I. C. AGARWAL &
G. D. AGRAWAL

intermediate rate water filtration for hot and developing countries

INTRODUCTION

The provision of safe and aesthetically acceptable drinking water to the community is of vital importance for maintenance of public health. The role of public water supplies, that are bacteriologically unsafe, as vectors of enteric and other water-borne diseases has been established by many incidents and investigators(1). The efficacy of water treatment to check water-borne diseases was convincingly demonstrated, among other incidents, by the dramatic results of Altona and Hamburg in Germany during the cholera epidemic of 1892. In this incident, using water from the same source, the Elbe River, Altona, which filtered its water supply, escaped entirely, while Hamburg, which used the water unfiltered, suffered a severe outbreak of disease. Realizing from such incidents the importance of prevention being better than cure, treatment of water before its consumption was initiated on a wider scale, especially in developed nations. Consequently mortality rate due to water-borne diseases dropped to extremely low levels. For example, according to the Manual of British Water Engineering Practice(2) the death rate from typhoid per million people dropped from 150 in 1900 to almost zero around the 1940s in England and Wales. However, primarily due to lower coverage of people by engineered water supply and sanitation schemes in developing countries, the mortality rate due to water-borne diseases is quite high. In Sri Lanka the mortality rate due to water-borne diseases was 102.8 per 100 000 during 1957 while according to a 1962 estimate, 45% of the urban population was covered by water supply schemes(3,4). In India the mortality rate due to enteric diseases is about 360 per 100 000 where 52% of the urban population and more than 55% of rural population were not served by adequate water supply by 1966(5).

To reduce the mortality rate in developing nations almost complete coverage of population by adequate and safe water supply schemes is required which will need enormous financial resources. Because of the imposed constraints of paucity of financial resources coupled with the restricted availability of skilled technical personnel and sophisticated equipment, either new water treatment methods have to be evolved or existing ones modified so that water treatment units can be developed which are cheap, simple and easy to construct, maintain and operate and which do not require either the incorporation of sophisticated equipment or attendance by skilled technical labour.

Among the various unit operations of conventional water treatment, filtration occupies a central and important place. Filtration of municipal water supplies is generally accomplished employing either slow or rapid sand filters. Pressure filters have been used but on very limited scale. Various modifications of sand filters, viz dual-media and multi-media filters, radial, upflow, biflow and horizontal filters, have been developed but have not been adopted on any scale in developing countries due to various operational problems and use of sophisticated equipment. In fact, viewed in the context of the needs of developing nations, the majority of which are hot countries, the rapid sand filter possesses the following disadvantages:

(i) technical supervision and regular laboratory testing to maintain acceptable filtrate quality

(ii) costly operation and complicated hydraulic design

(iii) employment of sophisticated equipment requiring skilled operation and maintenance and workshop facilities.

Slow sand filters also possess many disadvantages, namely high initial cost especially in cold countries where they have to be covered, requirement of large land areas and large labour force for cleaning process, and inability to cope with highly turbid waters. However in hot and developing countries where the disadvantages of high land costs, expensive labour and troubles caused by frost and reduced biological activity due to extremes of cold may be well within acceptable levels, many advantages of slow sand filtration may make it preferable to rapid sand filtration(6). These advantages include

(i) unmatched quality of treated water, particularly bacteriological quality

(ii) low cost of construction and operation

(iii) ease of construction and operation

(iv) conservation of wash water.

In view of these merits, the World Health Organization strongly recommends the use of slow sand filters in tropical and developing nations.

Objective of this study

In order to assign a major role to slow sand filters in hot and developing countries, it is desirable to reduce their disadvantages substantially. The disadvantages of these filters result primarily from the adoption of lower rates of filtration and absence of proper pretreatment to reduce the turbidity of filter influents to low levels. Alum-coagulation as pretreatment to the influents of slow sand filters has been found by the authors(7,8) to be suitable to reduce the turbidity to acceptable levels. This study was aimed at evaluating the performance of slow sand filters receiving alum-coagulated influents at conventional and higher rates of filtration. A detailed economic analysis was done to arrive at an optimal rate of filtration.

MATERIALS AND METHODS

Experimental filter units

In order to avoid the inherent disadvantages associated with the extrapolation of results obtained on the basis of laboratory-scale studies due to incompleteness of simulation of field conditions and to eliminate the effect of scale and environment on the natural development of schmutzdecke, the entire investigation was carried out at Kanpur Water Works employing either pilot-scale filters, especially constructed for this study, or full-scale existing filters.

The waterworks of Kanpur (population = 1.24 million, latitude = 26°30' N, altitude = 135 m above M.S.L., shade temperature = 3°-48°C) processes 205 Ml of water daily. An over-simplified flow sheet of Kanpur Water Works is presented in figure 1. The treatment given to raw water round the year includes sedimentation, alum-coagulation, flocculation, settling followed by either slow or rapid sand filtration and post-chlorination. However during periods of prolific algal growth on the filter beds occuring during the summer (March to June), copper sulphate at 1.5 to 4.5 mg/l and chlorine at 1.2 mg/l are added to raw water. During periods of high turbidities ($\gtrsim$ 2500 jtu) in the rainy season (July to October) alum is also added to raw water from the Ganges River at an additional point 2 (figure 1).

The full-scale slow sand filters used for this study were of the size 61m x 30.5m operating at a rate of 133 l/m^2h. Their media consisted of 250 mm of gravel and 900 mm of sand with an effective size of 0.3 mm and uniformity coefficient of 3.5. The under-drainage system consisted of the main U-shaped concrete channel and laterals formed by open-jointed bricks. The filters have manually controlled inlet and outlet sluice valves and the filtered water is discharged over the weir into an outlet chamber.

Pilot-scale filters

Two pilot-scale filters with a plan size of 0.92m x 1.83m were constructed in Kanpur Water Works. The media specifications were exactly the same as those for the prototype slow sand filters. The under-drainage system was also similar. The outside walls of the pilot-scale filters, unlike those of the prototype, had five piezometric tappings and five sampling ports each at various depths to record the head loss and to collect filter effluents at different depths down the bed. Both the pilot scale filters could be fed with the same coagulated, flocculated and settled water as that being fed to the prototype slow sand filters or with raw Ganga Water without prètreatment. The rate of flow in the pilot filters was adjusted by a sluice valve and was determined by collecting a suitable quantity of water in a measured time interval. As an additional check and to get a reliable measure of average daily velocities, water meters were installed to record the flow. Figure 2 gives the layout plan of the pilot-scale filters.

