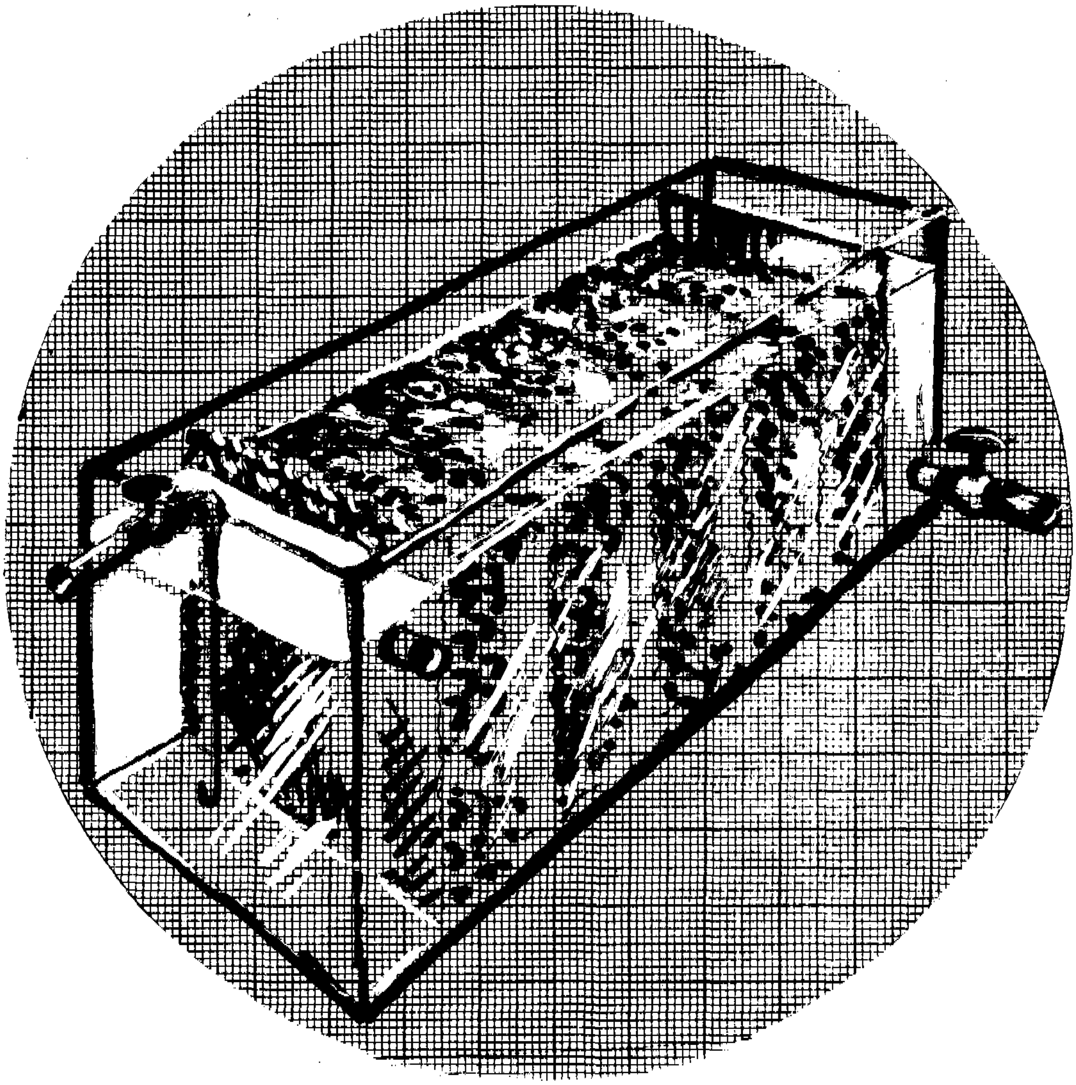
HORIZONTAL-FLOW COARSE-MATERIAL PREFILTRATION



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on

HORIZONTAL-FLOW COARSE-MATERIAL PREFILTRATION

by

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I INTRODUCTION

The main problem in using tropical surface waters as sources of water supply resides in the removal of turbidity particles mainly consisted of clay and suspended silt. Several methods of treatment have been developed to treat these turbid waters. The most common approach is the conventional rapid sand filtration process in which chemicals are used to coagulate and flocculate fine particles for further settling and filtration. This complex and expensive method of water supply seems inappropriate for rural areas in developing countries for financial, technological and administrative reasons. Considering these constraints in rural communities, slow-rate filtration seems to be the most suitable treatment process for surface waters. It is less complicated and, where land is not a limiting factor, usually requires less investment.

One problem in applying slow-rate filtration to turbid surface waters in tropical regions is that the suspended silt quickly blocks the filter. However, a slow-rate filter can be maintained in good working condition in spite of excessive turbidity (particularly inorganic turbidity) which causes rapid clogging of the filter surface, necessitating frequent cleaning. Where the raw water source contains high amounts of turbidity and algae, pre-filters (coconut fibre, pea gravel, crushed stone) can be used to remove most of the turbidity and algae before the water passes through a slow-rate filter (sand or burnt-rice-husk filter) for polishing and removal of remaining impurities. In this regard, the slow-rate filtration process developed at the Asian Institute of Technology in Bangkok using coconut fibre and burnt-rice-husk/sand as filter media either in series or dual arrangement is found to be quite efficient for community water supply in tropical developing countries [1/].

1/ THANH, N.C. and PESCOD, M.B. (1976), Application of Slow Filtration for Surface Water Treatment in Tropical Developing Countries, Research Report No. 65, Asian Institute of Technology, Bangkok, Thailand.

The horizontal flow prefiltration technique using coarse gravel or crushed stones as filter media is also a sound alternative in handling turbid waters. The main advantage of a horizontal-flow prefiltration is that when raw water flows through it, a combination of filtration and gravity settling takes place which invariably reduces the concentration of suspended solids. The effluent from the prefilter, being less turbid, can be further easily treated by the conventional slow sand filter or burnt-rice-husk filter.

Purpose of the Study

This study constitutes an additional step in the research of alternative methods of pretreatment to cope with the highly turbid tropical surface waters in developing countries. It has been reported that coconut fibre as a pretreatment filter showed remarkable potential to remove the major part of the turbidity in raw water offering satisfactory effluent for subsequent slow-rate filtration process. There is reason to believe that an horizontal-flow coarse material prefilter is also effective in handling turbid waters for further purification processes.

The specific purpose of this study was to assess the performance of horizontal-flow coarse-material prefilters in removing the major part of turbidity particles in raw water for subsequent treatment by slow sand or burnt rice husk filters. Tests were conducted on laboratory and pilot scales. The quality of treated water (turbidity and coliform removals) and the duration of filter runs based on the observation of head loss build-up (or filter clogging) were the main assessment criteria.

Performances of coconut fibre prefilter (previously investigated) and horizontal-coarse-material-prefilter are also comparatively reported.

II EXPERIMENTAL INVESTIGATION

This study was divided into two parts: a laboratory-scale study and a pilot-scale study. The following section describes the experimental arrangement of each category as well as the design parameters.

2.1 Laboratory-Scale Study

This small scale filter system was designed in order to process water for supply to a community of about 30 people or 6 families of 5 consuming 30 litres per capita per day.

2.1.1 Source of Raw Water

The raw water source is a canal near the laboratory of Environmental Engineering Division of the Asian Institute of Technology, Bangkok. It is an artificial pond with concrete embankments receiving rain water and water from another pond surrounding the campus. Silt and clay particles emanating from the muddy bottom build up the turbidity in raw water. Under normal conditions, the turbidity of this surface water ranged from 32 to 50 JTU. High turbidities of upto 76 JTU were recorded during raining days due to soil and silt drained into the canal. The alkalinity varied from 452 to 520 mg/l as $CaCO_3$ and pH 8.4 to 9.2. The water temperature ranged from 24 to 30°C and the coliform (MPN) level was from 75 to 2,400 per 100 ml. The high pH conditions were caused by algae which used up carbon dioxide in their photosynthetic activity and reduced the free carbon dioxide concentration below its equilibrium concentration with air.

2.1.2 Filter System Design

The filtration system consisted of a rectangular box packed with graded crushed stones and coupled with two circular slow sand filters. The experimental laboratory unit is shown in Fig. 2.1. Design details of this filtration system are given in Appendix A, Fig. A1.

The prefilter is made of 0.16 cm-thick galvanized iron sheets and measured 1.90 m x 0.40 m x 0.55 m. Graded crushed stones of

Fig. 2.1 Laboratory Filtration System

Burnt Rice Husk, Sand

Fig. 2.2 Pilot Filtration System

2-11 mm effective size were used as the filter material and were placed at 30 cm intervals and a depth of 0.45 m in the sequence of 9.1 mm, 6.4 mm, 4.4 mm, 2.8 mm followed by another 30 cm of 9.1 mm crushed stones serving as a supporting system. The effective size (E) and the non-uniformity coefficient (U) derived from the sieve analysis of crushed stones as shown in Fig. 2.3, are as follows:

Size Range, m	E, mm	U
2-6	2.8	1.38
3-8	4.4	1.39
5-9	6.4	1.26
7-11	9.1	1.22

The crushed stones were obtained from a local purchaser for 130 Baht[1/] per cubic metre.

The underdrainage system of this prefilter serves the purpose of providing an outlet for the filtered water to pass through without the penetration of fine material. This outlet consisted of three rectangular openings with size 8 cm x 6 cm covered with wire mesh as shown in Appendix A, Fig. A1. The crushed stones of 11-15 mm effective size were placed for a depth of 10 cm and a length of 15 cm from the outlet serving as an underdrainage device.

The two slow sand filters were of oil-drum type measuring 0.90 m in length and 0.55 m in diameter. The arrangement in each filter box was as follows:

Freeboard above supernatant water level	0.15	m
Supernatant water	0.30	m
Sand	0.30	m
Pea gravel underdrainage	0.15	m

The front of each filter box was cut and screw - covered with three 22 cm x 21 cm plexiglas windows. The purpose of doing this was to closely follow the development of the biological layer.

1/ Current exchange rate approximately 20.15 Baht - U.S.$1

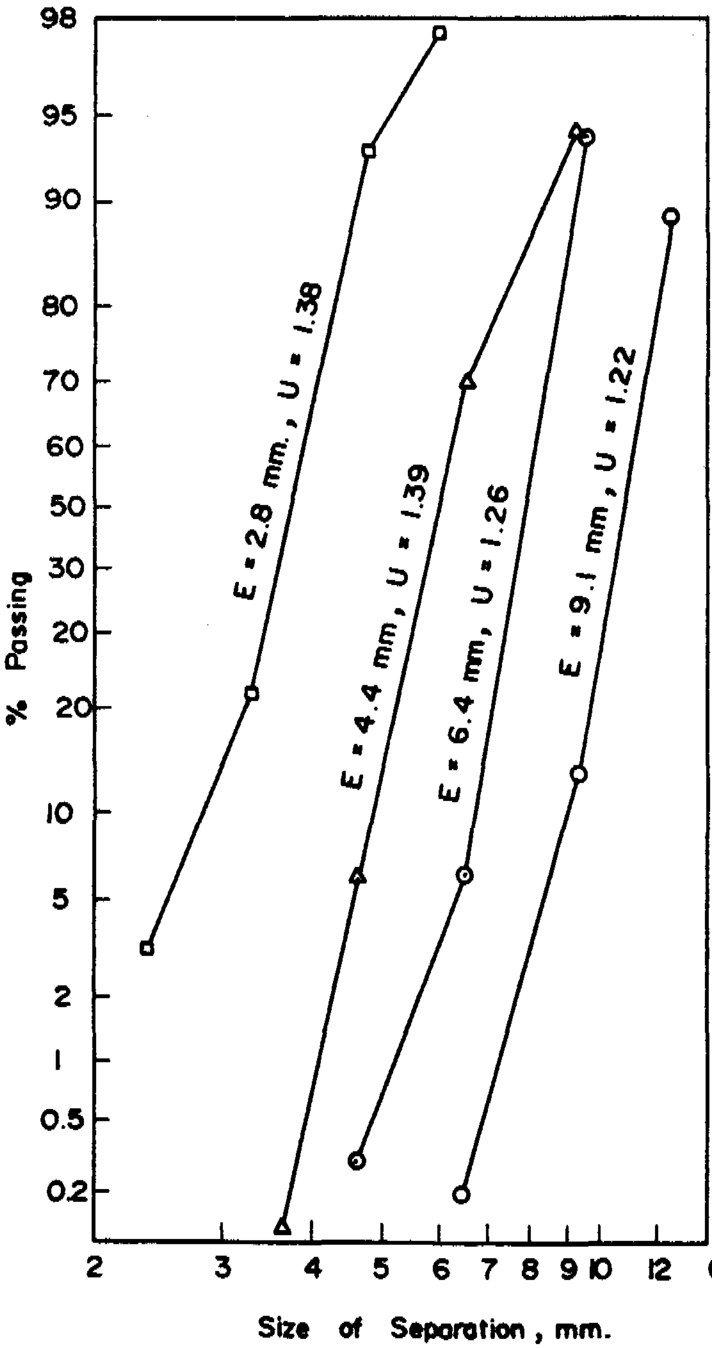

Fig. 2.3 Sieve Analysis of Crushed Stones (Lab. Horizontal Prefilter)

