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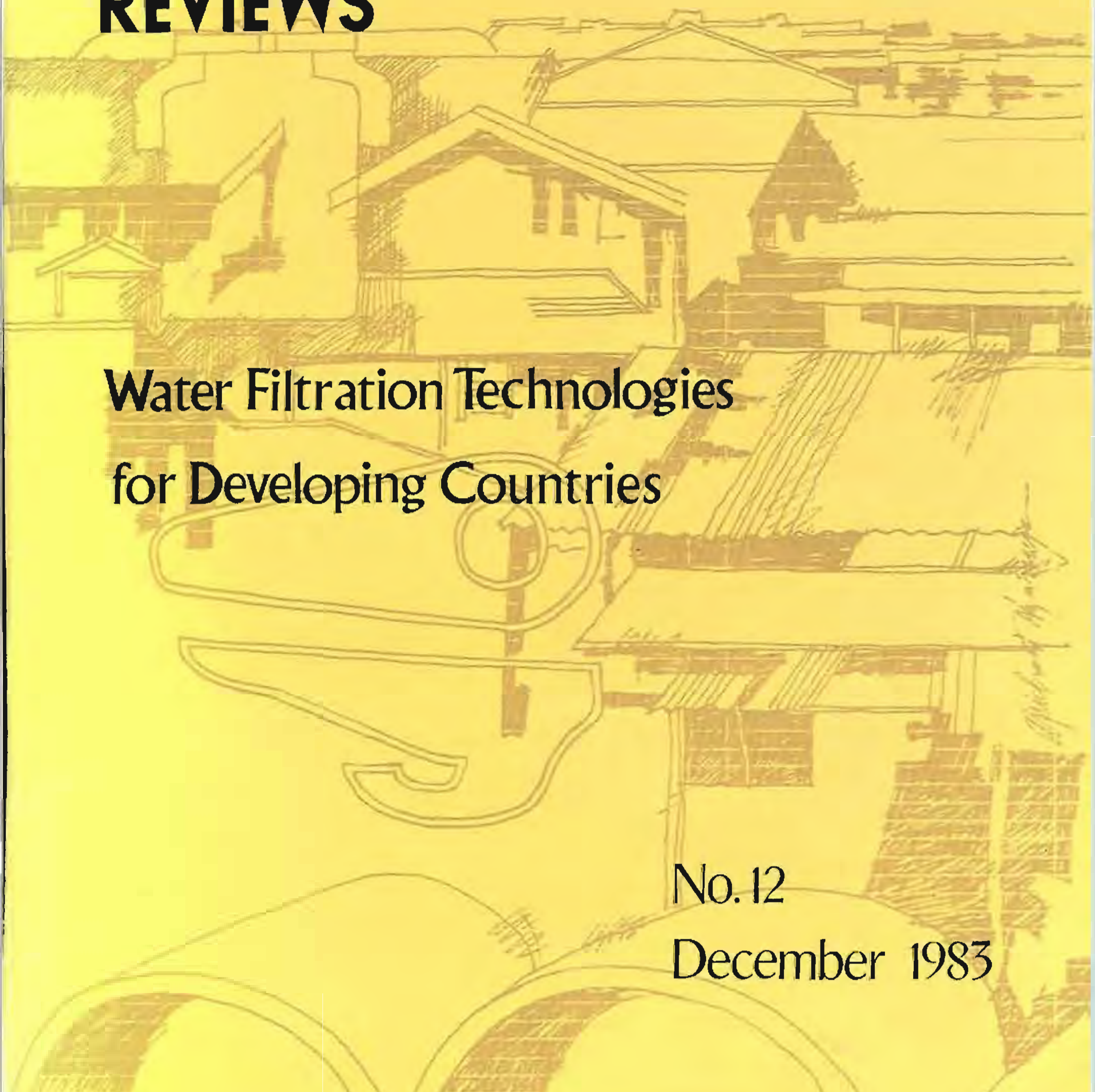

Water Filtration Technologies for Developing Countries

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C. Viswanathan

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WATER FILTRATION TECHNOLOGIES FOR DEVELOPING COUNTRIES

by

S. Vigneswaran

Assistant Professor
Environmental Engineering Division, AIT

D.M. Tam

Senior Information Scientist
Environmental Sanitation Information Center, AIT

C. Visvanathan

Graduate Student
Environmental Engineering Division, AIT

N.C. Thanh (Reviewer)

Editorial Board Member, ENSIC
Professor
Environmental Engineering Division, AIT

C.R. Schulz (Reviewer)

Research Assistant
Technology Advisory Group (TAG)
UNDP Interregional Project INT/81/047
The World Bank, U.S.A.

ENVIRONMENTAL SANITATION INFORMATION CENTER
BANGKOK, THAILAND
DECEMBER, 1983

Preface

The objectives of this review have been defined clearly by the authors in the introductory part, and so only a short note is necessary here. Perhaps the best summary of the reason behind the choice of this topic can be taken from the authors' words, indicating that they wish to introduce "the state-of-the-art of new or relatively new developments in water filtration as 'food for thought' for planners and designers ...who are involved in supplying clean water at an affordable cost to that half of humanity which does not have safe water near home."

This publication is a result of excellent teamwork. In the AIT team, the first two authors were classmates at AIT during 1968-1978, and both were former advisees of the first reviewer. The third author is an advisee of the senior author at the time of this writing. At the University of North Carolina at Chapel Hill, U.S.A., Kenan Professor (Emeritus) Daniel A. Okun initiated the review work to be carried out later by Christopher R. Schulz, his former advisee at Chapel Hill and is now based at the World Bank. ENSIC was fortunate indeed to have received the invaluable contribution from these two prominent figures in the field of water treatment.

This review is dedicated to the International Drinking Water Supply and Sanitation Decade 1981-1990.

The Editors

1981-1990

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Water Filtration Technologies for Developing Countries

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C. Visvanathan

1. INTRODUCTION

A safe and convenient water supply is of paramount importance to human health and the well-being of any society. In developing countries there are special features involved in achieving a satisfactory water supply, which must be carefully studied before general solutions based on the wide experiences obtained through their applications in developed countries are proposed. With this in mind, the present review concentrates on the unit operations of water filtration. Other unit operations in conventional urban water treatment plants, like rapid mixing, flocculation, sedimentation and disinfection - which have been well documented - will be omitted.

Filtration technologies are classified into two major categories, depending on the filtration rate: slow sand filtration and rapid filtration. Slow sand filtration has been extensively used in developing countries because of its simplicity in design, operation and maintenance with locally available skill. As extensive literature is available on slow sand filtration, the emphasis in the first part of this review is only on new developments in connection with slow sand filtration.

Rapid filtration options, on the other hand, have not been used in remote areas in developing countries due to the involvement of expensive or unavailable chemicals, sophisticated equipment, and relatively high-skilled personnel. Furthermore, experiences from various quarters have shown that the adoption of conventional filtration techniques in urban water treatment plants in developing countries has often been unsuccessful, since frequently they are poorly operated, partially destroyed or abandoned. However, the new modifications made to conventional rapid filtration may change the situation and make it suitable in urban areas in developing countries for the construction of new water treatment plants and for upgrading existing plants.

In this review, sections 2, 3 and 4 will deal with simple filtration technologies that are based on slow-rate filtration and are particularly suitable for small communities. From section 5 onwards, all the possible modifications of conventional rapid filtration and analyses of their suitability to developing countries, based on techno-economical considerations, will be presented. The review is not meant to serve as a manual for design, construction or operation. It simply introduces the state-of-the-art of new or relatively new developments in water filtration as "food for thought" for planners and designers. Consequently, the review will not present in detail the theoretical aspects of the relevant technologies, and only some brief discussion on theory will be given for introducing the subject under review. Instead, an evaluation of the pros and cons of the various technologies will be presented.

With a view to a wider dissemination of research results from one place to another, the authors will pay special attention to the studies carried out at the Asian Institute of Technology (AIT). Apart from documents dealing with specific topics which will be covered in this review, documents for general reading abound. Bibliographic items are incorporated in the list of references cited for further reading.

Notes on Turbidity Units

Whenever necessary, original data of different units from the literature have been converted to consistent units in order to facilitate comparison. However, this is not possible with turbidity. The turbidity of a suspension can be measured in terms of nephelometric turbidity units (NTU), Jackson turbidity units (JTU), and turbidity units (TU) on the silica scale. There is no direct relationship between NTU (which is the intensity of light scattered at 90° under defined conditions) and JTU (which is measured by the candle visual depth method). Turbidity is measured in terms of JTU when it is greater than 25 TU on the silica scale, whereas the NTU scale can be used for any turbidity ranges.

2. TRADITIONAL METHODS OF WATER FILTRATION

The rural populations in certain developing countries, because of their lack of resources and/or low level of technology, and since at the same time they are faced with an acute shortage of water and unacceptable water quality, adopt their own technology, known as traditional methods of treatment, to treat water on their own. This section describes briefly a few traditional filtration methods adopted by different countries. More details can be found in Jahn (1981).

2.1 Filtration Through Winnowing Sieve

This type of filtration is used when the water source is polluted by wind-born impurities such as dry leaves, stalks and coarse particles. The raw water is passed through a winnowing sieve, and the impurities are filtered. This type of filter is widely used in villages of the Bamaka area, Mali. The method cannot be used when the raw water is highly turbid or muddy, since this sieve cannot filter fine suspended particles in raw water.

2.2 Filtration Through Cloth

Thin white cotton cloth or a discarded garment is used as the filter medium. This filter can filter raw water containing such impurities as plant debris, insects, dust particles or coarse mud particles. Filtration of suspended particles present in the water can be achieved only to a very small extent. Therefore, this type of filtration is not suitable for highly turbid waters. It is most suitable for filtration of well water. This practice of cloth filtration is quite common in villages in India, Mali, the southern part of Niger and probably in many other parts of the developing world.

If the raw water is muddy and highly odorous, then wood ash from the Sal tree (Shora robuta) is mixed in the water and filtered through the cloth. This type of filtration is widely used in some Indian villages.

2.3 Filtration Through Clay Vessels

Clay vessels with a suitable pore size are sometimes used to filter highly turbid water. Turbid water is collected in a big clay jar and allowed to settle down. Then the water in the jar will trickle through the porous clay wall of the jar. This trickled water is collected in a vessel (usually a clay pot) by placing it at the bottom of the porous clay jar. This method of water filtration is common in Egypt.

2.4 Filtration Through Plant Material

Wiry roots of the Rhizoma from the "ramachham" (Vetiveria zizanoides) are placed in a clay jar, which has tiny holes in its bottom. Raw water is poured into this jar, and then the water is allowed to filter through this layer of roots. The water then trickles through the tiny holes at the bottom of the jar. The filtered water is collected at the bottom of the jar. Usually this filtered water is very clear and has a pleasant smell. This type of water filtration is common in Southern Kerala, India.

2.5 Jempeng Stone Filter Method

This type of water filtration method is developed in Saringan batu Jembeng, Bali, Indonesia. Here, a small artificial pond or a by-pass model is cut by the side of the irrigation canal, which carries muddy water (Fig. 1). Jempeng stone filter units are placed in the artificial ponds of the by-pass model. The filter unit is carved out of a porous material called "cadas". This unit has an average height of 60 cm, a diameter of 50 cm, and a wall with a thickness of 10-12 cm. This unit is placed on the top of a stone-supporting gravel bed. Muddy water filters through the porous wall of the filter unit and gets collected inside. This type of unit can be used as a village water treatment unit. It can treat even highly turbid water. The main feature of this unit is that the only cost involved is the investment cost. Practically there is no operational or maintenance cost such as for cleaning.

2.6 Filtration of Springwater as Source Protection Means

Source protection and improvement are permanent methods of ensuring the water quality against pathogens, harmful chemicals and other kinds of contaminants. In contrast, disinfection is a continuing task that does not deal with the cause of contamination. In China, where emphasis is put on prevention, techniques for improving water sources are preferable to disinfection, and they should be part of the barefoot doctors' curricula. For this reason, experience has been gained from various techniques of water source protection and improvement, chiefly based on filtration, and they are well compiled by IDRC (1981b).

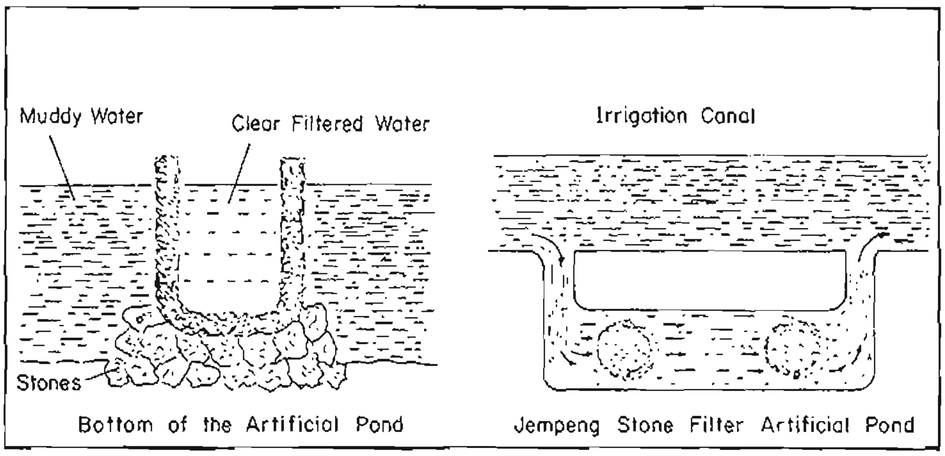


Fig. 1 : Jempeng Stone Filter

These filtration techniques (two types of which are shown in Fig. 2) are simple, and hence could be adapted elsewhere. Nevertheless, they may possess some limitations.

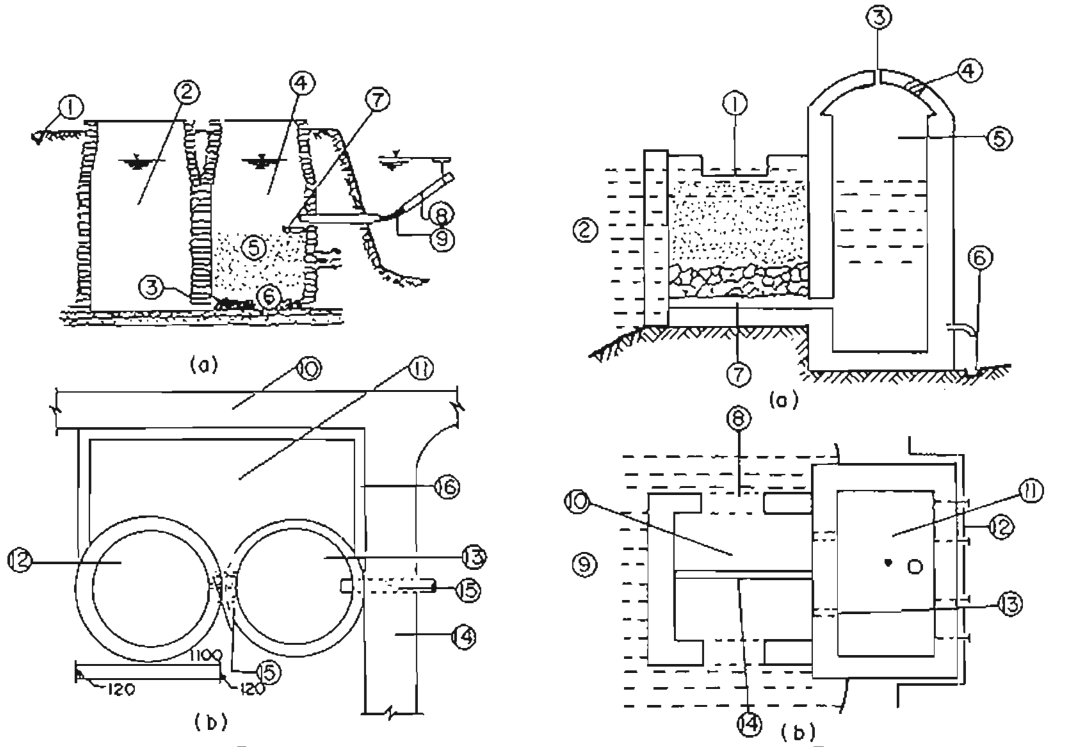
-- The first limitation arises from the fact that most of the described facilities for source protection and improvement are a type of "on-site" filter using sand. This material is a constraint in many large areas.

-- The second limitation of these designs is the lack of easy maintenance procedures. When the filter medium is clogged after being used for a certain time, similar procedures used for cleaning slow sand filters are applied. That is, "5 cm of sand is taken off the surface layer, washed and replaced, and then if the filtration rate does not recover, all the sand must be removed and thoroughly washed" (IDRC, 1981).

It can be expected that for many communities where public cooperation is poor, such a tedious procedure will not be followed. When a filter which is supposed to protect/improve the source is blocked, the users may simply abandon the filter and turn to contaminated sources. But in places where the beneficiary community is well organized and managed, the provision of such water source protection and improvement is definitely recommended.

2.7 Conclusion

Even though these traditional methods are expedient and can remove certain types of particles in water, they may not assure satisfactory drinking water standards, even in terms of turbidity. Therefore, it is advisable to add disinfectants so that, whatever other defects these methods may have, they will yield at least water free from pathogens.



(a) the cross section ① ditch ② pure-water tank ③ water inlet ④ sand-filtering well ⑤ coarse sand ⑥ pebbles ⑦ stepping brick ⑧ intake pipe bamboo and ⑨ rubber joint
(b) the plan ⑩ earth ⑪ impervious apron ⑫ pure-water tank ⑬ sand-filtering well ⑭ earth ⑮ water inlet and ⑯ ditch

(a) the cross section ① intake, 55 mm higher than the sand surface ② source ③ vent ④ entrance ⑤ pure-water tank ⑥ ditch and ⑦ drain
(b) the plan ⑧ intake ⑨ source ⑩ sand-filtering well ⑪ pure-water tank ⑫ ditch ⑬ drain and ⑭ drain

Fig. 2 : Two Types of Sand-Filtering Wells in China

3. LOW-COST HOUSEHOLD WATER TREATMENT METHODS

The supply of safe drinking water in a short period is in practice a difficult task. In view of increasing population, the demand for water and investment in water treatment in developing countries, it is always advisable to look for simple and less costly household water treatment methods. The following are a few low-cost household water treatment methods which can be used in rural areas.

3.1 Filtration and Syphoning Techniques

Raw water is stored in a clay jar with a rigid plastic tube, and a small filter device is immersed in this storage jar below the water level. The filter medium can be as simple as just thin cloth, or a piece of cotton placed in such a way that it can filter the water. The other end of this rigid tube is connected to a flexible plastic tube and placed inside a filtered water storage tank (Fig. 3). This filtered water tank is placed below the raw water storage jar level. By using a small rubber bulb to create a suction at the outlet end of the flexible plastic tube, the water can be made to flow from the raw water storage jar to the filtered water storage pot. During this process, sedimentation of coarse particles will take place first in the raw water jar. Then the suspended solids present are filtered by the filtering device. This method can be used for low- and medium-turbid waters. The size of the unit can be chosen according to the domestic water requirement. When the filter unit gets clogged, it has to be replaced.

