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low cost water treatment for developing countries

INTRODUCTION

Developing countries in hot climatic regions have some major problems in common. India is the largest country by size and by population in this group. Problems of India are, therefore, likely to be representative of the problems of the countries in this group. Some of the major problems faced by India are:

1. Limited capital resources with nearly unlimited demand for capital investment in diversified fields making it difficult to fix priorities.
2. Lack of appropriate technology (in different fields including water treatment) to suit the prevailing conditions(1).
3. Large variations in temperature (season and location wise).
4. Cost and availability of power, materials and labour is in reverse order to that of industrialized nations.
5. Shortage of skilled and trained personnel.
6. Inadequate facilities for repairs, maintenance and communications.
7. Large scale unemployment or under employment of unskilled labour.
8. Large number of small isolated rural sectors (Table 1) (out of 550 000 villages 380 000 have populations of less than 500)(2). The majority of people of the rural sectors are illiterate, tradition bound, and poorly informed about advancements in science and technology.

Table 1 Population Percentage in Rural Sectors.

Industrialized Regions				Developing Regions				
N.Am.	U.S.S.R.	Europe	Average	INDIA	S.ASIA	E.ASIA	Lat.Am	Average
26.6	43.7	36.5	34.4	80	76	74.5	31.2	73.8

9. A large back-log in the provision of basic amenities in the rural sector resulting in a higher rate of migration to the urban sector.
10. Larger rate of population growth as compared to the industrialized nations(3) (Table 2).

Table 2 Population Growth Rate 1960 - 1970

Industrialized Regions				Developing Regions				
N.Am.	U.S.S.R.	Europe	Average	INDIA	S.ASIA	E.ASIA	Lat.Am	Average
17	18	8	13	22	27	19	34	25

These problems have considerable impact on the status of water supply and sanitation facilities in a country. The gravity of the impact will vary from country to country depending upon the availability of resources, population densities, education level and relationship with industrialized countries. The impact on the Indian scene, especially in the field of water treatment, can be summarized as follows:

1. Due to inadequate capital resources and pressing demands from agriculture, industry, education, family planning etc, in the first five 5-year plans, water supply and sanitation has received lesser priority (Table 3). The rural sector, though four times larger in population than the urban sector, has received very small allocations in the first four plans. The fifth plan, however, shows a slight reversal. The majority of the rural sector is still not covered with protected water supply. Out of 567 163 villages 28 830 were proposed to be covered till the end of the sixth plan.

Table 3 Capital Investment Allocations for Water Supply and Sanitation (In 100 000 Rs.)

Plan	I	II	III	IV	V
Urban sector	12.72	57	80.84	285	439.35
Rural sector	6.0	28	16.63	131	564.23
Total plan outlay	2356	4500	10 400	*15 904	37 250
Percent of total	0.8	1.9	0.9	2.6	2.7

(*Provisions for agriculture and transport were 2728 and 3287 respectively)

2. Due to lack of appropriate intermediate technology the bias is towards adopting the more sophisticated 'Western' solutions. In the last few decades conventional rapid sand filtration plants have become more common. A survey of ten representative water treatment plants carried out by NEERI nagpur(4) revealed the following:
 - a) More than fifty percent of plants had rapid sand filters and others had a combination of slow sand and rapid sand filters.
 - b) In eighty percent of the plants alum dosing equipment was out of order and very unscientific methods were adopted for dosing alum.
 - c) Sedimentation and pretreatment practices greatly varied. At some places sedimentation tanks were breeding grounds for molluscs and sponges.
 - d) In fifty percent of plants chlorine dosing equipment was out of order. In most of the plants capacities were inadequate for adhering to break-point chlorination or prechlorination.

- e) Counts of coliform and fecal streptococci were often recorded in finished waters.
- f) Filtrate turbidity ranged between 1.3 to 7.2 mg/l.
3. Due to paucity of funds sizes of treatment plants and water supply schemes are kept to the minimum (130 to 220 l/p d for towns and 50 to 75 l/p d for rural areas). The majority of the plants for towns have capacities between 8 to 30 Ml/d while those for rural areas have capacities between 0.5 to 5 Ml/d. For conventional rapid sand filter plants, cost per Ml/d varies inversely with plant capacity. A plant with higher than 50 Ml/d capacity is likely to cost £5000 per Ml/d while that with 10 to 25 Ml/d capacity may cost £6000 to £7500 per Ml/d. The cost of plants smaller than 1 Ml/d may be as high as £10 000 per Ml/d.
 4. The migration from rural sector to urban sector has adversely affected the agriculture oriented economy. The slums in urban areas are growing. The conditions in the rural sector become unstable and unpredictable, and in certain cases population is decreasing. Due to unprotected water, water-borne diseases still take a major toll. The only remedy is to provide the basic amenities including safe water supply and sanitation facilities to the rural areas without any further loss of time.
 5. In nearly all the cities water is supplied only for a few hours a day. This has not only adversely affected the rate of development but has made it difficult even to sustain the present growth. Ever-growing population and growing slums in cities are rapidly worsening the situation. The problem has to be faced and effectively solved.
 6. Due to hot climatic conditions, exposed large areas of water (such as in large settling units and slow sand filter units) give rise to problems of algal growths and to breeding of insects and micro-organisms. The temperature of a large water mass usually differs from the temperature of influent water which causes short circuiting and allied problems. Dust storms and cyclones cause wave action and dust pollution problems. Due to rise in temperature during the day time, floc and sludge particles get entrained with air bubbles and are difficult to retain in settling units. Solubility and reaction rates of chemicals are affected. Considerable water losses are also likely from large exposed water surfaces.
 7. Rainfall is quite heavy and occurs within a short specific period of the year. This causes large fluctuations in the quality and quantity of surface sources. The large amount of suspended load causes silting of water channels in the treatment plants and blocking of valves, sludge pipes and other equipment. Turbidity load is also very high during these periods.

The above discussion leads to the following conclusions:

1. The rate of providing water supply and sanitation facilities in developing countries needs to be increased manifold.
2. The conventional water treatment plant commonly used in industrialized countries is quite costly and has not proved suitable to the conditions prevailing in these developing countries. An effective alternative has to be found.
3. To meet the challenge effectively, it is necessary to develop an appropriate intermediate technology.

This paper is a humble effort to suggest some approaches for developing such an appropriate intermediate technology in the field of water treatment for the developing countries with hot climatic conditions.

REQUIREMENTS TO BE SATISFIED

1. Reduction in Cost. In the words of Lord Rutherford 'Americans (industrialized nations) have money, we have none hence we have to think'. The cost of water treatment plants, especially for small capacity plants, will have to be brought down to one third or one fourth (£2500 to £3000 per Ml/d) so that three to four times more population can be covered in the same allocations. However, low cost treatment does not mean low quality treatment. It means that ways and means have to be found to reduce cost without sacrificing quality.
2. Use of local material (such as construction material, filter media etc.) should be made possible.
3. Power requirements and requirements of chemicals should be kept to the minimum.
4. Finished water quality should not deteriorate with time.
5. To reduce undesirable effect of hot climate, large exposed water surfaces should be avoided.
6. The plant must be simple to operate and mechanical equipment should be kept to the minimum (nearly nil).
7. Costly and complicated controls should be eliminated.
8. Plants should be more sturdy and reliable. As chlorination cannot be fully relied upon, higher bacterial removal efficiencies should be aimed at in pretreatment and in filters.
9. To reduce cost and time in erection and installation a single unit treatment plant which could be prefabricated should be aimed at.
10. To avoid double pumping it should be possible to install the entire plant into a pressure system.
11. Chemical dosing equipment should have a wide range for dose adjustment. Dosing should automatically stop (during power failures) when the flow to the plant stops. The effect of temperature on the solubility of chemicals should not cause inaccuracies in dosing. The effect of chemicals on equipment parts (corrosion, deposition etc.) should not affect the accuracy of the dosing equipment. Unskilled or semi-skilled labour should be able to rectify it whenever necessary.
12. The plant should have adequate arrangements to deal with heavy silt and suspended load wherever it is expected.
13. Depth and other dimensions should be flexible to achieve economy under local conditions.