Analytical techniques

The following analyses were performed on raw and filtered water sample to evaluate the performance of filters in terms of various quality parameters

(i) coliform density by the multiple tube fermentation technique (presumptive test)

(ii) turbidity measured by using Hellige turbidimeter

Figure 1 SIMPLIFIED FLOW SHEET OF KANPUR WATER WORKS

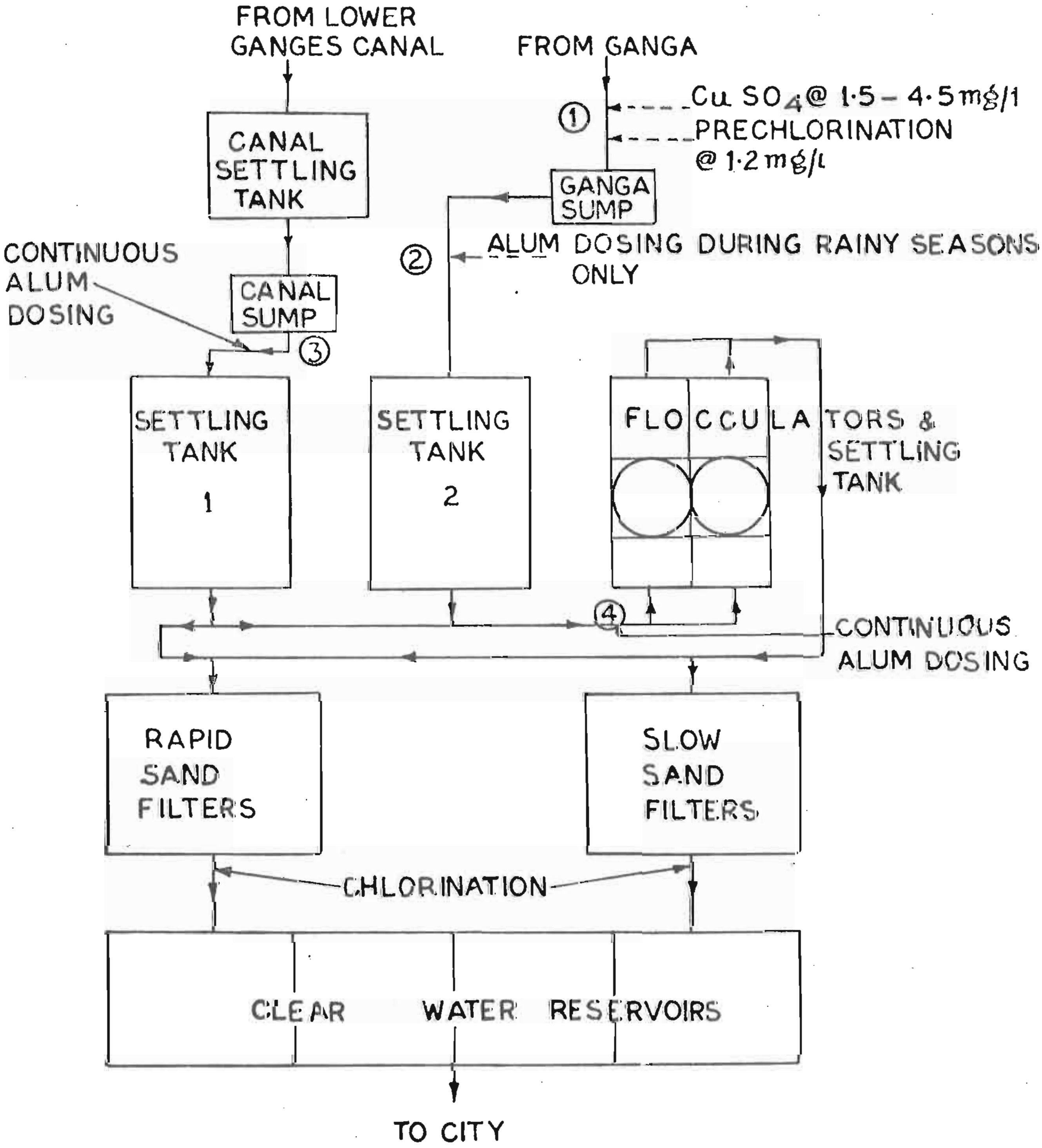
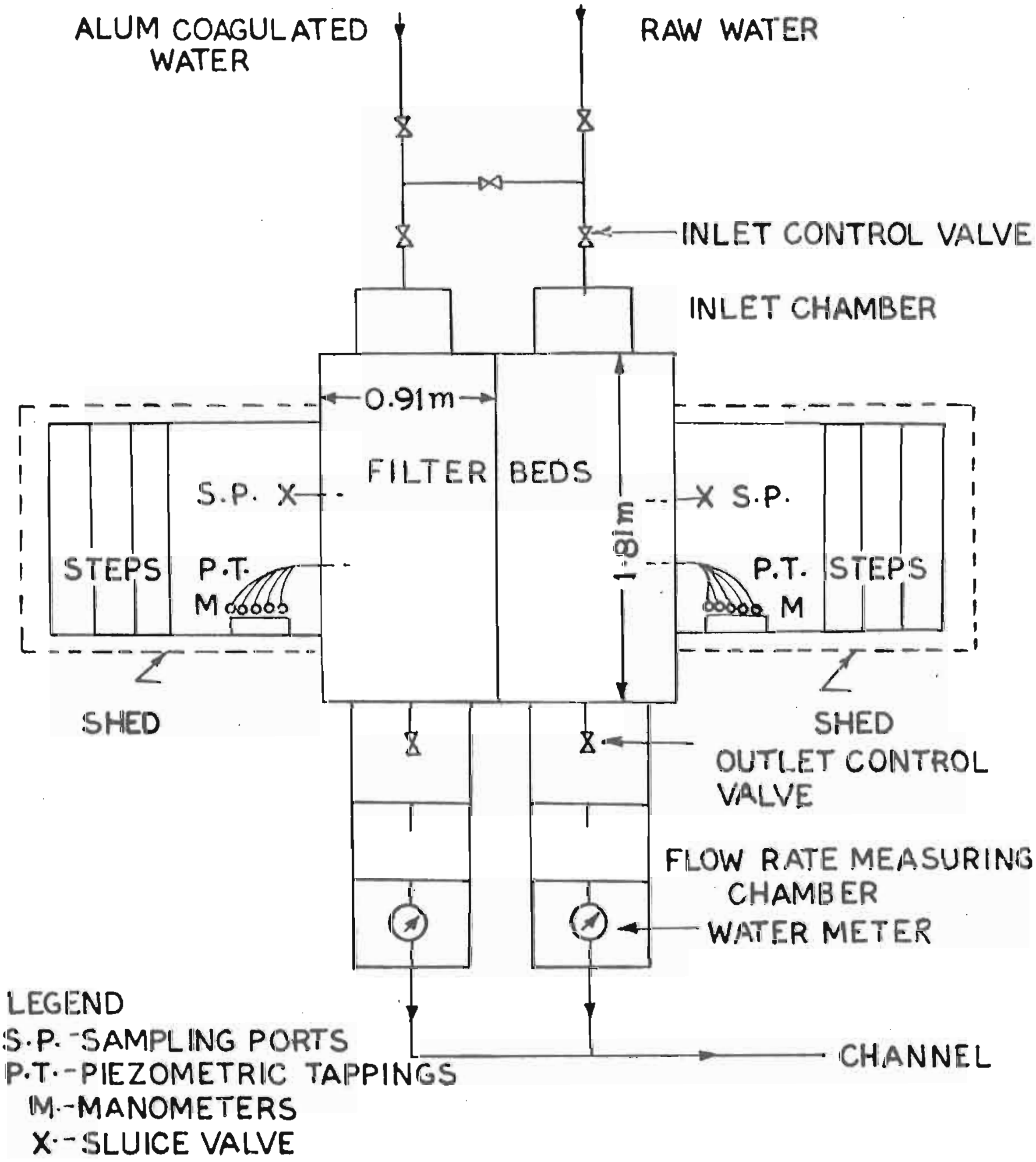