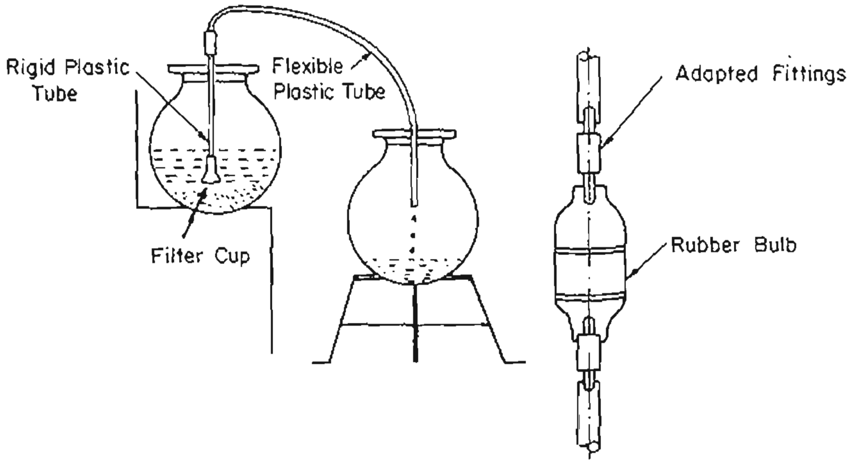


Fig. 3 : Suggestions for Syphoning from Clay Jars

3.2 Water Coagulation and Sand Filtration

3.2.1 Principles

Raw water is filled in a galvanized iron drum and then coagulant is added into it. Coagulation and settling take place in this drum. The settled water is collected through a PVC pipe connected to the drum and sent to a meshed sand filter unit (Fig. 4). This filter unit is immersed inside a clay pot, and the filtered water is collected in this pot. Usually this filtered water storage pot is fixed with a tap at the bottom of the pot for water withdrawal. When the filter unit gets clogged, the media and cloth are washed and used again.

3.2.2 Applicability

This type of system can be used to filter waters of medium turbidities, and one unit can be shared by 2 to 3 families of 4-5 members each. The clear water collected from the unit can be used for drinking and cooking purposes.

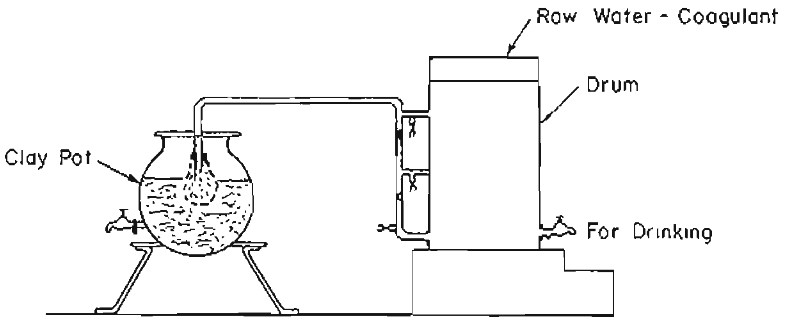


Fig. 4 : Household Unit for Coagulation, Filtration and Storage

3.3 Water Filter Canister

A water filter canister shown in Fig. 5 has been developed and tested by Frankel (1973). Using the canister intermittently wet-dry-wet-dry appears to be workable and produces a satisfactory water quality. Originally designed for individual soldiers in the field away from a field water treatment installation, the design can be adapted for farmers, for instance, who have to work during the day in their fields, or miners who have to work in a mine - groups of workers who are liable to be away from a pure drinking water source. Even though further testing is needed, final design and operating criteria can be recommended (Frankel, 1973).

3.4 Household Slow Sand Filtration Units

In at least every urban center of developing countries, there are in practice various household water filtration units, some are home-made and most are manufactured and marketed by commercial firms. They are too numerous to be elaborated, and only two units are described here.

3.4.1 Indian Design

This design (Fig. 6) applies the principles of conventional slow sand filtration to suit the household requirement and operating conditions in developing countries (Dhabadgaonkar, 1982).

This type of water filtration technique is designed for a family of 4, with a per capita water requirement of 10 liters per day. The main components of this unit are described below.

Filter Box with Inlet and Outlet Control Valves. The filter box is made of a circular AC pipe, and contains gravels at the bottom as a supporting medium and sand on the top as a filter medium. The function is the same as that of the conventional slow sand filtration unit with a continuous operation cycle (24 hours). The raw water storage tank is placed at a higher level than the filter unit, and the raw water is withdrawn from the storage tank through a flexible PVC tube. The flow to the filter unit can be controlled by adjusting the valves fixed in the flexible tube (near the outlet of the storage tank). The flow is adjusted using a float valve on the top of the filter unit.

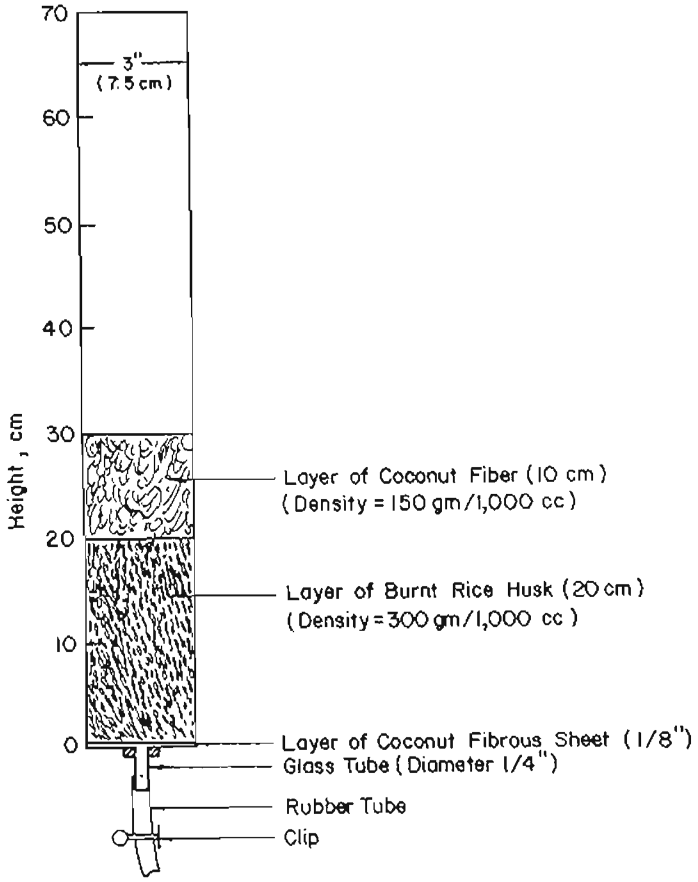


Fig. 5 : Design of Filtration Canister Showing Layers of Media Used in Laboratory Test

The raw water in the filter unit will trickle through the sand bed and is collected at the bottom of the unit. The outlet of the unit is connected to a piezometer tube and a visual aid. The visual aid unit will help to control the flow rate.

By looking at the visual aid unit, one can easily adjust the flow rate. The operation of this filter unit is simple, and can even be carried out by people who are not trained as technicians. The outlet tube of the unit is connected to the filtered water storage unit.

Raw Water Storage. The raw water storage can be a clay pot or a plastic container to hold a quantity of more than 40 liters (usually in the size range of 50 liters) of water. It is normally filled only once a day, and should be placed above the filter unit (around 2.0 m above ground level).

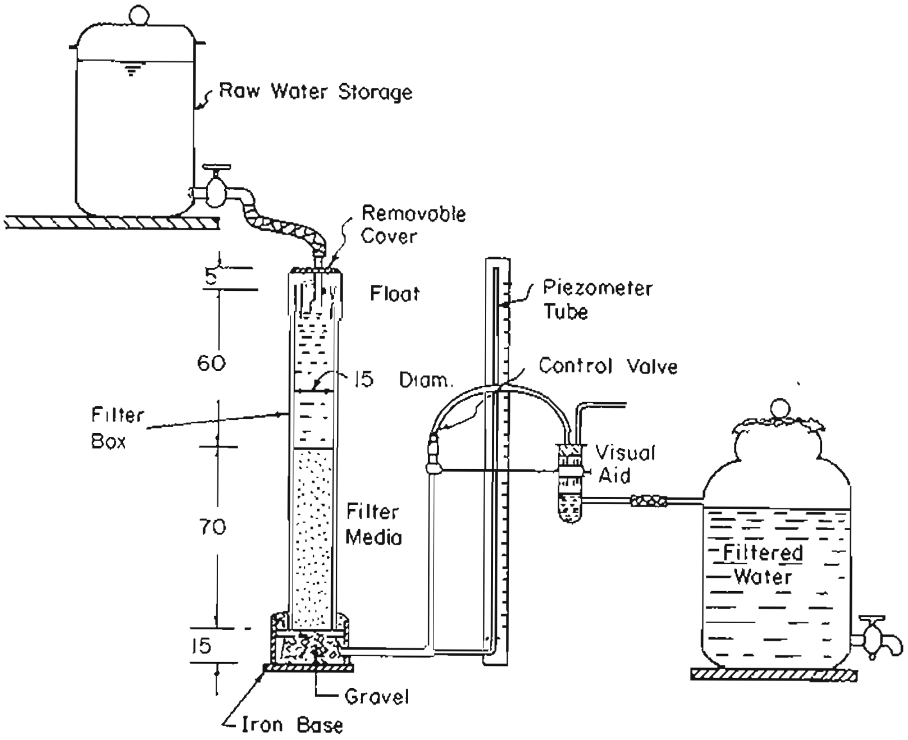


Fig. 6 : Household Filtration Unit, Indian Design (Dimensions in cm)

Filter Water Storage. This storage unit should have a capacity to hold at least a 2-day water demand (more than 80 liters), which means that it should generally have a capacity of about 100 liters. It is quite important to note that this unit should be made out of non-corrosive materials such as plastic or clay. This filtered water storage unit should have a tap at the bottom to withdraw water.

Filter Cleaning. The headloss build-up in the unit can be observed in the piezometer tube. When it reaches the maximum allowable limit, the inlet valve is closed and the filter run is stopped. The removable cover placed on top of the filter unit is removed with the float valve, and the top 10-20 mm of the top sand layer is replaced with new sand.

Design Criteria. The design parameters are summarized in Table 1.

Economics. As per Indian cost standards, the construction cost of this unit is approximately US$ 35, including the earthen raw water storage container and filtered water storage tank (Dhabadgaonkar, 1982).

Table 1: Design Parameters of Household Slow Sand Filtration Unit.

Parameter	Values
Filter Box	
Material	AC pipe
Diameter	15 cm.
Height of the filter box	150 cm.
Height of the supporting gravel	15 cm.
Height of the sand bed	70 cm.
Height of the supernatant water level	60 cm.
Height of the free board	5 cm.
Filter Media	Sand with E.S = 0.15–0.20 mm U.C. = 2–3.
Filtration Rate	0.1 $m^3/m^2 \cdot h$ (to get filtered water quantity of 40 l/day).
Filter Run (Backwashing frequency)	Depends on raw water characteristics.

3.4.2 Thai Design

This filter unit design is being promoted by the Sanitation Division of the Thai Ministry of Public Health. The filtration process consists of two stages, the first is with coarse sand and the second is with fine sand. Fig. 7 (Sanitation Division, 1983) illustrates the unit, which consists of two filter compartments, the second is incorporated with a clear water storage. Charcoal is used when the raw water contains colored or odorous materials. The total capacity of the filter is 50 liters, and the clear water storage capacity is 15 liters. An interesting feature is that water for non-drinking purposes can be obtained after is has been partially filtered through the first half of the unit, whereas drinking water can be obtained after it has been filtered by the whole filter media. This lightens the burden of the unit, and consequently extends the filter-run length. However, the two-compartment arrangement of the filter unit, as shown in Fig. 7, creates a flow of water in the order of fine--coarse--coarse--fine, which is irrational.

Design Criteria. Sand specifications are as follows:

- For coarse sand : the depth is 5 cm, and the size is 1.25-2.00 mm
- For fine sand : the depth is is 30 cm, and the size is 0.20-1.25 mm.

No details on the filtration rate and capacity are given.

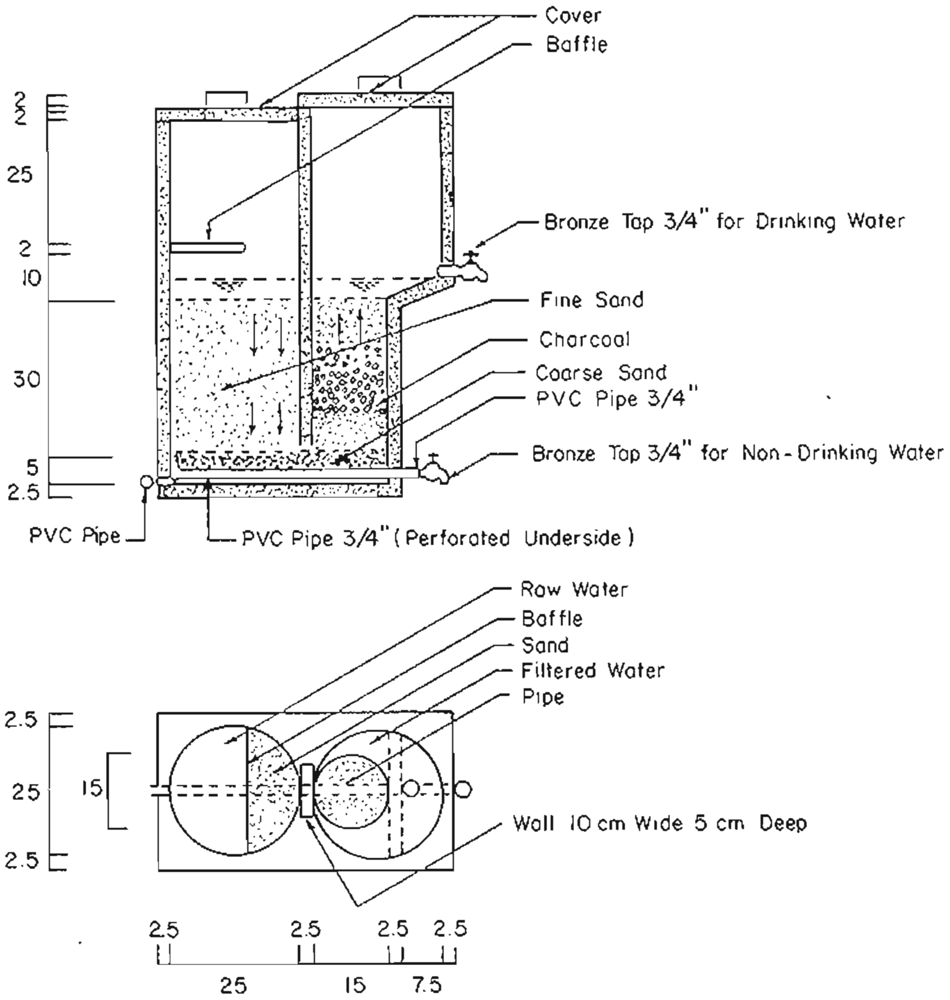


Fig. 7 : Household Filtration Unit, Thai Design
(Dimensions in cm)

Construction. The unit can be constructed on a self-help basis, using a wooden mold (which costs about 2,000 Baht or US$ 87, 1983 prices) or an iron mold.

The bill for construction materials is :

- 40 liters of cement
- 80 liters of construction sand
- 25 liters of filtration sand
- 12 pieces of concrete block

3.4.3 Advantages

++ The use of household water treatment methods should be encouraged, at least until a public water supply system is installed to deliver safe water at the consumer end. The household slow sand filter yields drinking water of high standards if properly disinfected.

++ Perhaps the most distinct merit of household water treatment units is that in places where they are affordable, the local authorities may find it is easy to encourage a willingness to pay from the users, since people will readily perceive that the unit is their own. An additional merit is that due to this feeling of ownership, the unit will be continuously kept in a state of good repair.

3.4.4 Disadvantages

-- In order to reduce the initial cost, a substantial number of householders should adopt this scheme, so that the units can be mass-produced.

-- Each householder should understand well how to operate and maintain his unit correctly. In many rural areas of developing countries, mass education to bring this knowledge to every household may be difficult.

-- There should be an effective system to distribute necessary materials such as sand, chemicals, replacement parts, etc.

-- The operating and maintenance cost per unit volume of water treated by household units is usually higher than that of community plants.

-- Household units are not likely to be readily accepted by poor families or families with ignorance or little awareness, and hence they may widen the gap between the rich and the poor, or between the knowledgeable and the ignorant.

-- The disadvantage noted above is compounded by the fact that household units are still too complicated for most applications in rural areas. Their proper use can be attained only through vigorous education, which is normally not possible under rural, backward circumstances.

3.4.5 Conclusion

Due to the above reasons, household water treatment units should be better considered only as a temporary solution for those who can afford or have sufficient awareness to adopt them.

4. SLOW-RATE FILTRATION

4.1 General

When designing a water treatment system for a rural population, one should adopt at least the following criteria : (i) low-cost technology (both low capital and operation and maintenance); (ii) use of locally available materials; and (iii) involvement of little or no skilled personnel for the construction as well as the operation and maintenance of the facility.

In rural areas, especially in developing countries, there is no problem of land availability. Therefore one could use the slow sand filters with success if the raw water is not highly turbid (less than 50 NTU). If the turbidity is high, then one has to have a pre-treatment prior to slow sand filtration. In place of slow filters, one could also use different types of filtration systems depending on the size of the community, the water source, the soil conditions below the water source, etc. Therefore, this section will present different types of filtration technologies which could be used in rural areas in developing countries.

4.2 Slow Sand Filtration (SSF)

Numerous documents on this well-known water filtration technology are available for detailed study. This part, therefore, gives only some overview of the basic aspects involved. The selected and annotated bibliography by the International Reference Centre for Community Water Supply and Sanitation (IRC/CWSS, 1977b) is a good reference tool to start with. The reader is also referred to various documents, among which is the comprehensive treatise by Huisman & Wood (1974), which is still a very useful reference on SSF. The paper by Huisman (1978) is a concise condensation of the principles and practices of SSF in developing countries, and is accompanied by stimulating discussions. IRC/CWSS has made great efforts in promoting SSF, and has produced excellent publications on this subject (IRC/CWSS, 1977a; 1977b; 1981a, 1983a; 1983b). In particular, the report of an international appraisal meeting (IRC/CWSS 1981a) contains an appraisal of the results and experience in the development, implementation and evaluation of demonstration SSF projects in Colombia, India, Jamaica, Kenya, Sudan, and Thailand. Paramasivam et al. (1981) give a brief state-of-the-art of SSF, and Komolrit & Chainarong (1979) detail the application status in Thailand. Up-to-date guidelines for operation, construction and maintenance of SSF plants in rural areas of developing countries have been prepared by van Dijk & Oomen (1978) and IRC/CWSS (1983a, 1983b). Economic data are not given in these publications.

4.2.1 Principles

Water is purified by passing it through a bed of fine sand at low velocities (0.1-0.3 m^3/m^2-h), which causes the retention of suspended matter in the upper 0.5-2 cm of the filter bed. By scraping out this top layer, the filter is cleaned and restored to its original capacity. The interval between two successive cleanings varies from a few weeks to a few months, depending on the raw water characteristics.

