15 APHA units at the end of the dry season to 130 APHA units at the end of the wet season when the large amount of soil solids are washed into the river; throughout the whole duration of the experiment for a period of 286 days the turbidity of the final water was consistently below 10 APHA units which corresponds with WHO acceptable limit[9].

This same degree of effectiveness is shown in Figure 5b which indicates that coliform MPN for the whole period is considerably in excess of 90/100 ml and for a considerable time exceed 160/100 ml. During the first 45 days operation the coliforms levels at 0.3 l/min were reduced from >160 to zero in an irregular manner suggesting the maturing of the bacterial film in the downward flow unit. After day 45 the bacterial numbers in the final water were consistently zero indicating safe water that does not require chlorination. Bacterial tests on the filters operated at 0.7 l/min indicate a less effective coliforms removal. Maturing of the filters appears to have been marginally more rapid but shortly after the maturing period, after some 20 days operation giving coliform MPN of zero, a breakthrough of coliforms occurred and results in the final water were erratic for a further 30 days. Coliforms MPN of more than 16/100 ml were found on two occasions. Two other minor breakthroughs of coliforms occurred in the periods of day 137 and 209 to 244. Measurements made of iron for the first 125 days indicate a consistent marked reduction in Fe. This is likely to be due to natural oxidation or reduction of iron salts in solution producing insoluble precipitates that can be removed in the upward and downward flow filter. The pH values of the raw water ranged from 7.4 to 8.8. During most of the first 125 days operation the filtration process produced effluents with slightly higher pH values. This is attributable to the oxidation of organic matter, the evolution of carbon dioxide and changes in the carbonate/bicarbonate balance in the final water.

B. Multiple upward flow series filtration

Five identical upward flow filters were set up operating at a net delivery rate of 0.3 l/min. This represents a loading rate of 3.44 $m^3/m^2/d$ on the filter.[2,6] The discharge from filters 2, 3, 4 and 5 were sampled for analysis so that the tests represent four applications of multiple upward flow filtration. The analyses are presented in Figure 6a - 6e. A duplicate series of upward flow filters was operated at a net delivery rate of 0.6 l/min (6.88 $m^3/m^2/d$). During the tests the upward flow filters were backwashed by draining weekly. Flow measurements were also regularly checked and regulated. No other operational changes were made.

Performance of upward flow filters in series

The turbidity of the raw water was consistently reduced to less than 10 APHA units throughout the length of the experiment by every combination of filters used and at each flow rate. The removal of coliforms at 0.3 l/min as indicated in Figure 6b shows much lower efficiency in the two stage system than in subsequent system with 3, 4 and 5 stages. A maturing period still appears to occur taking up to 88 days for 2 stages, 62 days for 3 stages and 48 days for 4 and 5 stages. Coliform removal was almost 100% from this period up to 130 and 144 days when a breakthrough of coliforms occured in each system, recovery was observed in the 3, 4 and 5 systems by day 160. This general level of coliform removal cannot be regarded as able to provide safe water and for this reason upward flow filtration alone cannot be recommended.

The removal of iron was sufficient to produce a water acceptable standard. Results at 0.6 l/min closely followed results at 0.3 l/min.

The same kind of elevation of pH was observed with upward flow filters as in the previous system.

Preliminary comparison of combined upward-downward flow filtration and multiple upward flow filtration

All the variations of upward flow and downward flow filtration systems used in series 1 were able to reduce the turbidity of the raw water to acceptable levels. Only systems incorporating downward flow filtration gave satisfactory coliform removal, and only after a maturing period. In all other cases chlorination would be considered a necessary final treatment before the water could be considered safe drinking water. Some improvements in Fe concentrations were observed but little significant difference can be seen in any of the alternatives tested.

Operation of pilot scale filters on Chao Phya River water: Series 2

The second series of tests was commenced in Jan. 1984. System 3 was a duplicate of system 1 used in the first series of experiments. This was operated in parallel with system 4 which made use of settlement for a retention time of 8.3 h followed immediately by an upward flow gravel prefilter containing the gravel of 3-5 mm. The overall flow rate in the gravel filter feeding both subsequent filtration system was 5 l/min. The flow rate in the prefilter represents 25.5 $m^3/m^2/d$. The downward flow filter used in both systems was a filter constructed of concrete chamber rings 0.8 m diameter and 1 m deep containing sand 0.9 m deep.

A. Upward flow and downward flow filtration units:

These were identical to those used in Series 1 experiments and operated at an intended flow rate of 0.3 l/min but monitoring as shown in Figure 7e indicated that this was not fully maintained for the whole duration of the experiment so far. At normal flow rates of 0.3 l/min the loading rates were 8.3 h retention in sedimentation, 3.44 $m^3/m^2/d$ in primary upward flow filtration and 0.86 $m^3/m^2/d$ in secondary downward flow filtration.

B. The operation of downward flow filtration only:

Raw water was settled for a retention time of 8.3 h and passed through the prefilter at a loading rate of 25.5 $m^3/m^2/d$ then through the downward flow filter at the rate of 0.3 l/min giving a filtration of 0.86 $m^3/m^2/d$.

The performance of downward flow filtration in Series 2:

Turbidity measured in the first 63 days showed a range of 17 APHA units at the start of the experiment rising to 70 by day 63. The downflow filter with prefiltration consistently produced final water with turbidity less than 10. Measurements of coliforms in the raw water showed concentrations consistently in excess of 1800 MPN/100 ml throughout the whole period of the experiment so far. The downward flow filter caused a rapid reduction in coliform numbers in the first 13 days followed by breakthrough of coliforms on day 21 for 10 days and day 42 for 3 days. From day 42 to day 63 no further breakthrough of coliforms has occured and values in the final water have been consistently < 2. Algae have been observed on the surface of the downward flow filter since day 10. The algae rapidly turned black and were removed on day 31 and day 41 but returned after a few days. Iron was presented in the raw water in the range 1.05 to 0.65 mg/l in the first 63 days. The downflow filter consistently reduced this to 0.28 to 0.05 mg/l. Small rises in pH were observed throughout the first 63 days consistent with changes in carbonate/bicarbonate balance.

Comparison of performance of different systems

A. Comparison of combined upward flow and downward flow filtration and downward filtration alone.

Turbidity removal by both systems was identical. The removal of iron showed insignificant differences between the two systems. Similarly the variations in pH were not significantly different. The removal of coliforms by the two systems shows a marked improvement in performance of the system using upward flow and downward flow filtration compared with downward flow alone as shown in Figure 7b 1) and 2). Coliforms breakthrough occurred in both systems at about the same time but the upward flow downward flow system showed breakthrough of much lower magnitude and marginally more rapid recovery. Stability with consistent coliform levels < 2 MPN/100 ml was reached in 42 days with the combined system compared with 45 days with the downward flow filter alone. Although the efficiency of both systems does not appear to be very different, it seems likely that the upward flow filter adds a measure of safety to sudden overloads to the system.

B. Comparison of the performance of upward flow and downward flow filtration in different periods

The operation of the systems were identical excepting for the addition of the gravel prefilter. Comparison of every parameter measured indicates that no significant difference in performance in the two periods attributable to the use of the gravel prefilter or changes in the characteristics of the raw water.

Summary and conclusions drawn from experiments in Series 1 and Series 2 to date

Water treatment systems employing combinations of settlement, gravel prefiltration, upward flow sand filtration and downward flow sand filtration at a range of flow rates corresponding to relatively low loading rates in conventional systems. Great value has been found in the use of gravel prefiltration to prevent overloading of the filters caused by large particles in the raw water. Combinations of primary upward flow filters and secondary downward flow filters gave better results than downward flow filters alone. Performance of the units at 0.3 l/min were consistently better for coliforms removal than system operating at 0.7 l/min. The Chao Phya river is a highly polluted source frequently extremely turbid and would not be considered as a suitable source for a drinking water supply.if any better source was available. This test must therefore be considered a severe test, indicating that after a sufficient maturing period the upward flow downward flow system can produce clear final water with bacteria levels below those considered a serious health risk.[1,5] Although the total absence of coliforms was not confirmed it would be considered by many water undertakings that water of this quality could be safely consumed without chlorination. Some removal of iron has been observed for which no satisfactory explanation can be offered.

Field tests at Huey Ploo using combined upward flow and downward flow sand filtration on water from the river *Tajin*

A field station was set up at Huey Ploo hospital about 80 km from Bangkok. A water filtration unit was provided consisting of a head tank (jar) filled intermittently by a bicycle powered pump. The flow from the head tank which also served for primary settlement was passed through an upward flow filter containing sand of grades up to 0.5 mm at 5.73 $m^3/m^2/d$ intermittently. The discharge from the upward flow filter was passed through a secondary downward flow sand filter containing the same grading of sand at 1.43 $m^3/m^2/d$. The flow rate in the system was controlled to a maximum of 0.5 l/min. The system is shown in Figure 8. The Tajin river was a very turbid river for the whole duration of the test ranging from 17.5 to 22.5 APHA units at the beginning of the dry season and up to 100 APHA units in the wet season. The euipment could only be monitored on a limited number of occasions when visits were possible but one of the local people was instructed on the checking and adjusting of the flow and the sampling of raw water and final water. Results are shown in Figure 9a-9d. Turbidity of the final water was within the acceptable limit of 10 APHA units on all but the first occasion. Coliform counts on the raw water ranged from >160 MPN/ 100 ml at the start of the test to short periods when it fell to 50 on day 117 and on day 285. Tests of the final water were generally less than 2 except for a period from day 130 to day 215 (2 results) when coliform counts reached 8 and 16 MPN/100 ml. After 410 days operation the coliform counts steadily rose until on day 510 the final water quality was indistinguishable from the raw water quality. During the whole period the sand filters had received routine maintenance. Tests for iron show that levels as high as 1.9 mg/l in the raw water could be reduced to less than 0.2 mg/l but in general iron removal performance was less efficient. Through most of the test period, a small rise in pH was observed.