Figure 2 LAYOUT PLAN OF PILOT-SCALE FILTERS



(iii) organic matter indirectly estimated as COD by dichromate reflux method with the modifications in the normalities of potassium dichromate and ferrous ammonium sulphate solutions as suggested by Medalia(9)

(iv) chlorine demand by DPD method

(v) algal content indirectly by chlorophyll extract method(10,11).

Schedule of filter runs

The entire study was conducted in two phases extending over a period of more than one year and consisted of 86 filter runs, 18 on pilot-scale filters and 68 filter runs on prototypes. During the first phase, filters of both types were operated at a conventional filtration rate of 133 l/m^2h to evaluate the performance of slow sand filters using alum-coagulation as pretreatment. In the second phase, the pilot-scale filters were operated at higher rates of filtration, viz 216, 408, 612 and 1000 l/m^2h. The prototype filters were later operated at 612 l/m^2h which was found to be the optimal filtration rate on the basis of economic analysis.

RESULTS AND DISCUSSIONS

This study was conducted to reduce substantially the demerits of slow sand filters which are found to be more suitable for hot and developing nations as these filters can produce filtrate of excellent quality at lower cost in the technological environment as obtainable in such countries. The main disadvantages of slow sand filters are primarily due to the adoption of lower filtration rates and absence of suitable pretreatment reflecting their inability to treat highly turbid waters.

As reported elsewhere(7,8), the authors have concluded, based on extensive experimental evidence, that alum-coagulation can successfully be employed as pretreatment to slow sand filter influents increasing their ability to treat even highly turbid raw waters and thus eliminating one big disadvantage of slow sand filters. This paper presents the effect of alum-coagulation on filtrate quality and the results of operating slow sand filters at much higher than normal filtration velocities so that the other disadvantages of these filters can be substantially reduced.

Effect of alum-coagulation on filtrate quality

As one of the main advantages of slow sand filter is to produce filtrate of excellent quality in comparison to high rate filters, it would be necessary to check that no deterioration in filtrate quality occurs as a result of adopting alum-coagulation as pretreatment. Therefore, several parallel runs of pilot-scale filters were made using raw and alum-coagulated filter influents at the conventional rate of 133 l/m^2h. The filtrates were drawn from different depths down the filter and their quality was evaluated regularly. Besides this 63 concurrent runs on seven prototype filters extending over a year were conducted and their filtrates regularly analysed for turbidity and coliform density besides other quality parameters like COD and chlorine demand which were done occasionally. For the sake of brevity, only typical results are presented in Table 1.

The main quality-parameters for evaluating the performance of a filter are turbidity and coliform-density as filtration aims at removal of suspended and dissolved impurities to improve the physical, chemical and biological (especially bacteriological) qualities of water.

Table 1 Filtrate Quality Parameters for Filters employing Raw Water and Alum-coagulated Water as Influents

Filtrate Quality Parameter	"Raw Water" Filter		Alum-Coagulated Water Filter	
	Influent	Effluent	Influent	Effluent
Turbidity, A.P.H.A.	5-75	Nil	3-15	Nil
Turbidity units	400-1800	0.06-1	10-50	Nil
M.P.N. of E.Coli per 100 ml	150-16 100	Nil-161	23-3500	Nil-21
Chlorine demand, mg/l (one typical value)	0.95	0.49	0.81	0.43
COD, mg/l	0.2-5.1	-	0.2-2.1	Nil-1.0
Algal content, mg/l	-	-	0.5-2.0	Nil

It is observed that though the turbidity of raw water varied over a wide range, both type of filters gave effluents of almost zero turbidity, except in one run of a filter receiving raw water of high turbidity as influent. The reduction in coliform density for raw water filters varied generally between 90 and 100% while that for alum-coagulated water filters ranged most of the time close to 95-100%. In the pilot-scale filters the efficiency of coliform reduction was sometimes poor in both cases, especially with first runs with washed sand possibly due to absence of fully developed schmutzdecke and heterotrophe zone. But the prototype filters which received only alum-coagulated influents mostly produced filter effluents that were almost free from the coliform group of bacteria. Thus it seemed that adoption of alum-coagulation as pretreatment helped in producing filter effluents that are almost bacteria-free.

Alum-coagulation also helped in producing filter effluents of lower chlorine demand in general as indicated by one typical value in Table 1. The low or almost zero values of COD and algal content of effluent from filters receiving alum-coagulated waters indicate good improvement in quality.

Thus in general, it can be concluded that alum-coagulation does not have any adverse effect on the quality of filtrate and on the contrary it may help in improving the overall quality of filter effluent.

Operating slow sand filters at higher rates of filtration

The main disadvantages of requirement of large land areas and consequently of large labour force for cleaning operations and high initial cost of construction result primarily from adoption of relatively very low rates of filtration, average values being around 125 l/m^2h in comparison to about 5000 l/m^2h for rapid sand filters. In the past higher rates of filtration were not adopted lest the schmutzdecke, considered to be a fragile and delicate layer of bacteria and organic matter and mainly responsible for filtration action, might puncture. Later Van de Vloed(12) and others including Huisman and Ives(6,13) explained the mode of action in slow sand filters. The uppermost layers of sand, inhabited principally by actively photo-synthesizing algae and called the autotrophe zone played only the secondary role in the overall purification process while the main role was assigned to lower layers called hetrotrophe zone assisted by the deepest layers termed the mineral oxidation zone. Because of the better understanding provided, higher rates of filtration have been recommended and used. As reported by Ridley(14), filtration rates of 150 l/m^2h, in comparison to 50 l/m^2h used in the past, have been employed as a result of the introduction of micro-straining and roughening rapid filtration as pretreatment. Further, at the Coppermills Water Works, London, the rate of filtration adopted is 250 l/m^2h.