PROPOSED APPROACHES

Economical and adequate ground-water is not available at many places and so tapping of surface sources becomes necessary. Depending upon the major conditions affecting the treatment required, the sources should be grouped and an economical treatment process should be evolved to suit the particular group. The surface water sources available in India could be grouped in the following categories:

GROUP A Sources where turbidity is below 20 mg/l for nine to ten months of the year and seldom crosses the limit of 100 mg/l. Chemical impurities are within tolerable limits. No serious algal colour or odour problems exist.

Springs and Khadas (small streams through rocky areas) in hilly areas of Punjab, U.P., Himachal Pradesh and other states, comparatively clear tail waters of power houses (like that of Koyana, Bhira etc.), waters of shallow wells and high level storage reservoirs and lakes fall in this group.

GROUP B Turbidity is below 50 mg/l for about eight to ten months but for the remaining months it rises very high even beyond 3000 mg/l. Suspend load and silt load is also heavy. Chemically the quality conforms with permissible standards. Pollution is moderate because high dilution is possible.

Ganga canal and other similar canals, rivers receiving melted snow, reservoirs in catchments receiving heavy rains (like that of Vaitarna) fall into this category.

GROUP C Turbidity is usually higher than 100 mg/l and varies considerably during the year. Pollution is of higher degree, but problems of odour and colour are not serious.

Rivers taking sewage of cities and towns or where rains are well distributed over the year fall into this category.

GROUP D Sources where serious algal problems exist or where certain chemical contaminants or toxic materials need to be dealt with.

Certain pockets of Rajasthan, Gujarath, Orrisa, Assam, Tamilnadu, Maharashtra, have such situations. In some places salinity is of the order of 1500 to 3000 mg/l, fluorides are beyond 4 mg/l, iron and manganese beyond 5 mg/l.

In India the majority of the sources fall into the first two groups.

APPROACH SUGGESTED FOR SOURCES IN GROUP A

For sources in this group a single unit treatment using a suitable filter should be possible. To develop a filter unit to suit all the sources in this category may not be possible and economical, and therefore, a flexible design approach has to be developed. For a small village the unit has to be very simple, which can give longer length of runs and which can be locally fabricated using local materials. If it is not attended the quality should not deteriorate, though the quantity may get reduced. For higher altitudes a prefabricated compact unit which can be easily transported has to be developed. The quality of the sources may considerably vary from place to place and economy could be achieved if the design is flexible enough to take advantage of favourable situations. The presently used conventional rapid sand filters or even slow sand filters have nearly a standard design and need a particular quality of influent for successful operation. However, to achieve economy a flexible design to suit the conditions of the source will be required. To develop a filter unit that will be most economical and suitable under specific conditions, proper understanding of filtration mechanism and parameters and relationships to measure and predict the filter performance have to be developed. A comparatively easy design procedure can then be evolved. Presently available information could be made use of for this purpose and if necessary research work has to be undertaken to evolve a sound and simple design procedure. The author had an opportunity to devote some years to this purpose and design approach evolved is presented in brief:

To measure filter performance a filter coefficient

$$\lambda_0 = \frac{\log_{10} c_0/c}{L} \dots(1)$$

has been commonly used(5,6). It has dimensions of L^{-1} and it is dependent on media grain size 'dm'. The author has suggested a new filter coefficient called the 'filter coefficient of contact', denoted by 'E'(7). It is defined by the relationship

$$(1 - E)^n = \frac{c}{c_0} \dots(2)$$

- c_o - initial concentration
 c - concentration after 'n' contacts
 n - number of contacts or media grains along the flow line given by L/dm where dm is the media grain size.
 L - length of filter media along the flow

The filter coefficient E is dimensionless and is nearly independent of media grain size and hence is more suitable where local sands with varying grain size will have to be used (Table 4).

Table 4 E_o and λ_o for different filter columns
(for nearly the same value of n)

Grain size, mm	2	1.41	1	1.41+0.6	2+0.6	1.2+0.6
Length, mm	500	350	250	350+150=500	300+200=500	400+100=500
n	250	250	250	500	484	500
c_o	46	46	46	41	41	41
c	13	13	11	0.15	0.21	0.15
Rate - v *m/h	5.4	5.4	5.4	5.4	5.4	5.4
E_o	0.00506	0.00502	0.00506	0.00118	0.0117	0.0118
λ_o	0.02	0.0316	0.049	0.112	0.106	0.112
Alum mg/l	nil	nil	nil	20	20	20

*m/h = cubic metres/square meter per hour 1 m/h = 1.67 cc/sq cm per minute

(Only coagulated water was used as filter influent. E_o and λ_o are values of respective filter coefficients for clean beds.)

The most significant removal mechanisms in filtration of water through sand are:

1. Mechanical straining
2. Sedimentation
3. Coagulation and electrokinetic phenomenon.

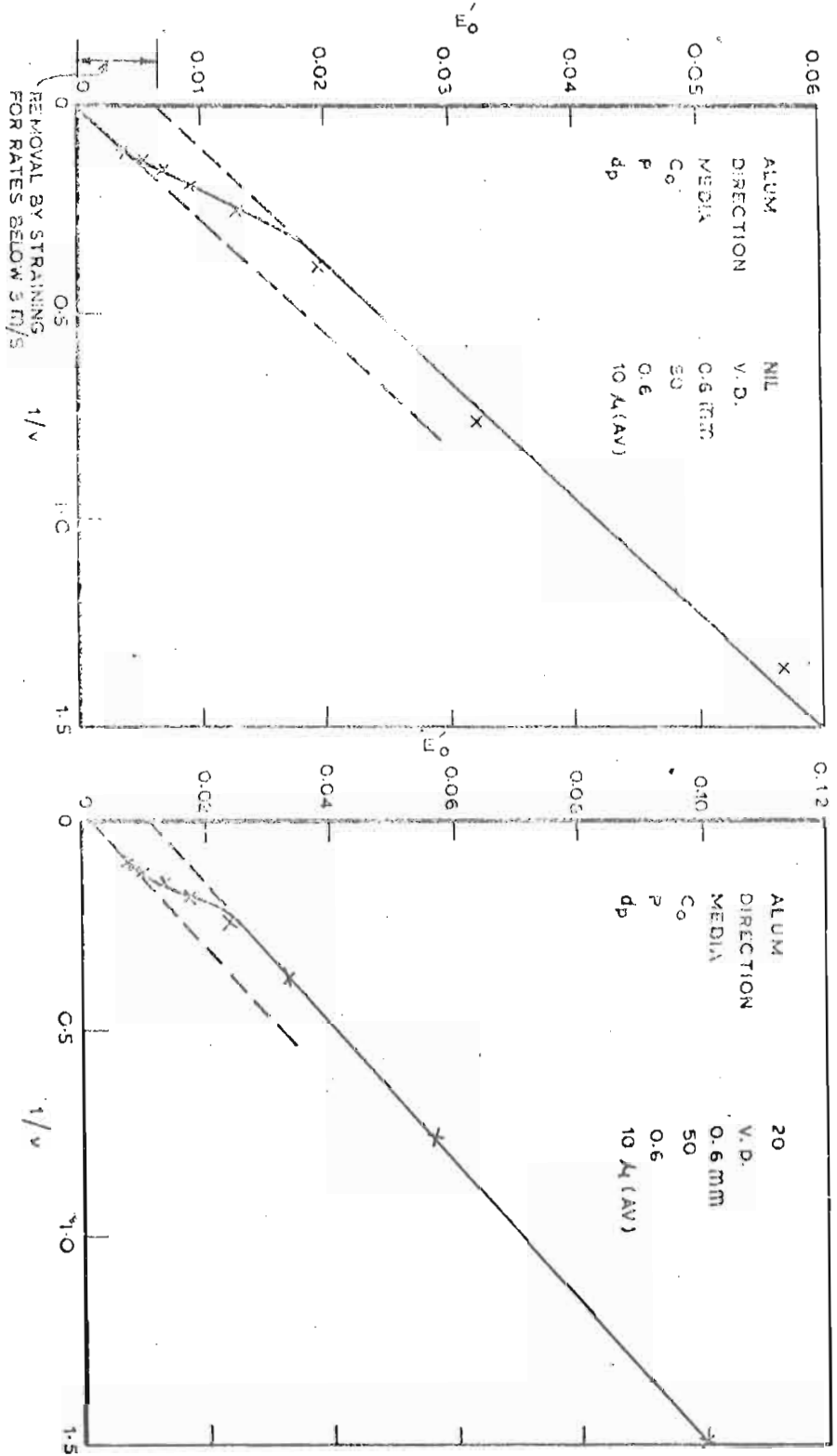
The contribution to removal by mechanical straining could be obtained by using the relationship

$$(E_o)_{Str} = 3.5 \left(\frac{dp}{dm} \right)^{\frac{3}{2}} \dots (3)$$

dp - size of particles in suspensions.

To avoid deterioration of quality with the length of run, and to achieve higher bacterial removal by the formation of a mat similar to that in slow sand filters 'dm' has to be properly chosen. The value of E_o is nearly inversely proportional to the rate of flow v . So an appropriate rate of flow can be chosen to suit the sand that is available in the local area. Figure 1 gives the variation of E'_o (value of E_o corrected for the effect of 'n', depth and rate of flow (v)). From Table 4 and figure 1 it can also be seen that by using a suitable dose of coagulant, a higher value of E_o could be obtained. Alum dose increases head loss and forty percent of the optimum alum dose found by jar test gives the optimum filter performance(9).

Figure 1 VARIATION OF E'_0 WITH $1/v$ (FINE SAND)



The head loss at any time during the filter run could be estimated by the relationship

$$H - H_0 = K\sigma \quad \dots (4)$$

H - final head loss

H_0 - initial head loss

σ - specific deposit (by volume)

K - a constant

Removal by mechanical straining is not very much affected up to the rate of flow of 3 m/h (7) (figure 1). The following design procedure is suggested:

1. Some trial runs should be carried out with the water to be treated using a standard filter column. A filter column with 1 mm sand 100 mm deep can serve the purpose. The rate of flow on this filter could be maintained at 6 m/h. Raw water coagulated with 40 percent of optimum dose (as given by the jar test) should be used.
2. From the data collected the value of E_0 (filter coefficient of contact for standard filter column) and the value of K should be estimated.
3. By using the following relationship(7) a suitable filter design to give the desired value of filtrate quality could be arrived at.

$$E_0 = E_0 \left(\frac{N_1}{N_s} \right)^P \cdot \frac{v}{v_s} \quad \dots (5)$$

N_s - operational number of standard filter ($= \frac{L}{d_m v_s} = \frac{10}{0.1 \times 10} = 10$)

N_1 - operational number of proposed filter ($= \frac{L}{d_m \cdot v}$)

E_0 - filter coefficient of contact for proposed filter

v - rate of flow in the proposed filter

P - a constant (average value 0.55)

L - length of media in the proposed filter

If the value of K is obtained for the sand to be used, and for the rate of flow adopted, the head loss at any time during the run could be estimated.

Thus it will be seen that by using local sand and local material it should be possible to design a filter that can suit the local conditions. If the sand size is kept about 0.5 mm and rate of flow is kept between 1.2 to 3 m/h it should be possible to obtain the desired filtrate quality throughout the entire length of filter run. Table 5 gives the performance obtained with fine media low rate filter columns.

Different types of filters that have been tried either with a laboratory scale model or with a pilot plant are shown in figure 2 to figure 5.

Fine Sand Low Rate Filter (Figure 2)

In this filter the sand size could be from 0.3 mm to 0.55 mm. The depth of sand bed will be between 150 and 300 mm depending on the sand size. The rate of flow could be between 1.2 and 3 m/h depending upon the influent quality, sand size and final head loss desired. The depth of filter tank could be kept between one to two metres depending upon the local conditions. The rate of flow does not vary appreciably and so an automatic rate controller is not required. Initially the water level in the filter could

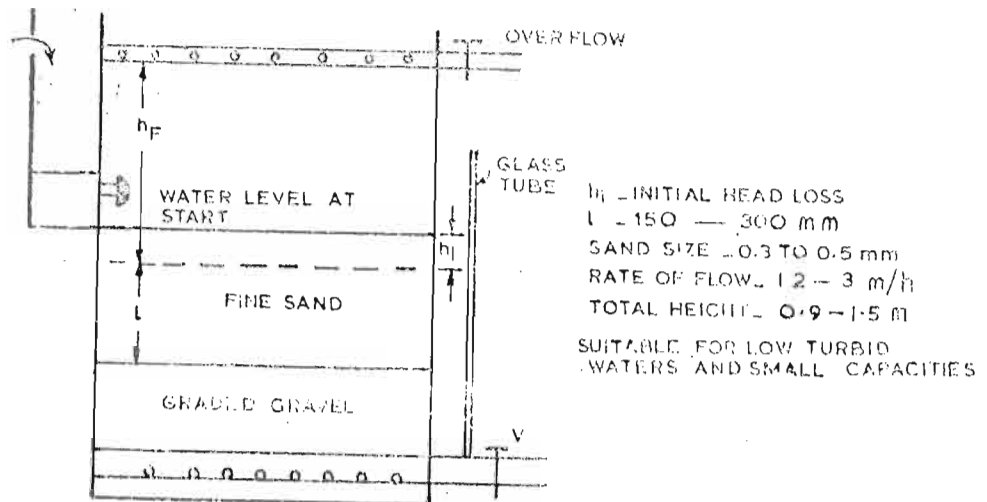
Table 5 Performance Data for Fine Sand Low Rate Filters
(Laboratory Studies)

C_o 40 to 50 mg/l Alum 20 mg/l Temperature 15° - 19°C.