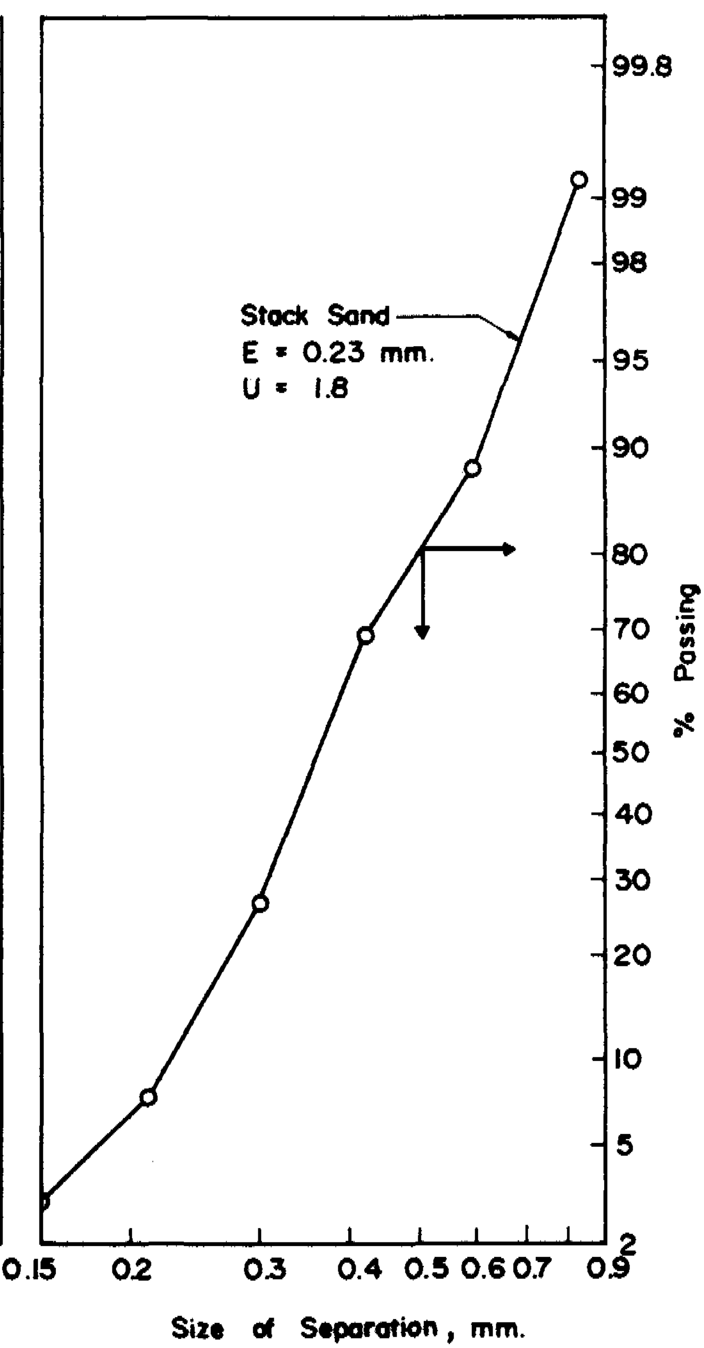

Fig. 2.4 Sieve Analysis of Sand (Lab. Horizontal Prefilter)

Stock sand used in this part of study presented an effective size (E) of 0.23 mm and a non-uniformity coefficient (U) of 1.8, as shown in Fig. 2.4. The cost of sand was about 100 Baht per cubic meter.

Between the bottom of these filters and the filter bed lay three 5 cm zones of pea gravel with gradings of 0.7-1.4 mm, 2.0-4.0 mm and 6.0 to 12.0 mm. This arrangement serves as the supporting medium and also the under-drainage system for the filters.

2.1.3 Operation and Maintenance

Raw water was drawn from the canal by means of a 1-hp centrifugal pump to the inlet of the horizontal prefilter. The constant water level in this compartment was maintained by the use of a 2 cm-overflow pipe. A constant effluent flow of 0.6 m^3/m^2-h was manually controlled by a gate valve located on the outlet side of the prefilter. Pretreated water was then admitted by a 0.5-hp centrifugal pump to two slow sand filters. Constant flow rate of 0.15 m^3/m^2-h was maintained in each filter by gate valves at the delivery point of slow sand filters.

The filter run was interrupted when the outlet regulating valves of slow sand filters was fully open due to the bed resistance. The horizontal prefilter offered no sign of clogging during the study and cleaning was not required. The cleaning of sand in slow sand filters was effectuated by manually scraping off the surface layer to a depth of about 2 cm. Prefilter and slow sand filters were operating under covered conditions.

2.2 Pilot-Scale Study

This study was initiated with a view to evaluate the performance of a horizontal flow coarse material prefiltration unit coupled with a slow sand and a burnt rice husk filter, and also to conduct a comparative assessment between the horizontal flow coarse material prefilter and the coconut fibre prefilter, the latter being studied in a previous investigation [1/].

1/ THANH, N.C. and PESCOD, M.B. (1976), Application of Slow Filtration for Surface Water Treatment in Tropical Developing Countries, Research Report No. 65, Asian Institute of Technology, Bangkok, Thailand.

2.2.1 Source of Raw Water

The raw water source is the same canal used in a previous study by THANH and PESCOD [1/] (1976). Under normal conditions, the turbidity of this surface water ranged from 24 to 50 JTU. Fluctuations in turbidity were particularly marked during rainy days when runoff from the surrounding area carried silt and soil into the canal. Under these conditions a turbidity of up to 114 JTU could be occasionally recorded. This canal is also an artificial one but with earth embankments, thus imparting higher levels of turbidity than in the case of laboratory scale study, during the rainy days.

2.2.2 Filter System Design

Fig. 2.2 gives a view of the pilot filtration system. Design details are given in Appendix A, Fig. A2 and A3. This system is very similar to the laboratory-scale system, except that a burnt-rice-husk filter was introduced in addition to a sand filter.

The horizontal prefilter design was an adaptation of the design of a rectangular sedimentation basin, with an inlet zone, an outlet zone and a filtration/settling zone. It was a rectangular tank, made of bricks and concrete, measuring 6 m long, 1.5 m wide and 1.0 m deep. The bottom was designed with a 1:100 slope providing easy flow for the pretreated water to leave the outlet zone. Graded crushed stones were horizontally packed in the prefilter, from coarse-fine coarse, to a depth of 0.80 m. This arrangement is shown in details in Fig. A2 in Appendix A. In the order of compaction from the inlet to the outlet, the effective size (E) and the non-uniformity coefficient (U) derived from the sieve analysis as shown in Fig. 2.5, are as follows:

Size Range, mm	E, mm	U
9-20	15.7	1.4
4-12	6.8	1.5
3- 9	4.5	1.7
2.5- 8	3.5	1.5
2.5- 6	3.4	1.3
3- 9	4.5	1.7
10-25	15.7	1.4

1/ THANH, N.C. and PESCOD, M.B. (1976), Application of Slow Filtration for Surface Water Treatment in Tropical Developing Countries, Research Report No. 65, Asian Institute of Technology, Bangkok; Thailand

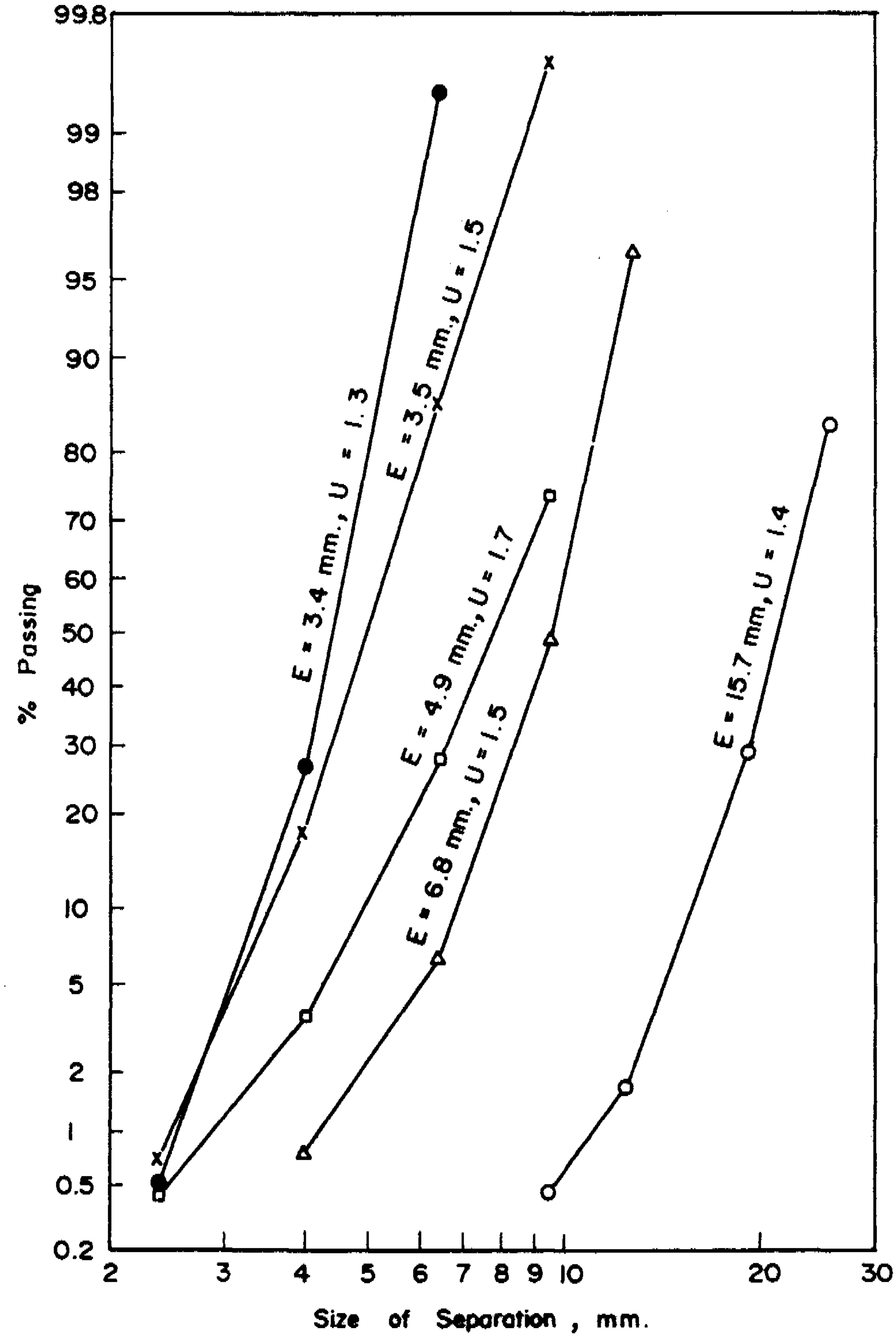

Fig. 2.5 Sieve Analysis of Crushed Stone

(Pilot Horizontal Prefilter)

A 1.5 m x 0.10 m wire mesh aperture is provided at the bottom for the underdrainage system as outlet.

The burnt-rice-husk filter (F_1) and the sand filter (F_2) were of the same configuration, each being made of three 1 m long, 1.54 m I.D. precast concrete sewer pipes. The arrangement in each filter box was as follows:

Freeboard above supernatant water level	0.50 m
Supernatant water	1.20 m
Sand/Burnt rice husk	1.00 m
Crushed stone underdrainage	0.30 m

Design details of the filters are given in Appendix A, Fig. A3. It is appropriate to point out that efforts have been made to apply design criteria of slow-rate filters suggested at the First Meeting of Project Participating Institutions, Voorburg, The Hague, The Netherlands, 22-30 November 1976.

A distribution system was provided at the entrance of the raw water into the supernatant water reservoir so that the medium below was not disturbed by turbulence. The constant level above the media was maintained by the use of an overflow pipe. Flow was controlled by rotameters and gate valves located on the outlet side of the filter. Head loss development was recorded by manometers.

The bottom of these two filters were designed with a 1:25 slope for easy flow of the treated water to the outlet. Between the bottom of these filters and the filter beds lay three 10-cm layers of crushed stone with gradings of 6.4-12.7 mm, 12.7-19.1 mm and 19.1-25.4 mm. This arrangement was provided to prevent the filtering medium from entering and chocking the drainage waterways.

From the results of sieve analyses, presented in Fig. 2.6, burnt rice husk presented an effective size (E) of 0.56 mm and a non-uniformity coefficient (U) of 1.55 mm compared with sand of E = 0.25 mm and U = 1.68. Stock sand and burnt rice husk were used so that expensive grading could be avoided.