In the light of this discussion coupled with the fact that alum-coagulation as pretreatment produced filter influents of uniform quality and low turbidity, it was thought that much higher rates of filtration could be successfully adopted without seriously affecting the filtrate quality. To explore this, pilot-scale filters were run at rates of 216, 408, 612 and 1000 l/m^2h. Later prototype filters were also operated at 612 l/m^2h. In all the runs, filters received alum-coagulated influents.

Table 2 presents the summary of results of operating the filters at higher rates of filtration. The rate of 216 l/m^2h has been excluded from the list as only one run was made with this rate.

Table 2 Summary of Results of Operating Filters at Higher Rates of Filtration.

Rate of filtration l/m^2h	Length of filter run days	Quantity of water filtered per run l/m^2	Days lost in scraping and recoupment per run*	Effective yield l/m^2h	% reduction in land area required
133	40	$128x10^3$	3.5	122	0
408	15	$147x10^3$	3.5	332	63
612	10	$147x10^3$	3.5	454	73
1000	3.5	$84x10^3$	3.5	500	85

* average amount of time lost for prototype filters of 61m x 30.5m size in Kanpur Water Works using manual labour for cleaning and recoupment of sand.

It is seen from the table that by increasing the rate from 133 to 1000 l/m^2h the effective yield increased from 122 to 500 l/m^2h and the land area requirement decreased by 85% though the length of run dropped from 40 to 3.5 days. However, increase in rate of filtration beyond a certain value (around 612 l/m^2h) does not result in concommitant decrease in land area requirements. Therefore to arrive at a rational optimum rate of filtration, a complete economic analysis is essential.

Economics of higher rates of filtration

To make the analysis more meaningful it was decided to consider not only slow sand filtration but also rapid sand filtration. Four rates of filtration were considered in each case. The basis of the cost analysis is presented in the Appendix. The local currency (Rupee has been converted into pounds at Rupees 20 = £1.

Costs of filtration and other items at four different rates of filtration for both rapid and slow sand filters were computed and are furnished in Tables 3 and 4.

Table 3 Summary of Cost Data for Rapid Sand Filtration

Rate of filtration l/m^2h	Length of filter run days	Cost per million litres of water (£)						
		Filtration			Power	Alum	Chlorine	Total
		Cost on interest etc*	Operational cost	Total cost				
5000	1.56	0.59	0.22	0.81	0.02	0.49	0.19	1.51
5880	1.00	0.51	0.30	0.81	0.02	0.49	0.19	1.51
8820	0.52	0.35	0.40	0.75	0.02	0.49	0.19	1.45
11 760	0.31	0.29	0.55	0.84	0.02	0.49	0.19	1.54

* Includes cost on interest, depreciation and maintenance and repairs.

The total cost of water treated is nearly the same for rates of 5000 and 5880 l/m^2h, while it is least for the rate of 8820 l/m^2h.

Table 4 Summary of Cost Data for Slow Sand Filters

Rate of filtration l/m^2h	Length of run days	Cost per million litres of water (£)						
		Filtration			Power	Alum	Chlorine	Total
		Interest etc	Operational	Total				
133	40	0.64	0.11	0.75	0.01	-	0.15	0.91
133	40	0.64	0.11	0.75	0.01	0.49	0.15	1.40
408	15	0.26	0.11	0.37	0.01	0.49	0.15	1.02
612	10	0.19	0.12	0.31	0.01	0.49	0.15	0.86
1000	3.5	0.21	0.26	0.47	0.01	0.49	0.15	1.12

A comparison of data presented reveals that the overall cost of filtration employing slow sand filtration is always less than the cost for rapid sand filtration for conditions as obtainable at Kanpur Water Works. Further, the cost of filtration is lowest for rapid filtration at the rate of 8820 l/m^2h and for slow sand filtration at the rate of 612 l/m^2h. It is seen that at optimum conditions of operation slow sand filtration at a rate of 612 l/m^2h is 51.2% cheaper than optimal rapid sand filtration at a rate of 8820 l/m^2h, both employing alum-coagulation as the pretreatment. Based on a saving of 51.2% the actual amount of money saved for a filtration capacity of 100 Ml/day would amount to £1788 per annum or £89 400 for the design life of 50 years for slow sand filters.

To find out the optimal rate of filtration both for rapid and slow sand filters, the cost response curves for both the cases are presented in figures 3 and 4. It is observed that rates of 8100 and 625 l/m^2h can be assumed to be optimal rates of filtration for rapid and slow sand filters respectively in conditions as obtainable at Kanpur Water Works.