Time after start in min	A. Sand - 0.55 mm uniform Rate - 3 m/h Depth - 300 mm		B. Sand - 0.4 mm Rate - 1.8 m/h Depth - 150 mm	
	C	Head loss mm	C	Head loss mm
0	1.5	100	1	60
120	0.5	110	0.3	70
240	0.2	120	0.1	78
420	0.15	150	nil	170
720	0.15	200	nil	380
1080	0.1	330	nil	700
1440	0.1	400	nil	900

be kept a few inches above the sand top and flow adjusted with an outlet valve. If the influent rate is controlled the level on the filter bed will rise as clogging proceeds and the discharge will be nearly constant. If the filter remains unattended it will start overflowing, and the discharge will be reduced but the filtrate quality will not deteriorate. The filter could be cleaned by scrapping the upper layer of sand and replacing it, or by surface jets or by back wash. It is suitable for small communities where low turbidity waters are to be treated.

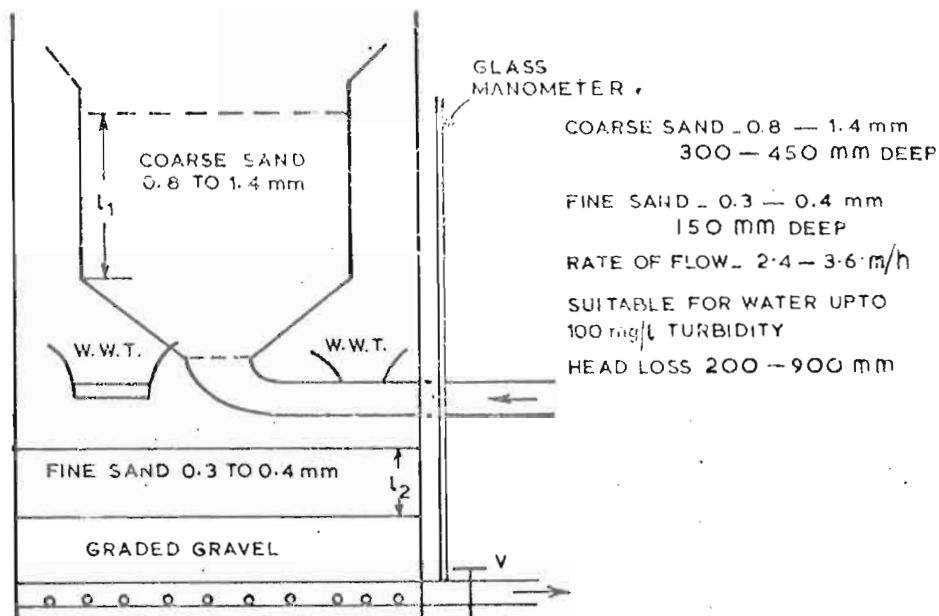
Figure 2 LOW RATE FINE SAND FILTER



Stage Filter (figure 3)

When the turbidity is likely to be higher (up to 100 to 200 mg/l) a stage filter will be more suitable. The coagulated water is first filtered through coarse sand (0.8 to 1.4 mm) and then admitted to a bed of fine sand (0.3 to 0.4 mm). The filter could be operated at 1.2 to 4.8 m/h rate of flow depending upon the turbidity of raw water. A filter of the size of the oil drum (0.6 metres diameter and 0.9 metres high) can give a yield of 10 to 15 l/min. The cleaning is done by back wash process. For coarse sand raw water could be used for back wash. Due to the conical shape of the central drum it is possible to wash the coarse sand at lower pressure and less rate of flow than usually required. This filter gave very satisfactory results during pilot plant studies, giving an effluent of less than 0.5 mg/l turbidity throughout the run of 1440 minutes. The influent turbidity varied between 50 to 100 mg/l and the rates of flow through coarse and fine sand were 6 m/h and 3 m/h respectively. The final head loss in coarse sand was 220 mm and that in fine sand was 250 mm. The coarse sand column acted as a prefiltration unit for a period of about six hours, but after that it acted as a flocculation and settling unit. Good size dense flocs could be seen coming out of the coarse sand bed which were settling on the top of the fine bed. The size of these flocs was of the order of 0.1 to 0.5 mm and they could settle against a vertical flow of 6 m/h. At first the head loss in the coarse sand bed gradually increased up to 220 mm but later on it was nearly constant at this value. Similar observations have been independently reported by Kardile(12).

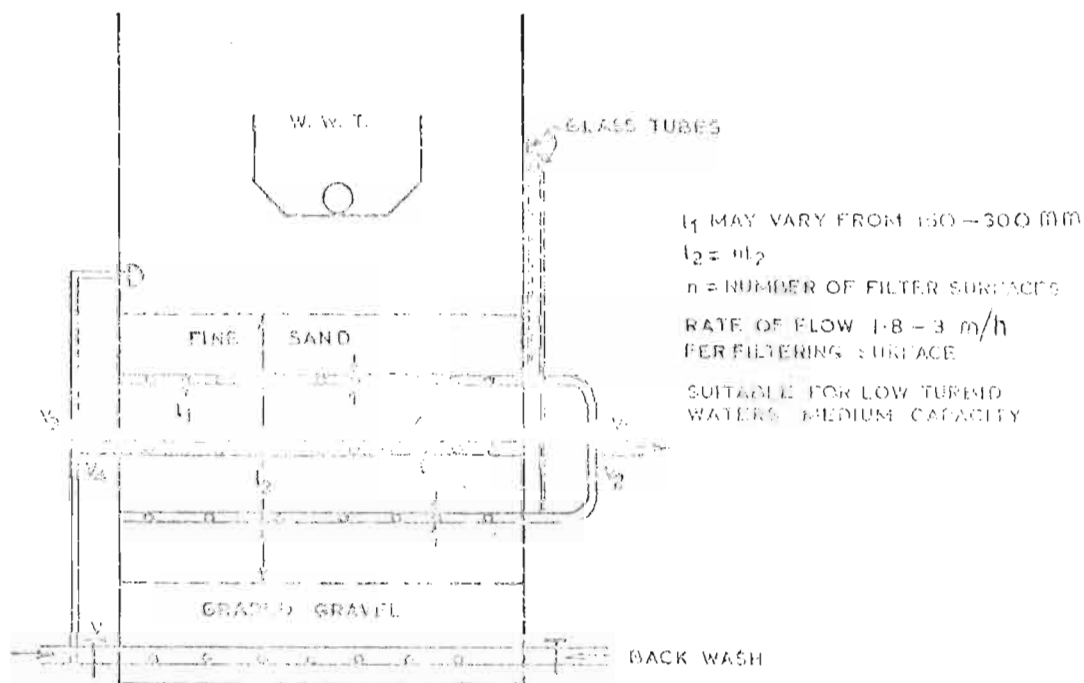
Figure 3 STAGE FILTER

MIMO Filter (figure 4)

When a filter of larger capacity is needed to treat low turbid waters, the MIMO (multi inlet multi outlet) filter is quite suitable. In this case raw water (coagulated) is admitted at different levels in the sand bed and filtered water is also withdrawn at different levels. Though the filtration rate is low, the yield per square metre of occupied area increases with increase in depth. Due to a lower rate of filtration better quality filtrate is obtained. The head loss could also be kept at any desired level. In pilot plant scale studies (0.4 Ml/d) the filter gave

very good performance. With an average turbidity of 50 mg/l the effluent turbidity was less than 0.5 mg/l at a rate of filtration of 2.8 m/h. As the filtration area used was four times the plan area the total yield was 11.2 cubic metres/square metre per hour. It gave a head loss of only 450 mm after a continuous run of 27 hours. The filter was also successfully subjected to a shock load of 500 mg/l turbidity for about ninety minutes.