The removal mechanisms of particles in a slow sand filter include mechanical straining, sedimentation and adsorption, and chemical and biological activities. Large and fine particles of suspended matter are deposited at the surface of the filter bed by the action of mechanical straining and sedimentation respectively, while colloidal and dissolved impurities are removed by the action of adsorption. By chemical and biological oxidation, the deposited organic matter is converted into inorganic solids and discharged with filter effluent. Microbial and biochemical processes, and hence the removal of impurities, take place chiefly in the top layer of the filter bed, the "schmutzdecke".

4.2.2 Effects of Intermittent Operation

Purification in a slow sand filter is essentially a biological process, and the filters depend upon a balanced biological community in the zoological film (the "schmutzdecke") for efficient functioning. For this reason, it is desirable to design the filters to operate continuously without interruption and, as far as possible, at a constant filtration. However, the operation of slow sand filters in most developing countries is intermittent due to the financial difficulties in employing operators to run the plants round the clock. A survey conducted by the National Environmental Engineering Research Institute (NEERI) in India has shown that most of the slow sand filters used in small communities work for part of the day only (Paramasivam & Sundaresan, no date). Paramasivam et al. (1980) from their comparative study concluded that the bacteriological quality of filtered water is adversely affected due to intermittent operation. They proposed two alternatives to overcome this disadvantage, namely :

** Declining-rate filtration (section 6.1) after a cycle of continuous operation.

** Incorporation of a separate raw water storage tank at a higher elevation to feed the filters, so that the operation can be made round-the-clock.

4.2.3 Design Criteria

The important design parameters in SSF are the depth of the filter bed, the filter media size, the filtration rate, and the depth of the supernatant water level. As far as possible, these design parameters should be based on experience obtained with existing treatment plants which use the same water source of a similar quality. In the absence of reliable data from existing treatment plants, pilot plants can be used to determine suitable design criteria. The values presented in Table 2 can serve as helpful guidelines.

4.2.4 Economics

A detailed cost estimate based on 1979 prices (in Nagpur, India, and excluding contractor's profit) from various materials and items of work has shown that the filter bed cost per m^2 is Rs. 350 (US$ 43.75), and the cost per meter of wall length is Rs. 570 (US$ 71.25). Table 3 (Paramasivam et al., 1981) gives the costs for filters ranging in total areas from 50 to 2,000 m^2. With a supply rate of 70 lpcd, this would serve a population range from 1,700 to 68,000 people. A large percentage of villages and small towns in developing countries fall within this population range.

The percentage of an increase in cost with reference to the minimum of a two-filter unit is shown in Table 4. This table indicates that the number of filters can be raised from 2 to 3 by spending roughly 2 to 8% more money. Building 5 units instead of 2 costs roughly from 6 to 22% more. It can be concluded that there is no significant cost penalty for building more than 2 filters in order to gain reliability and operation flexibility.

Cost analyses for SSF in Thailand are provided by Komolrit & Chainarong (1979) and Thanh et al. (1981).

Table 2: Design Parameters of Slow Sand Filtration.

Design Parameters	Range of Values
1. Filtration Rate	0.1 $m^3/m^2 \cdot h$ (0.1-0.2 $m^3/m^2 \cdot h$)
2. Area per Filter Bed	10-100 m^2
3. Number of Filter Beds	Minimum of 2
4. Depth of Filter Bed	1 m (1.0-1.4m)
5. Specification of Sand Medium	E.S. = 0.15-0.35 mm, U.C. = 2-5
6. Height of Supernatant Water	1 m (1.0-1.5 m)
7. Underdrain System:—	
a) Standards bricks b) Precast concrete slabs c) Precast concrete blocks with holes in the top d) Porous concrete	One of these systems can be used as underdrain system without further hydraulic calculations
e) Perforated pipes (laterals and Manifold type) (attractive for small filters)	Maximum velocity in manifold and in laterals = 0.3 m/s Spacing of laterals = 1.5m Size of holes in laterals = 3 mm (2-4 mm) Spacing of holes in the laterals = 0.15 m (0.1-0.3 m)
f) Gravel or broken stones (suitable for a filter bed of maximum area of 25 m^2)	Height of gravel layer = 4-15 cm Gravel size = 25-50 mm

4.2.5 Advantages

++ Slow sand filtration is an appropriate treatment method for surface waters since its power requirements are minimal, and no chemicals that are expensive or difficult to acquire are needed. Chlorine is normally used, but the required dosage is reduced because of biological treatment in the filter bed. In short, slow sand filtration is an efficient method for the removal of organic matters and pathogenic organisms.

++ The design, construction and operation can be made with locally available materials and skills. No special equipment is needed except the common pipe work and appliances. Therefore, if sufficient filter bed materials are available, the cost of construction becomes very low.

Table 3: Cost (Indian Rs.) of Slow Sand Filter

Area m^2	Indian Rupees			
	Two Units	Three Units	Four Units	Five Units
50	37 234	40 300	42 980	45 407
100	62 908	67 240	71 204	74 467
150	86 700	91 990	96 618	100 859
200	109 468	115 600	120 958	125 814
300	153 336	160 816	167 198	173 400
400	195 814	204 480	212 048	218 934
500	237 414	247 048	255 540	263 236
600	278 400	288 934	298 236	306 729
700	318 872	329 872	340 304	349 378
800	359 002	371 200	381 860	391 629
900	398 780	411 716	423 072	433 400
1000	438 236	451 960	463 886	474 762
1200	516 786	531 720	544 830	556 800
1500	533 072	649 852	664 478	677 874
2000	824 830	844 188	861 082	876 472

**US$1 = approximately Rs. 10*

++ If the influent turbidity is less than 50 NTU, no chemicals or pre-treatment facilities are needed.

++ Sludge handling problems are minimal, since the sludge quantity produced is small and has a very high dry matter content.

In addition, the following advantages can be obtained if slow sand filters are operated in declining-rate mode after one or two shifts of constant-rate operation:

++ Declining-rate mode may be applied during nighttime, resulting in significant savings of labor and capital investment costs.

++ It results in an extra water production of 0.5 m^3/m^2-d for 8 hours of declining-rate filtration and 0.7 m^3/m^2-d for 16 hours without any additional operation and labor costs.

++ This mode of operation maintains a consistently good bacteriological quality of the filtered water, which can otherwise be adversely affected by intermittent operation. In fact, effluent quality is better when the filtration rate declines towards the end of the run.

Declining-rate filtration will be discussed further in section 6.1.

Table 4: Percentage Increase in Cost (Indian Rs.) of Two Units When a Given Number of Filter Units is Provided for a Given Area

Area (m^2)	Rate of Cost Increase		
	Three Units (percent)	Four Units (percent)	Five Units (percent)
50	8.23	15.45	21.95
100	6.68	12.90	18.37
150	6.10	11.44	16.33
200	5.60	10.49	14.93
300	5.81	9.04	13.08
400	4.42	8.29	11.80
500	4.05	7.53	10.87
600	3.78	7.12	10.17
700	3.44	6.72	9.56
800	3.39	6.36	9.08
900	3.24	6.09	8.68
1000	3.13	5.85	8.33
1200	2.68	5.42	7.74
1500	2.65	4.96	7.07
2000	2.34	4.39	6.26

4.2.6 Disadvantages

-- Waters of high turbidity (more than 50 NTU) are not suitable for slow sand filtration. In this case, some pre-treatment has to be applied.

-- Slow sand filtration cannot handle high concentrations of colloidal turbidity, even with pre-treatment facilities.

-- Slow sand filtration requires a large area of land and a large quantity of filter medium.

-- In some areas, sand is not locally available but has to be hauled from another area. This increases the cost substantially.

-- If the development of certain type of algae in unacceptable amounts is expected, it becomes necessary to install a roof structure to prevent the entrance of sunlight, and this adds to the expenses.

-- A sudden change in raw water quality (like an increase in turbidity during the rainy season) could upset the performance of biological filters.

4.3 Horizontal-Flow Coarse-Media Filtration

4.3.1 Principles

Horizontal-flow pre-filtration using coarse gravels or crushed stones as filter media is a sound technique in handling highly turbid waters. The main advantage of horizontal-flow filtration 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. At the same time, biological mechanisms similar to those in slow sand filtration help remove pathogens. Research at the Asian Institute of Technology (Thanh & Ouano, 1977; Thanh, 1978) has indicated that the unit can account for 60-70% of turbidity removal and for about 80% of coliform removal.

The horizontal pre-filter design follows the rectangular sedimentation tank with inlet, outlet and filtration/ sedimentation zones. In the direction of flow, water passes through various layers of graded coarse material in the sequence of coarse--medium--fine--medium--coarse (Fig. 8). Each layer of gravel is separated by a strong wire mesh.

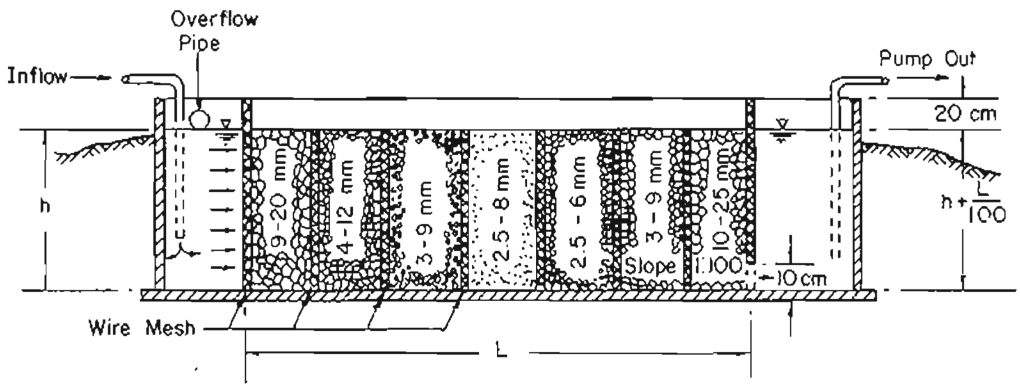


Fig. 8 : Horizontal-Flow Coarse-Media Filter

4.3.2 Design Criteria

A series of research on horizontal-flow coarse-media filtration have been conducted by AIT (Chenboonthai, 1978; Equina, 1979; Sivakumar, 1976; Thanh, 1978; Thanh & Ouano, 1977). The results from these researches have formed a good data base for the process. The design criteria of horizontal-flow pre-filtration is presented in Table 5. If the inlet and outlet compartments are exposed to sunlight, there may be algal growth. This can be prevented by having a cover against the sunlight. Further details on design, operation and maintenance procedures can be found from a manual prepared by Thanh & Hettiaratchi (1982).

4.3.3 Economics

The cost of one m³ of treated water is approximately US¢ 5 (1978 prices in Thailand), which is quite reasonable as far as rural water supply is concerned.

Table 5: Design Parameters of Horizontal Flow Pre-Filter

Parameter	Range of Values
Filtration Rate	0.3-1.0 $m^3/m^2 \cdot h$
Optimum Filtration Rate	0.5 $m^3/m^2 \cdot h$ for low turbid waters (15-50 NTU) 0.3 $m^3/m^2 \cdot h$ for high turbid waters (up to 150 NTU)
Depth of Filter Bed	1 m (0.8-1.5 m)
– Water level	0.8 m
– Free board	0.2 m
Length of the Filter	5 m (4-10 m)
Length: Width Ratio	1:1 to 6:1
Area of the Filter	10-100 m^2
Specification of Filter Bed (in the direction of flow)	9-20 mm gravel 4-12 mm ,, 3-9 mm ,, 2.5-8 mm ,, 2.5-6 mm ,, 3-9 mm ,, 10-25 mm ,,
Slope at the Bottom	A slope of 1/100 is provided towards the effluent end to facilitate the flow of pretreated water
Covering of Inlet and Outlet Compartments	This is made if the filter is exposed to sunlight

4.3.4 Applicability

This filter can be successfully used as a pre-treatment unit to waters with a turbidity of 150 NTU and over. Like slow sand filtration, this type of filtration is not effective in removing the alkalinity and hardness of raw water.

4.3.5 Advantages

++ This type of horizontal-flow pre-filter can be successfully used as a pre-treatment unit for waters with a turbidity range of 50-150 NTU.

++ The cost of this system is relatively low.

++ Operation and maintenance can be carried out by non-skilled or low-skilled laborers.

++ Cleaning of this pre-filter is not required frequently. In fact, cleaning is only necessary about once every 4-5 years.

++ It can withstand the seasonal variations of water quality.

4.3.6 Disadvantage

-- The land requirement for the system is high, and may be even higher than with slow sand filtration.

-- Crushed stones as filter media may be a constraint.

4.3.7 Application Status

The water treatment plant at Jedee Thong Village, Thailand, uses a horizontal-flow coarse-media filter to pretreat the raw water prior to the application to slow sand filtration for potable water supply to approximately 720 residents. Table 6 summarizes the performance of the system. Several full-scale systems of this type have been operating in rural Thailand for some years without any trouble (Thanh & Hettiaratchi, 1982).

Table 6: Performance of Horizontal Pre-Filter and Slow Sand Filter in Jedee Thong Village Water Treatment Plant. (Thailand)

System	Turbidity (JTU)		Total Coliform (MPN/100 ml)		Head Loss, Development (cm/day)	Filter Run
	Influent average	Effluent average	Influent average	Effluent average		
Horizontal Pre-Filter	25	12	5000	1000	0.6	
Slow Sand Filter		3		100	0.5	More than 5 months

4.4 Filtration with Alternative Media

4.4.1 Principles

A series of research projects at the Asian Institute of Technology (Fan, 1974; Frankel, 1973;1977;1979; Jaksirinont, 1972; Leow, 1976; Low, 1973; Sevilla, 1971; Thanh & Pescod, 1976; Wagh, 1977) were carried out with the intention of seeking alternative media for the conventional materials used in water filtration. Various materials were tried, such as pea gravel, raw rice husk, burned rice husk, coconut fiber, etc. The research has led to the development of an appropriate-technology type filter which consists of two stages, namely:

** A first-stage filter (roughing filter) using shredded coconut husk fiber as a filter medium to filter out the coarse suspended solids from the water.

** A second-stage filter (polishing filter) using burned rice husk as a filter medium to remove the residual turbidity and other contaminants.

It is believed (Frankel, 1977) that the first stage, through surface phenomena, serves a role similar to that of coagulation/flocculation, hence for many waters no coagulants need to be used. However, for some water sources, small dosages of coagulants may be necessary to complete the coagulation/flocculation process in the first stage. The second stage is similar to that of a sand filter. In addition, the presence of the burned carbon in this stage serves to some extent to absorb organic materials similar to absorption by activated carbon. Past experiences have confirmed these assumptions. Low (1973), from his studies on two-stage filtration, concludes that the system can produce an effluent which can meet the WHO drinking water standards in terms of turbidity and color.

Fig. 9 (Frankel, 1977) shows a system installed for the Bicol River Basin Council Program Office, the Philippines, and Fig. 10 (Frankel, 1979) illustrates a smaller unit built at Bansom, Thailand. If the turbidity of raw water is low enough, the first-stage filter can be eliminated, as shown in Fig. 11 (Frankel, 1977). The piping can be arranged in such a way that the users can take either the raw water or treated water, depending on the purpose. Alternatively, instead of separate, two-stage filtration, the two materials, burned rice husk and coconut fiber, can be combined into a single-stage, dual-media filtration unit. Thanh & Pescod (1976) state that, from an economic point-of-view and in terms of filter run, this scheme is more effective than the series filtration system.

4.4.2 Design Criteria

Table 7 gives the design criteria of this innovative filter system. More details can be found from Frankel (1977).

4.4.3 Operation and Maintenance

Guidelines for the operation and maintenance of the filter have been prepared by Frankel (1979). The following paragraphs describe briefly the salient points.

Filter Media Preparation

Shredded coconut fiber may be prepared by soaking the husk for 2-3 days in water, then shredded by pulling off the individual fibers one by one and removing the solid impurities which bind the fibers. The fibers can also be purchased from coir factories or upholstery stores. Both long and short fibers can be used as the filter medium.

Partially burned rice husk (taken from the drier furnace of a rice mill) is sieved using a 1/8" mesh wire screen (or mosquito net). The sieved burned rice husk is put in water and mixed, then the supernatant water with fine ashes are discarded. This washing procedure is repeated three times.

Cleaning of Filters

Coconut Fiber Filter. When the headloss is equal to the freeboard above the medium (which is 1 m), the filter run is stopped and the used coconut fibers are replaced with new coconut fibers. If the purchase of new fiber is difficult or expensive, the medium is cleaned by soaking and pounding the medium, then rinsing it with clean water.

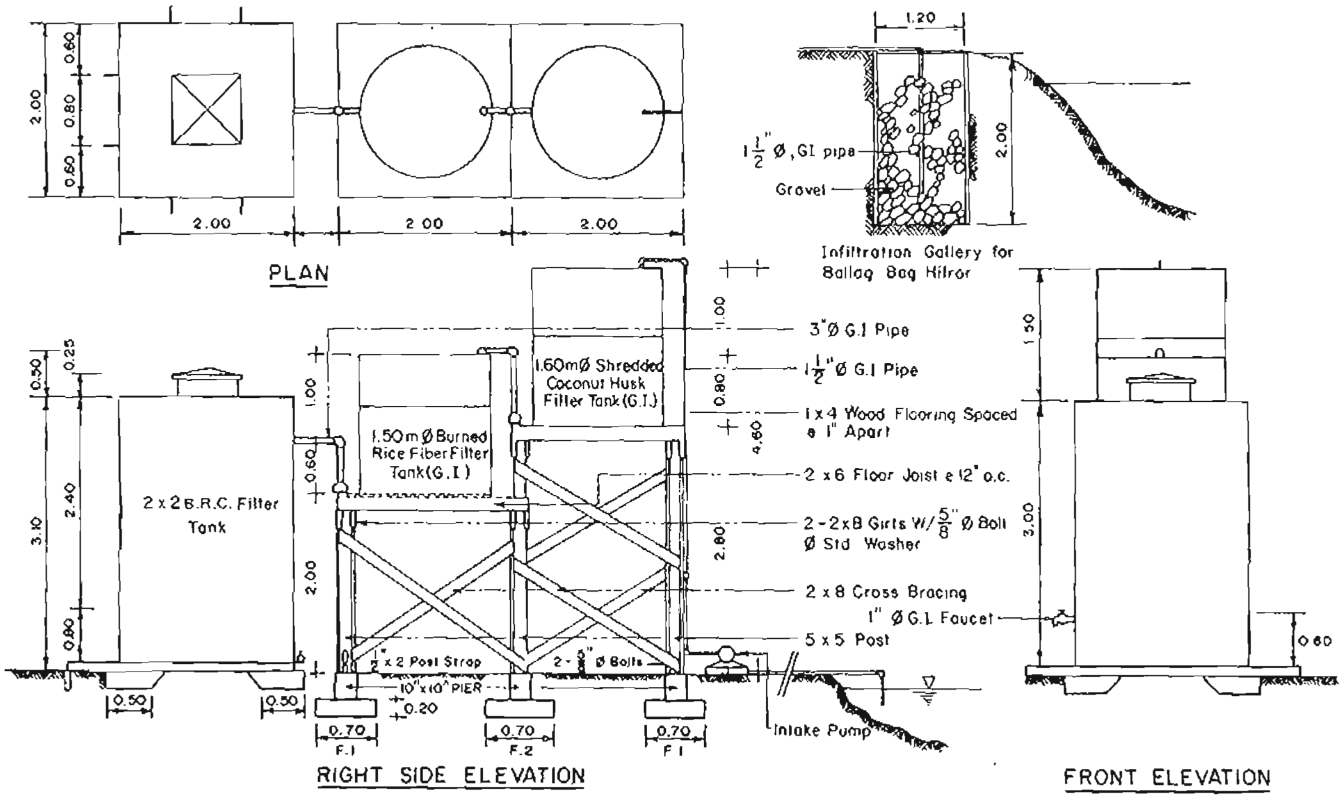


Fig. 9 : Schematic Diagram of Two-Stage Filter
(Dimensions in cm, except otherwise indicated)