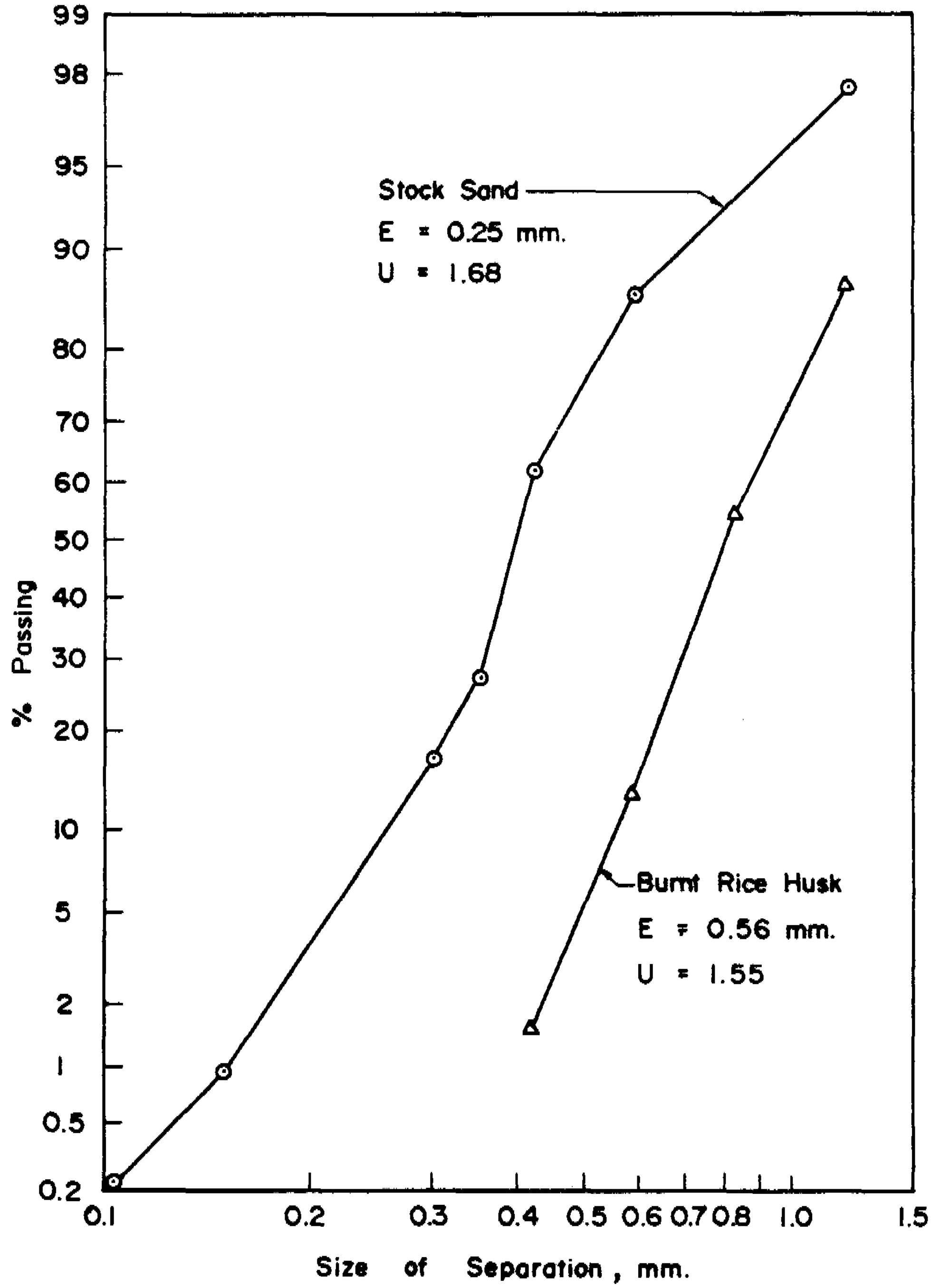

Fig. 2.6 Sieve Analysis of Sand and Burnt Rice Husk
(Pilot Horizontal Prefilter)

2.2.3 Filter Operation and Maintenance

Filtration rate of 0.6 m^3/m^2-h (or 12 l/min) was maintained at the outlet of the horizontal prefilter in order to satisfy the feeding requirement for the sand and the burnt-rice-husk filters which were operated at filtration rate of 0.15 m^3/m^2-h (or about 5 l/min).

Canal raw water was admitted to the inlet of the horizontal prefilter by means of a 2-hp centrifuged pump. Excess water was withdrawn through a 2-in overflow pipe and returned to the canal. Pretreated water of the horizontal prefilter was then distributed by a 1-hp centrifugal pump to two slow-rate filters F_1 and F_2.

The filter run was ended when the filter started to be blocked. This blocking was indicated by the headloss measurement. It was also noticed that the horizontal prefilter showed no warning of clogging, thus required no cleaning. It is expected that this type of prefilter could operate for 4-5 years before any bed cleaning is necessary. The cleaning of sand and burnt rice husk was carried out by manually scraping off the surface layer to a depth of 2-4 cm.

III EXPERIMENTAL RESULTS AND DISCUSSION

This chapter presents the performances of a laboratory scale filtration unit and a pilot-scale unit and assesses the effect of scale-up. Similarly, the performance of the above mentioned systems are compared with the results obtained from the studies when shreded coconut fibres were used as prefilter media, to determine the range of applicability and limitations of different processes.

3.1 Laboratory Scale Filtration Unit

As already mentioned in the section of experimental investigation; a small filtration unit was designed to make a thorough assessment of the extent of the applicability of the horizontal flow coarse media filter when coupled with a slow sand filter for the treatment of tropical surface waters. This part of study extended from March to June 1977 was divided into two filter runs of about 44 days each, heralded by the blocking of sand bed when the outlet regulating valve was fully open. The quality characteristics of raw water and effluents from the prefilter and sand filters, was monitored daily. The bacteriological quality (total coliforms, E. coli) of raw water, pretreated water and final treated water was determined at 4-5 days intervals. Other characteristics, such as BOD_5, COD, iron, manganese, hardness, dissolved oxygen were also examined regularly. All analyses were carried out according to Standard Methods 1/. Detailed data are tabulated in Tables B1 to B6 in Appendix B and the relevant results presented in the following sections.

3.1.1 Turbidity Removal

Fig. 3.1 shows the variations of turbidity in the raw water, in the prefilter effluent and in the final treated water. The values plotted represent the five day averages. Raw water turbidity varied between 32 to 53 JTU during the first run and 32 to 75 JTU during the second run, while the mean value of turbidity in the effluent

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1/ Standard Methods for the Examination of Water and Wastewater, APHA, AWWA, WPCF (1975).

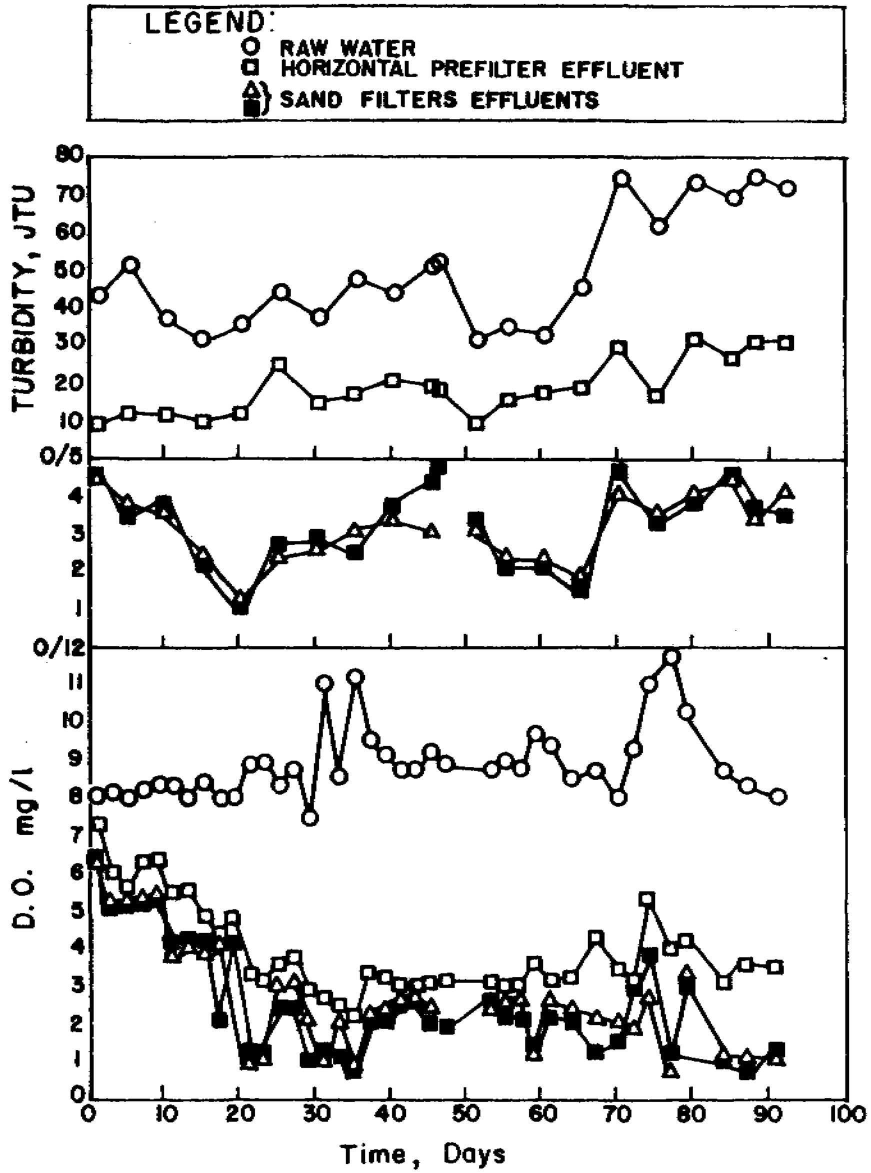

FIG.3.1 TUBIDITY AND DISSOLVED OXYGEN OF RAW WATER AND EFFLUENTS FROM DIFFERENT FILTERS

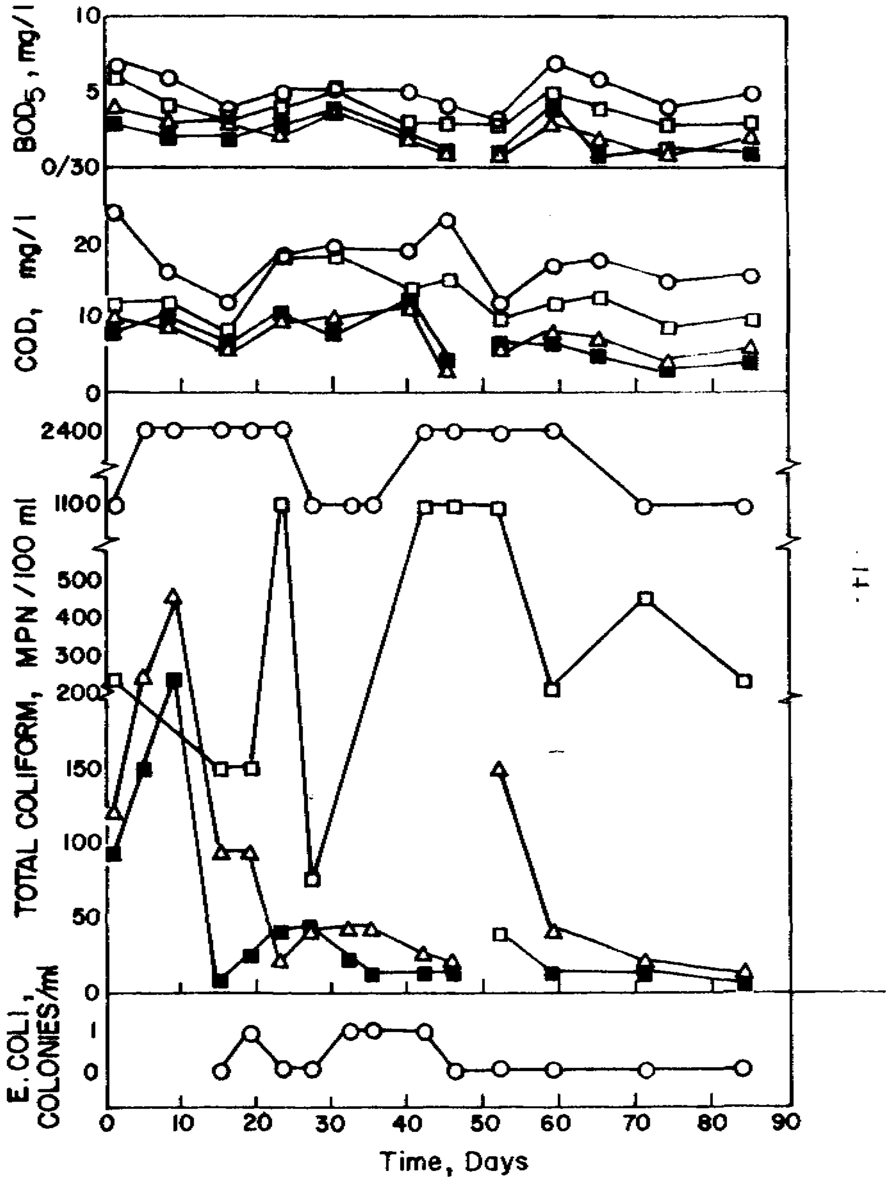

FIG. 3.2 RESULTS OF BOD_5, COD MPN TEST FOR TOTAL COLIFORM AND PLATE COUNT FOR E.COLI TESTS

from the horizontal-flow prefilter was about 15 JTU, indicating 60-64 percent removal efficiency. From the record of 92 days of continuous operation, it can be seen that the turbidity of the water produced by the prefilter was relatively dependent on the raw water turbidity and the prefilter did not show any sign of clogging.

The two slow sand filters performed quite alike in turbidity removal of the prefilter effluent. The turbidity of treated water was relatively good and remained in the range of 1 to 5 JTU in all cases. The filter run was concluded after 44 days of continuous operation as a result of sand bed clogging. The overall efficiency removal by the prefilter-slow sand filter system was about 94 percent.