Figure 4 MIMO FILTER



Graded Horizontal Filter (figure 5)

This filter is suitable when higher capacities are needed to treat waters with a medium turbidity load (100 mg/l). In this case the flow direction is mainly horizontal. Table 6 shows the effect of direction of flow on filter performance.

It will be seen that the horizontal flow direction gives better performance than other flow directions. The yield per unit of occupied area could be increased by increasing the depth. Though graded material is used, different types of media are not needed as in the case of multilayer filters. The size of media and grading can be chosen to suit the performance desired and need not depend on back-wash water requirements as in the case of multilayer filters. Thus it will be seen that the horizontal graded filter can have wider applications. A radial horizontal filter named as 'the Simater continuous sand filter'(13) has also been used successfully.

Other types of filters that could be used with advantage are up flow or contact filters, dual or multi-media filters or a combination of pre-filter and a dual media filter. At Ramteek, Nagpur(12) a 2.25 Ml/d capacity plant has been constructed in April 1972 which consists of a pre-filter unit of packed gravel and a dual media filter using crushed coconut shell instead of anthrasite. The crushed coconut shell is much cheaper than anthrasite and will be locally available in most of the places

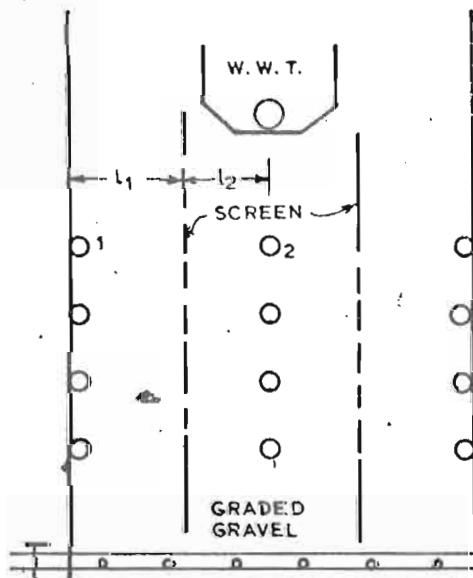
on sea coast areas. It has a specific gravity of 1.4 to 1.5 when soaked in water. It is nearly inert to dilute HCL and the loss of weight after 100 hours of back-wash is less than one percent(14). The plant is giving good performance at a designed rate of 0.77 m/h. It has cost only £6250 (or less than £3000/MLD). It has no costly equipment or controls.

In most of the above filters automatic rate controllers could be dispensed with. Simple glass tube manometers could be used to adjust the desired discharge. These filters could be covered and can be installed in a pressure system. In India amoebic dysentery and other water-borne diseases are still quite common. Chlorination could not be completely relied upon, as much higher bacterial removal efficiency is very desirable. When coagulated water is passed through fine sand beds at low rates a high bacterial removal efficiency is achieved. Hence low rate finer sand and minimum pretreatment should be the key words for filter design in developing countries which are just opposite to the slogan 'higher rate, coarser media and efficient pretreatment' presently adopted in industrialized countries.

Table 6 Effect of direction of flow on filter performance.

		Sand: 0.6 mm diameter Depth: 500 mm Filtration rate: 6 m ³ /m ² h Alum: 15 mg/l Initial turbidity, C ₀ : 60 mg/l			Sand: 1.0 mm diameter Depth: 500 mm Filtration rate varied Alum: 20 mg/l Initial turbidity, C ₀ : 40 mg/l					
		Head loss		length of run of run minutes	Average filtrate turbidity C mg/l	Filtration rate m/h. (m ³ /m ² h)				
Flow direction	Initial H ₀ mm	Final H mm	1.2			2.4	4.8	7.2	8.4	Filtrate turbidity, C mg/l
	Vertical upward	312		1300	500					0.8
Vertical downward	317	1800	600	0.3	0.14	0.29	1.0	3.3	5.8	
Horizontal	310	1100	600	0.3	0.1	0.19	0.8	2.5	4.0	
		1770	1000	0.35						

Figure 5 GRADED HORIZONTAL FILTER

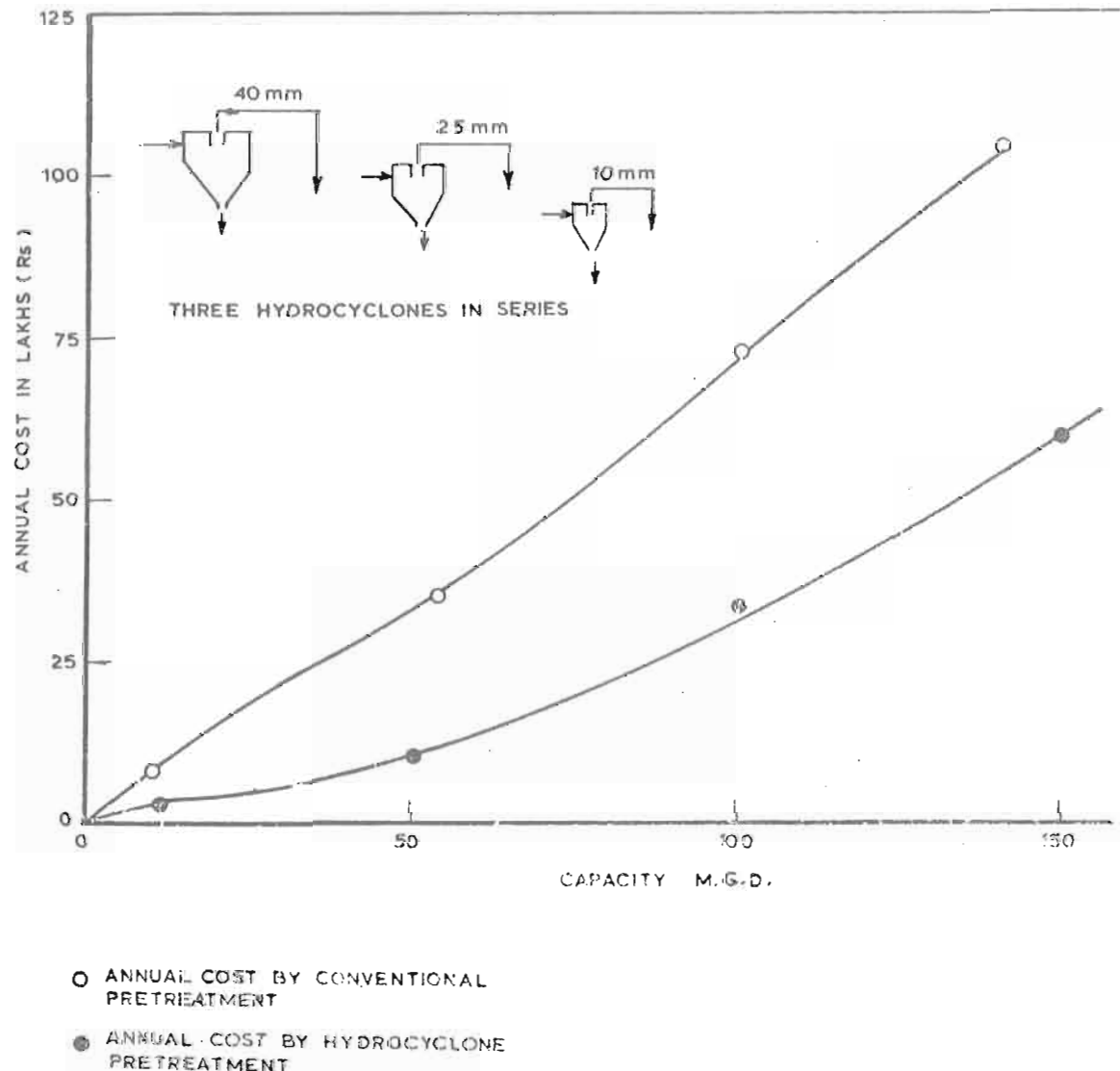


- 1- INLET PERFORATED PIPES
- 2- OUTLET PERFORATED PIPES
- l₁- COARSE SAND 0.8 — 1.4 mm
- l₂- FINE SAND 0.35 — 0.5 mm
- SUITABLE FOR MEDIUM CAPACITIES
(UPTO 100 mg/L TURBIDITY)