Figure 3 COST RESPONSE CURVES FOR RAPID SAND FILTERS

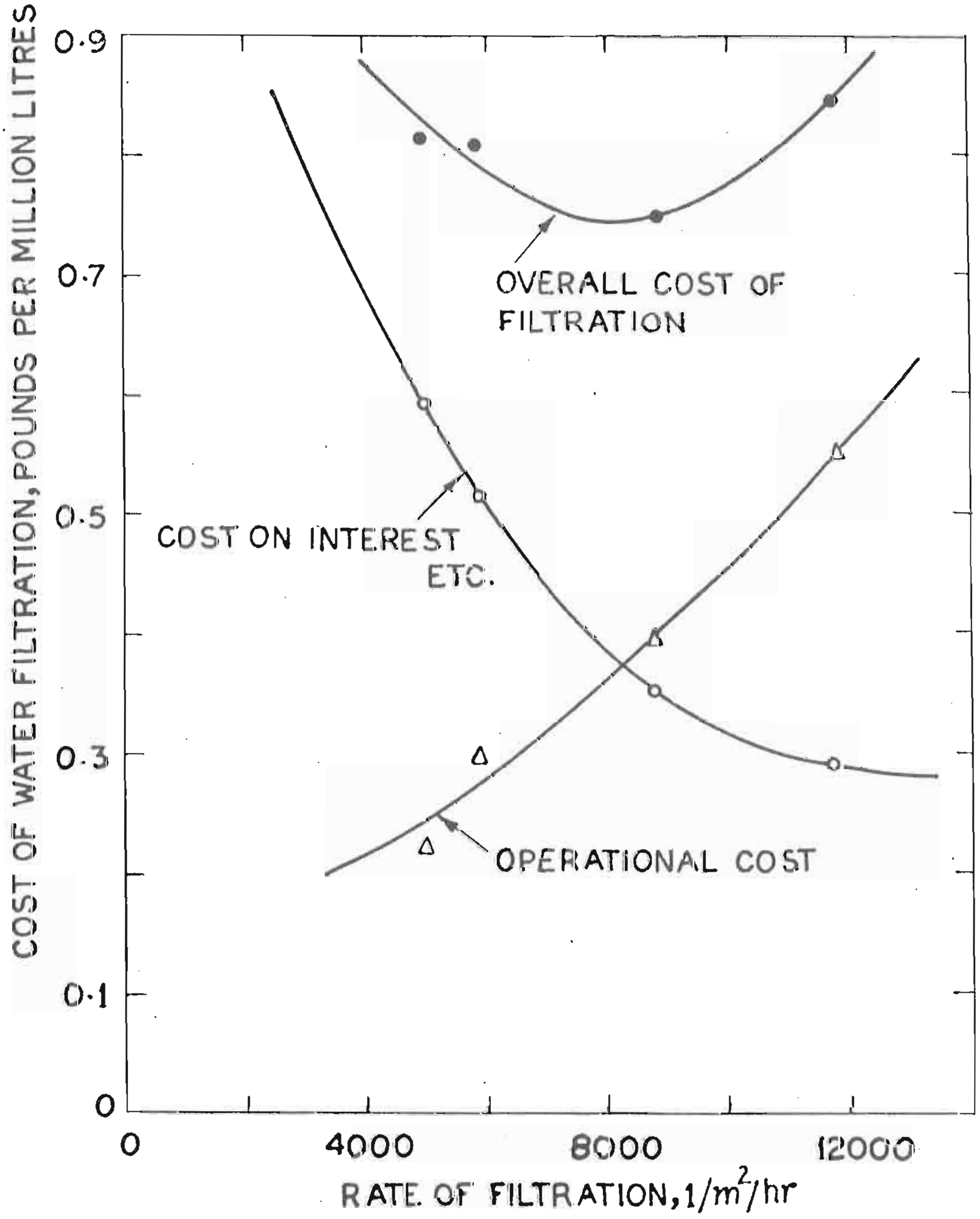
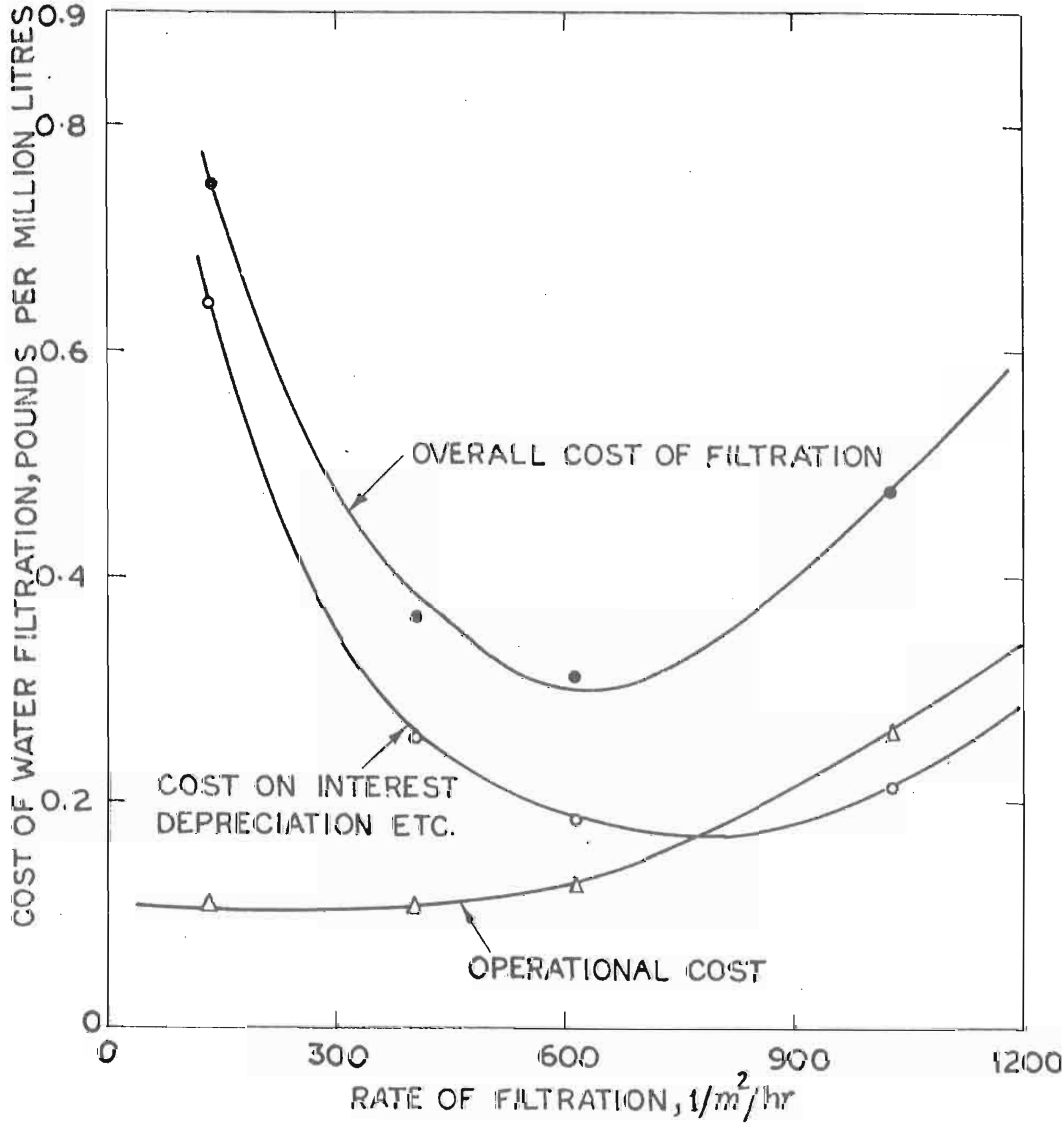


Figure 4 COST RESPONSE CURVES FOR SLOW SAND FILTERS



Distribution of removals and head loss along depth at higher rates of filtration

Though higher rates of filtration will be highly desirable as they substantially reduce the land requirements and cost of treatment, but it should be ensured that the removal of impurities and hence build-up of head loss is confined to the top layers of sand. If the impurities travel deep down in the bed because of increased rate of filtration, the quality of the effluent will deteriorate and head losses in the lower layers of the bed will progressively increase and scraping will not be effective in removing the impurities to restore the filter.

To check the distribution of removals and head loss the variation of filtrate turbidities and head loss build up along the depth of bed are plotted in figures 5 and 6 for four rates of filtration, namely 133, 216, 612 and 1000 l/m^2h.