3.1.2 Coliform Organisms and E. coli

The organisms most commonly used as indicators of pollution are *E. coli* and the coliform group as a whole [1/]. *E. coli* is of undoubted faecal origin, but the precise significance of the presence in water of other members of the coliform group has been much debated. However, from a practical point of vie in relation to the present situation in many rural communities, *E. coli* presence in treated water is the important quality criterion in considering village water supply.

Fig. 3.2 reports count results of total coliforms and *E. coli*, in raw water and effluents from the prefilter and the slow sand filters. The raw water total coliform most probable number (MPN) varied from 1,100 to 2,400 per 100 ml of sample and negligible or no *E. coli* were detected. These coliform organisms presumably originated from the faecal rejections (streptococous *faecalis*) of fish living in the canal and soil (*A. aerogenes*) surrounding the canal. The effluent from the horizontal prefilter had a coliform count which varied from 75 to 1,100 MPN per 100 ml. The fluctuation of coliform organisms in the horizontal prefilter effluent seems to be independent of the coliform organisms in raw water. In general, the horizontal-flow prefilter accounts for 70-75 percent removal of coliform organisms while the sand

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1/ World Health Organization (1971), International Standards for Drinking-Water, 3rd Edition.

filters accomplish 23-28 percent removal of the remaining coliform organisms resulting in an overall removal of 95-98 percent. In conclusion, it is appropriate to say that the treated water is safe for drinking purposes as far as E. coli is concerned.

3.1.3 Dissolved Oxygen

Dissolved oxygen content in raw water and effluents from different filters was regularly recorded. Fig. 3.1 also shows the variation of DO concentration at different sampling points. High DO concentration in raw water, varying from 7.4 to 11.8 mg/l, is the result of intense photosynthetic activity in the canal. The DO in the horizontal prefilter effluent varied from 2.2 to 7.3 mg/l (55 percent drop) while it was from 1 to 6 (21 percent drop) in the final treated water. The drop in the DO concentration in the prefilter and slow sand filters could be attributed to the biological activity and the redox reactions with metals respectively discussed under the BOD_5-COD and Fe-Mn sections.

3.1.4 BOD_5 and COD

Raw water showed concentrations of 4-7 mg/l of BOD_5 and 12-24 mg/l of COD. Fig. 3.2 shows the BOD_5 and COD concentrations of raw water and effluents from the horizontal prefilter and slow sand filters. The decline in the BOD_5 and COD concentrations across the horizontal prefilter and sand filters followed the same pattern as the decrease in DO concentration, hereby confirming the hypothesis that some biological activity occurred throughout the filtering media. In terms of BOD_5 and COD removal, the horizontal prefilter accounted for about 24 percent and 28 percent respectively whereas the sand filters showed 32 percent and 29 percent respectively, giving an overall average removal of 56 percent for BOD_5 and 57 percent for COD.

The BOD_5 and COD concentrations in the final treated water varied from 1 to 4 mg/l and 3 to 12 mg/l, respectively. It is evident that the total filtration process could not completely remove microbial organisms. Therefore, if the water is stored for a long time, the residual organic matter should be sufficient to support the build-up of microbial colonies resulting a depletion of oxygen to a certain extent.

3.1.5 Iron and Manganese

Iron content in raw water varied from 0.1 to 0.5 mg/l as shown in Fig. 3.3 and was brought down to 0.1-0.25 mg/l after the horizontal prefiltration accounting for about 58 percent removal. Further removal of iron to 0.02-0.04 mg/l took place in the sand filters denoting approximately 23 percent removal. Although iron removal in the sand filters is high, most of redox reactions seem to have occurred in the horizontal prefilter oxidizing the ferrous ion in the presence of DO.

Raw water contained nil or negligible amount of manganese as also indicated in Fig. 3.3. Analyses for manganese in effluent from the horizontal prefilter and in final treated water revealed no trace of this metallic substance.

3.1.6 Alkalinity and Hardness

Alkalinity and hardness in raw water ranged from 452 to 520 mg/l as $CaCO_3$ while hardness was in the range of 54 to 76 mg/l as $CaCO_3$. Since alkalinity and hardness are properties of water due to the presence of dissolved cations and anions, the filtration process is unable to alter the essence of these characteristics as may be observed from Fig. 3.4. However, as far as the acceptability of this water for domestic use is concerned, alkalinity and hardness remained in the highest desirable level, e.g. 100 mg/l as $CaCO_3$ for total hardness [1/].

3.2 Pilot-Scale Filtration Study

As previously described, the pilot scale filtration unit consisted of a horizontal flow coarse material prefilter coupled with two slow-rate filters, one packed with burnt rice husk (F_1) and the other with

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1/ World Health Organization (1971), International Standards for Drinking Water

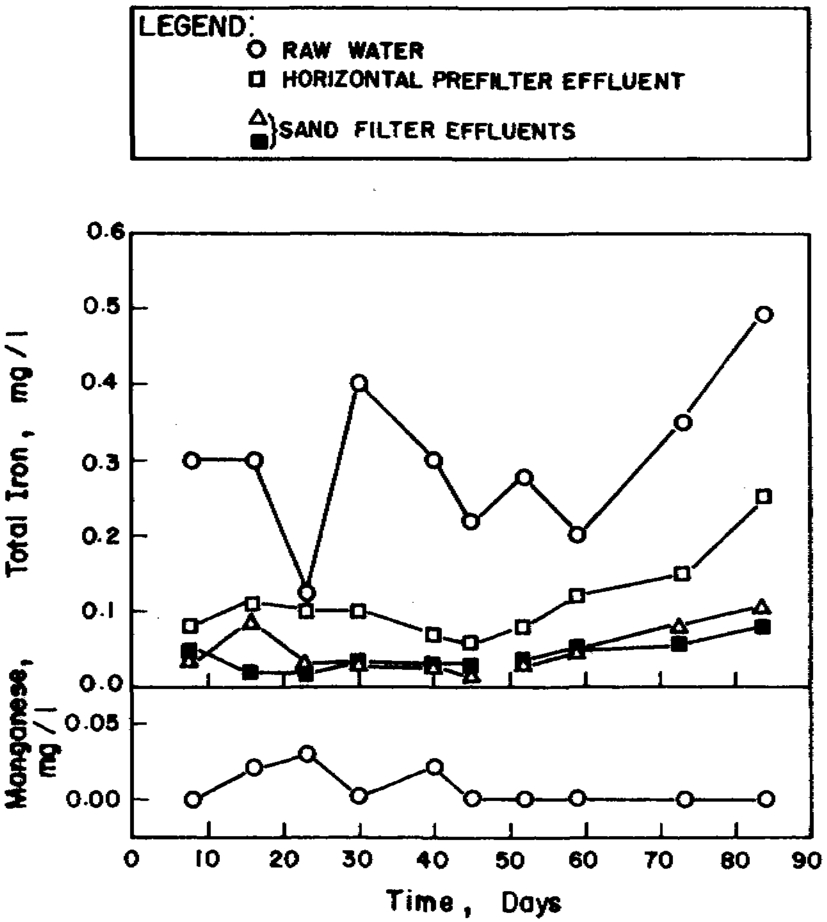

FIG.3.3 TOTAL IRON AND MANGANESE OF RAW WATER AND EFFLUENTS FROM DIFFERENT FILTERS

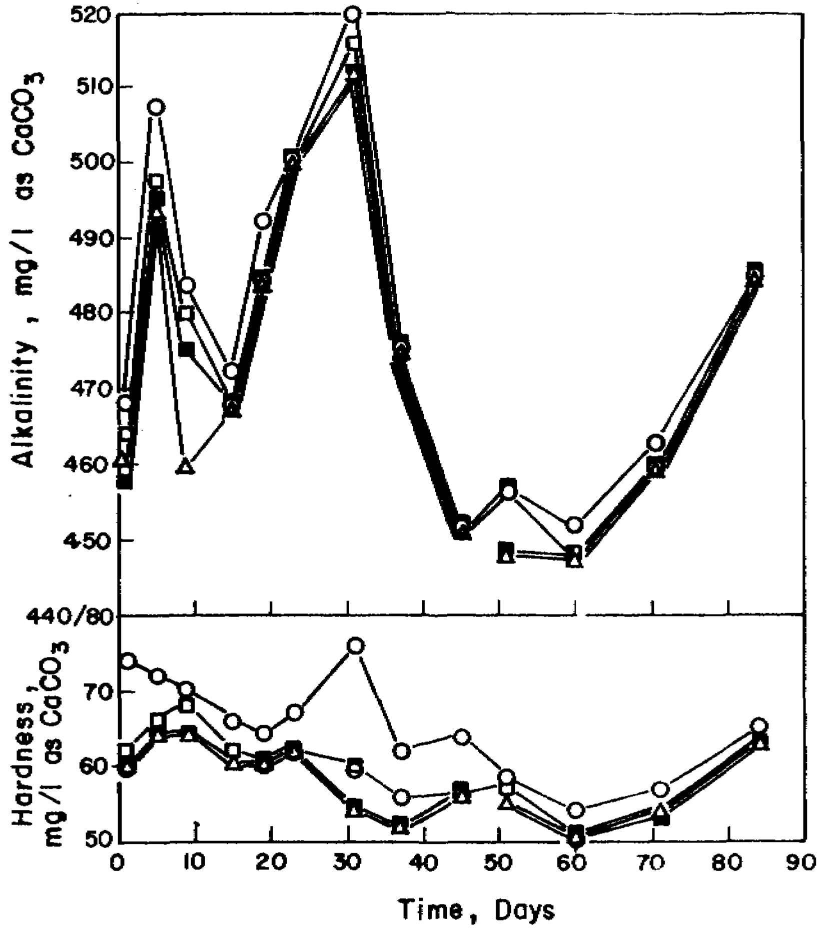

FIG. 3.4 ALKALINITY AND HARDNESS OF RAW WATER AND EFFLUENTS FROM DIFFERENT FILTERS

sand (F_2). Performance of these systems are compared with the bench scale model to determine the effect of scale up. Attempts are also made to compare the horizontal flow coarse material prefiltration with the results obtained when using shredded coconut fibre. This part of study started on May 1977 and still goes on at the moment of this report writing-up. Head loss build-up through the beds of sand and burnt rice husk was daily recorded. The same physical, chemical and microbiological characteristics of raw water and effluents from different filters as in the case of laboratory scale study were measured and the results tabulated in Table C1 to C7 in Appendix C. The discussion of the results is presented in the following sections.

3.2.1 Turbidity Removal and Head Loss

It has been reported that the coconut fibres constitute a potential filtering medium to remove sufficient turbidity from raw waters and produce an effluent acceptable for subsequent treatment by sand and burnt rice husk filters. In a previous study carried out by THANH and PESCOD [1/] (1976) when raw water turbidity varied from 25 to 45 JTU during 108 days of continuous operation, the mean value of turbidity in the effluent from coconut fibres prefilter was about 12 JTU, denoting a 63 percent removal efficiency. In the present study, turbidity in raw water fluctuated between 25 and 60 JTU, except during rainy days when turbidity went up to 80-114 JTU. The turbidity in the effluent from the horizontal prefilter varied from 10 to 20 JTU after a maturation period of about 20 days. At the start the turbidity from this prefilter decreased continuously from 60 to 10 JTU. The initial high effluent turbidity which continuously reduced as the prefiltration process progressed, could have been caused by very large pore sizes of the newly prepared bed. Fig. 3.5 delineates the turbidity in raw water and effluents from different filters. It can be seen that the horizontal prefilter accounts for 54 to 79 percent re-

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1/ THANH, N.C. and PESCOD, M.B. (1976), Application of Slow Filtration for Surface Water Treatment in Tropical Developing Countries, Research Report No. 65, Asian Institute of Technology, Bangkok, Thailand.

moval of raw water turbidity with an average value of 63 percent. In this regard, coconut fibres and coarse material prefilters behaved alike. However, the horizontal prefilter is more reliable in producing a constant effluent quality and affords longer serviceable life than shredded coconut fibres filter.

Both slow sand and burnt rice husk filters were allowed to operate at filtration rate of 0.15 m^3/m^2-h. The slow sand filter (F_2) developed rapid head loss rate as also recorded in Fig. 3.5, making it necessary for frequent cleanings after 10-20 days of operation. After five repeated short filter runs, it was discovered that the sand bed surface became black and clogged. Microscopic examination revealed the presence of an aquatic organism, a type of larva midge Ablabesmyia Chironomiclae. Sand was removed from the filter box for a thorough washing and put back in its place. A new run was initiated on 25 May 1977, the filter being covered in order to avoid possible contamination. After 55 days of continuous operation, head loss recorded was 57 cm at the rate of about 1.04 cm/day. If linear extrapolation is applied for a total permissible head loss of 1.0 m, a filter run for 3½ months could be achieved. During these 55 days of continuous operation, final treated water was of excellent quality in terms of turbidity varying between 0 and 2 JTU only. Subsequent discussion on the slow sand filter applies only for this continuous period of operation.

The phenomenon of clogging by this aquatic organism was not observed in the bed of burnt rice husk filter (F_1). Fig. 3.5 also records the head loss development in this filter, and it can be seen that the head loss build-up was very slow even after 4½ months of continuous operation, i.e. averaging a head loss rate of 0.14 cm/day. In general, the burnt rice husk filter produced water with a very good quality, the turbidity ranging from 1 to 5 JTU as depicted in Fig. 3.5. With regard to turbidity removal, burnt rice husk filter and sand filter are very competitive in their performance.