TREATMENT APPROACHES FOR SOURCES IN GROUP B

For the sources in this group high turbid waters are likely to be met with for a few weeks in a year. A complete conventional pretreatment will not be needed for most part of the year. A suitable alternative requiring lesser capital cost should be evolved to deal with this problem effectively. One of the approaches is to use a series of hydro-cyclones as pretreatment units. A hydrocyclone can take a load of 600 to 4200 m/h as compared to 1.2 to 9 m/h in the case of conventional settling units (15,16). Due to such high loadings, capital cost and space requirements are reduced to a substantial extent. Though a hydrocyclone needs a higher pressure (0.6 kg to 1.6 kg/sq cm) no coagulant is needed. It has no moving parts and needs very little maintenance. Experiments carried out at Roorkee(16) showed that particles as small as 3 microns and specific gravity 2.65 could be removed and an efficiency as high as 88 to 90 percent could be achieved by using suitable hydrocyclones in series. Figure 6(16) shows the comparison of annual cost for pretreatment by hydrocyclone and by conventional units. The other approach may be to use shallow depth settling units like tube settlers, with continuous sludge removal arrangements.

Figure 6 COMPARATIVE ANNUAL COST OF PRETREAT



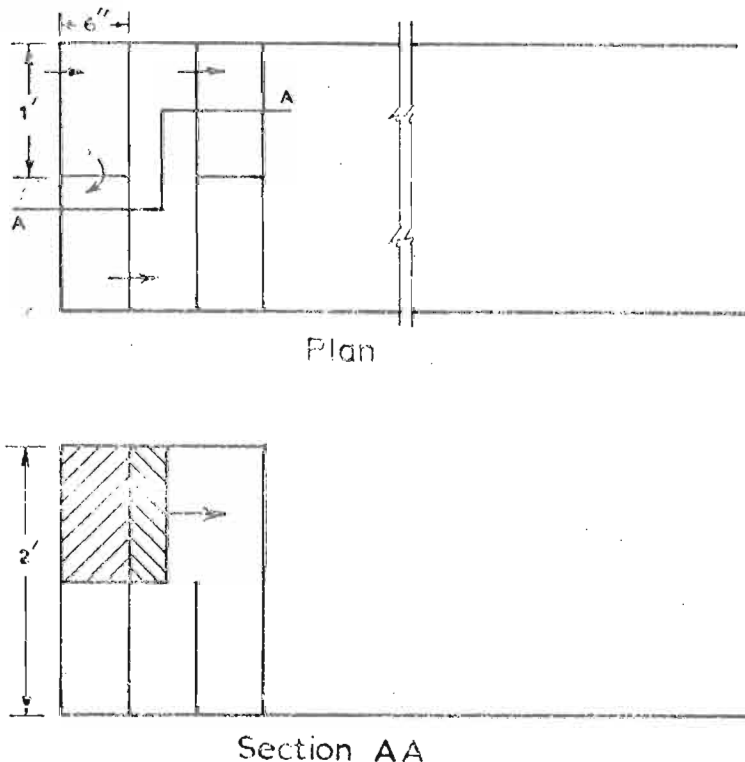
APPROACH FOR TREATMENT OF SOURCES IN GROUP C

In these sources high turbidity and pollution may continue for a major portion of the year, and full pretreatment may be necessary. The mechanism of flocculation is now better understood. Camp(17) showed that if the velocity gradient (r.m.s. value) is kept in the range of 20 to 40 per sec. and if 30 to 40 minutes time is allowed for flocculation good results are obtained. The author(18) has shown that if effort is made to distribute power uniformly over the entire section of the flocculation chamber and if more quantity of water per unit of power consumed is moved in the chamber, the time and power required could be reduced. If baffled channels are designed with this new approach they could be suitable for small capacity plants. A baffled channel flocculator (0.4 ML/d flow) with a velocity gradient of 20/sec. and a detention time of ten minutes gave satisfactory results (figure 7). Another approach that has been tried is allowing an upward flow of water through a column of suitable solid media. The velocity gradient can be obtained by the relationship

$$\bar{G} = \sqrt{\frac{g h}{\nu t}}$$

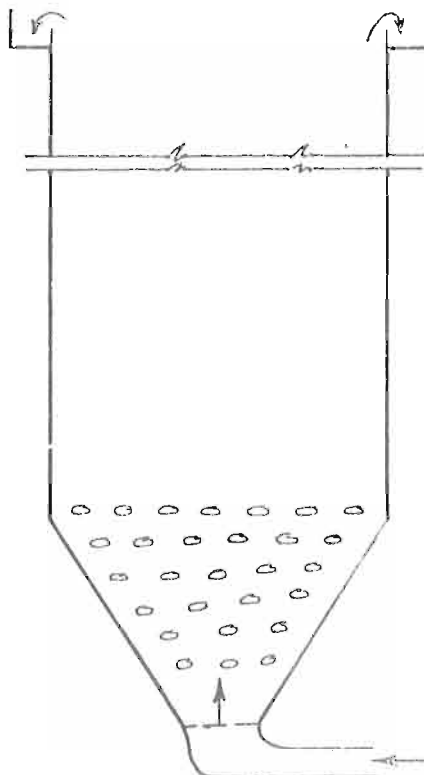
where 'h' is the head loss, 't' is the time of detention and ν is the kinematic viscosity.

Figure 7 BAFLED CHANNEL FLOCCULATOR (1 ML/d)



By properly choosing the type of media, its size and flow rate, the desired range of velocity gradient can be obtained. Good dense flocs were obtained by passing pre-coagulated turbid water through a 4 mm gravel bed, 600 mm deep at a rate of 24 m/h. In this case power will be distributed uniformly in the entire chamber. Both these flocculators have no moving parts and will need very little maintenance. These will be suitable for small capacity schemes. If an air compressor is available flocculation could also be achieved by the use of compressed air.