A note on the removal of iron

The tests carried out so far show some considerable reduction on iron concentration probably caused by oxidation of iron salt to insoluble oxides or the reaction of iron salts with H_2S which can be formed in filters due to anaerobic biological action. This can be checked by examining the oxygen status of inlet and final waters.

Recommendations for further work on sand filtration

Experiments so far have shown that small scale filters can effectively remove excess turbidity, reduce coliform levels to less than 5 for long periods, and reduce iron-levels in waters tested to date. The equipment is low cost, easily constructed and easily operated.

Further development should be directed at simplifying the filtration units concentrated on a combination of upward flow primary filtration followed by downward flow secondary filtration. It is desirable that portable units should be made for more comprehensive field tests on a range of different types of water. It is desirable that monitoring of field tests should be made at more frequent intervals than has been possible in the first series of tests. In addition to tests on other types of raw water, other grades of sand must also be investigated. It is hoped that a program can be devised so that a filtration unit can be made up of a suitable size to supply drinking water to a range of communities, and from the analyses of the raw water and the flow rates used, a filter cleaning routinely can be developed to ensure that filtration is carried out at the most effective rate possible.

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Table 1. The Analyses of the Chao Phya River Water form 1982-1983.

Water Properties	Maximum Permissible Level(ppm)	Mar. 1982	Apr.	May	Sep.	Oct	Nov.	Dec.	Jan.	Feb.	Mar.	Apr	May	Range
Physical Properties														
- Gross appearance	clear, no-colour	brownish	brownish	brownish	brownish	brownish	brownish	brownish	brownish	brownish	brownish	brownish	brownish	brownish
- Turbidity (APHA)	< 10	15	95	34	100	130	29	44	29	35	17.5	7.5	90	15-130
- pH	6.5-9.2	8.4	8.3	8.1	7.8	8.2	7.8	7.7	7.7	8.8	8.1	7.4	7.8	7.4-8.8
- True colour	50	5	13	8	13	20	13	10	10	12.5	5	5	5	5-20
- Odour	unobjectable	unpleasant smell	same	same	same	same	same	same	same	same	same	same	same	unpleasant sme
Chemical Properties														
- Total hardness as $CaCO_3$	500	110	110	115	115	85	100	103	102	100	110	103	125	85-125
- Alkalinity	–	117	96	83	93	73	98	98	98	120	105	98	100	73-120
- Chlorides as Cl	600	26	42	53	38	86	73	23	23	23	21	22	31	21-86
- Fluoride	0.8	1.1	1.2	1.1	1.1	1.2	1.1	1.1	1.1	1.3	0.8	0.3	0.5	0.3-1.3
- Iron	1.0	–	3.8	1.5	3.3	3.1	0.5	0.5	0.5	1.0	1.91	1.7	1.9	0.5-3.8
- Manganese	0.5	0	0	0.05	0.05	0.3	0.2	0	0	0.4		0.05	0.03	0-0.4
Organic Pollution														
- Permanganate Value*	–	–	8.8	–	11.3	7	9.5	7.5	7.5	8.5	10.5	8.5	5.5	5.5-11.3
- Coliform (MPN/100 ml)	10	> 36	>36	>36	>36	>36	>36	>160	>160	>160	>160	>160	>160	over limit of safety
*15 min at 100° C														

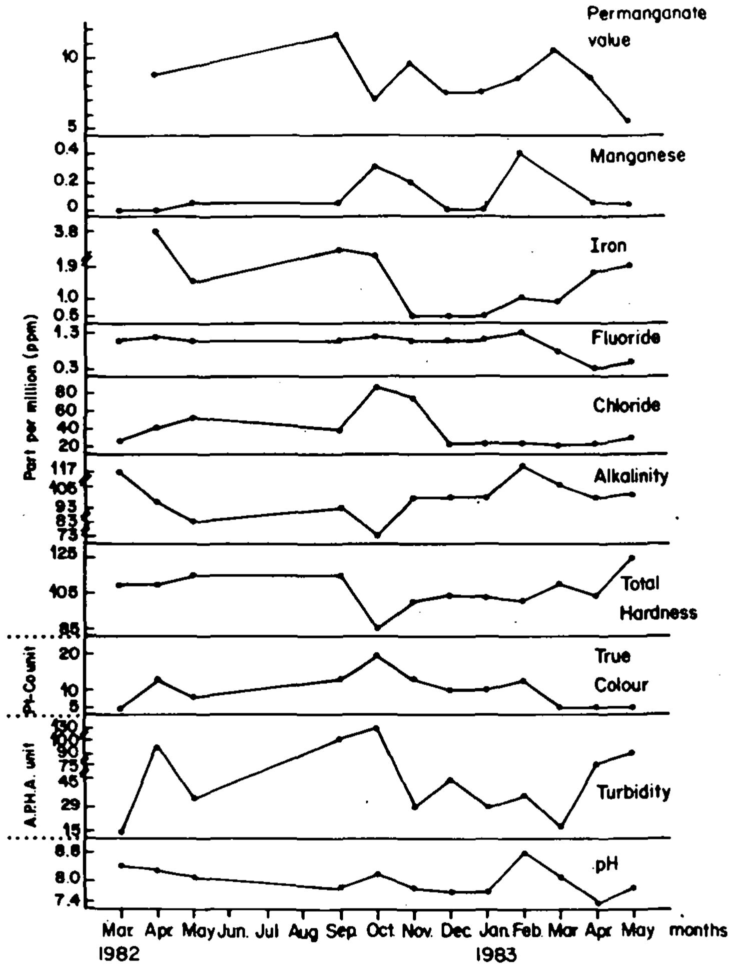

Fig. 1 The analysis of the Chao Phya river water from March 1982 to May 1983.

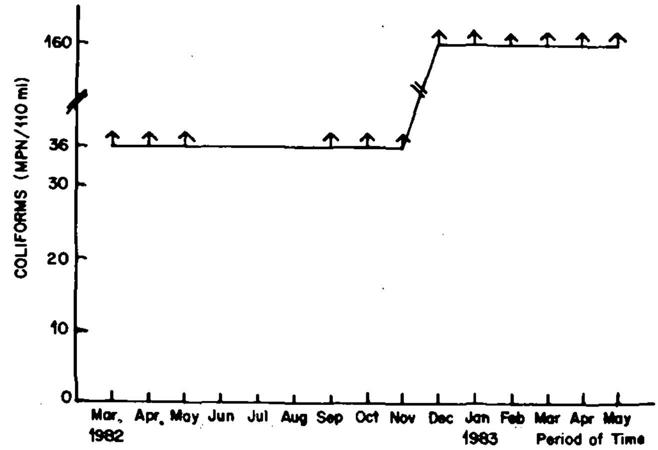

Fig. 2 Coliform counts of the water samples from the Chao Phya river from March 1982 to May 1983.

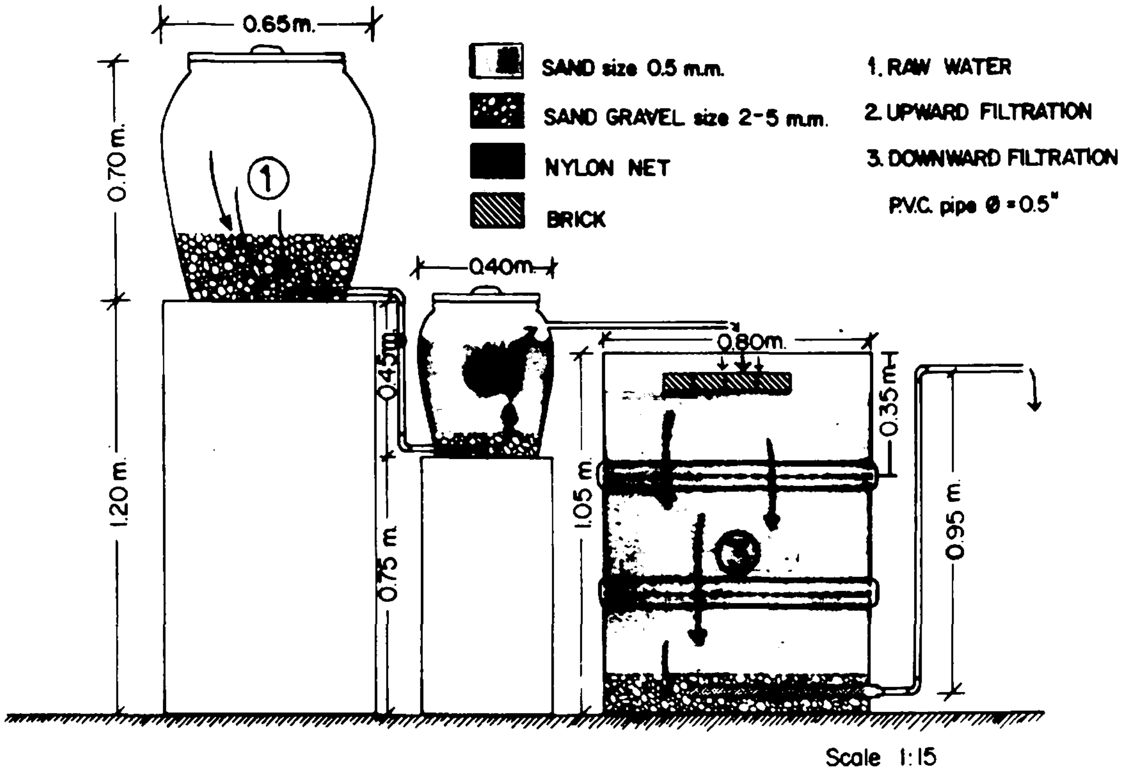

Fig. 3 Series filter set-up.