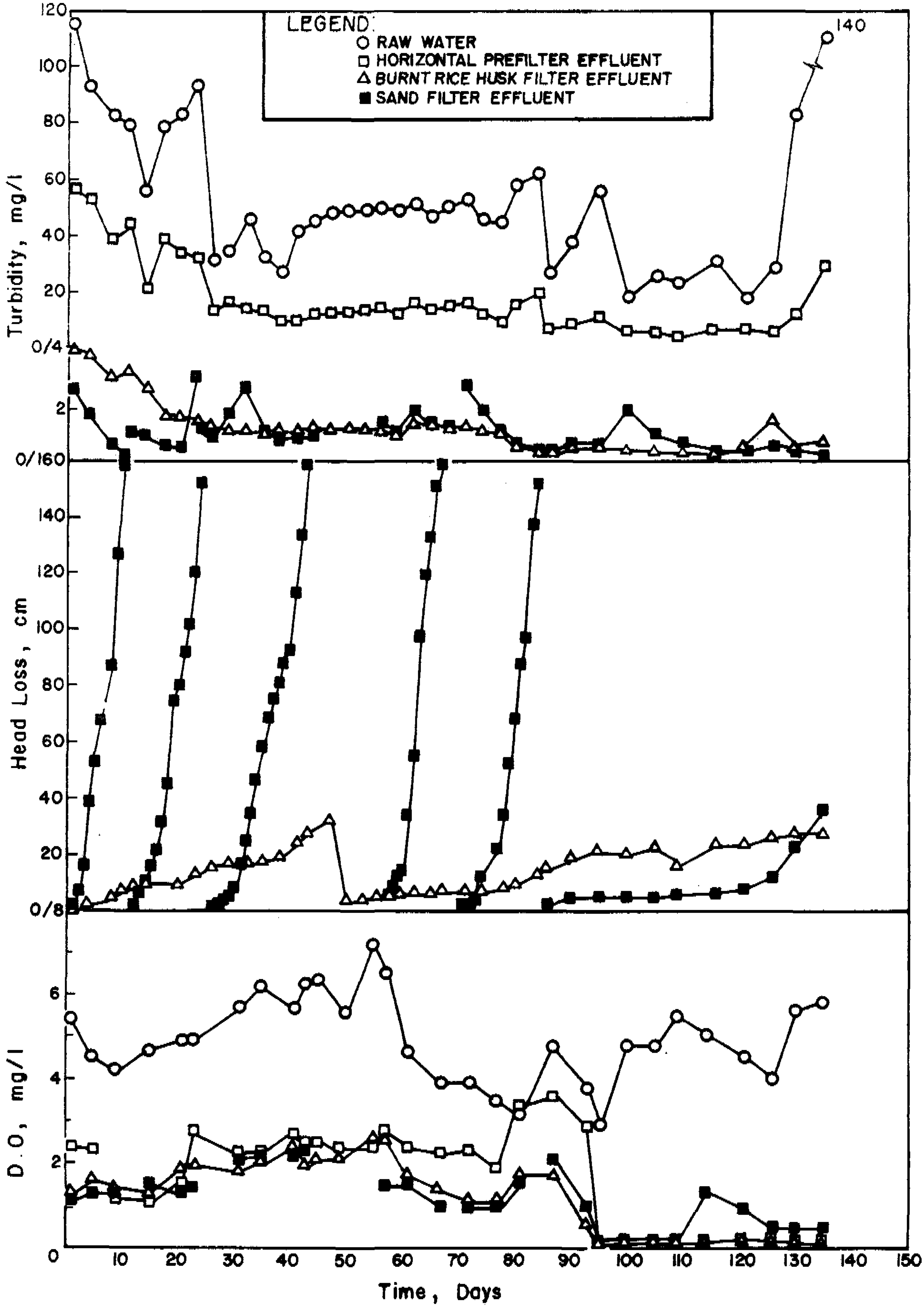


FIG.3.5 TURBIDITY AND DISSOLVED OXYGEN OF RAW WATER AND EFFLUENTS FROM DIFFERENT FILTERS AND HEAD LOSS OF BURNT RICE HUSK AND SAND FILTERS

3.2.2 Coliform Organisms and E. Coli

From the microbiological point of view, what has been said in the laboratory-scale study could also be applied in the case of pilot-scale study. Fig. 3.6 exposes the count analyses of total coliforms and E. coli in raw water and effluents from various filters. Raw water contained 1,100-2,400 coliforms (MPN) per 100 ml and a few or nil E. coli in most of the cases. Considering the number of coliform organisms in the treated water from sand and burnt rice husk filters and the situation where the rural population has been using unsafe waters for decades, it may be said that the final treated water could be considered acceptable for the purposes of village community needs. Moreover, insignificant numbers of E. coli in the treated water provide a degree of security against epidemic outbreaks.

3.2.3 DO, BOD_5, COD, Fe and Mn

DO in raw water fluctuated between 3 to 7 mg/1, BOD_5 between 5 to 12 mg/1 and COD between 12 to 32 mg/1, as can be seen from Figs. 3.5 and 3.6, respectively. During 95 days of continuous operation, DO in the horizontal effluent declined by about 55 percent and ranged from 1 to 3 mg/1. During the same period, a concentration of 1-2.4 mg/1 of DO was detected in the effluent from the burnt rice husk filter. No conclusion could, however, be drawn from the data on the sand filter during this operation period. After 95 days, DO in the horizontal prefilter effluent dropped to zero, occasioning anaerobic conditions prevailing in the sand and burnt rice husk filters. Fortunately, BOD_5 and COD were low in the treated waters, creating no adverse effects on the acceptability of this water for rural domestic uses.

Fig. 3.7 depict the records of Fe and Mn analyses in raw water and effluents from various filters. It can be seen that raw water contained insignificant amounts of Mn, but fair amounts of Fe, ranging from 0.3 to 0.8 mg/1. It is interesting to note that the horizontal prefilter accounted for substantial removal of iron (about 45 percent) and the sand and burnt rice husk filters, another 40 percent, providing a final treated water with an iron content readily acceptable for

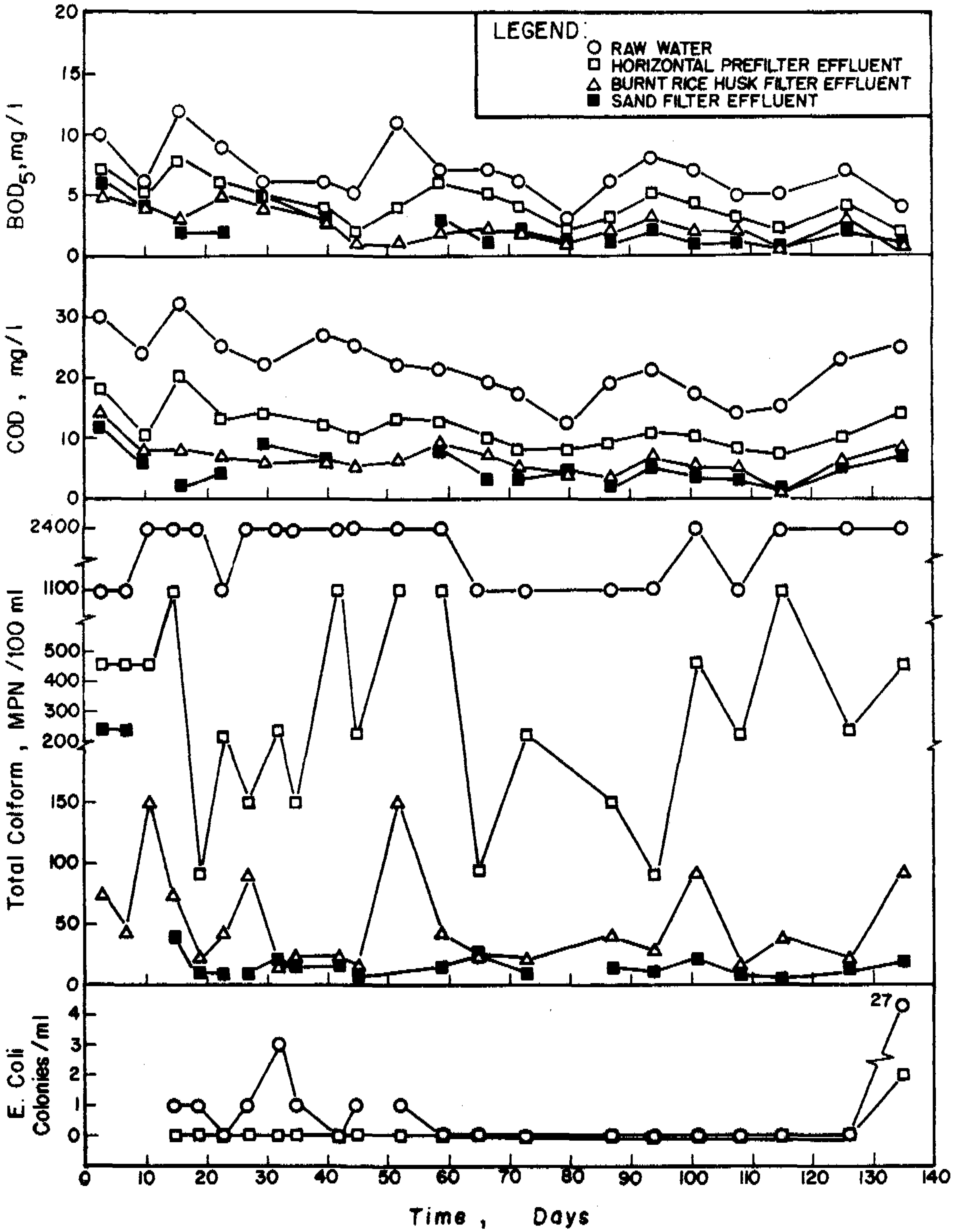


FIG. 3.6 RESULTS OF BOD_5, COD, MPN TEST FOR TOTAL COLIFORM AND PLATE COUNT FOR E. COLI. TESTS

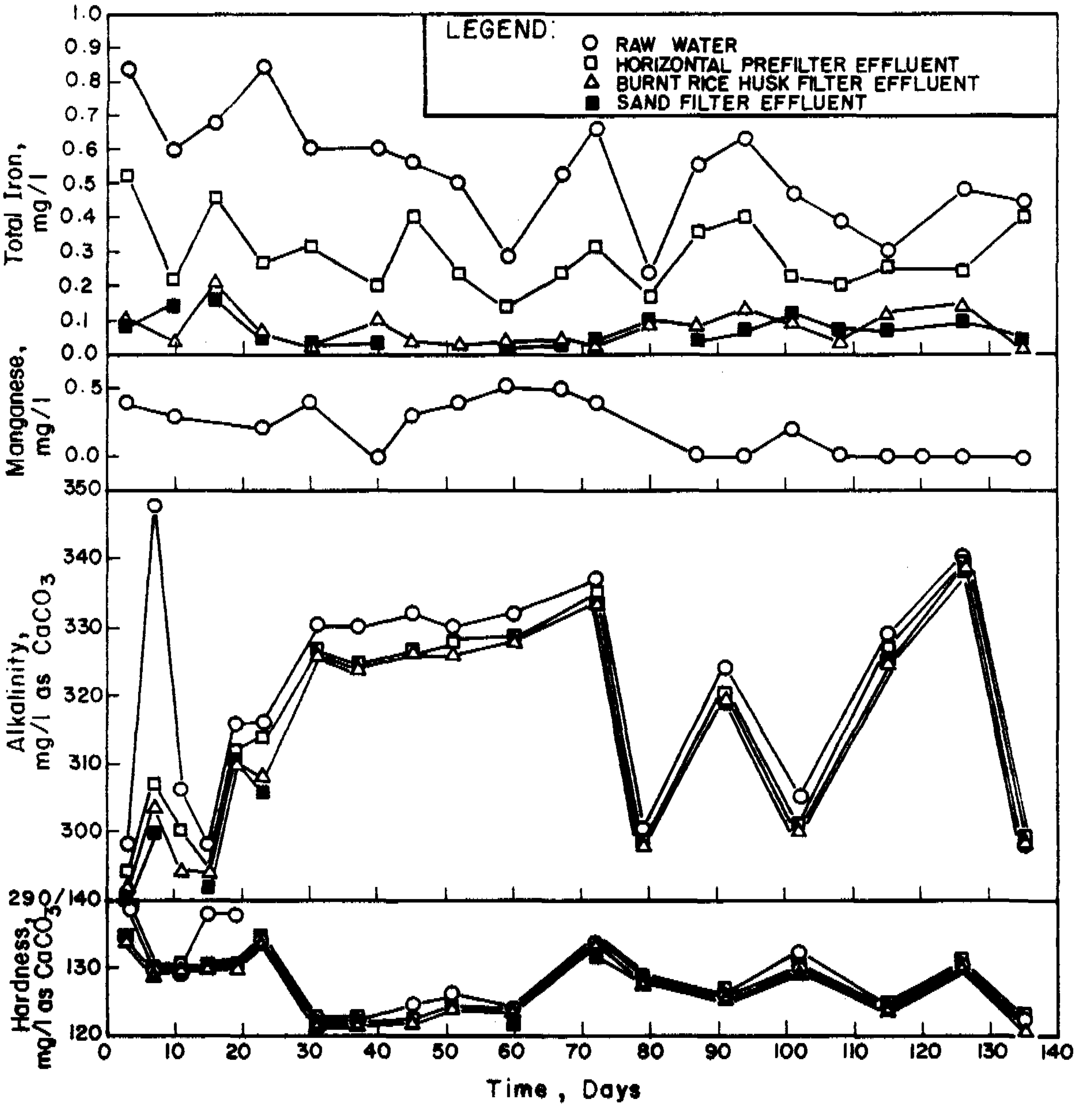


FIG. 3. 7 TOTAL IRON, MANGANESE, ALKALINITY AND HARDNESS OF RAW WATER AND EFFLUENTS FROM DIFFERENT FILTERS

domestic uses. The organic material present in raw water was not significant enough to create oxygen depletion. It is believed that the major decline of oxygen across the horizontal prefilter was not mainly due to biological activity, but rather due to the chemical reaction between oxygen and iron.