Figure 8 SOLID MEDIA FLOCCULATOR



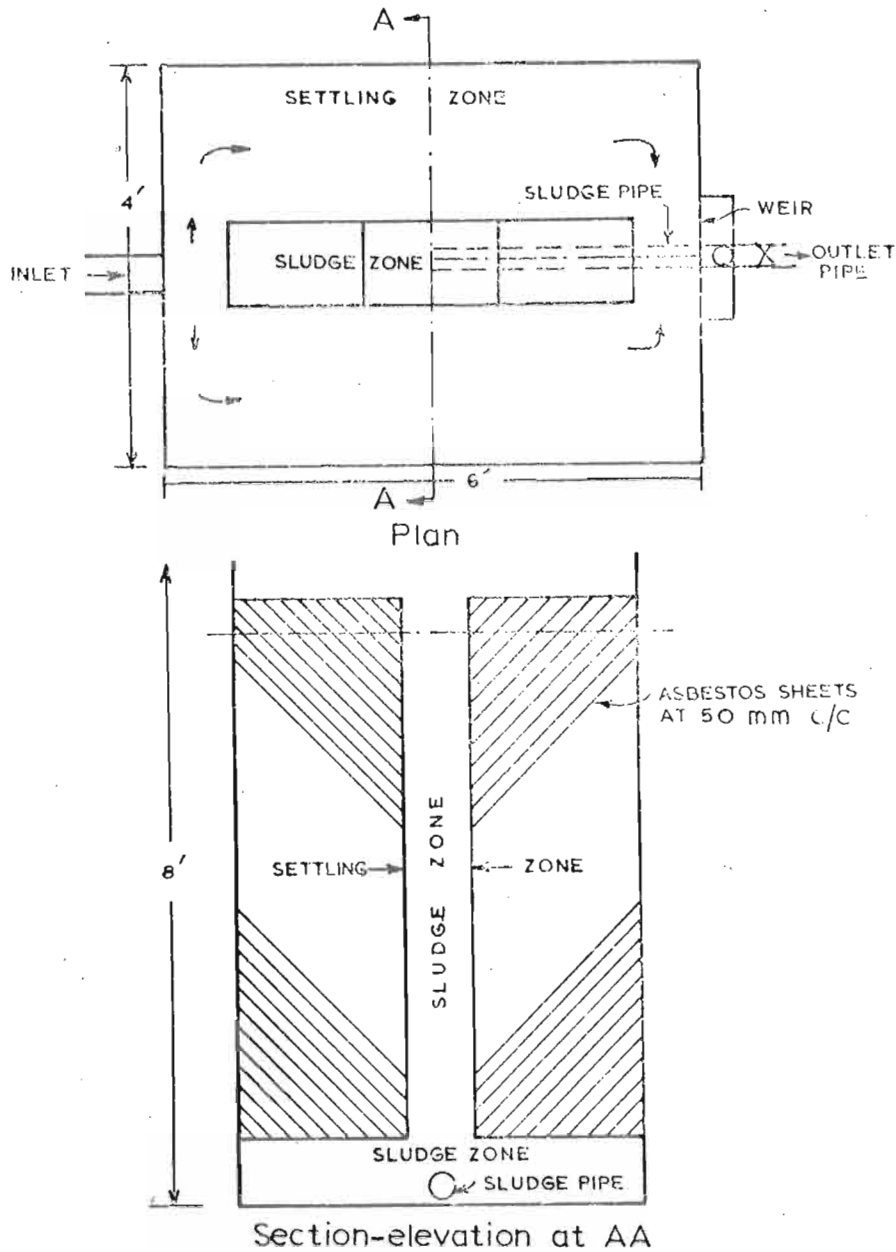
As regards settling units, mention has already been made of hydro-cyclones and tube settlers. Many other designs of smaller depth settlers could also be tried. A "Multi Bottom Settler" (figure 9) was tried both at laboratory scale (six bottoms) and pilot plant scale (36 bottoms). It could achieve an efficiency of about 80 percent with a detention time of six to eight minutes, (19). The sludge could be removed continuously. The unit is very compact and needs no scraper mechanism. It could be used under a pressure system. Any one of the above filters described could be used to treat the settled water.

Chemical Dosing Equipment

In all the above cases coagulation is required to be adhered to and chlorination will also be necessary. The present equipment for alum dosing needs three to four tanks for preparing alum solution, one constant level tank, some weir or valve and a float arrangement to adjust the dose. These units have not proved very successful. Due to deposits of aluminium salts or due to corrosion at higher temperatures the mechanism fails at one or the other point. A simple and sturdy dosing equipment which will need much less attendance and in which the dose will vary with the discharge is needed. It should also have a wide range for dose adjustment. Solubility of alum varies with temperature. It is as low as 55 g/l at 10°C and 90 g/l at 30°C. It should be seen that no error is involved due to this variation in solubility of alum.

The approach that can be tried is the parallel flow approach by using a saturated solution of alum. Figure 10 shows the arrangements that can be used with raw water inlet channels. The jar test will be performed by using the saturated solution from the alum chamber. If still conditions are reached at the raw water inlet of the dosing chamber the dose could

Figure 9 MULTI BOTTOM SETTLER

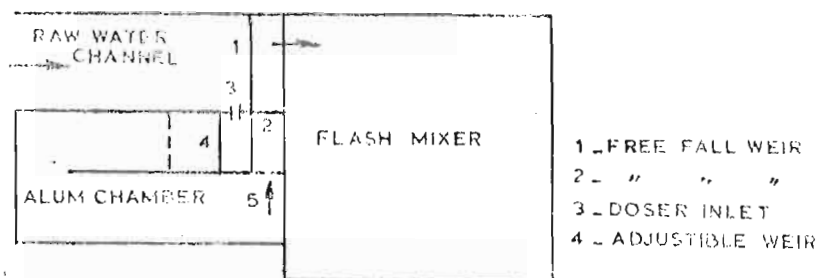


(NOT TO SCALE)

be adjusted by adjusting the width of the inlet weir. Other arrangements could also be made to control the quantity of water admitted to the dosing chamber. As the dose control is at the inlet it will not be affected by the alum solution. If the flow is stopped the level will go below the sill of the weir and dosing will stop automatically. Once the dose is adjusted it will vary with the discharge. Alum can be dumped into the alum chamber to the desired level and so no accurate measurement of alum will be needed.

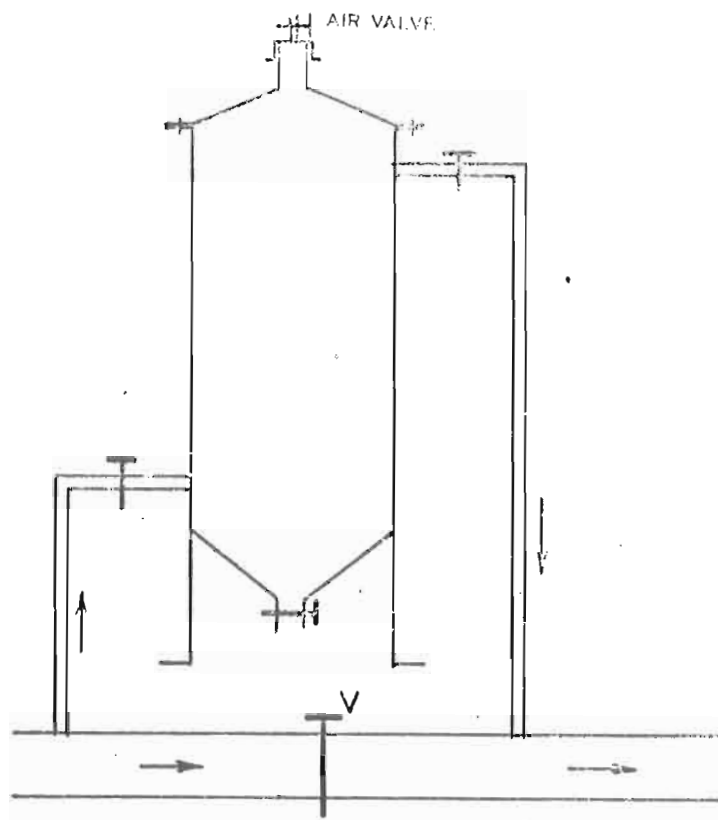
Chlorine dosing may need a different type of arrangement. In small capacity plants the use of bleaching powder is more convenient than chlorine gas cylinders, but it is difficult to obtain saturated solution of bleaching

Figure 10 PARALLEL FLOW CHEMICAL DOSER.



powder. Beyond ten percent strength foaming occurs and particles of lime and bleaching powder become suspended. These block the openings used for dosing. Ten percent solution of bleaching powder gives about 30 000 mg/l residual chlorine. The dose of chlorine required is usually very small (0.2 to 0.4 mg/l) and little variation could be permitted in this dose. A pressure doser based on the principle of dilution was tried at Roorkee(20) to chlorinate a tube-well water supply of 90 cubic metres per hour (figure 11).