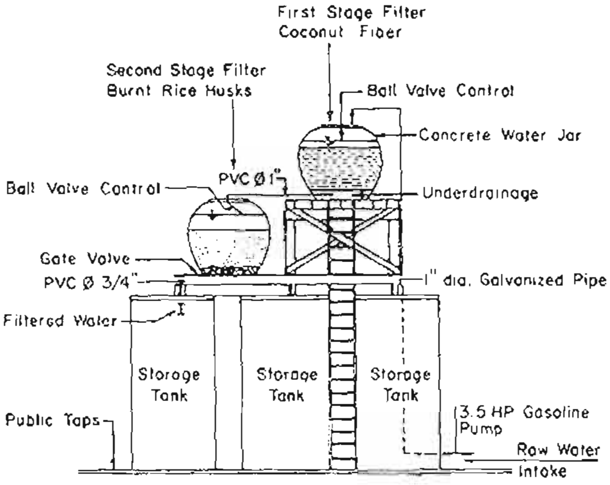


Fig. 10 : Two-Stage Filtration Unit Constructed at Ban Som, Korat, Thailand

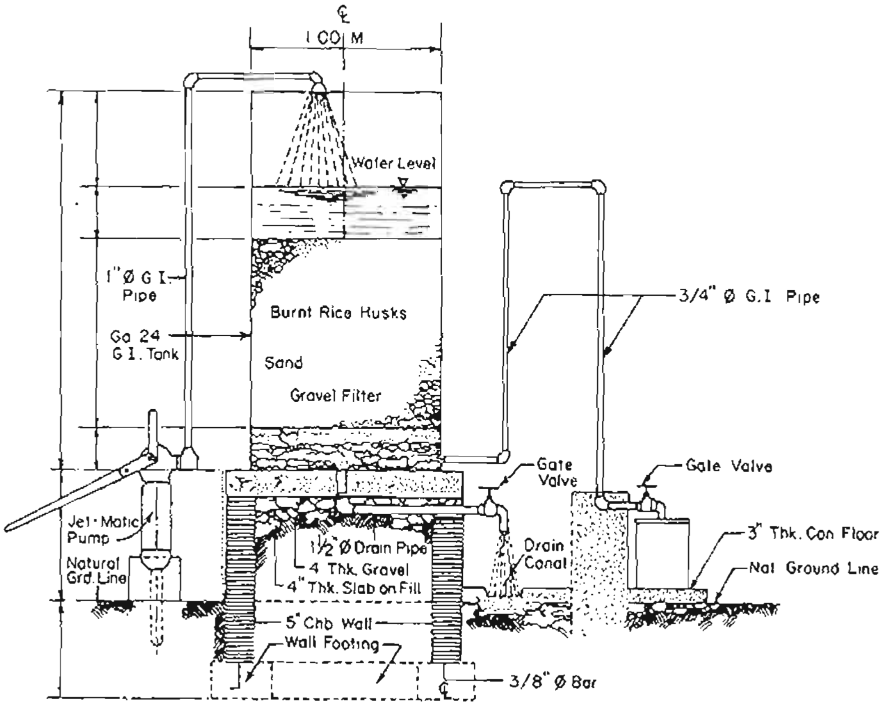


Fig. 11 : Single-Stage Burnt Rice Husk Filter

Table 7: Design Parameters of Two-Stage Filtration

Parameter	Range of Values	
	Coconut Fiber Filter (1st Stage Filter)	Burnt Rice Husk Filter (2nd Stage Filter)
Filter Depth	60-80 cm	60-80 cm
Freeboard	1.0 m	1.0 m
Filtration Rate	1.2-1.5 $m^3/m^2 \cdot h$	1.2-1.5 $m^3/m^2 \cdot h$
Underdrain System		
i) Gravel layer (supporting media)	Pea gravel of 1/8 to 1/4" (5 to 10 cm depth)	
ii) Lateral, manifold underdrain system	Main drain and lateral pipe material: G.I. or PVC pipes.	
	Spacing between orifice:	0.3 m
	Spacing between laterals:	0.3 m
	Diameter of orifice:	0.6 cm
	Ratio of area of orifice to lateral:	1:2
	Ratio of area of lateral to main drain:	1:1.5

Burned Rice Husk Filter. When the headloss is higher than 1 m, pumping is stopped and the top 10 cm of the medium is scraped off and the operation is started in a normal way. If the medium depth is less than 0.6 m after the scraping operation, a new medium needs to be inserted.

In both filters, filter washing takes place once in every three to four months, depending on the turbidity of the raw water.

4.4.4 Economics

A comparative analysis (Wagh, 1977) has evaluated the alternative filtration techniques, namely (a) coconut fiber followed by burned rice husk in two-stage filtration, (b) coconut fiber followed by burned rice husk in single-stage, dual-media filtration, and (c) burned rice husk followed by sand in single-stage, dual-media filtration. It has been concluded that, compared with conventional water filtration methods, these alternative techniques are more favorable. The unit operation costs of these techniques at different capacities when compared with conventional filtration methods are lower. In addition, the mean subsidy per capita per year for the alternative techniques is much lower than that for a conventional system, thus rendering them economically more effective. With regard to the alternative techniques available, option (c) is the most economic system. A capacity expansion study, also by Wagh (1977), reveals that - under the economic settings of Thailand - as the plant capacity in terms of the population served increases, economies of scale are obtained, in the sense that the subsidy required for the system becomes zero at a certain value of population served.

In field application, the cost of the system is very low : as of 1977, one peso (US¢ 13) contribution per family per month was collected for the maintenance of the installations in the Philippines (Tam, 1980). Experience from several field-scale installations in Southeast Asia indicates that the total construction cost - including pump, filtered water storage jars and public taps - amount to less than US$ 2 per capita (Frankel, 1979).

4.4.5 Advantages

++ This two-stage process operates at a filtration rate 10-15 times higher than in slow sand filtration, and this reduces the construction cost considerably.

++ It removes color and taste due to the adsorption capacity of burned rice husk.

++ It is simple in construction, operation and maintenance.

++ It can handle high turbidities.

++ It is very cost-effective.

4.4.6 Disadvantages

-- In most cases bacteriological removal is insufficient, and consequently some simple post-disinfection is required.

-- After a few months of operation, due to the biodegradability and odor problem of coconut fiber, the filter medium has to be replaced with new materials which have to go through preparation steps as described above. Failing to do this would result in objectionable treated water. The system therefore requires more maintenance labor than conventional slow sand filtration.

4.4.7 Application Status

Pilot plants to test the concept of two-stage filtration (coconut fiber followed by burned rice husk) were operated during 1973-1974 in Cambodia, Laos, Thailand, and Vietnam. The results are reported by Frankel (1979) and SEATEC (1975). Some larger units have been built in the Philippines. Generally, the tested filters show the advantages and disadvantages of presented above. The systems in the Philippines perform consistently well, with an average of 90% removal of coliforms.

Recently, the interest in this system has been rekindled by Arbuthnot & Thomas (1981), who recommend it as a substitution for costlier sand filtration.

4.4.8 Conclusion

Even though this filtration system may not be able to produce water up to the WHO drinking water standards in terms of coliform content, it can offer a significant improvement over no treatment at all. In places where sand is not available to use in conventional filtration, the system could well be the only choice.

4.5 SWS Filter System

An "SWS" unit (which stands for "Sea Water Supplies") developed in the U.K. applies the new concept of filtration of raw water right at its source. The SWS unit is not strictly considered as a filter, but it is a device to make the sea bed or river bed itself an efficient natural filter. This type of unit was initially used for marine use, but it can be used for potable water use too.

4.5.1 Principles

The SWS unit is a rectangular box with a false ceiling consisting of a compression-molded slotted plate. The unit is built of corrosion-free fiberglass. The village SWS unit has a cross section of 60 cm x 30 cm, and weighs about 8 kg. This unit is buried, open end down, in the sea or river bed as shown in Fig. 12 (Cansdale, 1979b). The top of the unit should be at least 15 cm below the river bed. From the bottom of the unit, 3/4 of the height is packed with coarse sand and gravel media. The remaining 1/4 of the height of the unit is empty, and a suction pipe is connected to this part of the unit. Sand is then filled around the unit in such a way that there is no empty space. The suction pipe of the unit is connected to an intake pump. When this pump is switched on, water from the bottom trickles through the river bed and reaches the filter media of the unit. From here, the water is filtered by the filter media as the water flows up to the top of the unit. The clean water is then taken out through the suction pipe. It is important to maintain a correct pumping rate, since over-pumping may cause fines to be drawn into the discharge pipeline. The complete technical data and guidelines concerning this filter unit are presented by Cansdale (1979a, 1979b).

4.5.2 Design Criteria

Table 8 presents some suggested design criteria for the unit.

4.5.3 Economics

For a large unit, with an output of 40,000 l/h, the total cost over a period of 5 years was 360 pounds sterling (1979 prices) in the U.K. This corresponds to 20 pence per day, including 1 pence per 5000 liters for electricity and 5 pence for petrol (Cansdale, 1979b).

4.5.4 Applicability

This filter system can be used to supply water for fish farming, swimming pools, industrial use, agricultural use, etc. For public water supply, it is mainly used as a pre-filtering unit which will reduce significantly the subsequent treatment. For industries, the unit can likewise be used as a pre-treatment unit. Therefore, other pre-treatment operations like sedimentation can be eliminated.

4.5.5 Advantages

++ In this unit there is no moving part. Moreover, no chemicals are needed. Consequently maintenance is kept to a minimum.

++ It is also easy to install and operate. Installation takes hardly one hour for a river bed unit.

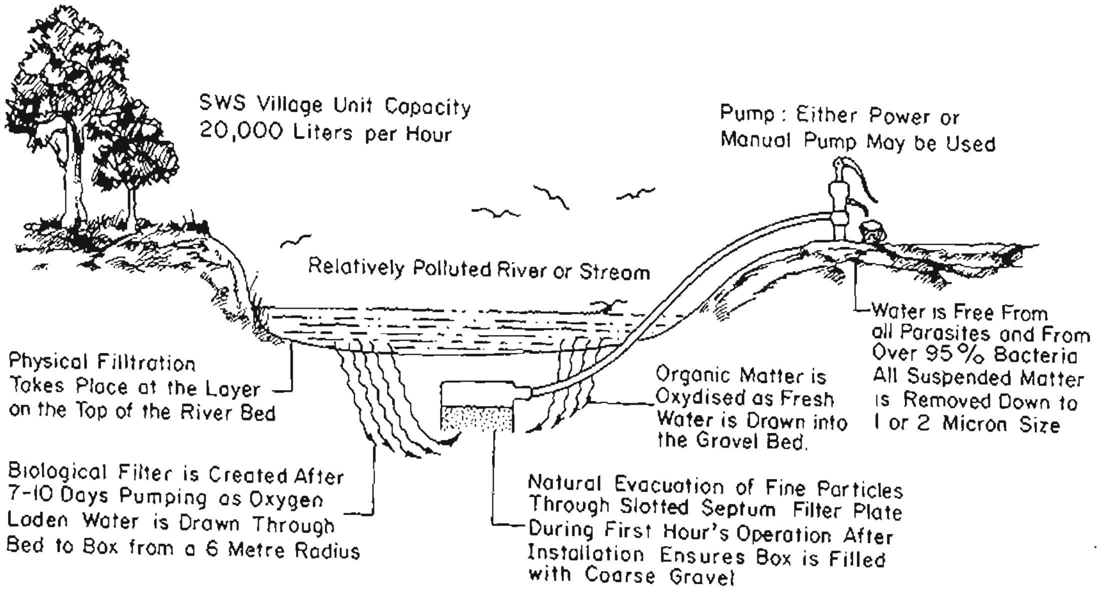


Fig. 12 : The SWS Water Filtration System

Table 8: Design parameters of SWS Filter System

Parameter	Range of Values
Unit	i) Square shape box of 60 x 60 cm (maximum) with a depth of 40 cm. ii) A hollow section of 10 cm between the top portion of the media to roof of the box. This hollow section has a series of distance pieces to give stability and stop collapse of the unit under vacuum.
Filter bed media	Coarse sand and gravel of size between 0.5 to 5.0 mm can be used. Both very fine sand especially of wind-blown origin (0.2 mm) and very large stones (50 mm) are not suitable as filter media.
Suction head	The maximum allowable total suction head should be kept below 7 m.
Deliver line	– Flexible ~~armounded~~ armoured hose is needed from the unit to at least to the highest water level. – Semi-rigid PVC pipes can be used from the river edge and also for delivery line.
Pumps	Handpump with 4 m^3/h.

++ It is a simple process, and there is no need for skilled operators.

++ The system can be operated continuously or intermittently.

++ The space requirement is minimal.

++ It is a remarkably low-cost system.

4.5.6 Disadvantages

-- This unit can work only where there is permanent surface water.

-- In deep muddy beds, steep rocky shores and gorges, this unit cannot be used.

-- Nigam (1981) claims that "no backwashing is necessary because the stream starts percolating through other points when the bed is choked at one place". This claim may not be true in the long run, since eventually all of the surface of the filter may be choked, and hence finally the filter may need to be cleaned. Taking the filter out of the river bed to clean it is a troublesome task.

4.5.7 Application Status

The system has been installed in Malaysia, the Philippines, Singapore and Thailand. Initial results indicate that problems developed at each site, so there is room for improvement. Not all sites are difficult, but each site may require a custom designed modification (Cansdale, 1979b).

This type of filter was later installed at Hardwar, India, to filter the highly polluted and highly turbid River Ganges water (Nigam, 1981). The unit installed was made of a 3 mm thick MS plate rectangular box with a false ceiling consisting of a wooden slotted plate and filled with coarse sand and gravel in the box, with a wire mesh at the bottom (Fig. 13). The unit was immersed with the open end facing the river bed in such a way that the top surface was not less than 30 cm below the river bed and 60 to 90 cm below the top surface of the water. After being installed, it was connected with a 80 x 80 mm pump having 12 l/s discharge at 30 m head. Here the river bed itself was used as the filter media and no addition of chemicals was found to be necessary. The filtered river water from the unit was pumped into the river for about 20 hours at the beginning of the operation, and then water was driven into the pipeline. After that, it was chlorinated with a solution of bleaching powder through a feed-type chlorinator. The river water turbidity was reduced from 75 ppm to 2 ppm using this filtration system. Coliform removal was also significant. Here the coliform removal was found to vary from 1,800/100 ml to none.

Recently, the latest form of the SWS unit with its own built-in filter has been making an important contribution to disease control in the Gezira project in the Sudan (Anon, 1983). The modified version incorporates a tubular slotted mini-filter, and is filled with sand and gravel. The self-contained unit, which also incorporates a fabric filter to allow easy cleaning, is only half the size of the original one. Tests in the Sudan have been designed to check the filter's effectiveness in improving biological quality and in removing the parasite Schistosoma.

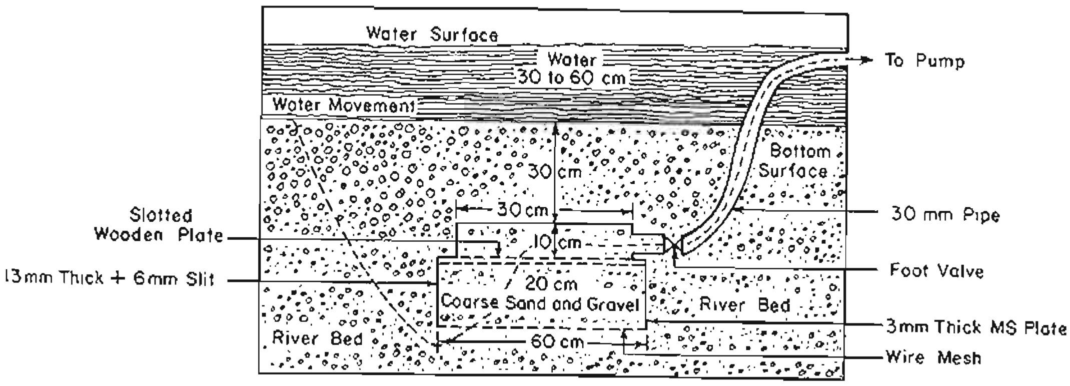


Fig. 13 : Schematic Diagram of the SWS Filter

4.6 Modified Shore Filtration

4.6.1 Principles

The principles of this treatment method are same as that of the infiltration gallery. Here, a cylindrical plastic pipe with small holes on the top surface is located under the canal or spring bed. The location of the pipe depends on the canal or spring soil conditions, and the flow rate conditions. If the soil is clay, then the pipe should be placed horizontally. If it is sandy soil, then the pipe should be placed vertically as shown in Fig. 14 (Jahn, 1981). During this operation, infiltered water from the canal or spring passes through the filter media, trickles through the holes on the top surface of the pipe, and flows through it. This water is later collected in a drum placed near the canal or spring bed.

4.6.2 Design Criteria

For filter media, the sand grain size is 0.3-0.5 mm and the gravel size is 0.7-0.9 mm, although gravel of larger sizes can be used. For piping, a pipe with a diameter of 40 cm is adequate.

4.6.3 Applicability

This type of unit generally functions only for part of the year. During the dry season or flood season this unit can not be operated. So the villagers cannot depend on this unit throughout the year for their water supply.

4.7 Water Coagulation with After-Treatment Using Sand Filtration

4.7.1 Principles

In this method, the raw water is stored in a galvanized iron drum and coagulant is added to the water. The dosage of the coagulant addition is determined from weekly jar tests. Then the settled water from this drum is collected through the outlet pipe and sent to a distributor (Fig. 15). The flow of water to the distributor is controlled by adjusting the outlet valve of the drum. The distributor is filled with coarse sand, and the settled water flows through this coarse sand bed and passes into the second drum, which is placed just below the distributor. The second drum consists of a fine sand filter. Here a gravel bed is usually placed at the bottom of the fine sand as a supporting medium. The filtered water is collected directly from this gravel bed through a pipe placed at this gravel layer.