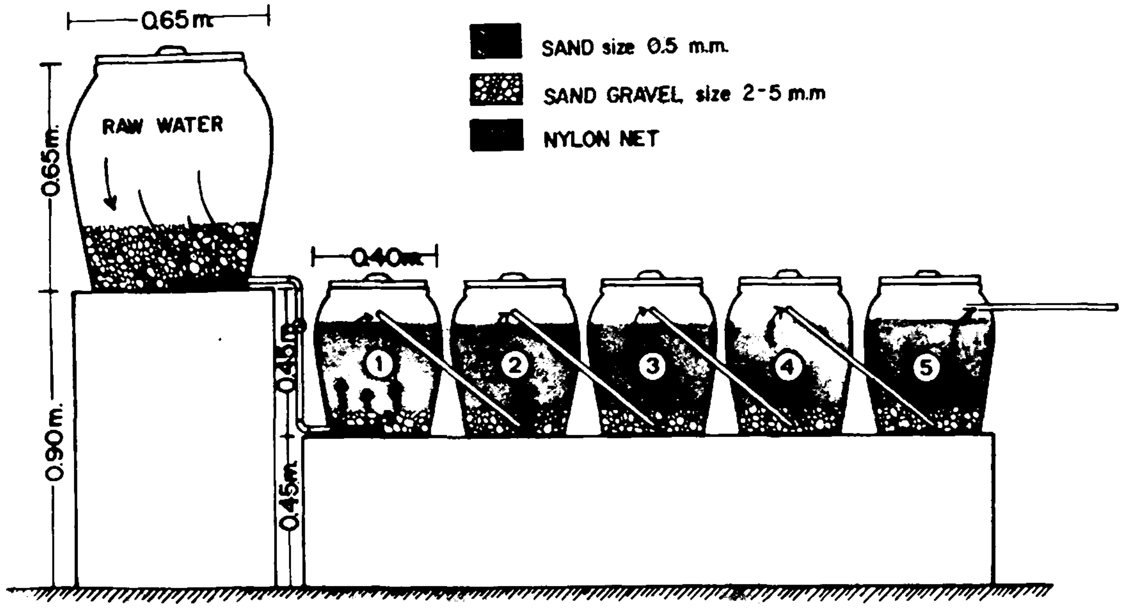

Fig. 4 Series upward flow filter set-up, 2U-5U.

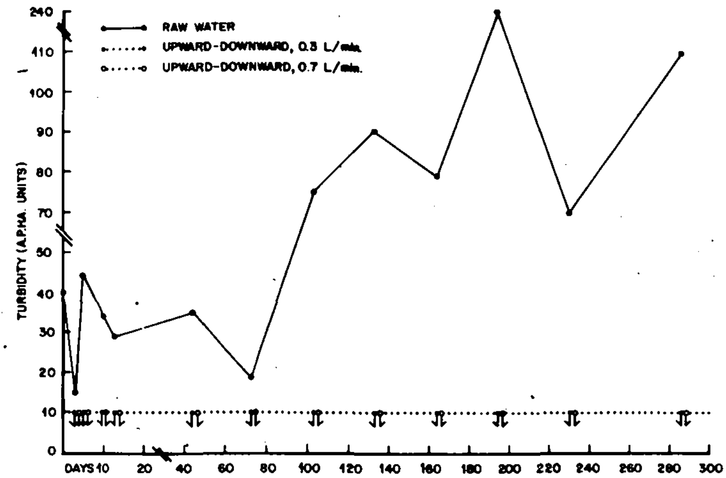

Fig. 5a **Turbidity of the Chao Phya river water before and after filtered through upward-downward water filters with flow-rates of 0.3 and 0.7 l/min.**

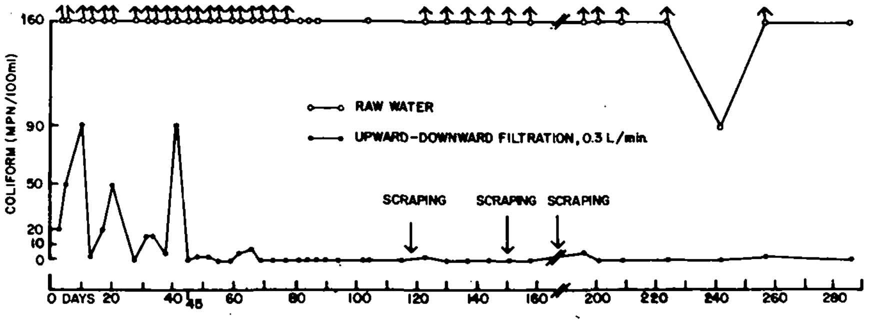

Fig. 5b 1) **Elimination of coliforms in water samples from the Chao Phya river by upward-downward flow filter with the flow-rate of 0.3 l/min.**

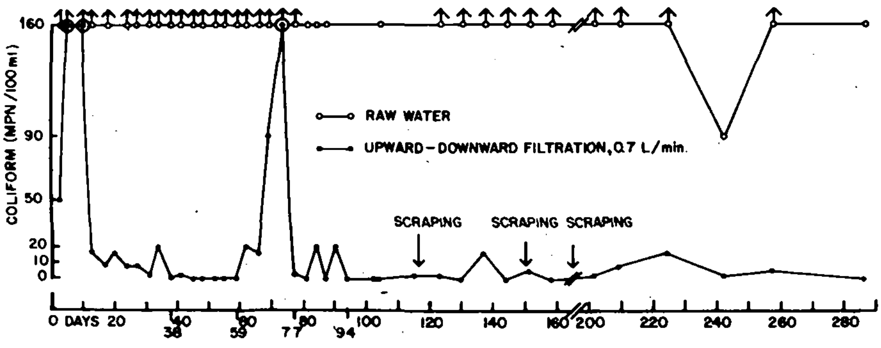

Fig. 5b 2) **Elimination of coliforms in water samples from the Chao Phya river by upward-downward flow filter with the flow-rate of 0.7 l/min.**

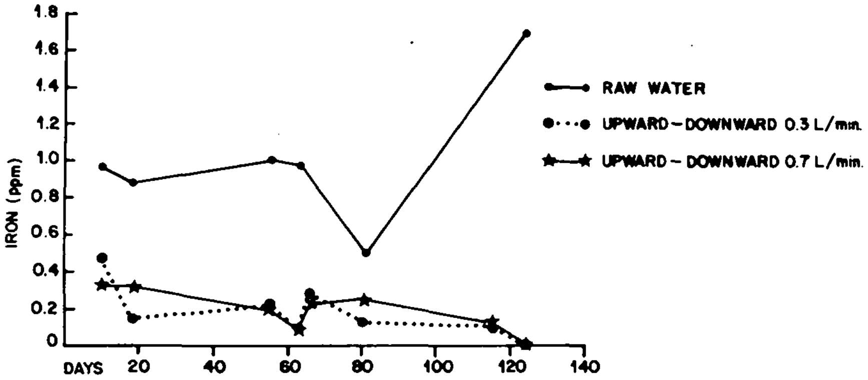

Fig. 5c Elimination of iron in water samples from the Chao Phya river by U-D water-filters with the flow-rates of 0.3 and 0.7 l/min.

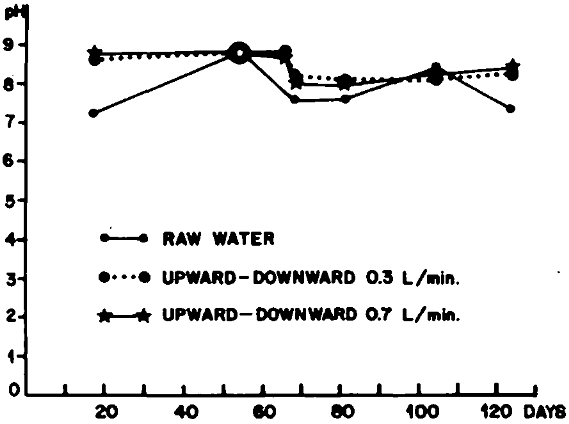

Fig. 5d The pH value of water samples from the Chao Phya river before and after filtered through U-D water-filters with flow-rates of 0.3 and 0.7 l/min.

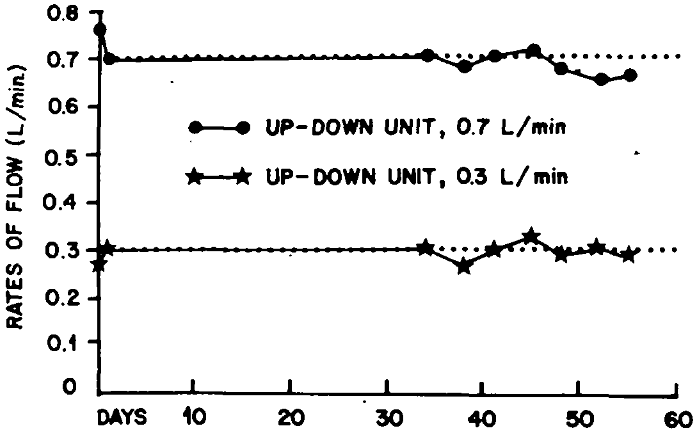

Fig. 5e Rates of water samples from the Chao Phya river flowing through U-D water-filters.