Figure 5 VARIATION OF EFFLUENT TURBIDITY WITH DEPTH AT FOUR RATES OF FILTRATION

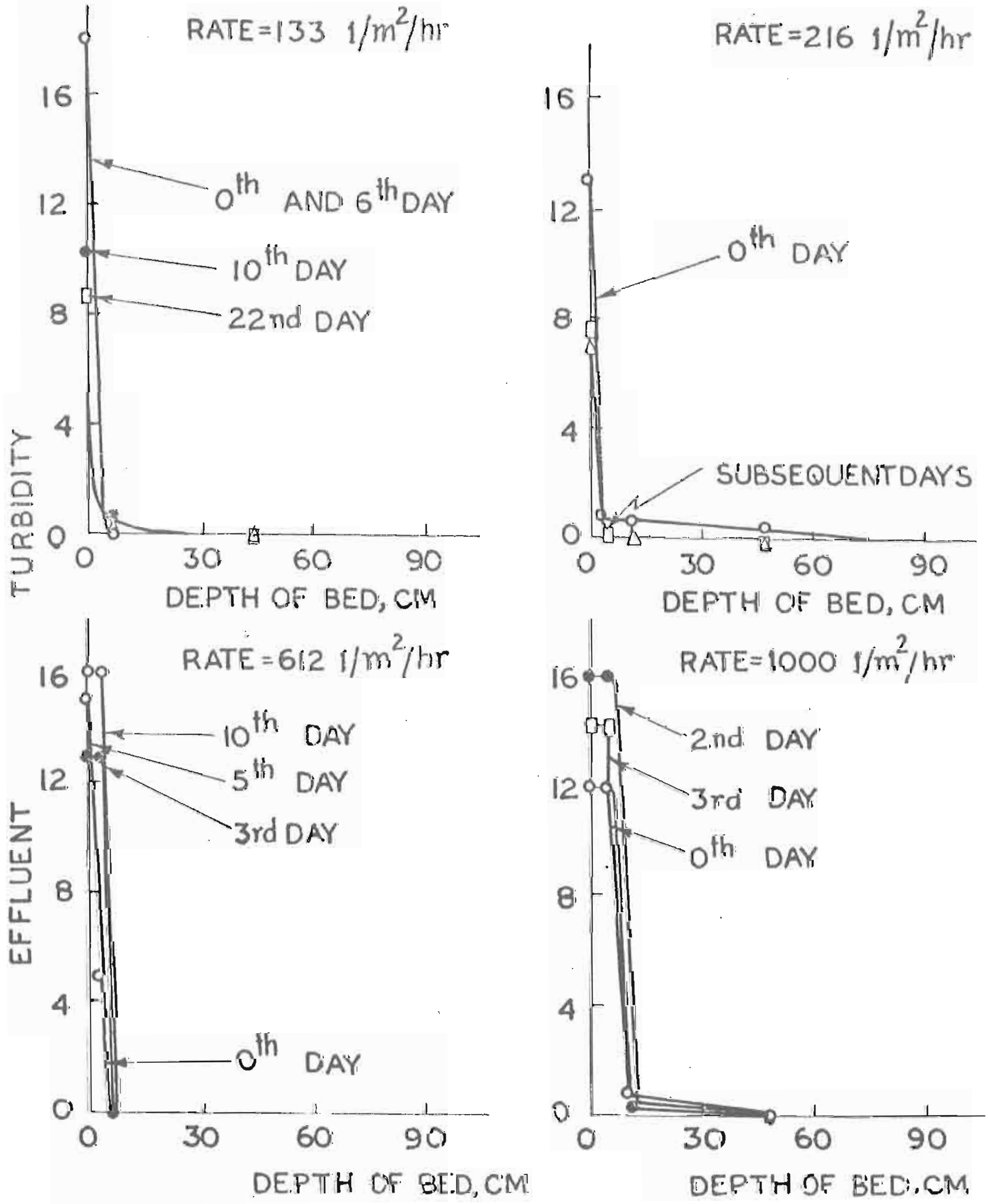
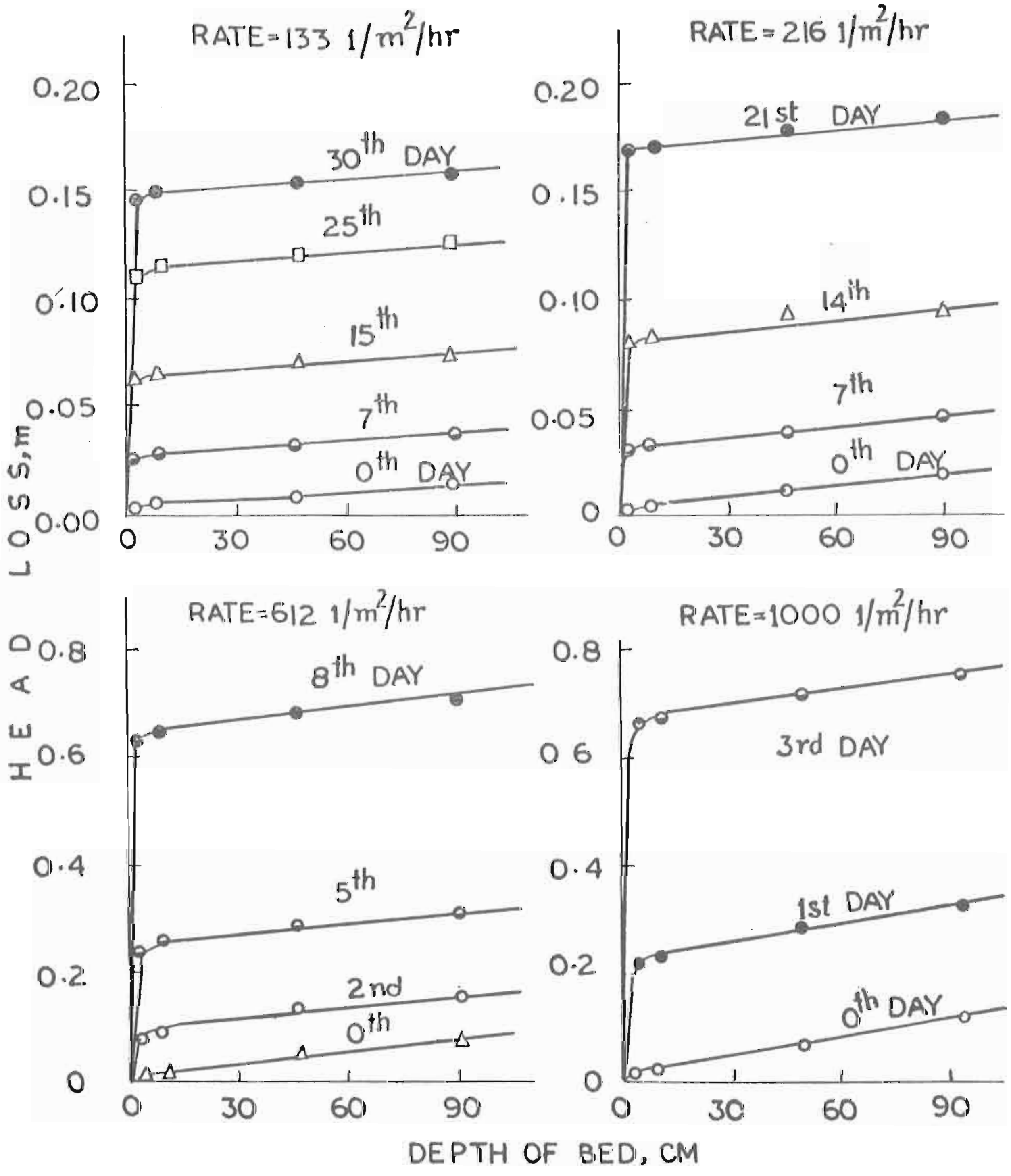