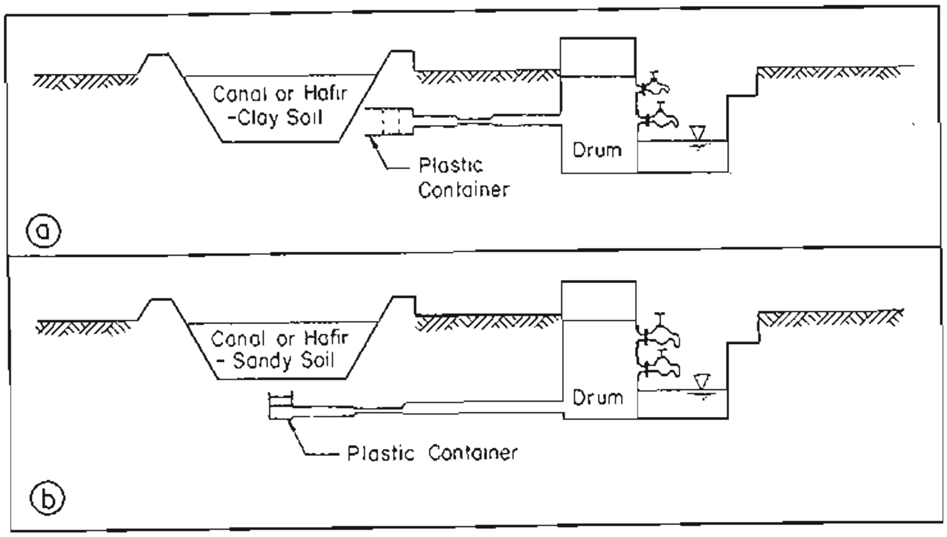


Fig. 14 : Construction Proposal for a Continuously Operating Village Unit in Which Water from Canals or Rain Reservoirs is Treated with Sand Filters
Fig. a : Suitable for Clay Soil
Fig. b : Suitable for Sandy Soil

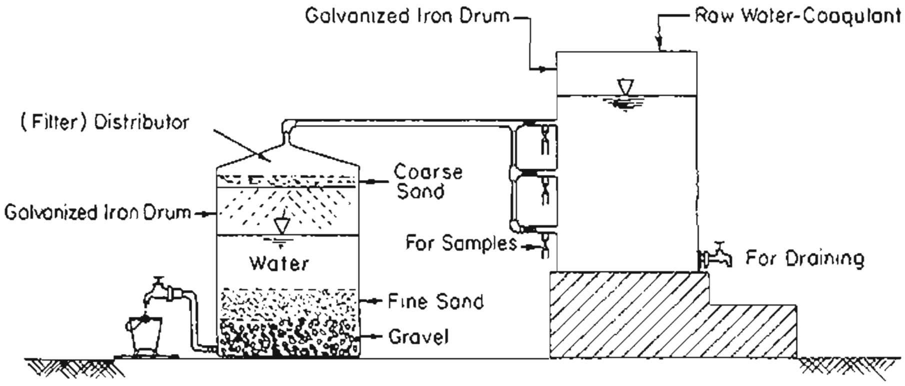


Fig. 15 : Construction Proposal for a Small-Scale Village Plant Utilizing Water Coagulation and Sand Filtration

It should be noted that, due to its simplification, the design is compromised by the fact that no facility for mixing coagulants and flocculation is provided. Consequently, slow sand filters are liable to clog easily.

Cleaning is done according to the frequency of clogging. The coarse sand in the distributor is taken off, washed and reused. The top 1-2 cm of the fine sand in the filter drum is scraped away. This sand is either discarded or washed and reused.

4.7.2 Design Criteria

Sand with grain sizes of 0.4-0.5 mm and 0.2-0.3 mm for coarse and fine sand, respectively, is used as the filter media.

4.8 Conclusions on Slow-Rate Filtration

As summarized in Table 9, the selection of a suitable filtration system or pre-filtration system depends on the raw water characteristics, pretreatment, posttreatment, land availability, availability of materials, skilled labor, the size of the community, soil conditions etc. When more than one of the above-mentioned filtration systems becomes suitable technically, the cost and degree of operation and maintenance become the screening criteria.

Table 9: Characteristics of Alternative Filtration Methods Small Community Water Supplies

Parameter	Modified Shore Filtration	Slow Sand Filtration	Two-Stage Filtration	SWS Filtration	Horizontal Flow Pre-Filter
1) Raw water requirement	Not specified	< 50 NTU	< 150 NTU	Can be used even for high-turbid waters	< 200 NTU
2) Extent of treatment	Used as pretreatment unit	Produces good quality of water in terms of turbidity and bacteriological contents	Produces good quality of water in terms of turbidity and bacteriological contents	Used as pre-treatment unit	Used as pre-treatment unit
3) Pre-treatment	–	If raw water turbidity is more than 50 NTU, as pretreatment unit like horizontal flow filter is necessary	If raw water turbidity is greater than 150 NTU, multi-stage unit or coagulation step is necessary	–	–
4) Post-treatment	Depending on water quality, slow sand filter followed by disinfection	Preferably disinfection	Preferably disinfection	Depends on raw water quality (generally slow sand filter followed by disinfection)	Depends on raw water quality (generally slow sand filter followed by disinfection)
5) Filtration rate	–	0.1-0.2 $m^3/m^2 \cdot h$	1.2-1.5 $m^3/m^2 \cdot h$	–	0.3-1 $m^3/m^2 \cdot h$
6) Filter media size	Sand (covering material is optional)	Sand (E.S. = 0.15-0.35 mm, U.C. = 2-5)	Coconut fiber shredded and washed. Burned rice husks of E.S. = 0.3-0.5 m and U.C. = 2.3-2.6.	Coarse sand and gravel of size between 0.5 to 5 mm can be used	Gravel 9-20 mm 4-12 mm 3-9 mm 2.5-8 mm 2.5-6 mm 3-9 mm 10-25 mm

Table 9: (Cont'd)

Parameter	Modified Shore Filtration	Slow Sand Filtration	Two-Stage Filtration	SWS Filtration	Horizontal-Flow Pre-Filter
7) Filter Media depth	–	1-1.4 m	0.6-0.8 m	0.3 m	0.8 m
8) Underdrain System	–	Lateral-manifold system (for small filter	Lateral-manifold system under the sup-	–	–

Table 9: (Cont'd)

Parameter	Modified Shore Filtration	Slow Sand Filtration	Two-Stage Filtration	SWS Filtration	Horizontal-Flow Pre-Filter
7) Filter Media depth	–	1-1.4 m	0.6-0.8 m	0.3 m	0.8 m
8) Underdrain System	–	Lateral-manifold system (for small filter units) or standard bricks or precast concrete blocks with holes in the top or porous concrete (This underdrain system is under the supporting gravel layer)	Lateral-manifold system under the supporting gravel layer	–	–
9) Supernatant level	–	1-1.5 m	1.0 m	0.1 m	–
10) Cleaning Procedure	–	Scrape out the top few centimeters and replace with new sand (or the sand is washed and replaced).	Used coconut filter is replaced with new (or washed) coconut fiber material In the case of burnt rice husk, top 10 cm is scrapped off and replaced with new media	–	Cleaning is done periodically, compartment by compartment Gravel in the particular compartment is taken out and cleaned and replaced.
11) Cleaning Frequency	–	Once in every 2 months (frequency depends on raw water quality)	Once in every 3 to 4 months (depends on raw water quality).	–	Once in 2-5 years (depends on raw water quality)

Table 9: (Cont'd)

Parameter	Modified Shore Filtration	Slow Sand Filtration	Two Stage Filtration	SWS Filtration	Horizontal-Flow Pre-Filter
12) Construction					
i) Cost of construction	Average	Average (if the appropriate sand size is available)	Low	Low	Average
ii) Land requirement	Large	Large	Average	Small	Large
iii) Materials of construction	Wall supports of bricks, concrete blocks in weak soil	i) Concrete ii) Ferrocement iii) Reinforced concrete	Wooden support structure, concrete or G.I. jars for filter tank	Rectangular fiber glass box of 0.6 x 0.6 x 0.4 m	i) Brick work ii) Ferrocement iii) Reinforced concrete
iv) Construction	Difficult	Less difficult	Simple	Simple	Less difficult
13) Operation					
i) (Skilled operator requirement)	No	No	No	No	No
ii) Ease of operation	Simple	Simple	Very simple	Very simple	Simple
14) Maintenance cost	Low	Average	Low	Low	Average
15) Special Requirement	Near the river or water source	None	None	Near the river or water source	None
16) Size of community per unit	Unlimited	Medium population	Less than 1,000 people	Large unit (with an output upto 40,000 1/h)	Medium population

5. MODIFICATIONS OF FILTER MEDIA SIZE

The first step in designing a filter should be the selection of the media. The ideal medium should be of such size, depth and specific gravity as to provide an acceptable effluent, give a long filter run, have a high rate of application with low headloss requirements, and be easily cleaned with a minimum amount of water and/or air (Walters, 1979a). It is not possible to design a filter that is optimum in all respects. The rational way of selecting the media depth requires experimental studies at bench scale (or better still, pilot scale) with the raw water intended to be treated.

The filter media commonly used for filtration of water are:

a) Silica sand (specific gravity of 2.65 and in round form);

b) Anthracite coal (specific gravity of 1.35-1.75 and angular); and

c) Garnet sand (specific gravity of 4-4.2).

Each of these media has certain advantages and disadvantages that make it, either singularly or in combination with the other media, the best selection for a particular application.

Filtrate quality is a function of media size and bed depth. For a constant bed depth, finer media will produce better quality water. However, the length of the filter run is shortened. Therefore, filter media selection must be based on the characteristics of the water to be filtered and the requirements for the filter effluent.

The conventional rapid filter generally uses sand with an effective size of 0.6 mm and a uniformity coefficient of 1.5-2.0. This results in stratification of the media after backwashing, in which the fine medium remains at the top and the coarse medium at the bottom of the filter bed. This sand arrangement will restrict the effective use of the entire filter bed. To overcome this problem of gradation, two alternative media have been proposed, notably (i) dual-media and multi-media filters, and (ii) coarse size, narrowly graded media filters.

5.1 Dual-Media Filtration

5.1.1 Principles

Dual-media filtration has been investigated for quite a time, and several studies have been conducted at the Asian Institute of Technology (Binh, 1975; Pescod & Theera, 1972; Pescod & Karot, 1973; Supote, 1976; Thanh et al., 1979; Vigneswaran, 1978).

Traditionally, only sand is used for the filter bed, with a filter depth of 0.6 to 1.0 m and a grain size of 0.4 to 1.2 mm. In this single-medium sand filter, stratification takes place during the backwashing, resulting in the very fine size of the medium accumulating at the top of the bed and the coarse particles remaining at the bottom. As a result of this, a major portion of the suspended matter is removed in the top (10 to 15 cm) of the bed. The particles which escape this top few centimeters of the bed tend to pass through the rest of the filter. Such conventional single-medium filters are normally restricted to a flow of 5 m^3/m^2-h and an applied turbidity of 10 NTU or less. This shortcoming can be overcome if the arrangement of different sizes of grains is reversed, that is, if the arrangement is made from coarse to fine in the flow direction. In order to have this arrangement, media of different sizes and different specific gravity should be used: the lighter and coarser material at the top and heavier and finer material at the bottom. This arrangement is known as dual-media filter. Generally a coarse medium of low density such as anthracite (specific gravity = 1.35 to 1.70) over a fine but heavier medium, like sand (specific gravity = 2.65 to 2.70) is used. On backwashing in an upward direction, the coarse and lighter grains remain over the fine and heavier medium. This makes the penetration and removal of impurities take place throughout the entire bed.

5.1.3 Media Selection

In dual-media filtration, the size of the media must be carefully selected so that the water used for fluidizing and re-stratifying the bed does not cause severe intermixing. Optimum conditions for minimizing the intermixing exist, depending on the media type, specific gravity and size involved. Various researchers have given different size ratios for minimum intermixing of media as presented in Table 10. Extensive researches have been carried out to study the advantages and disadvantages of intermixing filter media in dual-media filtration (Conley & Hsiung, 1969; Deb, 1969; Dostal & Robeck, 1966; Hudson, 1963). It is evident from these studies that two schools of thought prevail in the selection of grain size for the design of dual-media filtration.

Table 10: Calculated Size Ratios to Cause Mixing.

Equation	Calculated Effective Size Ratio (Anthracite: Sand)	Comments
Fair *et al.* (1968)	2.38:1	Neglects settling, based on laminar flow backwash.
Conley & Hsiung (1969)	2.63:1	Neglects backwashing, considers hindered settling.
McCabe & Smith (1967)	2.73:1	Neglects backwashing, considers hindered settling.
Camp's Value (1961, 1971)	3.00:1	Based on experience.
Mazumdar (1984)	2.07:1	Based on pilot-scale study

One opinion is that the grain size of coarse anthracite and fine sand should be chosen in such a way that the intermixing at the interface will be minimized. The second opinion indicates that the controlled mixing among filter media is beneficial because it reduces the tendency to form an impervious layer at the interface during filtration. An experimental investigation (Mazumdar, 1984) carried out at the Asian Institute of Technology indicates that the intermixing of media is beneficial because of the slower rate of headloss development, although the effluent quality deteriorates slightly with the increase in the extent of intermixing (i.e., with the increase in the size ratio between anthracite and sand).

Anthracite coal is not available in many developing countries. In India, a material called "natural coke" is available in large quantities in some of the coal fields which can be used as a filter medium in place of anthracite. The major disadvantage of natural coke is that it is not homogeneous and hence not suitable as a filter medium. Bituminous coal is not as suitable as anthracite coal, also because it is not homogeneous. It has as many as three constituents, namely vitrain, durain and fusain, with different hardnesses and specific gravities (De, 1976).

Another material which is available in India and can be used as a filter medium is garnet sand. It is available in India both as sand and in lump form in fairly large quantities, especially in pegmetite veins in crystal form. Crushed coconut shells have also been used successfully as coarse media in India. Garnet sand (with an effective size of 0.12 mm and a specific gravity of about 4) has been used in the U.S.A. as the lowest stratum in three-media filters. Its disadvantage is that, due to its weight, it requires higher rates of backwash for cleaning.

If natural coke is not altogether dependable as a filter medium, a dual-media bed may be tried with coarse sand (with a size of 0.8 mm) on top and fine garnet (with a size of 0.15 mm) at the bottom. One has to be careful in selecting garnet sand as its specific gravity varies from 3.2 to 4.5.

In India, two other minerals, ilmenite and magnetite are available in abundant quantities and can be used as a substitute for garnet. The possibility of using these materials as filter media has been verified in the U.S.A. and the U.K. Other developing countries should try to make use of any suitable materials that are locally available. Due to lack of field data, alternative media should be tested in pilot filters before implementation.

Some important characteristics of a variety of coarse materials that can be used in dual-media filtration are given in Table 11 (De, 1976). For more discussion on filter media selection, the reader is referred to Kawamura (1975) and Walters (1979a).

5.1.3 Cleaning of Filter Media

The common method of backwashing is air scouring followed by water fluidization backwash. Air is introduced at a rate of 54 to 90 m^3/m^2-h for 3 to 5 minutes and followed by a water wash at a rate of 36 to 54 m^3/m^2-h.

This method of air-water backwashing requires sophisticated equipment and skilled operators. In order to overcome this difficulty, a backwashing system with the effluent from other units can be practiced, as discussed under section 9.6.

Table 11: Certain Combinations of Filter Media Used in the USA

Media	Thickness of Layer (in)	Grain Size (mm)
1. Anthracite Coal	24	1
Silica Sand	6	0.3
2. Anthracite Coal	22	0.7 and 0.8
Silica Sand	8	0.3 and 0.4
3. Anthracite Coal	18	0.7
Silica Sand	10	0.45
Graded coarse sand and gravel	16	
4. Anthracite Coal	8	1.4 to 2.4
Silica Sand	8	1.2 to 1.4
Garnet Sand	8	0.7 to 0.8
5. Anthracite Coal	24	1.0 to 2.0
Silica Sand	9	0.6 to 0.8
Garnet Sand	3	0.4 to 0.8
6. Anthracite Coal	18	1.0
Graphite Sand (sp gr-2.4)	9	0.35
Garnet Sand	3	0.15
Garnet Gravel	3	1.0
Silica Gravel	18	No 10 to 1½ in x 2 in (at bottom near underdrain)

*1 in. = 2.54 cm

5.1.4 Advantages

++ Dual-media filtration can be operated at a filtration rate two or three times greater than that of single-medium sand filtration, and can consequently reduce the required filter surface area by the same factor.

++ It can also accept a higher influent turbidity loading.

++ Dual-media filters can be easily retrofitted in existing filters to increase plant capacity. For example, a layer of coarse lighter material about 15 cm in depth can be placed over an existing sand bed with virtually no change in plant structure or method of operation, depending on the hydraulic capacity of the influent and effluent piping or channels (Schulz & Okun, 1983).

++ Since the coarse-to-fine grain arrangement in the flow direction makes use of the entire bed in efficient filtration action, the filter runs are prolonged significantly.

5.1.5 Disadvantages

-- In most developing countries, comparatively light but physically suitable materials like anthracite coal are not available. However, materials lighter than sand such as natural coke and heavier than sand such as garnet, ilmenite, and magnetite, which are found in large quantities in developing countries, can be used in combination with sand in the dual-media filters.

5.1.6 Application Status

The concept of dual-media filtration has been successfully applied at the Kanpur water treatment plant in India. The cost of the lighter medium is higher than that of sand, but still economy could be achieved (Patwardhan, 1981).

The results of anthracite-sand filtration studies at the Samsen Waterworks, Bangkok, indicate that a combination of 80 cm anthracite with an effective size of 0.95 mm, and 40 cm of sand with an effective size of 0.58 mm is the most suitable at filtration rates of 12.5 and 20 m^3/m^2-h (Karot, 1968; Pescod & Karot, 1973).

5.2 Coarse Single-Medium Filtration

5.2.1 Principles

Although conventional single-medium filters with sand of an effective size in the range of 0.45-0.55 mm do an excellent job of removing suspended solids, filter clogging occurs rapidly. Replacing the top of the sand depth with anthracite of a larger size improves the length of runs, but the deeper penetration of solids results in greater difficulty in cleaning the medium. A study performed on dual-media filters and coarse single-medium filters indicates (EPA, 1977) that coarse-medium, unstratified bed filters produced an effluent comparable to those of dual- and multi-media filters. This coarse-medium filter also results in higher storage capacity, and hence longer filter runs, as compared with dual- or multi-media filters (Walters, 1979a; 1979b). A comparative study performed at Ames, Iowa indicates that solid storage in multi-media filters was approximately one-third that in coarse-sand beds. Depending on the available head, raw water quality and filtrate quality, the coarse sand filters can be operated at a higher filtration rate.

Therefore, narrowly graded (by sieving) coarse sand with an effective size of 2mm and placed to a greater depth can be used in developing countries instead of sand with a smaller effective size (0.45-0.55 mm) and a larger uniformity coefficient (about 1.5).

More details on the principles of the process can be found from Walters (1979a, 1979b).

5.2.1 Advantages

++ The filter can be operated at a higher rate, and this would reduce significantly filter construction cost.

++ The demand can be increased in the existing units by replacing the medium with narrowly graded coarse sand and operating at a higher filtration rate.

++ The deeper penetration and higher storage capacities in the narrowly graded coarse-medium filters leads to the longer filter runs.

5.2.3 Disadvantages

-- Due to the large medium used, particle deposition will be throughout the filter. This makes the backwashing requirements high. Generally, air-water backwashing is used in coarse-medium filters. The rate of air and water used in backwashing depends on the size of the medium. For example, sand of 2 mm effective size needs washing rates of 90-110 m^3/m^2-h of air and 19-24 m^3/m^2-h of water. These requirements are higher than those for conventional filters.

-- Since the commonly used gravel in the underdrain system will be disturbed by high energy air-water backwash, the underdrain system in the coarse sand filter has to be modified. The underdrain system in the latter case consists of a concrete or steel false bottom with polypropylene nozzles. Here only filtered water should be used for backwashing to avoid plugging the nozzles.