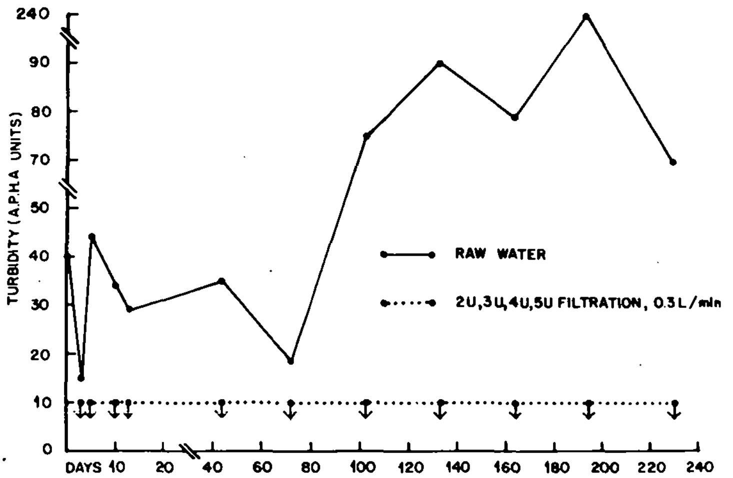

Fig. 6a 1) Turbidity of the water samples from the Chao Phya river before and after filtered through upward flow filters in series, 0.3 l/min.

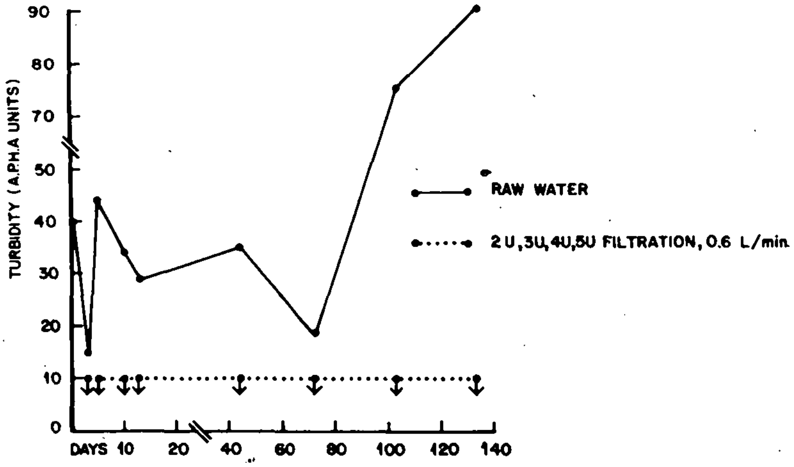

Fig. 6a 2) Turbidity of the water samples from the Chao Phya river before and after filtered through upward flow filters in series, 0.6 l/min.

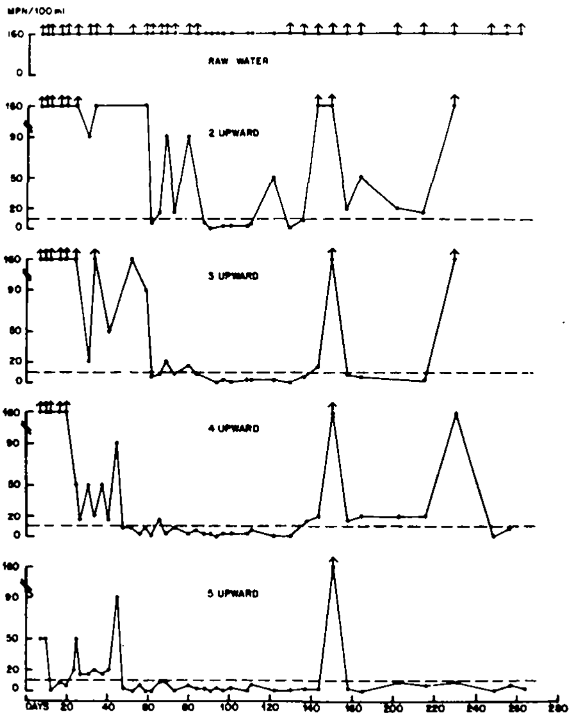

Fig. 6b 1) **Elimination of coliforms in the water from the Chao Phya river by upward flow filters in series (2U-5U) using the flow rate of 0.3 l/min.**

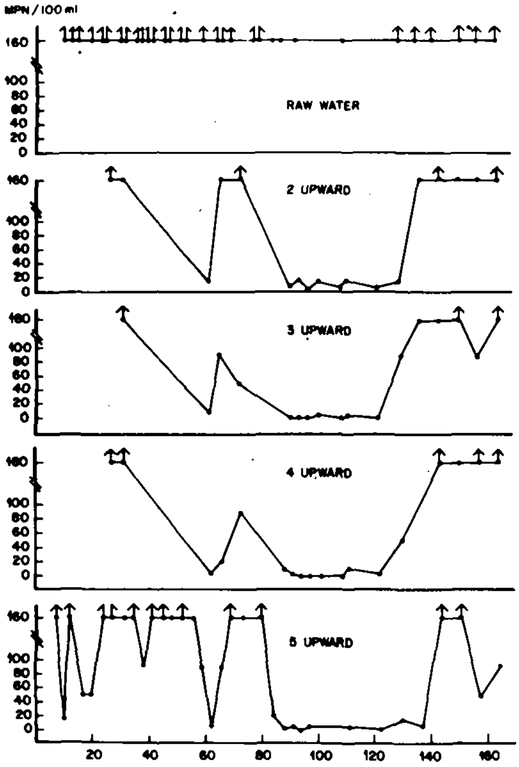

Fig. 6b 2) Elimination of coliforms in the water from the Chao Phya river by upward flow filters in series (2U-5U) using the flow rate of 0.6 l/min.

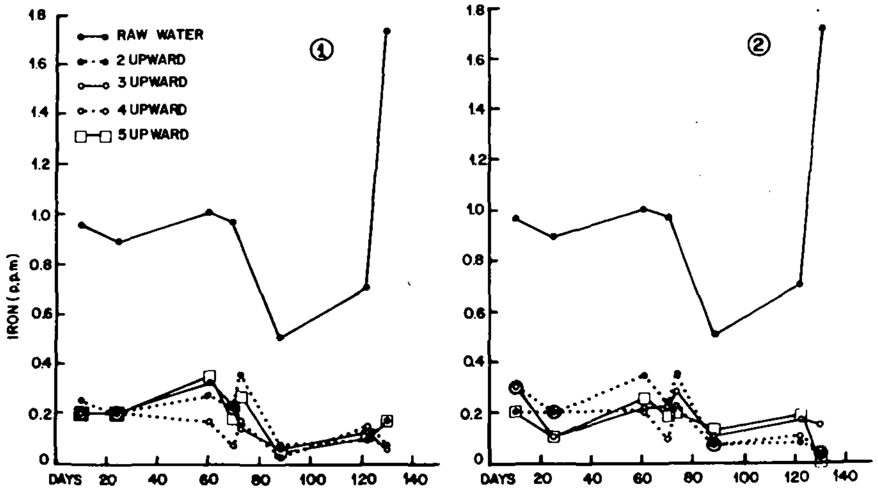

Fig. 6c Elimination of iron in water samples from the Chao Phya river by upward-flow filters in series using the flow-rates of 0.3 l/min. (1) and 0.6 l/min. (2)

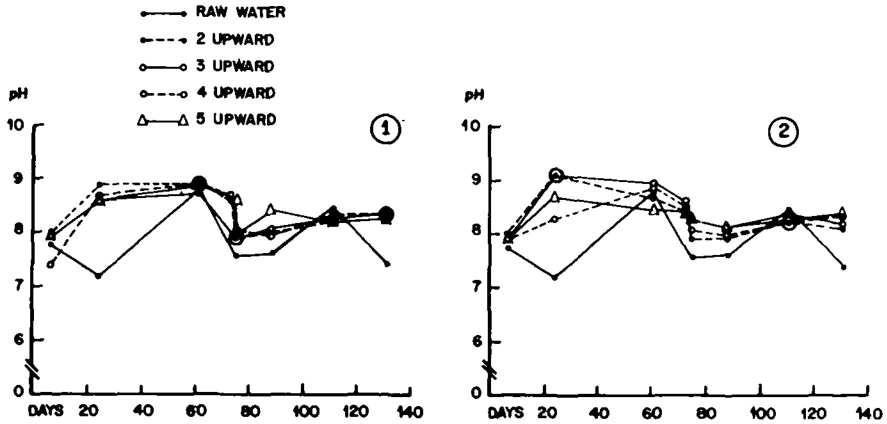

Fig. 6d The pH values of the water samples from the Chao Phya river before and after filtered through upward-flow filters in series, 0.3 l/min. (1) and 0.6 l/min. (2)

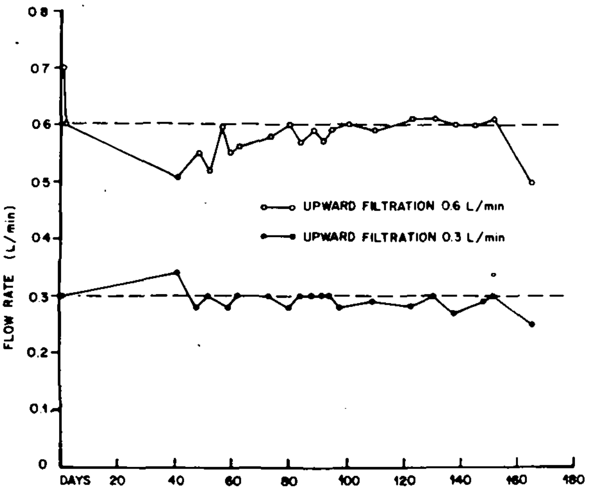

Fig. 6e Net dilivery rates of upward-flow filters in series.