Figure 6 PATTERN OF HEAD LOSS DISTRIBUTION AT FOUR RATES OF FILTRATION



The nature of the curves confirm that with alum-coagulation pretreatment, as proposed by the authors, almost all the removals are distributed in the top 100 mm or so and little impurities penetrate deeper in the bed even at the highest flow rates. From figure 5 it is observed that the effluent contained little or no turbidity almost from the start of the filter run at all the rates of filtration. Determination of non-filtrable residue also confirmed that filter effluents contained little suspended solids.

The pattern of the head loss curves in figure 6 indicates that the majority of head loss occurred in the top 50 mm or so. The head loss in the lower layers remained constant as evidenced by the substantially parallel portions of the head loss curves for lower layers and the head loss in lower layers was close to the values computed from the Kozency-Carman equation for clean and unclogged bed of porous media. Thus from figures 5 and 6 it is established that little impurities travelled deeper into the bed even at the highest rate of filtration till the last day of the filter run.

Effect of higher rate of filtration on filtrate quality

Partly because of the importance of rate of filtration of 612 l/m^2h, being close to the optimum value, and partly with a view to present the typical and representative trends, the effect of only this rate of filtration on filtrate quality is discussed. The results of various analyses performed on influents and effluents of filters operating at a rate of 612 l/m^2h are presented in Table 5.

Table 5 Performance of Filter at a Filtration Rate of 612 l/m^2h.

Quality parameter	Influent	Effluent
Turbidity, APHA Units	7-15	Nil
M.P.N. of E.Coli, per 100 ml	39-3500	15-93
COD*, mg/l	4.8	1
Algal content*, mg/l	0.9	Traces
Non-filterable residue mg/l	5.22	Traces

* one typical value only

Comparison of results of Table 5 with those at the rate of filtration of 133 l/m^2h in Table 1 shows that except in coliform density, the effluent at the higher rate is similar in quality to that at the lower rate of 133 l/m^2h. Because of the compulsory practice of post-disinfection even a higher coliform density of about 90 per 100 ml against up to 35 at conventional rates can be accepted, especially when effluents from rapid sand filters having an M.P.N. of E.Coli of 161 and greater are found entirely acceptable at Kanpur Water Works.

Advantages of operating slow sand filters at higher rates of filtration

From the results presented, it is observed that the following advantages result from operating slow sand filters at rates of filtration much higher than the conventional rates.

(i) Reduction in land area requirement: by operating filters at 612 l/m^2h, the land area required is only one-fourth that at the conventional rate.

(ii) Increase in quantity of water filtered: the effective yield of the filter per unit area per unit time increases 3.7 times by increasing the rate from 133 to 612 l/m^2h.

(iii) Overall economy in cost of water treated: the cost per million litres of water treated is £0.86 at near optimal rate of slow sand filtration compared to £1.45 for near optimal rate of rapid sand filtration, indicating an overall saving of about 51%. It may be mentioned that treatment cost for slow sand filtration using uncoagulated influents is £0.91. This leads to the observation that adoption of higher rates of filtration more or less offsets the additional cost incurred in alum-coagulation. This advantage is in addition to the very important advantages of filtering much more water per unit area per unit time even when the turbidity of raw water fluctuates within an extremely wide range which is unacceptable in case of conventional slow sand filters.

(iv) Effluent quality: the effluent quality at higher rate of filtration is not adversely affected. Though the coliform density may be somewhat higher at higher rates, it is still much less than that of the effluents of rapid sand filters.

(v) No need of backwashing: since almost all the removals and head loss occur in the top few centimetres of sand bed even at the highest rate tried, the scraping effectively restores the filter. Therefore, there is essentially no need of backwashing the filters. This is a very important advantage as backwashing requires sophisticated equipment, complicates the hydraulic design of filters and is comparatively very costly.

(vi) Absence of taste and odour: as a result of reduced length of run at higher filtration rates, there is little possibility of disintegration of algae and consequently no taste and odour are detected in the effluents. On the contrary, the problem of taste and odour in effluents has been reported at conventional filtration rates by Ridley(14).

(vii) Reduction in growth of filamentous algae: again, as a result of reduced length of run of 10 days, there is little time for the excessive growth of filamentous algae which starts growing profusely after about 10 days according to Ridley. As a result, scraping and cleaning of the sand is more easy and quick and may be more advantageous economically also.

It is observed, therefore, that as a result of using alum-coagulation as pretreatment before slow sand filters, intermediate rates of filtration (in between those adopted for slow and rapid sand filters) can be successfully employed. This intermediate rate water filtration, as proposed by the authors, results in many advantages and is highly suitable for hot and developing countries. Intermediate rate filters retain the advantages of slow sand filters, namely simplicity in construction, operation and maintenance, efficiency and cheapness, while they eliminate or reduce the disadvantages of slow sand filters substantially.

CONCLUSIONS

On the basis of this study extending over a period of more than a year employing pilot and prototype filters in Kanpur Water Works, the following conclusions may be drawn.

1. Alum-coagulation can be successfully adopted as pretreatment to slow sand filter influents without any adverse effect on the overall quality of filter effluents. This will enable the slow sand filters to treat even highly turbid waters.

2. As a result of adoption of alum-coagulation as pretreatment, slow sand filters can be operated at filtration rates much higher than conventional. Four filtration rates, namely 216, 408, 612 and 1000 l/m^2h were tried. Filtrate quality at all the four rates was acceptable.

3. Because of the adoption of higher rates of filtration, intermediate rate filters would require much less land areas and capital investment on construction (including the costs of land and filter media) would be substantially reduced. At a rate of 612 l/m^2h these filters would require only one-fourth of the land area required by slow sand filters operating at the rate of 133 l/m^2h to filter the same quantity of water.

4. The cost of treatment of water employing intermediate rate filtration at near the optimal rate of 612 l/m^2h is 51.2% cheaper compared to the cost of treatment using rapid sand filtration at near the optimal rate of 8820 l/m^2h in conditions as obtainable at Kanpur Water Works.