5.3 Multi-Layer Sand Filtration

Patwardhan (1981) mentions of a very compact process which is patented by him. It consists of several sand layers one over the other, and each layer works independently as a filter unit. This is achieved by distributing settled water at various heights in the medium and collecting filtered water by pipes suitably placed at different heights as well. The rate of filtration can be adjusted, depending upon the size and the depth of the medium. The yield per unit area is quite large, though the actual filtration rate could be less than the conventional rate. This gives a higher efficiency as lower rates are used. The influent water is admitted into the chamber over a weir. The rate is controlled at the inlet. The outlet chamber bottom is slightly above the sand top. Initially, the water level remains a little above the sand and rises gradually as the headloss builds up. Thus, the rate is controlled automatically, eliminating the need for an automatic rate controller. The level in the bed indicates the headloss, and this being the case headloss gauze is not needed. As the area required is much smaller, the backwash requirements are also considerably reduced, resulting in economy. As the outlet is above the sand bed, negative pressure never develops in the bed and this avoids air-binding troubles. No detailed performance data are presented, although it is stated that these filters have been successfully used in ten plants in India and are operating satisfactorily.

5.4 Crushed Stone as Filter Media

Rao (1981) has conducted a laboratory-scale study using crushed stone with an effective size of 0.47 mm and a uniformity coefficient of 1.38 mm, in comparison with sand (effective size of 0.45 mm and uniformity coefficient of 1.38). At both filtration rates of 4.8 and 9.6 m^3/m^2-h, the performance of the crushed stone filter is better than that of the sand filter with respect to turbidity removal, bacterial removal and filter-run length. The study suggests that stone medium, which can be easily prepared out of waste dust from stone quarries, can bring about savings in the construction cost where sand has to be carted over long distances, and at the same time can permit operation of the filter at a high rate without decreasing the filtrate quality.

5.5 Conclusion

The characteristics of dual-media filters and coarse-medium filters are compared with those of conventional rapid filters in Table 12. Since both dual-media filters and coarse-medium filters can be operated at higher filtration rates (10-15 m^3/m^2-h) and have higher storage capacities, their construction costs become relatively lower. On the other hand, coarse-medium filters require a large filter medium depth in order to produce an acceptable filtrate quality, and this increases the construction cost. The possibility of using dual-media filters depends on the local availability of a suitable coarse, light filter medium.

The major disadvantage of coarse-medium filters is that they require a sophisticated air-water backwash system, and thus skilled personnel, because of the deeper penetration of particle deposition. One possibility of overcoming this air-water backwash is to use the filtrate of other filter units directly for backwashing. If this arrangement is provided, coarse-medium filters can be used in large water treatment plants in developing countries with success. For dual-media filters, air-water backwash systems are not necessary. They can be adequately cleaned using simpler surface-wash systems with no moving parts.

Table 12: Summary of Design Parameters of Coarse-Media and Dual-Media Filters

Parameters	Conventional Filters	Coarse-Media Filters (narrowly graded)	Dual-Media Filters
1) Filtration Rate	5 $m^3/m^2 \cdot h$	Higher rate (10-15 $m^3/m^2 \cdot h$)	Higher rate (10-15 $m^3/m^2 \cdot h$)
2) Filter Media Size	E.S. = 0.6 mm U.C. = 1.5 mm	Coarse sand (narrowly graded) (for ex. 0.9-1.1 mm sand)	Usually anthracite and sand (If anthracite is not locally available, a substitute material for anthracite can be used. Size should be carefully chosen to minimize the intermixing of media) For ex. Sand: E.S. = 0.5 mm, U.C. = 1.5 and Anthracite: E.S. = 0.8 mm, U.C. = 1.5 can be used
3) Filter Media Depth	0.8-1.0 m	Generally higher depth 1.5-2.0 m. (to meet the effluent standard)	Total depth of the filter media is higher than that of conventional filter.
4) Supernatant Water Level	Same in all three cases.		
5) Cleaning Procedure	High-rate water backwash or air-water backwash	Generally air-water backwash. Back wash requirements are higher due to deeper penetration of particles	Generally air-water backwash. Backwash rates and extent of fluidization should be carefully chosen to minimize intermixing
6) Under Drain System	Lateral-manifold system	Concrete or steel false bottom with polypropylene nozzles	Concrete or steel false bottom with polypropylene nozzles
7) Raw Water Turbidity	5-10 NTU	Can be used for moderate turbidity range, about 30 NTU	Can be used for moderate turbidity ranges, about 30 NTU

Table 12: (Cont'd)

Parameters	Conventional Filters	Coarse-Media Filters (narrowly graded)	Dual-Media Filters
			Whole bed is used in efficient

Table 12: (Cont'd)

Parameters	Conventional Filters	Coarse-Media Filters (narrowly graded)	Dual-Media Filters
8) Filtration Action	Only top few centimeters of filter bed participates in efficient filtration action	Whole bed is used in efficient filtration action	Whole bed is used in efficient filtration action
9) Filter Run Length	24 hours	At least 2 times greater than that of conventional filter	At least 2 times greater than that of conventional filter
10) Percentage of Filtered Water Used for Backwashing	3%	Higher than that of conventional filter (because of deeper penetration of particles and higher storage capacity)	Nearly in the same range as that of conventional bed filter
11) Special Equipment	No	Air-water backwash	Air-water backwash
12) Skilled Labor	No	Additional labor for operation of air-water backwash system	Additional labor for operation of air-water backwash system
13) Operational & Maintenance Costs		Lower	Lower
14) Capital Cost		Lower than that of conventional filter (because of lower area requirement)	Lower than that of conventional filter (because of lower area requirement)
15) Chemical Cost	Same for all three filters		

6. MODIFICATIONS OF FLOW RATE

Conventional rapid filtration operates at a constant rate of approximately 5 m^3/m^2-h. Researches performed on the variation of flow rate have indicated that high-rate filtration and declining-rate filtration are advantageous in most instances. If one achieves the desired filtered quality with a higher filtration rate operation at an comparable operational and maintenance cost which is comparable to that of a conventional rapid filter, then one could achieve a significant capital saving by using a high-rate filter. Similarly, researches have indicated that declining-rate filtration produces a better effluent quality than does the conventional process. Therefore, if one could obtain the same capacity of filtered water with equal capital investments, declining-rate filtration would have a definite advantage over conventional rapid filtration. Another advantage of using declining-rate filtration is that it does not require automatic rate control.

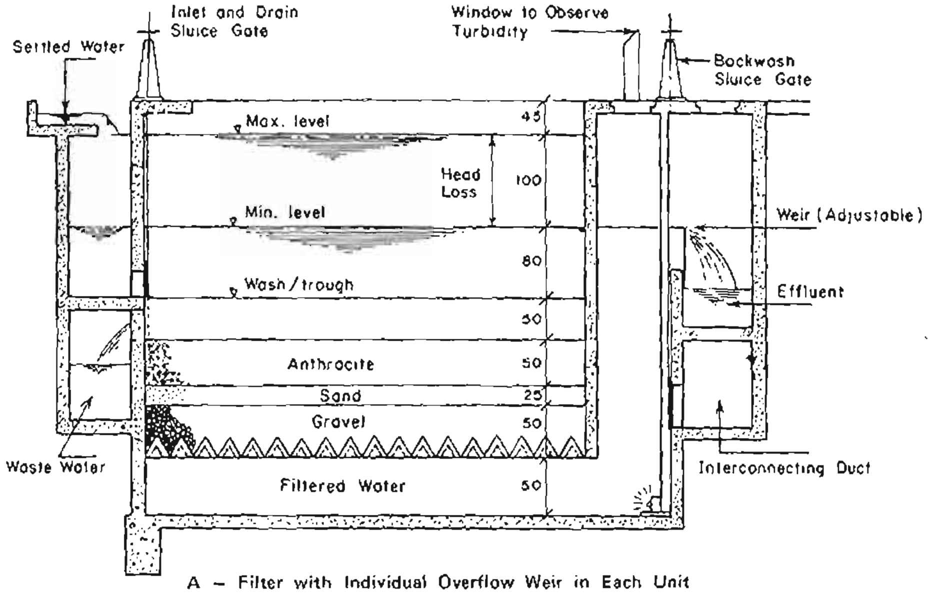
6.1 Declining-Rate Filtration

6.1.1 Principles

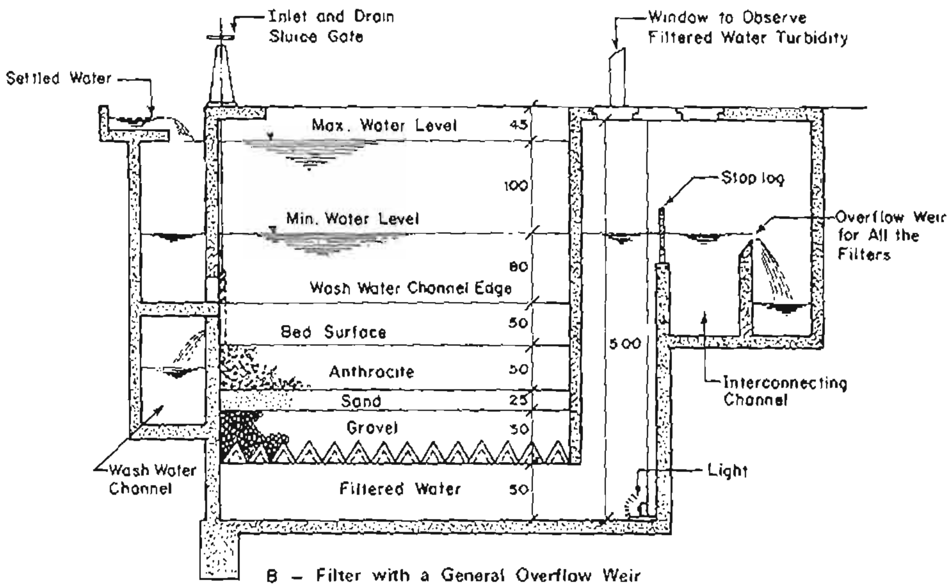
The concept of declining-rate filtration is not new. Basically, no rate-of-flow controller is used in this system, and instead it is replaced by a fixed orifice. So the filtration rate is allowed to decline from a maximum value at the beginning of the run when the filter is clean to a minimum value at the end of the filter run when the filter needs backwashing.

Fig. 16 (Valencia, 1977) shows two typical declining-rate filter arrangements, both are designed for backwash with the filtrate collected in the effluent channel. In the first arrangement with inter-connecting conduit and individual weir (Fig. 16A), in order to backwash each filter it is necessary to open - besides both individual gates (influent and drain) - those that interconnect with the filter units, in case they are kept closed to measure the flow produced by each one. In the second arrangement with a common weir and wooden sluice gates (Fig. 16B), the only requirement is to operate two gates to start the backwashing. These two gates could be integrated into a single one with two positions: one when sliding downwards, which could close the drain and open the inlet; and the other, causing the opposite effect when sliding upwards. In this fashion, only a single gate would be required to operate the filter. This arrangement is designed for backwash from the other filter units, which eliminates the use of a backwash pump and piping system. This backwash system is discussed in detail under section 9.6.

Fig. 17 shows another arrangement for declining-rate filtration (Cleasby, 1981). The filters are interconnected by a common influent header. The outlet discharge to a clear well is provided with a weir to assure a minimum static water level in the filters above the surface of the media. In such an operation, the water level is approximately the same in all operating filters, with the cleanest filter filtering at the highest rate and the dirtiest filter at the lowest rate. When the raw water feed line to the supernatant water is closed, the supernatant water will be filtered at a continuously declining rate due to a continuous reduction of the head of the supernatant water.



A – Filter with Individual Overflow Weir in Each Unit



B – Filter with a General Overflow Weir

Fig. 16 : Declining-Rate Filter Arrangements (Dimensions in cm)

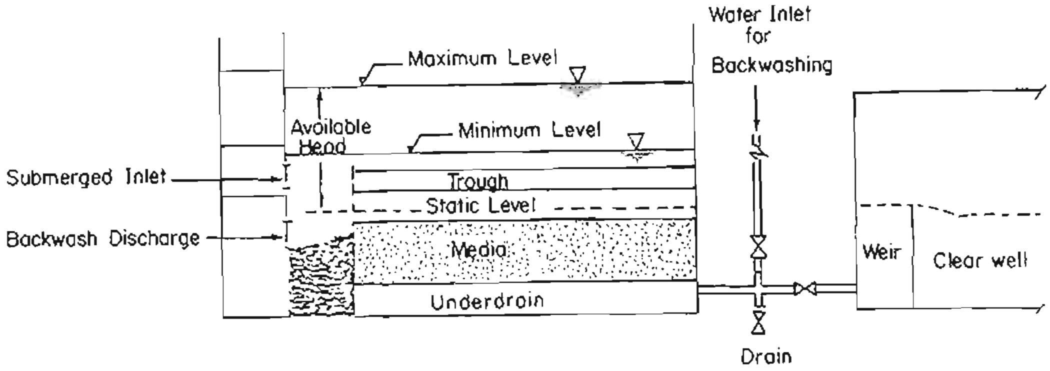


Fig. 17 : Typical Arrangement for Declining-Rate Filter System

In practice, several (a minimum of four) filters are used in series, and the water level is maintained essentially the same in all operating filters at all times. This is achieved by providing a relatively large influent header pipe or channel to serve all of the filters, and a relatively large influent valve or gate to each individual filter.

The operational concept is shown in Fig. 18 for a four-filter system, based on general observations at two full-scale water plants (Cleasby, 1981). As the filter units become dirty, the water level rises gradually in all four filter units. At some pre-determined level, one filter unit must be backwashed. Thus, the first level, A, is the level of all filter units just before backwashing. During the backwash of one unit, the remaining units must pick up the flow from the dirty unit removed from service; thus the remaining units all rise to some maximum level before the newly-backwashed unit is placed back in service. The rise to the high level, B, is a function of the water level prior to the wash, the filtration rate, the number of filter units in service, the duration of backwash, and the amount of upstream storage that rises with the filter water level.

Finally, when the newly backwashed filter unit is put in service, it operates at a higher filtration rate than before it was removed from service for backwashing. Therefore, the total filter output is increased above the input, and the water level falls to a new lower level, C.

According to Cleasby (1981), research was conducted in the U.K. to compare the performance of a four-filter declining-rate system and a constant-rate filter. Both systems were operated with two different surface waters that had been pre-treated by alum coagulation and sedimentation. The investigators concluded that the declining-rate system produced better water quality and a longer filter run than the other system. In addition, their data supported the hydraulic behavior presented conceptually in Fig. 18.

In this system, the available headloss is the height above the control weir in the clear water tank, and is approximately 1.75 to 2.5 m. The actual water level fluctuation during the operation is only 0.3 to 0.6 m, and depends on the number of filters and the size of the influent conduit. By having a large number of filters and a large influent conduit, the water level fluctuation can be reduced to 10 to 15 cm.

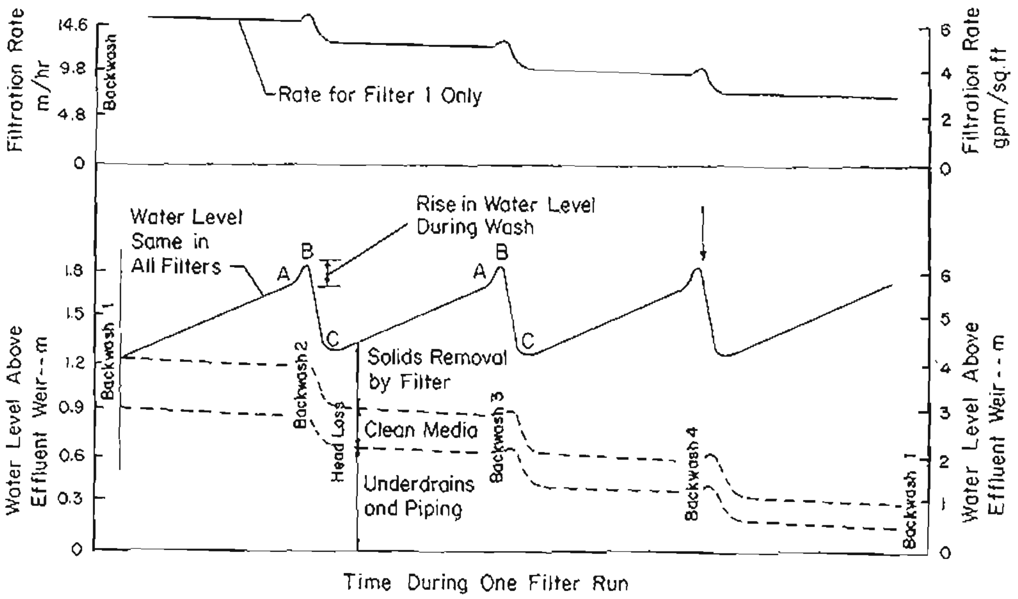


Fig. 18 : Water Level and Filtration Rate in a Plant with Four Declining-Rate Filters

Further details on the operational principles of the process are given by Cleasby (1981); Cleasby & DiBernardo (1980); DiBernardo & Cleasby (1980). Arboleda (1974) and Cleasby & DiBernado (1980) describe the theory and approach of hydraulic control; the former asserts that some plants were constructed in South America without a flow constrictor.

6.1.2 Design Criteria

Filter media: Single or dual media can be adopted. One experience uses anthracite (E.S. = 1.0 mm and U.C. = 1.4) of 45 cm height and sand (E.S. = 0.55 mm and U.C. = 1.5) of 15 cm height. For rational filter media design, refer to Amirtrarajah (1978). The media size is selected based on minimum intermixing.

Filtration Rate Variation: This depends on the raw water characteristics and effluent quality required. Past experiences suggest a variation in filtration rate from 50 to 150% of the average filtration rate. The orifice in the effluent control system should be sized in such a way that the filtration rate does not exceed the maximum allowable filtration rate value.

Water Level above the Control Weir: It varies generally from 1.75 to 2.5 m.

Water Level Fluctuation: It depends on the number of filter units and the volume of influent conduits. Generally, for a 4-filter system the fluctuation is only 0.3-0.6 m.

Details on the design of declining-rate filtration is presented elsewhere (Amirtrarajah, 1978).

6.1.3 Advantages

++ The water volume produced per unit of headloss is greater.

++ Less available headloss is required for the same filter run. Since less headloss develops as compared with constant-rate filtration, filter runs are longer.

++ If the filter effluent flows over a downstream weir or pipe outlet located above the elevation of the filter medium as shown in Fig. 17, negative headloss is prevented.

++ The underdrain can be inspected. Also, the clarity of the filtered water can easily be measured qualitatively by the operator.

++ For waters that show effluent deterioration towards the end of the run, declining-rate filtration produces a consistently and substantially better effluent quality than that obtained with constant-rate filtration.

6.1.4 Disadvantages

-- Unskilled operators may find difficulty in monitoring the plant throughput because of the different rates of filtration in each filter unit.

-- The required depth of the filter box may be greater than in conventional plants which are designed with the outlet located below the filter and which may produce negative pressure. However, if negative pressure is eliminated in the conventional plant design, this disadvantage disappears.

-- Declining-rate filtration is an uncontrolled system with little constant operator manipulation. Therefore, it cannot be used for delicate solid removal mechanisms.

-- The rate-limiting device (orifice) is generally sized for designed yearly peak loads which will permit a higher than necessary filtration rate in the early plant life. This high-flow during the early plant life can be avoided by using, for example, a smaller orifice in the control system.