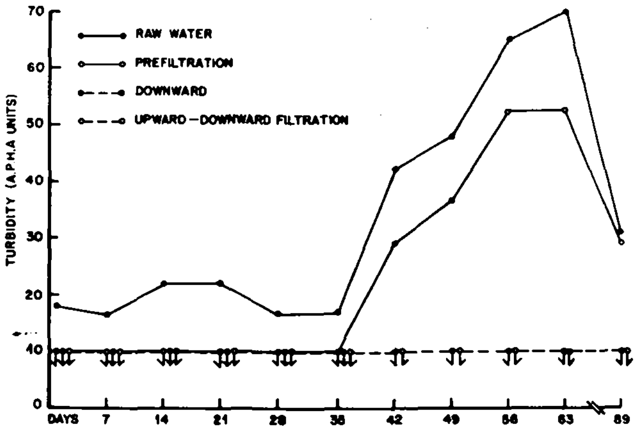

Fig. 7a Turbidity of the water samples from the Chao Phya river before and after treatment with prefiltration alone and prefiltration followed by downward or upward-downward filtration using the flow rate of 0.3 l/min.

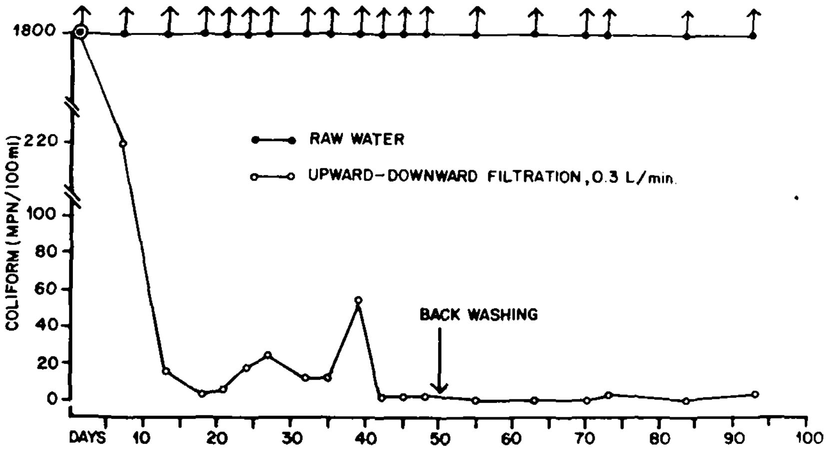

Fig. 7b 1) **Elimination of coliforms in the water samples from the Chao Phya river by the upward-downward flow filter using the flow rate of 0.3 l/min.**

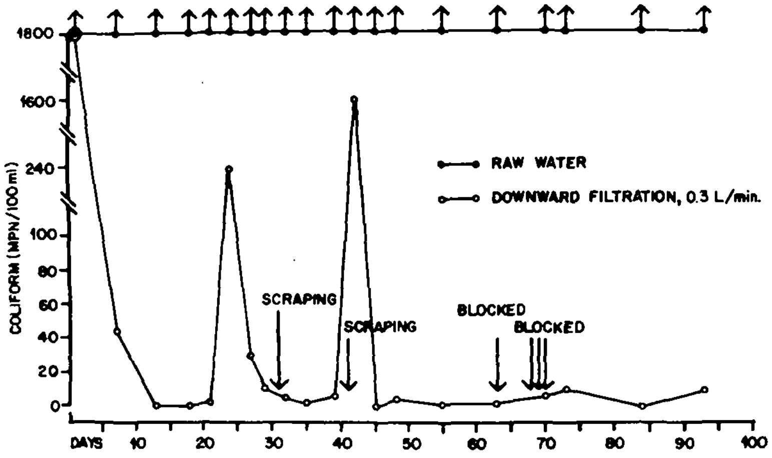

Fig. 7b 2) **Elimination of coliforms in the water samples from the Chao Phya river by the downward flow filter using the flow rate of 0.3 l/min.**

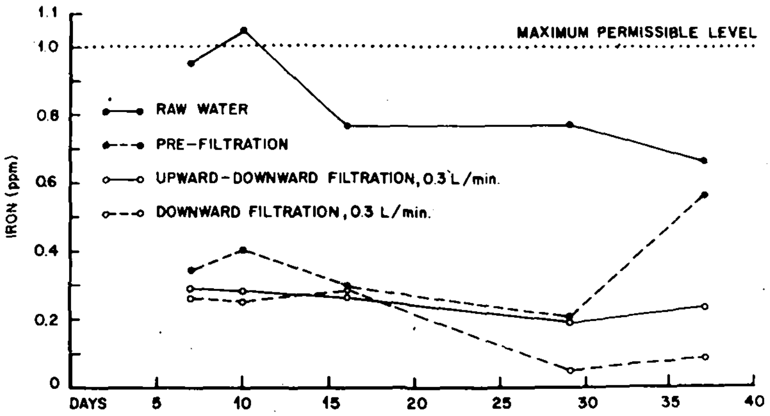

Fig. 7c Elimination of iron in the water samples from the Chao Phya river by prefiltration followed by downward or upward-downward filtration using the rate of 0.3 l/min.

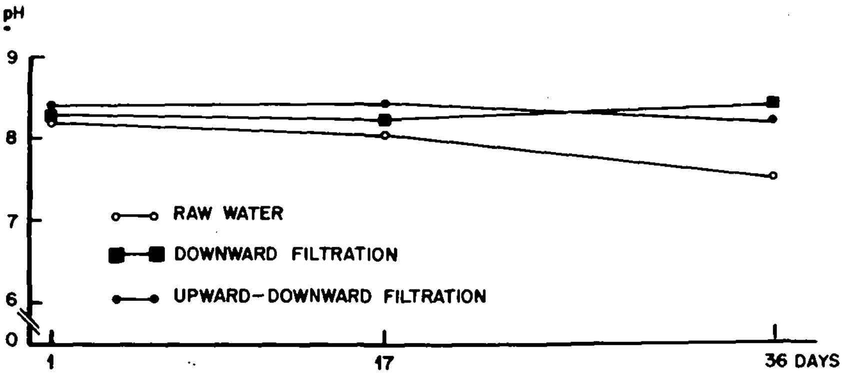

Fig. 7d The pH levels of the water samples from the Chao Phya river before and after treatment with downward or upward-downward filtration.

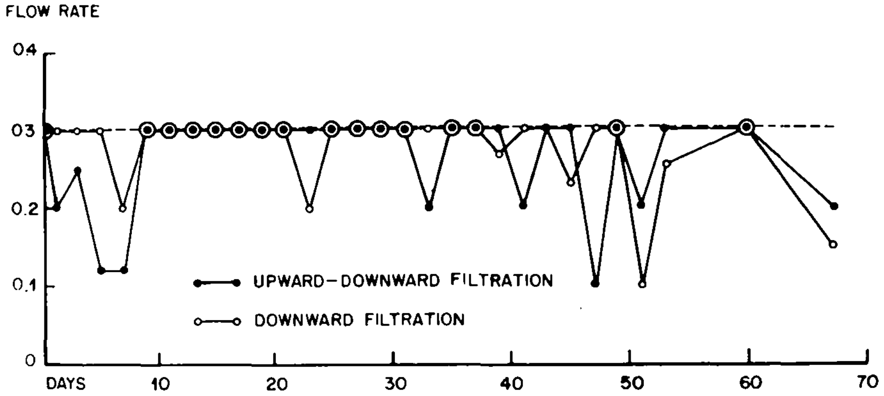

Fig. 7e Delivery rates of water-flow of a downward flow filter and an upward-downward flow unit adjusted at 0.3 l/min.

Fig. 8 A set of the upward-downward flow filtration unit and a bicycle powered pump at Huey Ploo Hospital.

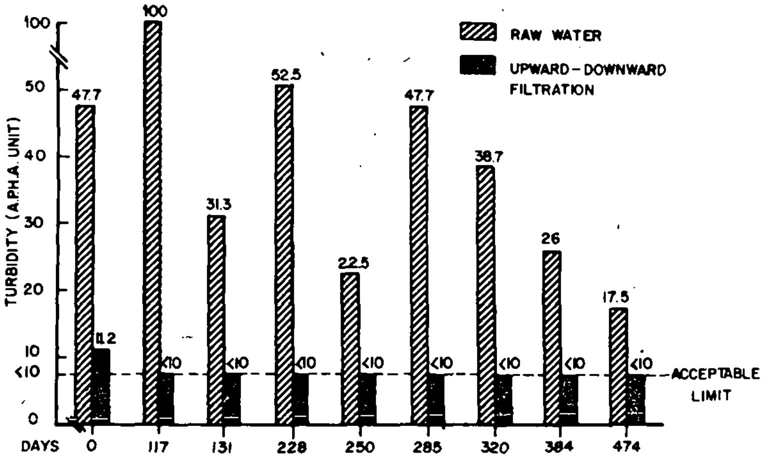

Fig. 9a **Turbidity of the water samples from the Tajin river before and after treatment with the upward-downward flow filter using a flow rate of 0.5 l/min.**

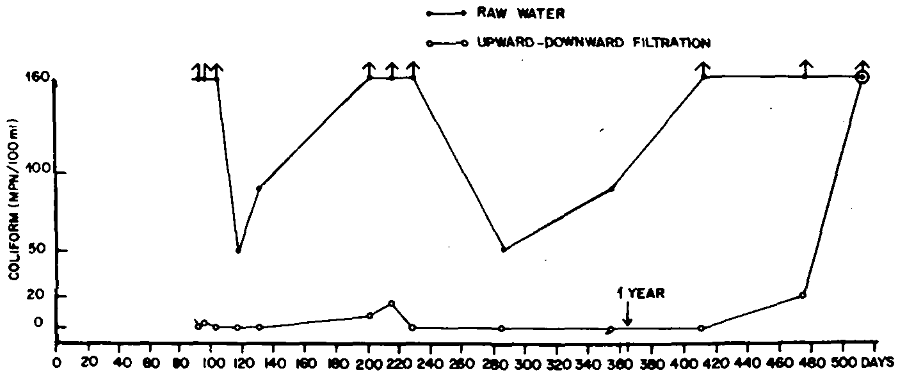

Fig. 9b **Elimination of coliforms in the water samples from the Tajin river using upward-downward filtration with the flow rate of 0.5 l/min.**