3.2.4 Alkalinity and Hardness

In this part of study, raw water was found to be moderately hard with hardness varying between 122 to 140 mg/l as $CaCO_3$ and alkalinity in the range of 300-350 mg/l as $CaCO_3$. As already discussed previously, neither the prefiltration nor the slow rate filtration processes could remove these two substances. But in general, their concentrations in the filtered water remained in the limits acceptable for rural water supply.

IV CONCLUSIONS

The highlights which come out from laboratory-scale and pilot-scale studies can be summarized as follows:

1. The performance of the pilot plant system is comparable to that of the bench scale model and the effect of scale-up is negligible.

2. Horizontal-flow coarse-material prefilter indicated high potential in removing turbidity of raw water. In general, it could account for 60-70 percent of the total turbidity removal. Compared to shredded coconut fibre, horizontal prefilter is more reliable in producing an effluent of uniform quality and provides a longer serviceable life.

3. In terms of head loss development and length of filter run, burnt rice husk demonstrated a net superiority over sand. However, it was felt that sand produced better quality water than burnt rice husk in terms of taste and palatability. In both cases, the final effluent turbidity was very good, in the range of 1 to 5 JTU, which is considered highly acceptable for village needs.

4. From the microbiological standpoint, neither sand nor burnt rice husk could completely remove coliform organisms from the raw water, but both could achieve quite substantial removals of these organisms which are generally of non-faecal origin. The absence of E. coli would provide a high degree of health protection to rural people now exposed to unprotected water supplies.

5. The concentration of organic matter present in raw water as expressed in terms of BOD_5 and COD was not high. On the other hand, DO concentration in the raw water is quite high, as the result of intense photosynthetic activity in the canal. This DO concentration tended to decrease across the prefilter bed. Presumably, this decline was due to chemical reaction between DO and iron which was present in quite substantial concentration in raw water.

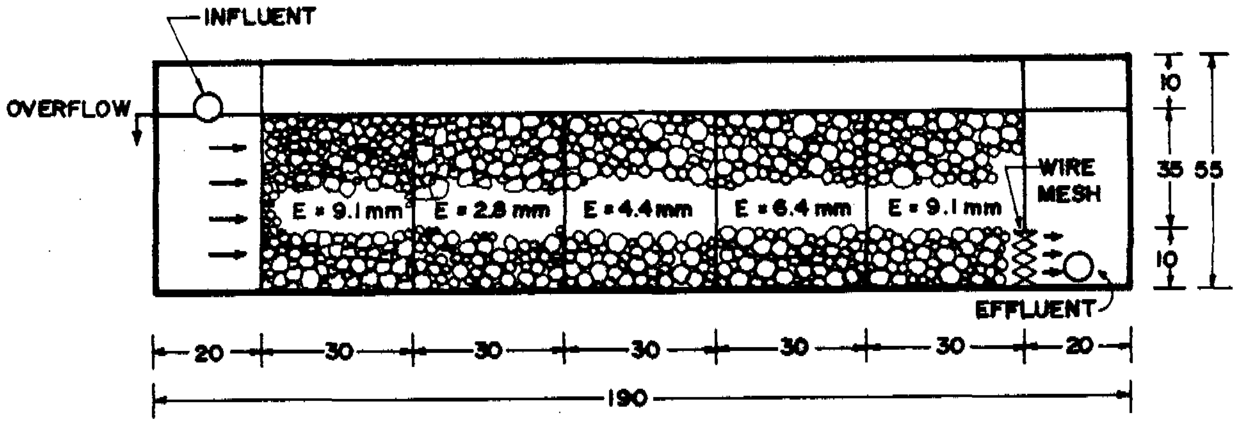
6. Neither the prefiltration nor slow-rate filtration processes could remove the alkalinity and hardness of raw water. However, as

far as the acceptability of the treated water for domestic use is concerned, alkalinity and hardness remained in the highest desirable level.

7. From an operational viewpoint, it is desirable to cover both prefilter and filter to avoid possible contamination from insects or flies which could short-circuit the filter runs.

APPENDIX A

DESIGN DETAILS OF LABORATORY-SCALE AND PILOT-SCALE FILTRATION SYSTEMS



Design of Laboratory-scale Horizontal Prefilter

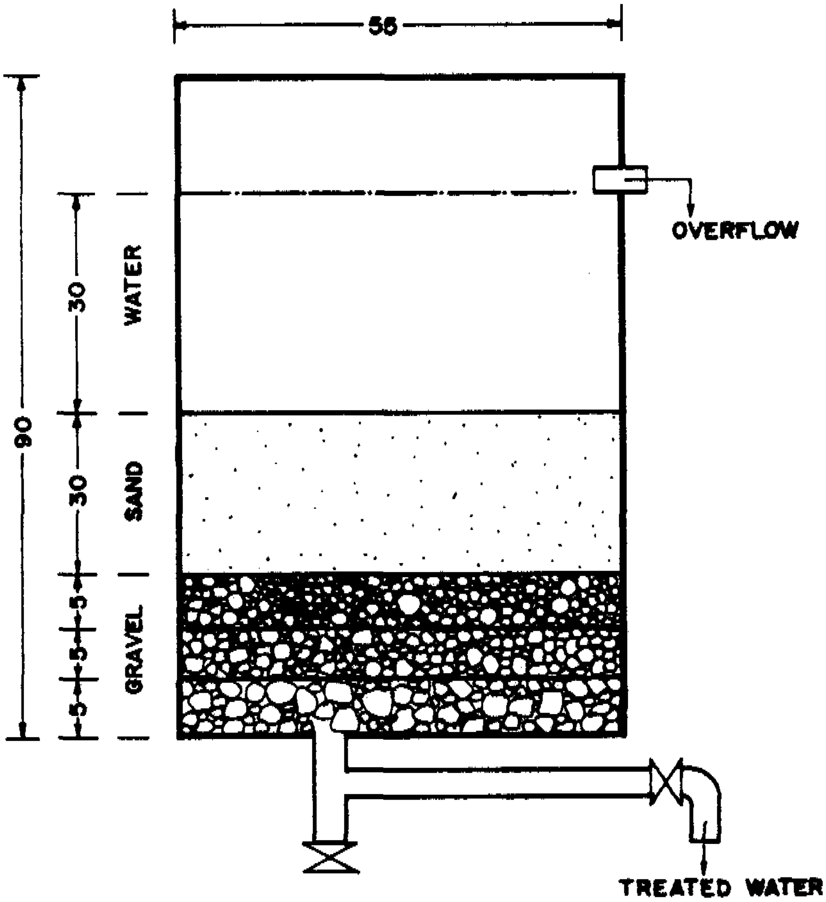


Fig. A-1 Design Details of Laboratory-scale Filtration System

(ALL DIMENSIONS ARE IN CENTIMETERS)

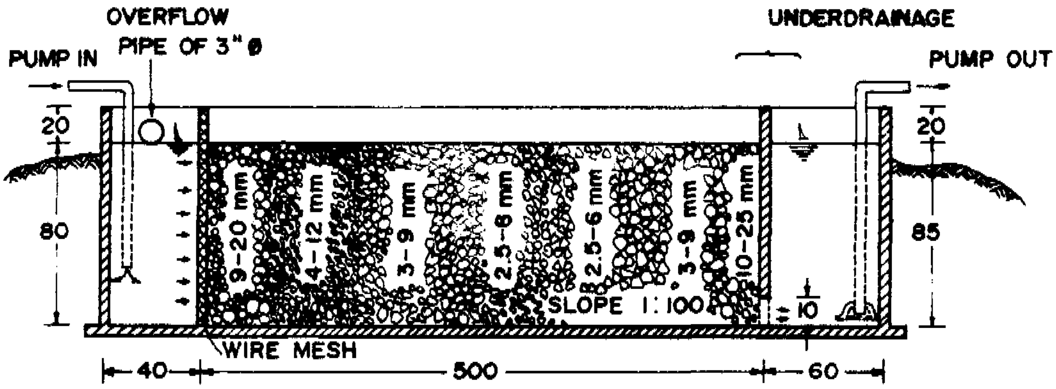


Fig. A-2 Pilot-scale Horizontal Flow Prefilter
(ALL DIMENSIONS ARE IN CENTIMETERS)

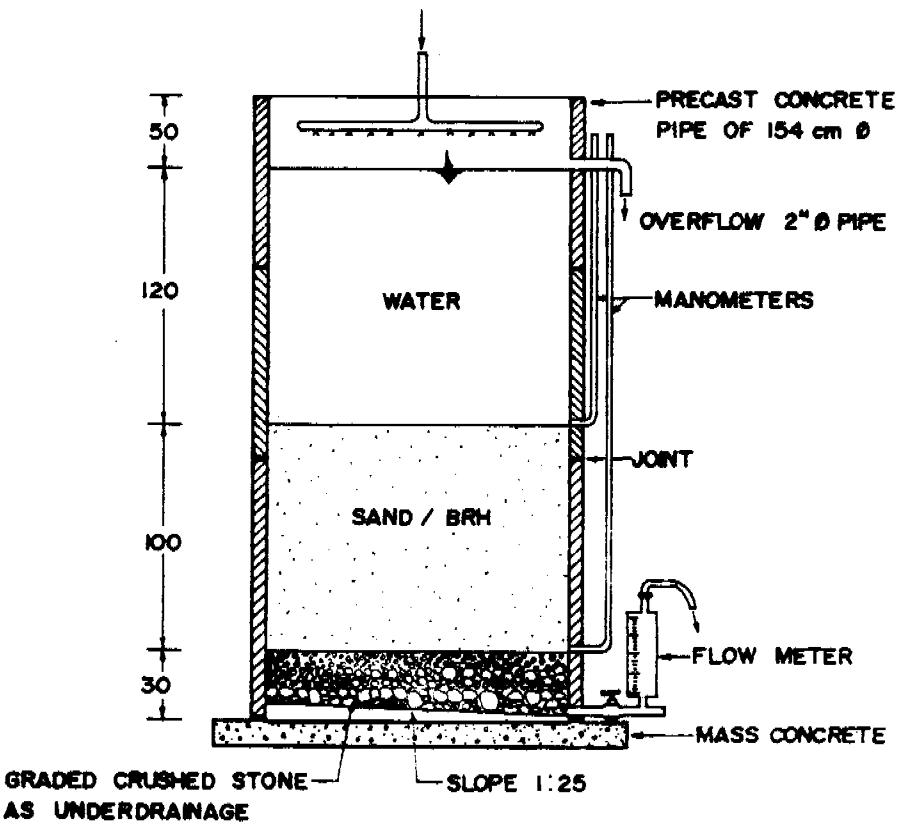


Fig. A-3 Pilot-scale Slow Sand / Burnt Rice Husk Filter
(ALL DIMENSIONS ARE IN CENTIMETERS)

APPENDIX B

RESULTS OF LABORATORY-SCALE FILTRATION STUDY

Table B1 - Turbidity of Raw Water and Effluents from Different Filters - Laboratory Scale

Run Duration, days	Date	Turbidity, JTU				Percent Removal			
		a	b	c	d	b vs a	c vs b	d vs b	Overall Average of c & d
1st Run									
1	1/3/77	43.	9	4.5	4.5	79	11	11	90
5	5/3/77	51	12	3.8	3.5	77	16	17	93
10	10/3/77	37	12	3.6	3.8	68	23	22	90
15	15/3/77	32	10	2.4	2.2	69	23	24	93
20	20/3/77	35	12	1.2	1.1	66	31	31	97
25	25/3/77	44	25	2.4	2.7	43	51	51	95
30	30/3/77	37	16	2.7	2.8	57	36	36	93
35	4/4/77	48	17	3.0	2.5	65	29	30	95
40	9/4/77	44	21	3.4	3.7	52	40	40	92
45	14/4/77	51	19	3.0	4.4	63	31	29	92
46*	15/4/77	53	18	2.8	4.8	66	29	25	93
μ		43.2	15.5	3.0	3.3	64.1	29.1	28.9	93.0
2nd Run									
51, 1	20/4/77	32	9	3.1	3.3	72	18	18	90
55, 5	24/4/77	35	16	2.3	2.1	54	40	40	94
60, 10	29/4/77	33	18	2.2	2.1	46	48	48	93
65, 15	4/5/77	46	19	1.9	1.5	59	38	39	97
70, 20	9/5/77	75	30	4.1	4.7	60	34	33	94
75, 25	14/5/77	62	17	3.5	3.3	72	21	22	94
80, 30	19/5/77	74	32	4.0	3.8	57	38	38	94
85, 35	24/5/77	70	27	4.4	4.4	61	32	32	93
88, 38	27/5/77	75	31	3.4	3.7	59	37	37	96
92, 42*	31/5/77	72	31	4.1	3.5	57	38	39	95
μ		57.4	23	3.3	3.2	59.7	34.4	34.6	94.0