6.1.5 Application Status

Cleasby (1969) applied successfully the concept of declining-rate filtration at the 53-mgd (200,600 m^3/d) Chan Chu Shan plant in Taipei, Taiwan, in 1968. The arrangement of the system is shown in Fig. 19. This operation mode produced better water than the constant-rate mode, but it gave somewhat shorter filter runs (about 48 hours) since no effluent valve adjustment was made during the run. The only precaution necessary to achieve success is to make sure that the water level remains at least 3" (7.5 cm) above the edges of the wash troughs following a backwash of one of the filters. This is essential to ensure that the flow can readily redistribute itself between the filters as they become dirty and are backwashed.

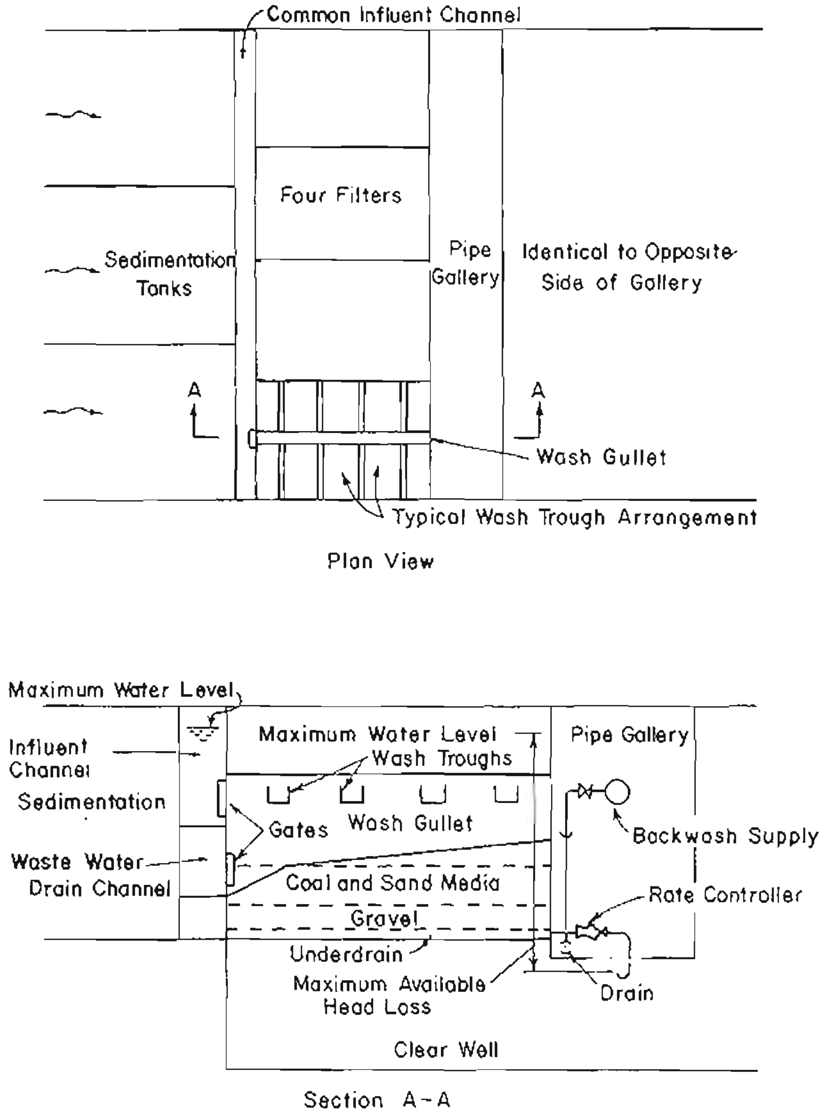


Fig. 19 : Filter Arrangement of Chan Chu Shan Treatment Plant

According to Valencia (1977), many plants have been operated in this fashion in Latin America, such as those in Medellin (Colombia), Lima (Peru), Cuenca (Ecuador), Curitiba (Brazil), and New Loredo (Mexico). As of 1980, over 50 plants of this type are functioning successfully in Latin America (Cleasby & DiBernado, 1980).

A six-cell declining-rate system operating at a high rate was designed for a water treatment plant at Cochabamba, Bolivia. The operational parameters are presented in Table 13. The experience in the declining-rate filters in Bolivia and elsewhere indicates that this type of filter can be successfully used in developing countries in large treatment plants.

Table 13: Design Parameters of the Filter Plant Used in Bolivia

Parameters		Values
Flow Rate Variations		8.5-12.5 m^3/m^2 h
Media Characteristics:		
Sand:	E.S. (mm)	0.5
	U.C.	1.65
	Depth (m)	0.2
Antracite:	E.S. (mm)	1.0
	U.C.	1.1
	Depth (m)	0.55
Filter Dimensions:		
	Length (m)	4.40
	Width (m)	2.25
	Depth (m)	5.90
Filter Bottom		It is made up with precast V-shaped concrete beams, perforated at both faces of each beam with 1.48 cm dia. holes. The space between the beams is filled with three layers of hollow plastic balls of 5 cm. dia. and filled with mortar. On this bottom, 0.45 m of graded gravel is laid.

6.2 High-Rate Filtration

6.2.1 Principles

High-rate filtration is the process which operates at a high filtration rate, about 10-15 m^3/m^2-h, as compared with the rate of conventional rapid sand filtration which is of the order of 5 m^3/m^2-h. Such high filtration rates are possible thanks to the development of (i) dual-media or multi-media, (ii) the control of flocculation by polyelectrolytes, and (iii) quality control of filtrate by sensitive turbidimeters. The process normally uses a dual- or mixed-media bed, while maintaining the required effluent quality. This is possible due to the fact that the entire bed is used efficiently. Very high filtration rates (24-48 m^3/m^2-h) have been successfully used with a special combination of media and the effective use of polymers as filter aids. However, such high rates - which are mostly for industrial purposes - are possible mainly because of particularly favorable raw water quality through pre-treatment, and of experienced professional plant supervision (Kawamura, 1975). It is generally believed that there are diminishing advantages in operating filters at rates above 24 m^3/m^2-d, because of (i) the high frequency of filter washing; (ii) the high quantity of washwater; (iii) the special supervision required; (iv) the requirements of filter aids and filter pre-conditioning, or both; and (v) special consideration required for the selection of media.

A seven-year operation at the Chicago plant indicates that the length of the filter run is almost inversely proportional to the filtration rate (Baylis, 1956). One has to take into consideration the filter-run length, since the shorter filter run in the high-rate filtration mode increases the operational cost by increasing the frequency of backwashing. The factors affecting filtration rates have been discussed by Hudson (1958).

6.2.2 Design Criteria

No definite design parameters of high-rate filtration can be given. Pilot tests should be carried to find optimum values. The filter-run length should be at least 20-25 hours for the economic operation of high-rate filters. Air-water backwashing is usually applied. Further details can be found from Kawamura (1975). The minimum process requirements of the Virginia State Department of Health are as follows (Kirchman & Jones, 1972):

** A method of control of the coagulation process;

** Equipment to indicate and record turbidity (raw and settled water, and filtrate);

** 0.5- to 3.0-minute rapid mix;

** 20-minute mechanical flocculation;

** 3-hour settling;

** Multi-media filter rates not to exceed 4.0 gpm/sq.ft (10 m^3/m^2-h), with raw-water average turbidities no greater than 2.0 JTU. Filtered water should be approximately 0.1 to 0.2 JTU with a maximum of 0.5 JTU.

6.2.3 Economics

The capital cost saving as a result of an increasing filtration rate is significant. Nevertheless, it should be noted that, for example, increasing the rate from 2 to 3 gpm/sq.ft (4.9 to 7.3 m^3/m^2-d) would result in a cost saving somewhat less than one-third, even though the filter area would be saved by one-third (Baylis, 1956). The reason is that the influent and effluent piping and conduit are the same for both schemes. Other equipment used in conjunction with the filter is also the same. The saving in operational cost is little, if any; however, the cost certainly should not be greater (Baylis, 1956). The fact that there is greater filter performance indicates slightly fewer filter washes, but this does not necessarily imply a saving in operational cost: certain equipment, such as backwash valves, is adversely affected by too little use.

6.2.4 Applicability

High-rate filtration is generally used for low-turbid waters. It is one of the economic solutions when one considers the expansion of the existing treatment plant. Upgrading of existing plants to high-rate filtration should be considered only when there is evidence that such a scheme will not adversely affect the plant performance. Increased rates of filtration should not be accompanied by a reduction in the designed mixing and settling times in the coagulation process (Baylis, 1956). Since the system needs better supervision than the conventional one, it may be better adopted in urban centers where monitoring facilities and skilled operators are available.

6.2.5 Advantages

++ The higher the filtration rate, the less the filter area which is required. This will lead to significant savings of capital and operational costs.

6.2.6 Disadvantages

-- The headloss is developed rapidly, and this results in an increase in backwashing frequency.

-- More skilled labor and close supervision are required in the operation and maintenance of high-rate filtration.

-- A high degree of pre-treatment is required if high-turbid water is to be filtered.

6.2.7 Application Status

According to Baylis (1950), a number of filters in Chicago, U.S.A. in 1948 started operating with filtration rates in excess of 2 gpm/sq.ft (5 m^3/m^2-h). A seven-year experience indicates (Baylis, 1956) that filters operated at a rate of 10 m^3/m^2-d may be maintained in service 97.9% of the time. A full-scale demonstration over a twelve-month period in Erie County, New York, U.S.A., provides detailed operational characteristics of the process (Westerhoff, 1971). The operating characteristics of various full-scale high-rate filtration plants in the U.S.A. have been reviewed by King et al., 1975) and Kirchman & Jones (1972).

High-rate filtration is widely used in developed countries, especially in Europe. Although high-rate filtration can easily be used in developing countries for new municipal water treatment plants and the expansion of existing treatment plants, it has not been used widely. A pilot-scale study (Karot, 1968; Pescod & Karot, 1973) conducted for the Samsen Waterworks in Bangkok, Thailand, indicates that long filter runs are possible without headloss exceeding 2.5 m at filtration rates of 12.7 and 20 m^3/m^2-h when mean influent turbidity is near 5 JTU, and filtered water turbidity can be maintained at less than 1 JTU. At a mean influent turbidity level near 10 JTU, it is possible to maintain acceptable filtered water quality (1 JTU), but the filter-run length decreases to near 12 hours at the highest filtration rate with the best media combination.

In the Rio de Janeiro plant, Brazil, sand filters constructed 25 years ago have been operating at rates of 9.7-11.9 m^3/m^2-h for more than 8 years, and they are producing water of excellent quality with filter runs of 24-30 hours (Wagner, 1983).

6.3 Conclusions on Modifications of Flow Rate

The design parameters of declining-rate filtration and high-rate filtration are summarized in Table 14. High-rate filters with dual- or coarse-medium arrangements have been successfully used in the West, and the accumulated experience as well as specific data support the concept that further application of these processes is warranted (King et al., 1975). This could be one of the economic solutions for the expansion of existing water treatment plants and for the construction of new plants in developing countries. In order to fully exploit economic benefits, filters should be designed to operate at the highest practical rates, which is economical even though washing must be done more frequently (Wagner, 1983). Here, more attention should be paid to the selection of the filter media and filtration rate so that the filtrate quality meets the required standard. Since the process has been widely used in the West for quite a time, planners and designers in developing countries can greatly benefit from the existing experience. It should be understood, however, that the optimum filtration rate in any given application needs to be determined for that specific installation on the basis of a thorough engineering study (King et al., 1975). On the other hand, high-rate filtration has some limitations, namely (i) it is suitable only for low-turbid waters, and (ii) it requires close supervision.

Declining-rate filtration produces better filtrate quality (especially during the latter stages of the filter run) than constant-rate filtration, and at the same time eliminates the use of automatic rate controllers and requires less operation effort. The process has not been widely adopted because it appeared to be a complicated system with rising and falling water levels considered to be of unpredictable magnitude. Since the process has been better understood, as Cleasby & DiBernardo (1980) suggest, "the engineer should begin to see the real beauty of this system in which the hydraulics of the filter itself regulates the flow through the filter and eliminates the need for complicated and expensive automatic control systems."

Table 14: Summary of Design Parameters for High-Rate and Declining-Rate Filtration.

Parameters	Conventional Constant-Rate Filtration	High-Rate (Constant Rate) Filtration	Declining-Rate Filtration
1) Filtration Rate	5 $m^3/m^2 \cdot h$	15-20 $m^3/m^2 \cdot h$	Varies during the filter run (Common value: 15 $m^3/m^2 \cdot h$ at the start to 5 $m^3/m^2 \cdot h$ at the end of the filter run)
2) Filter Media	**Depends on raw water characteristics and desired effluent quality. If fine medium is used, backwashing frequency will be increased. Therefore, filter medium size should be chosen in such a way that filtrate quality quality satisfies standard while head loss development rate is low.		
3) Filter Media Depth	0.8-1.0 m	Filter media depth is higher so that the effluent quality meets the standard.	Same as conventional rapid filtration
4) Cleaning		Same as conventional filter backwashing. (i) High-rate water back wash or (ii) Air-water backwash. Backwashing frequency and backwash water requirements would be higher due to the deeper penetration of particles.	Same as conventional filter backwashing. (i) High-rate water backwash or (ii) Air-water backwash.
5) Supernatant Water Level	0.8-1m.	0.8-1m.	Increases with the decrease in the filtration rate within the filter run. Variation depends on the headloss and number of filter units. Generally 1.75-2.5m
6) Under Drain System	Lateral-manifold type	Lateral-manifold type	As explained in text

Table 14: (Cont'd)

Parameters	Conventional Constant-Rate Filtration	High-Rate (Constant Rate) Filtration	Declining-Rate Filtration
7) Raw Water Turbidity	5-10 NTU	5-10 NTU	It can withstand higher raw water turbidities
		... better use of filter media	Due to the decrease in velocities

Table 14: (Cont'd)

Parameters	Conventional Constant-Rate Filtration	High-Rate (Constant Rate) Filtration	Declining-Rate Filtration
7) Raw Water Turbidity	5-10 NTU	5-10 NTU	It can withstand higher raw water turbidities
8) Filtration Action	Only top few centimeters of the filter bed participate in efficient filtration action	Slightly better use of filter media than the conventional	Due to the decrease in velocities during the filter run, effluent quality is better than the conventional.
9) Filter Run Length	24 hours	Shorter than the conventional	Longer than the conventional
10) Percentage of Treated Water Used for Backwashing	3%	More than 3%	3% (filter backwashing frequency is low)
11) Special Equipment	Rate controllers for automatic control (of flow rate)	Same as with conventional filtration	No rate controller is necessary
12) Skilled Labour		Requires more close supersion	Same as the conventional filters
13) Operation & Maintenance costs per Unit Volume of Filtered Water		Significantly less than that of conventional	Less than that of conventional
14) Capital Cost		Less than that of conventional filter (due to the less filter area requirement)	(i) Filter area requirement may be slightly lower than that of conventional (ii) No rate controllers necessary. Therefore the capital cost may be lower than that of conventional filters
15) Chemical Cost	Same in all three filters systems		

7. MODIFICATIONS OF FLOW DIRECTION

The flow in conventional rapid filtration is in the vertical downward direction. The major disadvantage in this process is that the flow meets the fine sand before reaching the coarse sand which is found at the bottom layer. If one inverts this flow direction to upward flow, then a better use of the filter media can be achieved. But the upflow filter creates a problem of fluidization, especially towards the end of the filter run. This problem can be overcome by using a grid system near the top of the filter medium or by operating the filters both in an upward and downward flow direction simultaneously. This section analyses the suitability of these two types of processes. The existing design criteria are also presented.

7.1 Upflow Filtration

7.1.1 Principles

Upflow filtration is one of the improved methods of water treatment. In this process, the raw water is fed at the bottom in the upwards flow direction and coarse-to-fine media filtration is achieved with a single medium in the direction of filtration, which makes better use of the entire filter bed. The problem with upflow filtration arises when the headloss exceeds the weight of the bed after a certain period of filter run, at which time partial fluidization of the medium occurs. This causes the escape of previously removed particles in the effluent. However, improved designs exist to overcome this problem of bed fluidization. The Russians and Dutch have worked extensively on upflow filtration and put forward many designs.

In the Soviet Union, Mints (1962) indicated that the fluidization of the bed during the upward flow can be prevented by controlling the filtration rate to 5-6.25 m^3/m^2-h and increasing the sand bed depth to 2-2.5 m. The Russians also use upflow filters with a contact clarifier arrangement and recommend an average coarse sand size of 0.9-1.1 mm (Fig. 20).

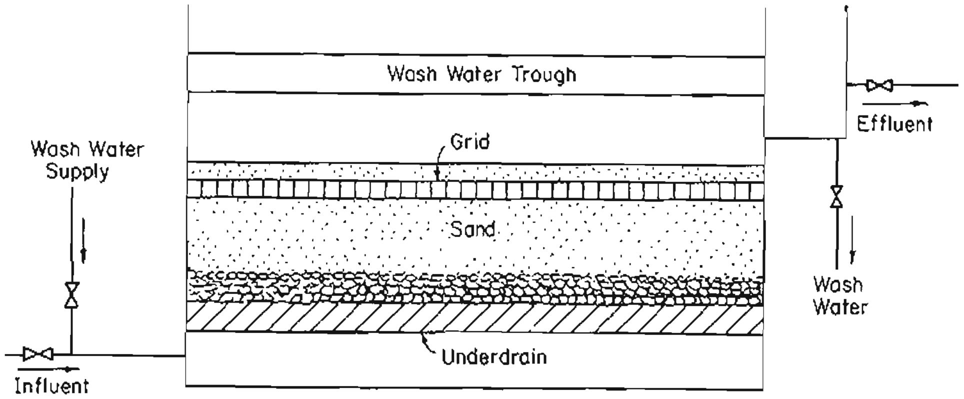


Fig. 20 : 'Contact Clarifier' Upflow Filter

The Dutch have worked extensively on upflow filtration and devised two new designs to overcome the problem of fluidization of finer layers of media during filtration (Hamann and McKinney, 1968).

Upflow filter with an effluent collection system just below the top layer of the filter media: By having the filtered water collection system near to, but below the top of the sand layer, one can overcome the problem of fluidization. (Anon, 1958). A drawback of this system is that one has to use a combination of air and water backwashing, because of the presence of a substantial amount of the removed particles at the bottom layers of the filter bed (Smith, 1959; Smit, 1963). This design later evolved to the biflow filtration scheme which is discussed in section 7.2.

Upflow filter with a grid placed on the top of the sand bed: The fluidization problem can also be overcome by placing a grid just below the top of the sand bed (Fig. 21). This grid system consists of parallel vertical plates. During filtration the sand arches against the grid and hence this grid provides sufficient resistance to prevent expansion of the bed and breakthrough or channeling at relatively high rates of upflow filtration (Smit, 1963). The spacing of the vertical plates should be close enough to provide resistance to sand expansion during upflow filtration, but not so close as to make upward flow backwashing difficult. Okun (1967) suggests that the grid spacing should be 100-150 times the size of the fine sand at the top of the bed.