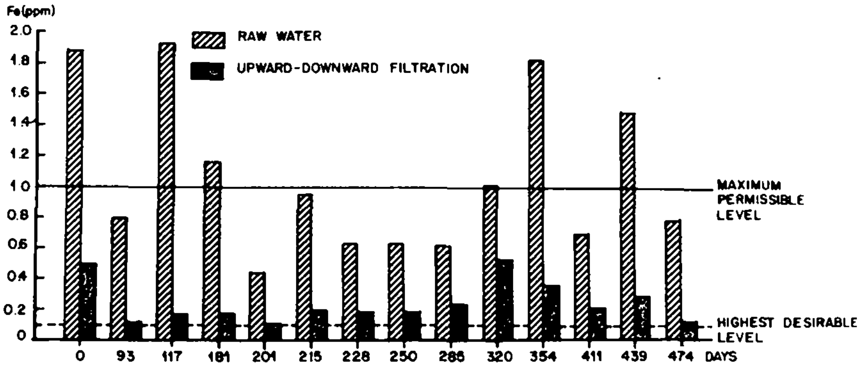

Fig. 9c Elimination of iron in the water samples from the Tajin river using upward-downward filtration with the flow-rate of 0.5 l/min.

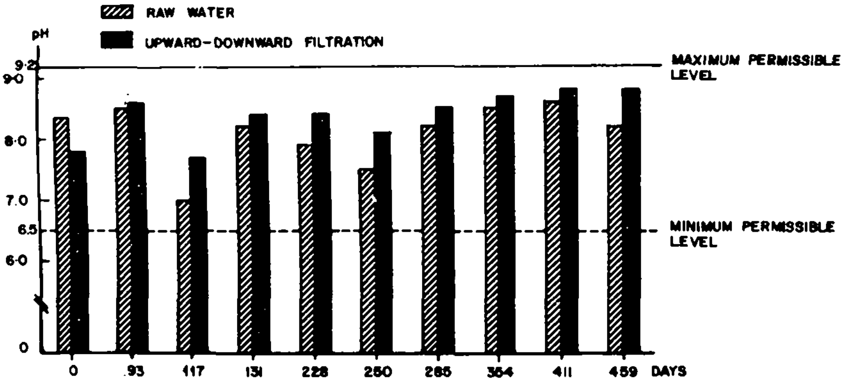

Fig. 9d The pH levels of the water samples from the Tajin river before and after treatment with upward-downward filtration with the rate of 0.5 l/min.

APPENDIX 1

LOW COST CONCRETE JARS FOR WATER STORAGE-THE JUMBO JAR

Villagers in many tropical areas use many types of vessels for storing water. This is particularly important in monsoon climates when many water sources temporarily fail for long period in the dry season. In rural Thailand there has been a traditional craft of jar making for many years. The system of using a bag filled with sand as a former and building layers of cement around it to form a jar of up to 2 m^3 has been described in many papers. The method of construction described here has been used to build jars up to 5 m^3 capacity but it is more usual to build jars of about 2 m^3 Using these large jars Thai villagers are able to collect rain-water in the wet season and store enough to provide a safe drinking water supply through the dry season.

The jars are strong, elegant and cheap, costing only about B 400 (US $ 20) using only materials that are easily available and tools that can be made by almost any craftsman. The principle of construction is to start with a precast base and to build a temporary core on the base using specially cast concrete bricks. The core is given its final shape by adding a coat of well puddled clay or if no clay is available certain types of sand are suitable. When the core is complete, two layers of concrete are applied with a layer of thin reinforcing wires between them. The final shape is achieved by smoothing the cement with a flexible metal strip used as a combined scraper, spatula and polisher. An old sawblade provides a suitable source. After the cement coats are completed and the jar has been able to set, the bricks and other materials used in the core can be removed and stored for reuse many times.

A skilled craftsman with one assistant can complete the necessary work to build the core and make the jar in a few hours. Unskilled craftsman can easily be trained to do this work though they will at first be shown and need more assistance.

The main use of the jars is for water storage but many other uses from water filters to septic tanks are possible.

Materials and tools:

1. Wood-metal template: for casting former blocks.
2. Floats: for applying clay and plaster (2 sizes; large and small).
3. Flexible scraper/spatula: for smoothing clay and plaster
4. Metal formers: (a) as template for the rim: 75 cm diameter and 10 cm wide.
    (b) as template for the base: 110 cm diameter and 5 cm wide.
5. Reinforcing wires.
6. Puddled clay for forming the shape.

Cement for moulding bricks

  - (a) 5 bags of cement } 1 : 3
  - (b) 1 cubic meter of coarse sand }
  - (c) Sufficient water to just moisten the mixture of cement and sand (do not make a too soft mixture)

8. Cement for plastering the jar
   - (a) 3 bags of cement } 1 : 2
   - (b) $\frac{1}{2}$ cubic meter of coarse sand }
   - (c) Sufficient water to make a soft mixture.

Making the template for the core bricks

The template for moulding the corebricks consists of a three side box made of wood with the dimensions shown in Figure 1 and a fourth side made from metal about 1 mm thick curved as shown in Figure 2. The two parts are held together in use by clipping one metal tongue to the slotted side of wooden section and holding the other metal tongue in place with a peg as shown in Figure 3.

Making the bricks for the core

1. Construct the template as shown in Figure 4 using wood and metal. Two pieces are required.
2. Assemble the template on a smooth base.
3. Fill the template with moulding cement by adding cement in layers and ramming each layer in place with a suitable wooden stick.
4. Smooth off the surface of the cement when the mould is filled.
5. Unfasten the template and remove taking care not to spoil the shape of the brick.
6. Reassemble the template and repeat until sufficient bricks have been made to construct the size of the jar required. For a 2 m^3 jar about 100 bricks are required.
7. Allow the bricks to dry undisturbed and protected from rain or excess sun for about 24 h. If necessary cover with wet sacking in hot weather.
8. The complete bricks can be recovered and reused many times.

Making the base of the jar

1. Place sand on a smooth floor and form a shallow smooth dome about 50 mm high and 1.1 m diameter.
2. Cover the sand dome with wrapping paper or thin plastic film.
3. Place the template for the base in position with the top of the dome in the centre.
4. Place reinforcing wires across the diameter of the template leaving about 150 mm surplus beyond each loop as in Figure 5a. so that the reinforcing wires for the walls of the jar can be attached.

5. Fill the template with the cement plaster to a depth of 50 mm and smoothing the surface with float to maintain an even thickness over the whole area of the dome as in Figure 5b.
6. Allow the base to dry overnight with the template in position.

To construct the temporary core of the jar

Commence work early in the morning in order to complete the jar in 1 day. An experienced craftsman can complete a jar in 3 h. Inexperienced workers may take longer but when the jar is started, work must continue until the jar is completed. If this is not possible, work can be temporarily stopped after the bricks has been laid for the core.

1. When placing bricks in position for the core, care must be taken to ensure that the lower 6 courses are laid with the narrow faces downwards and to reduce the diameter the upper 2 or 3 courses are laid with the narrow faces upwards as in Figure 6a.
2. To form the first course, layers of bricks are filled the joints carefully with puddled clay.
3. Form the second course by placing bricks in position sloping outwards at an angle approximately 25° or 30° from the vertical. If necessary to complete a course half bricks may be used.
4. After each course is completed, a ring of reinforcing wire is tied firmly around it as in Figure 6b.
5. Continue adding extra courses well bedded in puddled clay preserving the desired shape until the maximum diameter is reached at about the 6th course, adding more reinforcing wires as each course is completed.
6. The last two courses, 7th and 8th are laid with the bricks narrow face upwards and sloping slightly inwards to curve the shoulder of the jar.

Completing the shoulder of the jar core

1. In order to complete the shape of the core a form is made by placing 6 pieces of wood about 60 cm long, 1.3 cm thick and 5-8 cm wide in a circle on the top of the upper course of bricks taking care that the outer diameter is slightly smaller than the outer diameter of the bricks as shown in Figure 7.
2. Using 45 cm lengths of the same wood two more circles are built with decreasing diameters. This will require about 15 pieces as shown in Figure 7.
3. Using 30 cm lengths of the same wood 3 to 4 more circles of decreasing diameter are placed in position and adjusted so that the metal former for the rim 75 cm diameter will rest on the top layer.
4. At this stage check the formation of the shoulder carefully. Ensure that the slope is uniform and that no pieces of wood protrude from the general shape, and that the rim former is centrally positioned.

5. Place sheets of wrapping paper over the wooden slats in order to cover all the gaps and give a surface that will support the next layers of clay.

Preparing the surface of the core

1. Sufficient well puddled clay must be prepared free from stones and twigs and mixed to a uniform smooth plastic consistency.
2. Start applying clay with the float from the bottom of the core leaving the join between the core and the base clear. A uniform layer about 10-15 mm is required over the whole surface between the former of the base and the former of the rim as in Figure 8. The float with a curved blade can be used. Do not allow the clay to cover any part either of the metal formers at the base or the rim.
3. Carefully check the smoothness and regularity of the clay layer before proceeding. If necessary more clay can be added to improve the shape.
4. Where no suitable clay is available, certain types of fine sand can be used for shaping the core. Coarse builders sand is not suitable. The choice of suitable sand is not easy without some experiment but it is suggested that a sample of fine sand is moistened then a handful squeezed in the hand. If the sand does not hold together with a good impression of the fingers it is not worth proceeding.