<u>Legend</u>:

a = Raw water

b = Horizontal prefilter effluent

c & d = Sand polishing filter effluents (after horizontal prefilter)

* = End of each filter run of filters c & d

Table B2 - Dissolved Oxygen of Raw Water and Effluents from Different Filters - Laboratory Scale

Run Duration, days	Date	Dissolved Oxygen, mg/l			
		a	b	c	d
1st Run					
1	1/3/77	8.0	7.3	6.3	6.5
3	3/3/77	8.1	6.0	5.2	5.1
5	5/3/77	8.0	5.6	5.2	5.1
7	7/3/77	8.2	6.3	5.2	5.1
9	9/3/77	8.4	6.4	5.4	5.3
11	11/3/77	8.3	5.5	3.8	4.2
13	13/3/77	8.0	5.5	4.0	4.2
15	15/3/77	8.4	4.8	2.8	4.2
17	17/3/77	8.0	4.4	4.1	2.1
19	19/3/77	8.0	4.8	3.9	4.1
21	21/3/77	9.9	3.3	0.9	1.2
23	23/3/77	8.9	3.1	1.1	1.3
25	25/3/77	8.3	3.6	3.0	2.4
27	27/3/77	8.7	3.7	3.0	2.4
29	29/3/77	7.4	2.9	2.1	1.0
31	31/3/77	11.0	2.7	1.1	1.2
33	2/4/77	8.5	2.5	2.0	1.1
35	4/4/77	11.2	2.2	0.8	0.7
37	6/4/77	9.5	3.3	2.2	2.0
39	8/4/77	9.1	3.2	2.3	2.0
41	10/4/77	8.7	3.0	2.4	2.5
43	12/4/77	8.7	3.0	2.6	2.4
45*	14/4/77	9.2	3.0	2.4	2.0
μ		8.7	4.2	3.2	3.0

Run Duration, days	Date	Dissolved Oxygen, mg/l			
		a	b	c	d
2nd Run					
51, 1	20/4/77	-	-	-	-
53, 3	22/4/77	8.7	3.1	2.4	2.6
55, 5	24/4/77	8.9	3.0	2.4	2.2
57, 7	26/4/77	8.8	3.0	2.6	2.1
59, 9	28/4/77	9.6	3.6	1.2	1.3
61, 11	30/4/77	9.3	3.1	2.6	2.1
64, 14	3/5/77	8.5	3.2	2.4	2.0
67, 17	6/5/77	8.7	4.2	2.1	1.2
70, 20	9/5/77	8.0	3.5	2.0	1.5
72, 22	11/5/77	9.3	3.1	1.9	3.0
74, 24	13/5/77	11.0	5.3	2.7	3.8
77, 27	16/5/77	11.8	4.0	0.7	1.2
79, 29	18/5/77	10.3	4.2	3.3	2.9
81, 31	20/5/77	-	-	-	-
84, 34	23/5/77	8.7	3.1	1.1	1.0
87, 37	26/5/77	8.3	3.6	1.0	0.7
88, 38	27/5/77	-	-	-	-
91, 41*	30/5/77	8.0	3.5	1.1	1.2
μ		9.2	3.6	2.0	1.9

Legend:
- a = Raw water
- b = Horizontal prefilter effluent
- c & d = Sand polishing filters effluents (after horizontal prefilter)
- * = End of each filter run of filters c & d

Table B3 - BOD_5 and COD of Raw Water and Effluents from Different Filters - Laboratory Scale

Run Duration, days	Date	BOD_5, mg/l				COD, mg/l			
		a	b	c	d	a	b	c	d
1st Run									
1	1/3/77	7	6	4	3	24	12	10	8
8	8/3/77	6	4	3	2	16	12	9	10
16	16/3/77	4	3	3	2	12	8	6	7
23	23/3/77	5	4	2	3	18	18	10	10
30	30/3/77	5	5	4	4	19	18	10	8
40	9/4/77	5	3	2	2	19	14	12	12
45*	14/4/77	4	3	1	1	23	15	3	4
μ		5	4	3	2	19	14	9	8
52, 2	21/4/77	3	3	1	1	12	10	6	7
59, 9	28/4/77	7	5	3	4	17	12	8	7
65, 15	4/5/77	6	4	2	1	18	13	7	5
74, 24	13/5/77	4	3	1	1	15	9	4	3
85, 35*	24/5/77	5	3	2	1	16	10	6	4
μ		5	4	2	2	16	11	6	5

Legend:
a = Raw water
b = Horizontal prefilter effluent
c & d = Sand polishing filter effluents (After horizontal prefilter)
* = End of each filter run of filters c & d

Table B4 - Total Iron of Raw Water and Effluents from Different Filters - Laboratory Scale

Run Duration, days	Date	Total Iron, mg/l			
		a	b	c	d
1st Run					
8	8/3/77	0.30	.08	.04	.05
16	16/3/77	0.30	.11	.09	.02
19	19/3/77	-	-	-	-
23	23/3/77	0.12	.10	.03	.02
30	30/3/77	0.40	.10	.03	.03
40	9/4/77	0.30	.07	.03	.03
45*	14/4/77	0.22	.06	.02	.03
μ		0.27	.09	.04	.03
2nd Run					
52, 2	21/4/77	0.28	.08	.03	.03
59, 9	28/4/77	0.20	.12	.05	.05
73, 15	12/5/77	0.35	.15	.08	.06
84, 34*	23/5/77	0.50	.26	.11	.09
μ		0.33	.15	.07	.06

Legend:
- a = Raw water
- b = Horizontal prefilter effluent
- c & d = Sand polishing filter effluents (After horizontal prefilter)
- * = End of each filter run of filters c & d

Table B5 - Alkalinity and Hardness of Raw Water and Effluent from Different Filter

Run Duration, days	Date	Alkalinity, mg/l as $CaCO_3$ a	b	c	d	Run Duration, days	Date	Hardness, mg/l as $CaCO_3$ a	b	c	d
1st Run											
1	1/3/77	468	464	460	458	1	1/3/77	74	62	60	60
5	5/3/77	508	498	494	496	5	5/3/77	72	66	64	64
9	9/3/77	484	480	460	476	9	9/3/77	70	68	64	64
15	15/3/77	472	468	468	468	15	15/3/77	66	62	62	60
19	19/3/77	492	484	484	484	19	19/3/77	64	60	60	60
23	23/3/77	500	500	500	500	23	23/3/77	66	62	62	62
31	31/3/77	520	516	512	512	31	31/3/77	76	60	54	54
37	6/4/77	476	476	476	476	37	6/4/77	62	56	52	52
45*	14/4/77	452	452	452	452	45*	14/4/77	64	56	56	56
μ		486	482	478	480	μ		68	61	59	59
2nd Run											
51	20/4/77	456	456	448	448	51	20/4/77	58	52	50	50
60	29/4/77	452	448	448	448	60	29/4/77	54	50	50	50
71	10/5/77	463	460	460	460	71	10/5/77	57	54	54	53
84*	23/5/77	485	485	485	485	84*	23/5/77	65	63	63	63
μ		464	462	460	460	μ		59	55	54	54

<u>Legend</u>:

a = Raw water
b = Horizontal prefilter effluent
c & d = Sand polishing filter effluents (After horizontal filter)
* = End of each filter run of filters c & d

Table B6 - Total Coliforms and E. Coli of Raw Water and Effluents from Different Filters - Laboratory Scale

Run Duration, Days	Date	Total Coliform, MPN Index per 100 ml				Faecal Coliform, No. of Colonies per ml			
		a	b	c	d	a	b	c	d
1st Run									
1	1/3/77	1100	240	120	93	-	-	-	-
5	5/3/77	2400	-	240	150	-	-	-	-
9	9/3/77	2400	-	460	240	-	-	-	-
15	15/3/77	2400	150	93	9	0	0	0	0
19	19/3/77	2400	150	93	28	1	0	0	0
23	23/3/77	2400	1100	21	43	0	0	0	0
27	27/3/77	1100	75	43	43	0	0	0	0
32	1/4/77	1100	-	43	23	1	0	0	0
35	4/4/77	1100	-	43	15	1	0	0	0
42	11/4/77	2400	1100	28	15	1	0	0	0
46*	15/4/77	2400	1100	21	15	0	0	0	0
μ		1927	559	110	61				
2nd Run									
52, 2	21/4/77	2400	1100	150	43	0	0	0	0
59, 9	28/4/77	2400	210	43	15	0	0	0	0
71, 21	10/5/77	1100	460	21	15	0	0	0	0
84*,34	23/5/77	1100	240	15	9	0	0	0	0
μ		1750	502	57	21				

Legend:
a = Raw water
b = Horizontal prefilter effluent
c & d = Sand polishing filter effluents
* = End of each filter run of filters c & d

APPENDIX C

RESULTS OF PILOT-SCALE FILTRATION STUDY

Table C1 - Turbidity of Raw Water and Effluents from Different Filters - Pilot Scale

Run Duration, Days	Date	Turbidity, JTU				Percent Removal				
		A	B	F_1	F_2	B vs A	C vs B	D vs B	Overall $B-F_1$	Overall $B-F_2$
1, 1	1/3/77	114	56	4.2	2.5	50	46	47	97	98
4, 2	4/3/77	93	53	3.7	1.9	43	53	54	97	98
8, 8	8/3/77	81	39	2.7	0.9	51	20	21	97	99
10, 10*	10/3/77	79	44	3.2	0.5	44	51	48	96	91
					END			END		END
12, 1	12/3/77	60	24	3.0	1.0	61	34	24	96	87
17, 6	17/3/77	78	39	1.5	0.5	50	49	50	99	100
20, 9	20/3/77	82	35	1.5	0.6	58	40	41	99	100
23, 12*	23/3/77	93	33	1.3	2.9	64	34	32	99	97
					END			END		END
26, 1	26/3/77	31	13	1.0	0.8	59	39	40	97	98
29, 4	29/3/77	35	16	0.9	1.8	54	43	40	98	94
32, 7	1/4/77	45	15	1.0	2.3	67	31	29	98	94
35, 10	4/4/77	30	13	1.0	1.2	57	40	40	97	97
38, 13	7/4/77	27	10	0.9	0.8	51	33	34	97	98
41, 16	10/4/77	42	10	0.9	1.0	77	21	21	98	98
43, 18*	12/4/77	46	12	1.0	1.3	73	24	23	98	98
					END			END		END
47	16/4/77	48	12	1.0	-	76	22	-	98	-
50	19/4/77	49	12	1.1	-	76	22	-	98	-
53	22/4/77	49	13	1.1	-	74	25	-	98	-
56	25/4/77	51	13	1.4	-	74	23	-	97	-
59, 3	28/4/77	48	12	1.0	3.1	76	22	19	98	94
62, 6	1/5/77	52	15	1.5	2.6	70	27	24	98	94
65, 9	4/5/77	47	13	1.2	1.8	72	26	23	98	97
67, 11*	7/5/77	50	14	1.2	1.4	72	26	26	98	98
					END			END		END
71, 1	10/5/77	53	14	1.2	2.7	23	24	21	98	94
74, 4	13/5/77	46	12	1.0	1.7	73	23	22	98	97
77, 7	16/5/77	45	9	0.9	1.0	80	19	18	99	98
80, 10	19/5/77	58	16	0.6	0.6	72	27	27	98	98
84, 14*	23/5/77	62	20	0.4	0.3	68	31	31	100	100
					END			END		END
86, 1	25/5/77	25	7.5	0.5	0.2	70	29	30	99	100
90, 5	29/5/77	38	9	0.5	0.6	77	22	22	98	98
95, 10	3/6/77	56	11	0.4	0.5	80	19	19	100	100
100, 15	8/6/77	19	7	0.3	1.9	63	35	27	98	90
105, 20	13/6/77	26	6	0.4	1.0	77	22	19	99	96
109, 24	17/6/77	24	4	0.3	0.6	83	15	14	99	98
116, 31	24/6/77	32	7	0.4	0.3	78	21	21	99	99
121, 36	29/6/77	16	7	0.5	0.4	56	41	41	97	98
126, 41	4/7/77	28	6	1.5	0.5	79	16	20	95	98
130, 45	8/7/77	83	12	1.1	0.5	86	13	14	99	99
135, 50	13/7/77	140	30	0.7	0.2	79	21	21	100	100
140, 55	18/7/77	126	58	0.5	0.3	54	46	46	100	100
μ		55	18.8	1.2	0.6	67.4	29.4	24.5	98.1	98.0

Cont'd./

<u>Legend</u>:

A	=	Raw water
B	=	Horizontal prefilter effluent
F_1	=	Burnt rice husk filter effluent
F_2	=	Sand filter effluent
*	=	End of filter run