5. The intermediate rate water filtration, besides possessing all the above mentioned advantages, would not require the use of imported and sophisticated equipment. Being simple and cheap to construct, operate and maintain, it is highly suitable for hot and developing countries being labour-intensive rather than equipment-intensive.

REFERENCES

1. SEDGWICK, W.T.,(1902) Principles of Sanitary Science and the Public Health. Macmillan, New York, 170.

2. SKEAT, W.O., ed (1961), Manual of British Water Engineering Practice, 3rd ed. Inst. Water Engrs., Heffer & Sons, Cambridge, England.

3. MILLER, A.P., (1962) Water and Man's Health. Agency for Int. Development, Washington, D.C., 24.

4. DIETERICH, B.H. & HENDERSON, J.M. (1963) Urban Water Supply Needs in Seventy-five Developing Countries, W.H.O. Publ.Health Papers 23,80.

5. GOVERNMENT OF INDIA; Planning Commission (1966) Fourth Five-Year Plan - A Draft-Out line.

6. HUISMAN, L. (1970) Biological or Slow Sand Filters, Background Paper, W.H.O., WHO/CWS/RD/70.1.

7. AGARWAL, I.C. & AGRAWAL, G.D. Operating Slow Sand Filters with Alum-Coagulated Water. Symp. on Environmental Pollution, Jan.1973, Nagpur, India.

8. AGARWAL, I.C. & AGRAWAL G.D. Modified Filtration System for Developing Nations. Sent for possible publication in Water Research, England.

9. MEDALIA, A.I. (1951) Test for Traces of Organic Matter in Water. Anal. Chem., 23, 1318.

10. RICHARDS, F.A. with THOMPSON, T.G. (1952) The Estimation and Characterization of Plankton Populations by Pigment Analysis. J. Mar. Res., 11 (2), 156.

11. CREITZ, G.I. & RICHARDS, F.A. (1955) The Estimation and Characterization of Plankton Populations by Pigment Analysis. J. Mar. Res., 14, 211.

12. VAN de VLOED, A., (1955) Comparison between Slow Sand and Rapid Filters. Report, I.W.S.A. Congress, London.

13. IVES, K.J. (1971) Filtration of Water and Wastewater. CRC Critical Reviews in Env. Control, 193.

14. RIDLEY, J.E. (1967) Experience in the Use of Slow Sand Filtration, Double Sand Filtration and Microstraining. Proc. Soc. Water Treat. Exam., 16, 170.

APPENDIX

Basis of Cost Analysis

To compare the costs for the slow and rapid sand filters, cost per million litres (Ml) of water treated has been taken as the basis. The cost per Ml of water treated is calculated by dividing the annual cost per filter by its effective annual yield. The total cost of filtration per filter per annum, C_T, is given by

$$C_T = C. r + C d + C.m + O \qquad \text{(i)}$$

where C is the capital cost per filter; r, d and m are the annual rates of interest, depreciation and maintenance and repairs. O is the annual operational cost per filter unit and includes the cost of sand backwashing/scraping, recoupment and overhauling of filters and the cost of manpower involved in the actual operation and supervision of the filter.

Table 'A' presents the rates of land power, water alum and chlorine along with annual rates of interest, depreciation, maintenance and repairs adopted for calculations. Table 'B' provides the cost data for both types of filter in accordance with equation (i) to obtain the cost of filtration per filter unit per annum for prototype filters at Kanpur Water Works at late 1972 prices. Table 'C' includes sample calculations for the actual quantity of water filtered per unit per annum for the rates of filtration adopted for rapid and slow sand filters at Kanpur Water Works.

In all the tables original values in local (Indian) currency of Rupees have been converted into English currency at the rate of Rupees twenty equal to £1.

Table 'A'   Various Rates Employed For Computations

Sl. No:	Item	Rate	Comments
1.	Land cost	£2.38 per square metre	Rate of compensation paid by Kanpur Municipal Corporation for acquired land
2.	Interest on capital	7% per annum (p.a.)	Normal rates of interest charged by State Government on loans to Corporations.
3.	Depreciation		
	(i)	2% p.a.	For civil works of slow sand filter with design life of 50 years.
	(ii)	3% p.a.	For civil works of rapid sand filters with design life of $33\frac{1}{3}$ years.
	(iii)	4% p.a.	For mechanical equipment used in rapid sand filters.
4.	Maintenance and Repairs:		
	(i)	1%	For slow sand filters
	(ii)	2%	For rapid sand filters
5.	Power	£0.5 per 100 kWh	Rates at which Kanpur Water Works purchases/sells the particular item.
6.	Water	£8.0 per Ml	
7.	Alum	£14.0 per ton	
8.	Chlorine	£7.5 per 100 kg	

Table 'B' Cost Data on Slow and Rapid Sand Filters

S.No.	Item	Slow Sand Filter (Size 30.5m x 61m)			Rapid Sand Filter (Size 7.6m x 7.6 m)		
		Capital Cost	Annual cost on interest, depreciation and maintenance etc.	Annual operational cost	Capital Cost	Annual cost on interest, depreciation and maintenance etc.	Annual operational cost
		£	£	£	£	£	£
1.	Land	4444	311	-	145	10	-
2.	Civil works	9648	955	-	6300	756	-
3.	Mechanical equipment	50	6	-	5400	702	-
4.	Sand						
	(i) Scraping/backwashing*		-	80	-	-	566
	(ii) Recoupment	-	-	64	-	-	109
5.	Operation	-	-	67	-	-	147
6.	Supervision	-	-	5	-	-	33
	Total	14 142	1272	216	11 845	1468	855

* Includes cost of scraping and carting to sand washing machine in case of slow sand filter and cost of power on pumping air and water and cost of backwashing water (2% of filtered quantity) for rapid sand filter.

Table 'C' Sample Data on Quantity of Water Filtered and Cost of Filtration for Slow and Rapid Sand Filters

S.No.	Item	Type of Filter (Conventional Rates)	
		Slow	Rapid
1.	Quantity of Water Filtered		
	(i) No. of days lost in scraping/backwashing and overhauling, days/filter/year	32	14.4
	(ii) Total quantity of water filtered, Ml/year/filter	1980 (@ 133 l/m^2h)	1863 (@5880 l/m^2h)
2.	Cost of Filtration		
	(i) £	1488	2323
	(ii) £/Ml of water	0.75	0.81
3.	Other Costs all in £/Ml of water		
	(i) Alum (av.dose = 35 mg/l)	0.49	0.49
	(ii) Chlorine	0.15 (av.dose = 2 mg/l)	0.19 (av.dose = 2.5 mg/l)
	(iii) Extra power cost for lifting the water to average value of head loss	0.01	0.02
4.	Total cost of filtration		
	(i) without alum-coagulation	0.91	-
	(ii) with alum-coagulation	1.40	1.51