Applying the first layer of cement plaster

1. Sufficient plaster must be prepared and ready before this operation is started.
2. Remove the former from the base and spray with sufficient water to soak the cement base well.
3. Sprinkle dry cement powder all round the base ensuring the edge of the base is completely coated. This operation is important to ensure that the jar does not leak. Spray more water on the cement to moisten the whole of the edge of the base.
4. Without delay commence applying cement plaster with the large float starting at the edge of the base and working upwards and around the core making a layer about 15 to 20 mm thick up to the edge of the rim former as in Figure 9a.
5. When the first coating of cement plaster is completed the reinforcing wires are placed in position. First a circle of wire is placed around the shoulder about 10 cm from the rim. The loose ends of the wires in the base are then pulled upwards and more wires added. The wires are then pulled upwards and joined to the top wire ring with sufficient tension to lie smoothly on the surface neither embedded in the plaster nor lifted above it. Adjustments can be made by carefully twisting the wires.
6. When all 15 to 20 vertical wires are in place, a horizontal wire is applied to give 10 to 12 reinforcing rings in spiral form, joined to the verticals at the bottom and at the top only as in Figure 9b.

Applying the second layer of cement plaster

1. Apply the remaining cement plaster in a uniform layer over the whole structure in the same manner as the first layer, to give further 20 mm thickness as in Figure 10a. The total thickness of the finished plaster should be 30 to 40 mm.
2. To form the rim apply a plaster made as for brick, in a layer about 8 cm thick.
3. Using the special rim template, press the cement at the rim smoothly into place and form a neat ring of uniform shape and thickness as shown in Figure 10b.
4. Using the flexible scraper, wetted with clean water, work the whole surface of the jar from the base upwards to give a smooth uniform surface blending neatly into the rim.
5. At this stage the shape is completed and a final polish can be applied. After the jar has been allowed to stand for about 10 to 15 min, dry cement powder is applied by hand to give a smooth complete coating, then the flexible scraper is used to give a final polish as in Figure 10c.
6. If desired, a coat of water based paint can be applied to the outer surface before a final polish as in Figure 10d.

Removing the core form the jar

1. The completed jar must be left for not less than 24 h and then the core may be removed.
2. It is necessary for a small person to carefully enter the jar at the rim.
3. Commence by removing the wood slats, then remove the bricks layer by layer (Figure 11) The inner wires are also to be removed. The slats and the bricks can be cleaned and reused indefinitely.
4. All the remaining clay can be separated from the inside of the jar and stored for reuse if required. If left for another day, the final clay particles can easily be brushed off from the inner surface.
5. Using a suitable brush wet all the inner surface of the jar.
6. Apply a thin slurry of cement and water to the inside of the jar to prevent leakage.
7. After the work on the inside is completed, the jar is allowed to dry for at least 2 days before it can be used. If it is necessary to move the jar from the position where it has been built, it should be allowed to dry for at least a week.
8. The completed jar should not be filled immediately. It can be $\frac{1}{4}$ filled on the first day, $\frac{1}{2}$ filled on the second day, 3/4 filled on the third day and completely filled in 4 days.

Warning, a complete 2000 l jar will weigh about 250 kg when empty and 2250 kg when full, care should be taken to support the jar on a firm base.

The completed jar can be used for storing water without any further modification but it is advisable to provide a lid either made of wood or concrete.

Modification of the jumbo jar

1. Taps or pipelines can be fitted to the jumbo jar by cementing pipes or other fittings through the wall. Holes can be easily cut in the walls before the cement has lost its plasticity. If holes are required after the jar has hardened, careful use of a hammer and a narrow bladed chisel will suffice. Fittings can be secured with cement.
2. Jars can be used for fill and draw chlorination, and suitably modified can be used as upward flow or downward flow sand filters.
3. With slightly more extensive modification a satisfactory small septic tank can be made from a 2000 l jar.

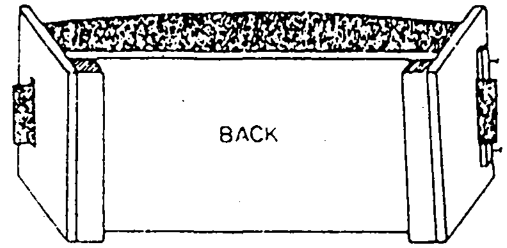

Fig. 1a The template showing three wooden sides.

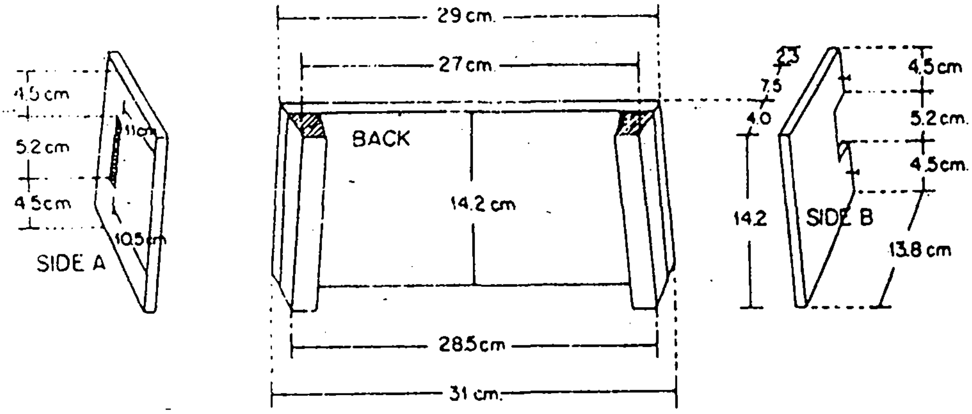

Fig. 1b The template showing wooden parts in details.

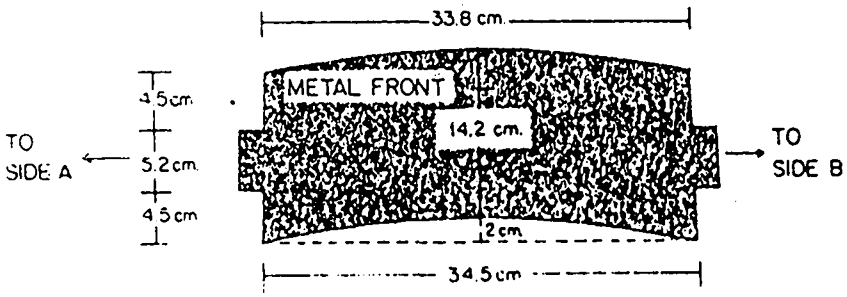

Fig. 2 The template showing the metal side in details.

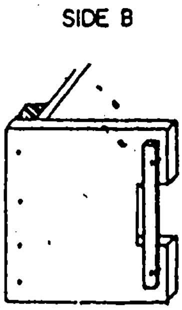

Fig. 3 Showing fixing pegs.

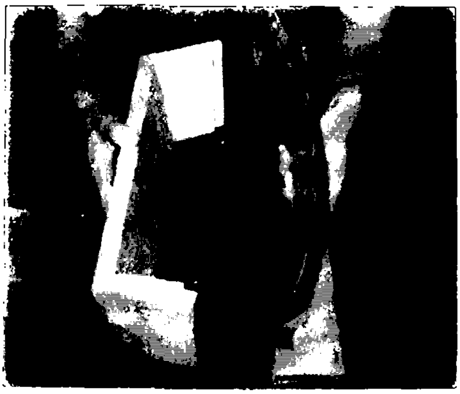

Fig. 4a Construction of the template.

Fig. 4b Showing the template with moulding cement and the complete bricks.

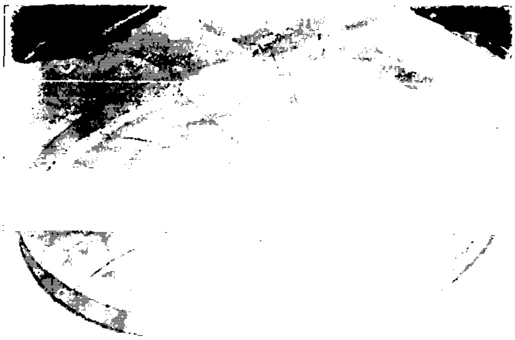

Fig. 5a The base of the jar with the template in position and the reinforcing wires.

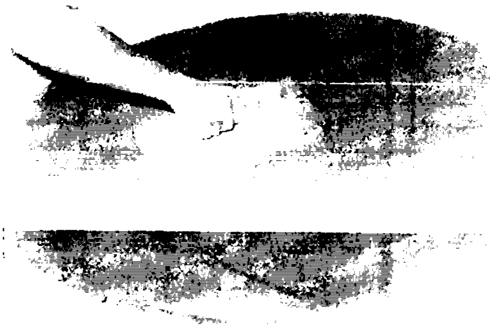

Fig. 5b Smoothing the surface of the base with a float.

Fig. 6a Construction of the temporary core of the jar.

Fig. 6b Showing reinforcing wires.

Fig. 7 The shoulder of the jar core made from pieces of wood.

Fig. 8 Coating the surface of the core with well puddled clay using the float.

Fig. 9a Applying the first layer of cement plaster with the large float.