Figure 11 PRESSURE PARALLEL FLOW DOSER



In a forty eight hours trial the dose varied between 0.2 to 0.3 mg/l. It automatically varied with the discharge. The required capacity of the doser could be calculated by using the following relationship:

$$X_n = \frac{(C - Y)^n}{C} \cdot X_0$$

- X_n - minimum concentration of dose to be maintained after 'n' minutes of operation, mg/l.
 C - capacity of doser in litres
 Y - rate of flow through the doser, l/min
 X_0 - initial dose of chlorine, mg/l
 n - interval in minutes for recharging the doser

After 'n' minutes the doser will have to be recharged with concentrated slurry of bleaching powder. The precipitated lime could be removed from the doser by opening the valve at the bottom.

These dosers could be fabricated at site and are expected to give more reliable performance. Their cost will also be much less than the presently used dosers.

TREATMENT APPROACHES FOR SOURCES IN GROUP D

Very little work has been carried out and reported in India which can be grouped under Low Cost Water Treatment. Every source in this group has its own peculiar problems and a method or approach found suitable for one may not be suitable for the other. However, approaches adopted for some common problems can be discussed.

Due to ample sunlight and uncontrolled pollution of catchments, problems of algal and weed growth are met with at some places. Madras city stores river water in large reservoirs where algal growth takes place and due to decomposition of organic matter, odour troubles were noticed at the slow sand filters(21). Open swimming pools, large settling units, connecting channels, shallow wells and lakes often show abundant algal growths. Due to the poisonous nature and heavy cost of copper sulphate the common method employed is heavy prechlorination. A small preventive dose of copper sulphate and chlorine were tried on Roorkee University swimming pool with some success. At Bhilai in the tanks used for storing and recirculation of cooling water abnormal weed growths were noticed. Use of corrosive chemicals was not possible and Gramoxone and Sodium arsenite were unable to control the problem. Manual weed cutting was also inadequate. An equipment called 'Bengal Chaki' was found to be very useful(22). It consists of a steel pipe with short pieces of small size pipes welded to it at right angles to its major axis. All the pipes are sealed and if necessary, sealed empty drums are attached to the end of the pipe. The chaki was dragged through the reservoir by winch and coil arrangements and brought to the shore a truck load of weeds every time.

Problem of excessive fluoride contents have been reported from certain pockets of Rajasthan, Andhra Pradesh, Tamil Nadu, Maharashtra, Punjab and Haryana. Though extensive survey work has still not been undertaken the information available indicates that the problem is of a serious nature at some places. It is said that a place in Rajasthan has been named Bankaner (Banka - bent, Ner - man) as many people in that area have defective bone structures, probably due to excessive fluorides.

Conventional approaches of using phosphoric compounds, activated alumina, activated carbon and exchange resins are quite costly and not suitable for small capacity plants. Efforts have been made by some workers(23) to

evolve cheaper ion exchangers. Vankatraghavan prepared an ion exchanger by digesting paddy husk in 1 percent KOH solution and then soaking it with 2 percent alum solution. It was tried in some field plants with some success. NEERI, Nagpur(23) has developed an exchanger named Defluoron 2, a sulphonated coal which works on the alum cycle. It has been successfully tried in laboratory and field plants. The cost reported is about 3p per 4000 litres of water treated. The rate of flow used is 5 l/h. The exchange capacity is about 650 mg of fluorides per litre of the medium (at bicarbonate alkalinity of 160 mg/l and a fluoride concentration of 8.1 mg/l). The exchange capacity decreases considerably with increase in alkalinity and decrease in fluoride contents. NEERI has also developed a simple and cheap chemical technique, called Nalgonda technique. In this raw water is first treated with lime and then with alum and is then flocculated and settled. The fluorides are reduced to the required level. The cost to treat one cubic meter of water per mg/l of fluoride is about 0.2p. The method appears to be simple, cheap and suitable for small capacity plants.

Another common trouble met with in certain (especially underground) sources is a high content of iron and manganese. A tube-well near Howrah is reported to have iron contents as high as 11 mg/l(24). At certain places dissolved CO₂ is responsible for red water troubles. Some workers (24,25) have proposed some cheaper and simpler approaches for small capacity plants. Raw water is first sprayed over a bed of coke or charcoal so as to give a contact time of 15 to 30 minutes. Then this water is either passed through a coarse sand bed or is stored for a few hours. Finally it is filtered through a fine sand bed at a rate of 0.2 to 1.8 m/h. Such plants are working quite satisfactorily at some places giving 80 to 88 percent reduction in dissolved CO₂ and reducing the iron contents to about 0.1 mg/l.

Provinces like Gujarat, Tamil Nadu and Maharashtra have large areas under saline track. States like Punjab, Rajasthan and Haryana have pockets of brackish water. Villages in these areas have nearly no other fresh water source. The conventional approaches like distillation, ion exchange, freezing etc. are costly and not suitable for small capacity village plants. The counter-current ion exchange technique is reported to be 25 to 30 percent cheaper than the conventional technique(26). A tubular reverse osmosis plant has also been tried to treat dilute sea water(27) but it needs pressures as high as 40 kg/sq cm and special types of membranes. Efforts have also been made to harness solar energy. Solar still plants that were tried gave a utilization efficiency of 30 to 50 percent(28) but the yield is very low, about 2.5 l/sq m per day. The capital cost of these units is nearly prohibitive.

Thus it will be seen that simpler and cheaper methods have been evolved for fluoride and iron removal, but suitable alternative methods have to be evolved to deal effectively with the algal and salinity problems.

CONCLUSION

The discussions and observations presented bring out the urgent need for developing an appropriate intermediate technology to solve effectively the problems of developing countries, especially in the field of water treatment.

The single unit treatment approach suggested for dealing with sources in group A is likely to bring down the cost substantially. The new types of filters suggested are very simple and compact. The flexibility of design and the low rate philosophy will help to achieve better performance and considerable reduction in capital and maintenance cost. All costly controls have been dispensed with. As the height of the filter tank and the head-loss are controllable factors full advantage could be taken of local conditions.

For sources in group B adoption of hydro-cyclone or multi-bottom settlers will eliminate the need for large settling units. These units are very compact and have no moving parts. The use of baffled channel and gravel flocculators for sources in group C will make the pretreatment much simpler. The proposed chemical dosing units are also quite simple and reliable. Thus it will be seen that the approaches suggested fulfil most of the requirements stated earlier.

The work done at present is scattered and lacks proper planning and co-ordination. It will be worthwhile if the developing countries can establish a research centre for evolving an appropriate intermediate technology in the field of water and waste-water treatment.

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