Table C2 - Head Loss in Sand and Burnt Rice Husk Filters - Pilot Scale

Run Duration, Days	Date	Head Loss, cm		Run Duration, Days	Date	Head Loss, cm		Run Duration, Days	Date	Head Loss, cm	
		F_1	F_2			F_1	F_2			F_1	F_2
1, 1	1/3/77	0	2	32, 7	1/4/77	16	24	73, 3	12/5/77		3
2, 2	2/3/77		5	33, 8	2/4/77		35	74, 4	13/5/77	7	10
3, 3	3/3/77		16	34, 9	3/4/77		47	77, 7	16/5/77		22
4, 4	4/3/77	2	39	35, 10	4/4/77	17	58	78, 8	17/5/77	8	35
5, 5	5/3/77		50	36, 11	5/4/77		68	79, 9	18/5/77		52
6, 6	6/3/77		65	37, 12	6/4/77		75	80, 10	19/5/77	9	69
7, 7	7/3/77		72	38, 13	7/4/77	18	80	81, 11	20/5/77		88
8, 8	8/3/77	4	87	39, 14	8/4/77		87	82, 12	21/5/77		97
9, 9	9/3/77		125	40, 15	9/4/77		92	83, 13	22/5/77		128
10, 10*	10/3/77	7	160	41, 16	10/4/77	24	110	84, 14*	23/5/77	13	152
			END	42, 17	11/4/77		135				END
12, 1	12/3/77	8	2	43, 18*	12/4/77	28	160	86, 1	25/5/77	15	2
13, 2	13/3/77		5				END	90, 5	29/5/77	19	4
14, 3	14/3/77	8	10	47	16/4/77	32	-	95, 10	3/6/77	21	5
15, 4	15/3/77		15	50	19/4/77	3	-	100, 15	8/6/77	20	5
16, 5	16/3/77		21	53	22/4/77	4	-	105, 20	13/6/77	22	5
17, 6	17/3/77	8	31	56	25/4/77	5	-	109, 24	17/6/77	16	6
18, 7	18/3/77		45	57, 1	26/4/77	5	5	116, 31	24/6/77	13	6
19, 8	19/3/77		75	58, 2	27/4/77		7	121, 36	29/6/77	13	8
20, 9	20/3/77	9	80	59, 3	28/4/77	6	12	126, 41	4/7/77	16	12
21, 10	21/3/77		92	60, 4	29/4/77		14	130, 45	8/7/77	17	23
22, 11	22/3/77		102	61, 5	30/4/77		34	135, 50	13/7/77	17	37
23, 12	23/3/77	13	120	62, 6	1/5/77	6	57	140, 55	18/7/77	20	57
24, 13*	24/3/77		155	63, 7	2/5/77		98	μ		12.7	14.2
			END	64, 8	3/5/77		120				
26, 1	26/3/77	15	1	65, 9	4/5/77	6	133				
27, 2	27/3/77		2	66, 10	5/5/77		151				
28, 3	28/3/77		3	67, 11*	6/5/77	7	160				
29, 4	29/3/77	16	4				END				
30, 5	30/3/77		8	71, 1	10/5/77	7	2				
31, 6	31/3/77		16	72, 2	11/5/77		2				

Legend: F_1 = Burnt rice husk filter
F_2 = Sand filter
* = End of filter run

Table C3 - Dissolved Oxygen of Raw Water and Effluents from Different Filters - Pilot Scale

Run Duration, Days	Date	D.O., mg/l			
		A	B	F_1	F_2
1, 1	1/3/77	5.3	2.3	1.2	1.1
5, 5	5/3/77	4.4	2.2	1.5	1.2
9, 9	9/3/77	4.1	1.2	1.3	1.2
					END
15, 4	15/3/77	4.6	1.1	1.2	1.5
21, 10	21/3/77	4.9	1.5	1.7	1.3
23, 12	23/3/77	4.9	2.8	1.8	1.4
					END
31, 6	31/3/77	5.7	2.1	1.7	2.1
35, 10	4/4/77	6.1	2.2	2.0	2.1
41, 16	10/4/77	5.7	2.6	2.1	2.1
43, 18	12/4/77	6.2	2.5	2.0	2.2
					END
45	14/4/77	6.3	2.5	2.1	-
49	18/4/77	5.5	2.3	2.1	-
55	24/4/77	7.2	2.4	2.3	-
57, 1	26/4/77	6.4	2.8	2.4	1.5
61, 5	30/4/77	4.3	2.4	1.6	1.5
67, 11	6/5/77	3.9	2.2	1.1	1.0
					END
72, 2	11/5/77	3.9	2.3	0.9	1.0
77, 7	16/5/77	3.3	1.9	0.8	1.2
81, 11	20/5/77	3.1	3.1	1.5	1.7
					END
87, 2	26/5/77	4.4	3.5	1.5	2.0
93, 8	1/6/77	3.8	2.9	0.6	1.0
95, 10	3/6/77	2.9	0	0.2	0.2
100, 15	8/6/77	4.8	0	0.1	0.2
105, 20	13/6/77	4.8	0.2	0.2	0.3
109, 24	17/6/77	5.4	0.4	0.5	0.2
114, 29	22/6/77	5.1	0.3	0.5	1.7
121, 36	29/6/77	4.5	1.8	1.0	1.0
126, 41	4/7/77	4.0	1.3	0.4	0.6
130, 45	8/7/77	5.6	1.5	0.5	0.6
135, 50	13/7/77	5.8	1.1	0.2	0.6
140, 55	18/7/77	5.1	0.4	0.4	0.4
μ		4.9	1.9	1.2	0.7

Legend:
- A = Raw water
- B = Horizontal prefilter effluent
- F_1 = Burnt rice husk filter effluent
- F_2 = Sand filter effluent
- * = End of filter run

Table C4 - BOD_5 and COD of Raw Water and Effluents from Different Filters

Run Duration, Days	Date	BOD_5, mg/1				COD, mg/1			
		A	B	F_1	F_2	A	B	F_1	F_2
3, 3	3/3/77	10	7	5	6	30	18	14	12
10, 10*	10/3/77	6	5	4	4 END	24	10	8	6 END
16, 5	16/3/77	12	8	3	2	32	20	8	2
23, 12*	23/3/77	9	6	5	2 END	25	13	7	4 END
30, 5	30/3/77	6	5	4	5	22	14	6	9
40, 15*	9/4/77	6	4	3	3 END	27	12	6	6 END
45	14/4/77	5	2	1	-	25	10	5	-
52	21/4/77	11	4	1	-	22	13	6	-
59, 3	28/4/77	7	6	2	3	21	13	9	8
67, 11*	6/5/77	7	5	2	1 END	19	10	7	3 END
72, 2	11/5/77	6	4	2	2	17	8	5	3
80, 10*	19/5/77	3	2	1	1 END	12	8	4	4 END
87, 2	26/5/77	6	3	2	1	19	9	3	2
94, 9	2/6/77	8	5	3	2	21	11	7	5
101, 16	9/6/77	7	4	2	1	17	10	5	3
108, 23	16/6/77	5	3	2	1	14	8	5	3
115, 30	23/6/77	5	2	1	1	15	7	1	1
126, 42	4/7/77	7	4	3	2	23	10	6	5
135, 50	13/7/77	4	2	1	1	25	14	8	7
μ		7	4	2	1	22	11	6	4

<u>Legend</u>:

A = Raw water
B = Horizontal prefilter effluent
F_1 = Burnt rice husk filter effluent
F_2 = Sand filter effluent
* = End of filter run

Table C5 - Total Iron and Manganese of Raw Water and Effluents from Different Filters

Run Duration, Days	Date	Total Fe, mg/l				Mn, mg/l			
		A	B	F_1	F_2	A	B	F_1	F_2
3, 3	3/3/77	0.84	0.53	0.10	0.08	0.04	nil	nil	nil
10, 10*	10/3/77	0.60	0.22	0.03	0.14	0.03	nil	nil	nil
					END				END
16, 5	16/3/77	0.68	0.46	0.21	0.16	nil	nil	nil	nil
23, 12*	23/3/77	0.84	0.27	0.06	0.04	0.02	nil	nil	nil
					END				END
30, 5	30/3/77	0.60	0.32	0.02	0.02	0.04	nil	nil	nil
40, 15*	9/4/77	0.60	0.20	0.10	0.04	nil	nil	nil	nil
					END				END
45	14/4/77	0.56	0.40	0.04	-	0.03	nil	nil	-
52	21/4/77	0.50	0.24	0.03	-	0.04	nil	nil	-
59, 3	28/4/77	0.28	0.14	0.03	0.02	0.05	nil	nil	nil
67, 11*	6/5/77	0.52	0.23	0.04	0.02	0.05	nil	nil	nil
					END				END
72, 2	11/5/77	0.65	0.31	0.02	0.03	0.04	nil	nil	nil
80, 10*	19/5/77	0.24	0.17	0.11	0.11	-	-	-	-
					END				END
87, 2	26/5/77	0.55	0.36	0.09	0.04	nil	nil	nil	nil
94, 9	2/6/77	0.63	0.40	0.14	0.07	nil	nil	nil	nil
101, 16	9/6/77	0.47	0.23	0.10	0.11	0.02	nil	nil	nil
108, 23	16/6/77	0.39	0.20	0.04	0.07	nil	nil	nil	nil
115, 30	23/6/77	0.30	0.26	0.12	0.07	nil	nil	nil	nil
126, 42	4/7/77	0.48	0.25	0.15	0.10	nil	nil	nil	nil
135, 50	13/7/77	0.44	0.40	0.01	0.04	nil	nil	nil	nil
μ		0.54	0.29	0.08	0.07				

<u>Legend</u>:

A = Raw water
B = Horizontal prefilter effluent
F_1 = Burnt rice husk filter effluent
F_2 = Sand filter effluent
* = End of filter run

Table C6 - Alkalinity and Hardness of Raw Water and Effluents from Different Filters - Pilot Scale

Run Duration, Days	Date	Alkalinity mg/l as $CaCO_3$				Hardness mg/l as $CaCO_3$			
		A	B	F_1	F_2	A	B	F_1	F_2
3, 3	3/3/77	298	294	292	290	140	140	134	134
7, 7*	7/3/77	348	308	304	300 END	130	130	130	130 END
11	11/3/77	306	300	294	-	130	130	130	-
15, 4	15/3/77	298	294	294	292	134	130	130	130
19, 8	19/3/77	316	312	310	310	134	130	130	130
23, 12*	23/3/77	316	314	308	306 END	132	136	132	132 END
31, 6	31/3/77	330	326	326	326	122	122	122	122
37, 12	6/4/77	330	324	324	324 END	122	122	122	122 END
45	14/4/77	332	326	326	-	124	122	122	-
51	20/4/77	330	328	326	-	126	124	124	-
60, 4*	29/4/77	332	328	328	328 END	124	124	124	122 END
72, 2	11/5/77	338	335	334	334	133	132	132	132
79, 9*	18/5/77	300	298	298	298 END	128	128	128	128 END
91, 6	30/5/77	324	321	320	320	126	126	126	126
102, 17	10/6/77	305	300	300	300	132	130	130	130
115, 30	23/6/77	329	327	325	325	124	124	124	124
126, 41	4/7/77	340	339	339	338	130	130	130	130
135, 50	13/7/77	298	298	298	298	122	122	120	122
μ		320	315	314	316	129	128	127	126

Legend:
A = Raw water
B = Horizontal prefilter effluent
F_1 = Burnt rice husk filter effluent
F_2 = Sand filter effluent
* = End of filter run

Table C7 - Total Coliform and Faecal Coliform (E. Coli) of Raw Water and Effluents from Different Filters

Run Duration, Days	Date	Total Coliform, MPN/100 ml				Faecal Coliform, Colonies/ml			
		A	B	F_1	F_2	A	B	F_1	F_2
3, 3	3/3/77	1100	460	75	240	-	-	-	-
7, 7*	7/3/77	1100	460	43	240	-	-	-	-
					END				END
11,	11/3/77	2400	460	150	-	-	-	-	-
15, 4	15/3/77	2400	1100	75	43	1	0	0	0
19, 8	19/3/77	2400	93	21	11	1	0	0	0
23, 12*	23/3/77	1100	210	43	9	0	0	0	0
					END				END
27, 2	27/3/77	2400	150	93	9	1	0	0	0
32, 7	1/4/77	2400	240	15	21	3	0	0	0
35, 10	4/4/77	2400	150	21	15	1	0	0	0
42, 17*	11/4/77	2400	1100	21	15	0	0	0	0
					END				END
45	14/4/77	2400	210	15	9	1	0	0	0
52	21/4/77	2400	1100	150	-	1	0	0	0
59, 3	28/4/77	2400	1100	43	15	0	0	0	0
65, 9*	4/5/77	1100	93	23	23	0	0	0	0
					END				END
73, 3*	12/5/77	1100	210	21	9	0	0	0	0
					END				END
87, 2	26/5/77	1100	150	39	14	0	0	0	0
94, 9	2/6/77	1100	93	28	11	0	0	0	0
101, 16	9/6/77	2400	460	93	21	0	0	0	0
108, 23	16/6/77	1100	210	15	7	0	0	0	0
115, 30	23/6/77	2400	1100	39	4	0	0	0	0
126, 41	4/7/77	2400	240	21	11	0	0	0	0
135, 50	13/7/77	2400	460	93	23	27**	2	0	0
μ		1927	448	52	13				

<u>Legend</u>:

A = Raw water
B = Horizontal prefilter effluent
F_1 = Burnt rice husk filter effluent
F_2 = Sand filter effluent
* = End of filter run
** = Contamination of raw water by a nearby anaerobic digester effluent