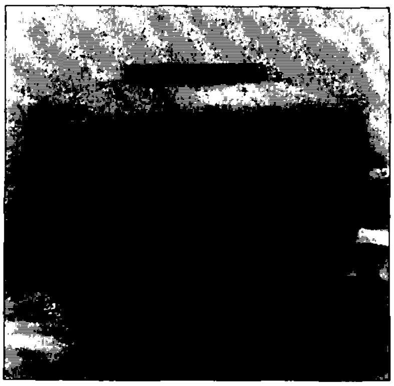

Fig. 9b The complete first layer of cement plaster and reinforcing wires.

Fig. 10a Applying the second layer of cement plaster.

Fig. 10b Construction of the rim of the jar.

Fig. 10c A final polish.

Fig. 10d Painting the outer surface of the jar.

Fig. 11a Removing the wood slats.

Fig. 11b Removing the bricks.

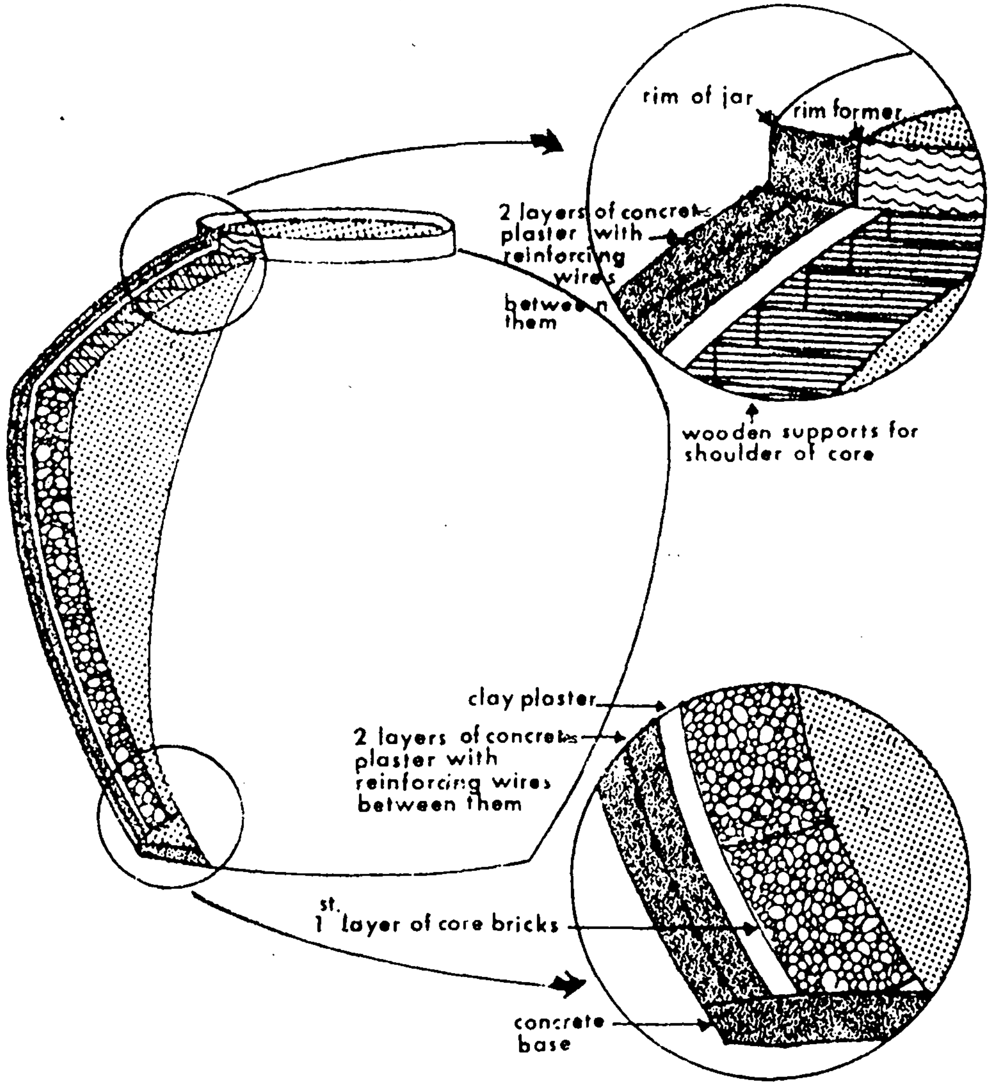

Fig. 12 Summary of all layers of the jar showing in cross sections.

Fig. 13 The jumbo jar having the capacity of 2000 litres or 100 pails of water or ten times the ordinary size jars.

APPENDIX 2

A BICYCLE POWERED WATER PUMP FOR VILLAGE USE

Objectives : to enable villagers to raise water from wells and other sources to tanks or pipelines to make good water easily accessable to all.

Advantages:

The pump is simple lift and force piston pump which can be operated by a bicycle thus independent of electric power. It can raise water to a height of more than 50 m.

The basic pump costs only about 800 Baht (US$ 40) as of 1984 in Bangkok.

Equipment:

1. The lift and force pump which is made in Thailand by many manufacturers and is easily available countrywide.
2. An ordinary bicycle, if necessary only the rear part is needed.
3. PVC pipe ∅ 25 and 35 mm for connecting the pump to the sources and the delivery.
4. PVC unions to enable pipe connections to be made and sufficient reducers and bends.
5. Foot valve for inlet to suction pipe.
6. Nylon rope knotted every 150–200 mm and formed into a driving belt to fit around the rim of the rear bicycle wheel and the drive pulley of the pump. The knots help to prevent slippage.
7. Iron or wooden frame to mount both bicycle and pump securely and stable enough to permit comfortable pedalling.

Installation on the base

1. (a) Using rear half of a bicycle only–fasten the frame of the bicycle firmly in position using additional metal supports. Fasten the pump firmly in position with the pulley aligned with the rear bicycle wheel. Fit driving belt in place.

   (b) Using a complete bicycle–a modified base is required to enable the complete bicycle to be fastened firmly in position with the unused sprocket on the bicycle wheel aligned with a larger sprocket replacing the drive pulley on the pump. Fit driving chain in place.

2. Adjust the tension of the driving belt or chain. A loose fit will slip, a tight fit will bind.

Operation:

1. Prime the pump with a little water.
2. Pedal the bicycle in the ordinary way. In trials, water was pumped : -

Height (m)	Flow rate (l/min)
2.5	8.4
5.0	7.2
10.0	7.8
15.0	7.4

Higher rates of flow could be achieved if extra efforts were made.

This low cost pump needs no electricity, can provide healthy exercise or may take advantages of natures inexhaustable supply of energy-boy power.

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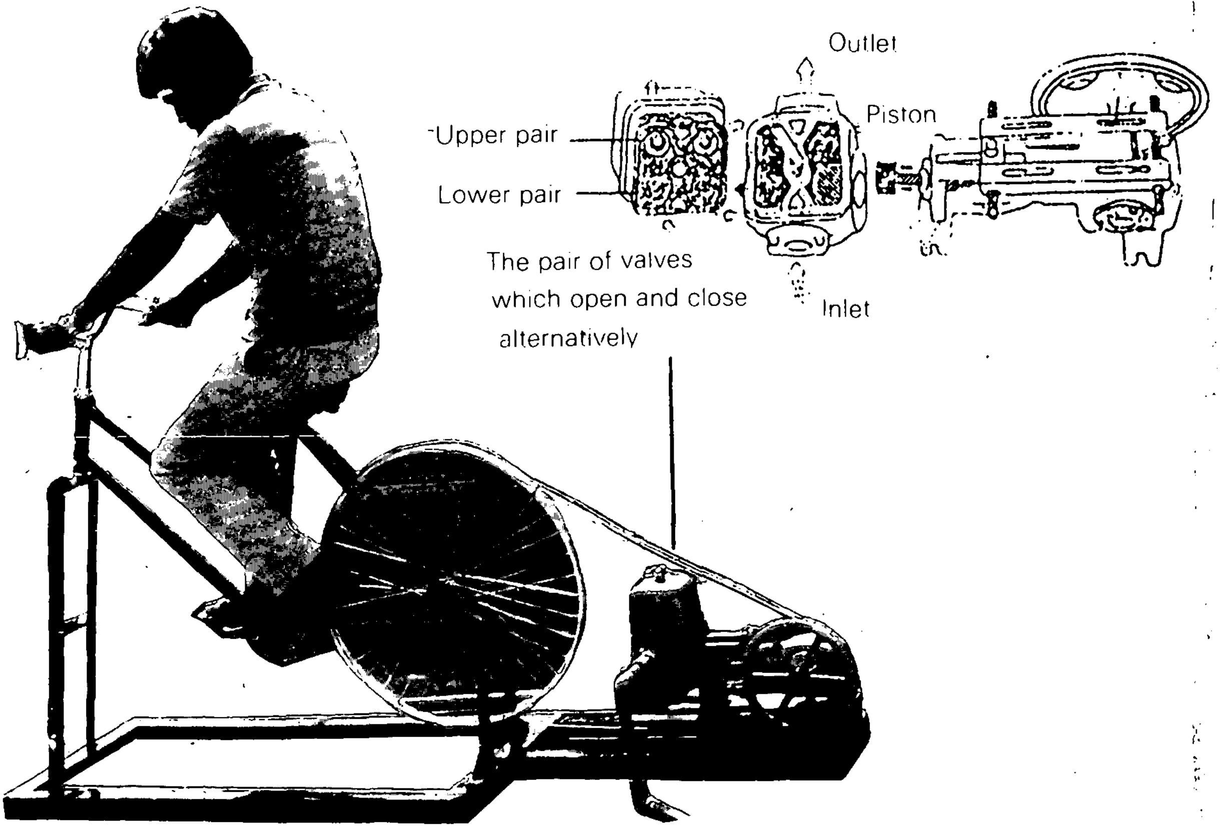

Fig. 1 **The bicycle powered piston pump. The parts of the pump are shown in details as above.**