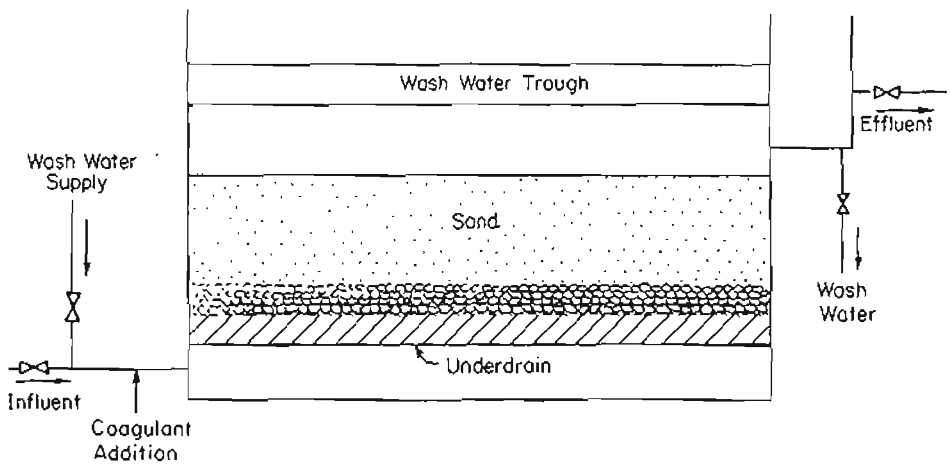


Fig. 21 : Upflow Grid Filter

A top layer of anthracite can be used to surround the grid when a high filtration rate is desired. This is because the anthracite seems to provide better arching conditions for preventing bed expansion (Hamann & Mckinney, 1968). This design has been found to have the advantage of operating at a higher filtration rate of 12.5-25 m^3/m^2-h (Anon, 1966). In this system, backwashing water as a percentage of water produced is also found to be less. This type of upflow grid filter has been extensively used for filtration of water for municipal and industrial supplies in Europe, Africa and America (Landis, 1966; Okun, 1967).

7.1.2 Design Criteria

Based on past experience, the design criteria presented in Table 15 are recommended.

Table 15: Recommended Design Criteria Values for Upflow Filtration

Parameters	Range of Values
Filter Media:– Single-Media –	1. E.S. = 0.6 mm, U.C. = 2-3 or 2. 0.9-1.1 mm, uniform coarse media (U.C. = 1.1)
– Dual-Media	Sand: E.S. = 0.6 mm, U.C. = 1.3-1.7 Anthracite E.S. = 0.9 mm., U.C. = 1.3-1.7
Filter Depth:–	2.0-2.5 m.
Filtration Rate:–	10-15 m^3/m^2-h

7.1.3 Applicability

Upflow filtration can be used only for low and medium turbidities (less than 80 NTU). When the turbidity of the raw water is higher, adequate pre-treatment facilities (like flocculation, sedimentation) should be provided. Upgrading of existing plants needs a modification of the underdrain system. A successful example is given by Hill (1960).

7.1.4 Advantages

As early as 1960, Hill cited the benefits of upflow filtration as follows:

++ No filter controller is required.

++ The filter cannot be run dry while in use.

++ The filter cannot become air-bound, or generate a negative head.

++ The underdrain system and subgrade perform their proper function, in the sense that the water passes through the coarse elements first and through the finer medium last.

++ Chlorination can be easily and effectively applied in the incoming water, which tends to maintain the medium in sterile conditions and assists in the operation of the filter.

++ Some of the suspended matter tends to settle out in the underdrain of the filter, thus reducing the extent of medium clogging.

++ With gravity upflow filters, the filtrate can be observed in bulk as it flows upwards through the medium to the clear water tank. Changes in color and appearance are, therefore, easily noticed.

++ Different layers of various types and sizes of the medium can be maintained in their proper position better than in downflow filters. The finer medium tends to move to the upper layers, where it is more effective and is in the correct position for the last stage of filtration.

++ The spreading of the medium, due to the upward direction of flow, tends to give efficient, in-depth filtration, and the whole of the medium, including the coarser grades, is made to work. In conventional rapid filtration, only the top few centimeters are used in effective filtration action.

++ If a breakthrough occurs, it can readily be observed and the filter is put out of action. This is not possible with a downflow filter.

++ The upflow filter is quite flexible in permitting alteration of the filtration rate without adverse effects to the filtrate.

++ Owing to its low loss of head (this needs not exceed 15" or 38 cm), the clear water tank can be sited at a higher level.

Other advantages include :

++ A reduction of headloss development during upflow filtration is observed due to the removal of a substantial amount of suspended particles in the coarse portion of the medium. In other words, if headloss is the limiting criteria for filtration, longer filter runs can be achieved by the use of upflow filters.

++ By using uniform coarse media (0.9-1.1 mm) or dual media in the upflow filters, the filtration rate can be increased significantly (up to 15-20 m^3/m^2-h), which significantly reduces the construction cost of the filter.

7.1.5 Disadvantages

-- An inherent problem with upflow filters is the built-in cross connection between the filtered water and washwater. Contaminated water occupies the same space above the filters as the filter effluent. There is always the possibility that the washwater will flow into the filtered water clearwell.

-- The major problem in upflow filtration is the deterioration of effluent quality, due to the escape of entrained particles from the medium, when the bed expands and fluidizes during the filtration process. This problem can be avoided by the provision of a grid system over the sand bed (as discussed above) or by having a larger depth of filter media.

-- Similarly, the flotation of the sand after headloss build-up may be problematic. Perforated pipes may be introduced about 15 cm below the sand top, in order to prevent the flotation of the sand and the chances of contamination of the filtered water (Patwardhan, 1981).

7.1.6 Application Status

Hill (1960) reports the conversion of two conventional gravity filters in Singapore and Johore into upflow filters. In Singapore, upflow filtration was adopted after extensive experimental work lasting about eight years. The operational parameters are shown in Table 16. By using upflow filtration, the capacity of the plants in Singapore was raised from 6,800 to 9,500 m^3/d, while the headloss was reduced from 198 to 35 cm. The filter run was increased from 20 to 50 hours. In the case of the Johore works, the throughput of the plant was increased from 12 to 32 mgd (45,420 to 121,120 m^3/d) without any actual increase in size. As of 1960, both plants had been in operation for about nine years.

Table 16: The Operational Parameters of Upflow Filters in Singapore

Parameters	Values
Depth of the Filter	15 in. (38.1 cm)
Filter Media Size (granite)	1/10-1/8. in (25-3.2 mm)
Filtration Rate	8.75 m^3/m^2-h
Backwashing System Air-water backwash	30 m^3/m^2-h for 10-15 minutes
Amount of Backwash Water	3% of the filtered water

More than 350 upflow filters had been installed in Western Europe by 1963. They operated at flow rates as much as 200% higher, and they delivered as much as 500% more filtered water per run than conventional down-flow filters using similar filter media (Smit, 1963).

A pilot-scale experimental study performed by Datar (1980) at the University of Sulaimania, Iraq, shows that a dual-media upflow filter can produce good effluent from raw water with a turbidity up to 30 JTU, without any pre-treatment like flocculation and sedimentation. The sand layer has a depth of 25 cm, with an effective size of 0.44 mm and a uniformity coefficient of 1.75, whereas the anthracite layer has a depth of 38 cm, with an effective size of 0.9 mm and a uniformity coefficient of 1.33. The gravel layer below the media has a depth of 59 cm and a size of 25-40 mm.

In the U.S.A., Daniel & Garton (1969) used up-flow filters of 10-cm lucite tubing as treatment units for pond water. A variety of filter media were tested at a flow rate of 2.5 m^3/m^2-h. Backwash was necessary once a week. Later, Rice et al. (1980) designed two up-flow filter units with the following specifications :

** The large unit : a 0.92-m diameter by 2.14 m tall tank used for filtration and storage for the unit, which also includes chemical feeder pumps with required chemical storage tanks, a pump and a tank for pressurized-treated water, and liquid level controls to make the unit completely automatic. The capacity is 3.6 m^3/h. The components are put together in a compact arrangement in a built-up module, making the system portable.

** The small unit : a 0.30-m by 0.30-m cross-section by 1.52 m tall tank used for filtration, and a tank height of 1.07 m used for mixing and settling.

The two units effectively reduce the turbidity of raw surface water to acceptable levels when operated at a flow rate of 2.5 m^3/m^2-h. Raw water with turbidities greater than around 80 NTU may require some type of pre-treatment.

7.2 Biflow Filtration

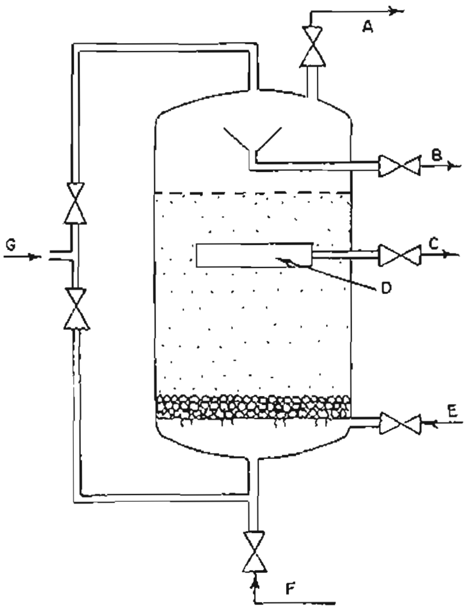
7.2.1 Principles

The design of a biflow filtration scheme was evolved from upflow filtration in order to prevent the expansion of sand in tne upflow filtration by imposing pressure on the top of the filter bed by downward filtration. It is based on the concept of increasing the flow rate and capacity between successive backwashes of a conventional downflow filter by providing a double flow : from the top of the bed downward, and from the bottom of the bed upward, toward a common collector system located within the bed. However, designs differ in the precise location of the collector system. In some designs, the collector appears to be midway in the bed. It is placed there, presumably on the assumption that the two halves of the bed perform similarly. A diagram of the unit is shown in Fig. 22 (Smit, 1963).

Biflow filters in Russia (Mints, 1962) use sand as the filter medium at a depth of about 1.5 m. The filtrate collector system is located about 0.4-0.6 m below the top of the sand. The downward and upward filtration rates are 5-6.25 m^3/m^2-h and 7.5-8.75 m^3/m^2-h respectively (i.e., the total filtration rate is 12.5-15 m^3/m^2-h). Backwash is achieved by an upward water flow at a rate of 47.5-55 m^3/m^2-h for 5 to 6 minutes.

The development of a biflow system in the Netherlands was apparently paralleled by the development of the Russian biflow filters (Hamann & McKinney, 1968). The Dutch biflow filter is of nearly the same design as the outlet system in the upper layers of a graded sand bed (Smit, 1963; Ives, 1961).

If the sand alone is used as a filter medium in the biflow filters, the downward filtration rate would decrease faster as the run progresses due to the fine sand clogging. To overcome this problem, Ling (1962) has suggested the use of a layer of anthracite over sand for the downward flow portion of the biflow filter. This modification would improve the output of the downwards filtration. A schematic diagram of a biflow filter of this type is shown in Fig. 23.



A Represents Air Outlet ; B, Backwash Outlet ; C, Effluent ; D, Collector System ; E, Air Inlet ; F, Backwash Inlet ; G, Influent.

Fig. 22 : Diagram of the Biflow Filter

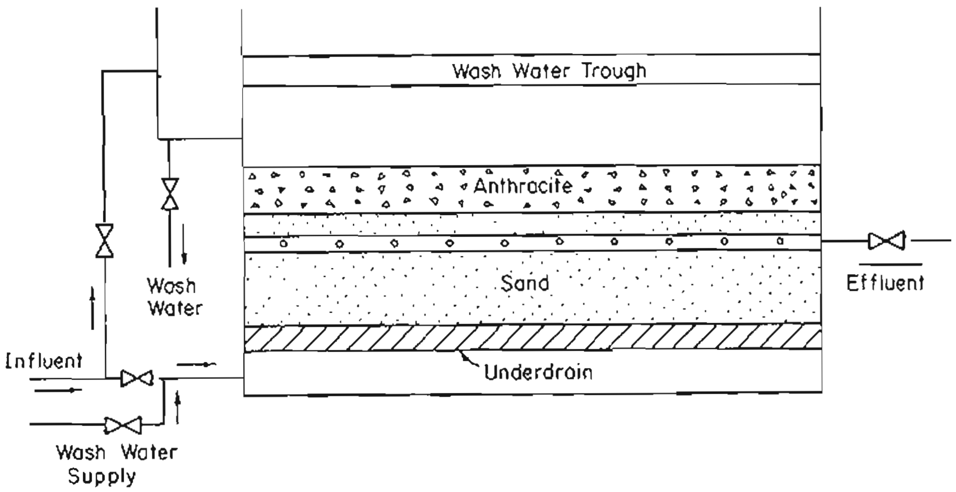


Fig. 23 : Proposed Biflow Dual-Media Filter

7.2.2 Design Criteria

Table 17 summarizes some of the important design criteria of biflow filtration.

Table 17: Design Criteria of Biflow Filters

Parameters	Range of Values
1. Filter Media:	
Sand	
Size	0.9-1.2 mm
Depth	1.5-1.7 m
(Dual media with anthracite and sand has been found better)	
2. Filtration Rate	
Downwards rate	5-6.25 $m^3/m^2 \cdot h$
Upwards rate	7.5-8.75 $m^3/m^2 \cdot h$
(Total filtration rate can be raised up to 20 $m^3/m^2 \cdot h$ if dual media arrangement is used)	
3. Filtrate Collection System	Located about 0.5-0.6 m below the top of the medium.
4. Backwash Rate (high-rate water wash)	47.5-55.0 $m^3/m^2 \cdot h$ for 5 to 6 minutes.
(Air-water backwash system is necessary if dual media arrangement is used).	

7.2.3 Economics

The Russian experience indicates that the initial cost of this system is 15 to 30% less than that of conventional systems. A comparative study made in Russia shows that the upflow filter construction cost is 20-30% lower than that of conventional filtration.

7.2.4 Advantages

++ In general, biflow filtration offers the advantage of very high output per unit area of the filter bed, especially when the dual-media arrangement is provided with proper conditions of raw water with polymer filter aids.

7.2.5 Disadvantages

-- The complicated piping, valving and control system limits its application in developing countries. Further, the filtrate collection system, which consists of slotted vinyl plastic tubing in most instances, has been troublesome and is subject to breakage.

7.2.6 Application Status

In Russia and in the Netherlands, biflow filters (AKX Filters) are used to some extent (Ives, 1964; Brown & Okun, 1965, Smit, 1963).

7.2.7 Conclusion

Extensive experiences in the Netherlands, the U.K. and Russia, and two installations in Singapore, indicate that this type of filter is one economical solution. It may be cost effective as far as the capital cost is concerned.

From the discussion, and as summarized in Table 18, it seems that the upflow filter with a grid system on the top is a feasible and economical solution in developing countries for medium-turbid waters, provided that there is a sufficient high-rate water backwash to clean the filter bed.

On the other hand, a relatively sophisticated operation procedure may disqualify the use of biflow filtration in developing countries.

Table 18: Summary of Design Parameters of Upflow and Biflow Filters

Parameters	Conventional Filters	Upflow Filters			Biflow Filters
		With increased bed depth	With effluent collection system below the top of the sand bed	With a grid placed on the top of the sand bed	
1) Filtration Rate	5 $m^3/m^2 \cdot h$	5-6.25 $m^3/m^2 \cdot h$	5-6.25 $m^3/m^2 \cdot h$	12.5-25 $m^3/m^2 \cdot h$	Downwards flow 5-6.25 $m^3/m^2 \cdot h$, upwards flow 7.5-8.8 $m^3/m^2 \cdot h$, total 12.5-15 $m^3/m^2 \cdot h$.
2) Filter Media type					
a) Media type	Sand	Sand	Sand or sand/anthracite	Sand or sand/anthracite	Sand/anthracite (preferred)
b) Media size	Generally E.S. = 0.6 mm U.C. = 1.5 (Depends on raw water characteristics and effluent quality)	Coarse sand of 0.9-1.1 mm	Coarse sand is recommended	Since anthracite gives better arching, dual media is preferred Sand: E.S. = 0.6 mm U.C. = 1.5 Anthracite: E.S. = 0.9 mm U.C. = 1.5	Dual media of sand/anthracite is preferred. Sand: E.S. = 0.6 mm U.C. = 1.5 Anthracite: E.S. = 0.9 mm U.C. = 1.5 mm
c) Media depth	Generally 1 m (depends on raw water characteristics and effluent quality)	2-2.5 m	Depends on the filter media size and raw water and effluent quality	Depends on the filter media size and raw water and effluent quality	Depends on the filter media size and raw water and effluent quality
d) Cleaning procedure	High-rate water backwash or air-water backwash	High-rate water backwash or air-water backwash	Air-water backwash (more particles are deposited at the bottom)	High rate water backwash or air-water backwash	High rate water backwash or air-water backwash

Table 18: (Cont'd)

Parameters	Conventional Filters	Upflow Filters			Biflow Filters
		With increased bed depth	With effluent collection system below the top of the sand bed	With a grid placed on the top of the sand bed	
3) Supernatant Water Level	0.8-1.0 m	1.0 m	Collection below the top sand layer	1.0 m	Collection is 30 cm below the top of the medium
4) Raw Water Turbidity	10 NTU	< 80 NTU	< 80 NTU	< 80 NTU	< 80 NTU
5) Filtration Action	At the top few centimeters only	Entire bed	Entire bed	Entire bed	Entire bed
6) Filter Run Length	24 hours (generally)	Higher	Higher	Higher	Higher
7) Percentage of Treated Water Used for Backwashing	3%	Higher than that of conventional filter (5%)	Higher than that of conventional filter (5%)	3% or less	3% or less
8) Special Equipment		For air-water backwashing method	For air-water backwashing method	Grid system (vertical grid spacing is 150 times the sand size)	Complicated valve controls are needed
9) Skilled Labour	For backwash operation	For backwash operations	For backwash operations	For backwash operations	Flow control and backwashing operations.

Table 18: (Cont'd)

Parameters	Conventional Filters	Upflow Filters			Biflow Filters
		With increased bed depth	With effluent collection system below the top of the sand bed	With a grid placed on the top of the sand bed	

Table 18: (Cont'd)

Parameters	Conventional Filters	Upflow Filters			Biflow Filters
		With increased bed depth	With effluent collection system below the top of the sand bed	With a grid placed on the top of the sand bed	
10) Operation and Maintenance Cost					
i) Power consumption per unit volume of filtrate	High	Low (longer filter run)	Low (longer filter run)	Lower (longer filter run & high filtration rate)	Lower (longer filter run and higher filtration rate
ii) Maintenance of equipment		High	High	High	High
iii) O & M cost for back washing		High	High	Equal or Lower	Equal or Lower
11) Capital Cost		Capital cost may be slightly higher than conventional filter; but use of few pretreatment units may be eliminated (e.g., flocculation & sedimentation units can be eliminated in contact — clarifier type filter)		Less than that of conventional filter (due to the higher filtration rate, the filter area needed is less)	15-30% lower than conventional filter
12) Chemical Cost		Same as conventional filters (except when contact clarifier type filters are used)			

8. ELIMINATION OF SOME OPERATIONS FROM CONVENTIONAL WATER TREATMENT

Conventional water treatment plants use the unit operations of rapid mixing, flocculation, sedimentation, filtration and disinfection. Depending on the quality of the water, one or more unit operations can be eliminated, whereby one could achieve a cost-effective water treatment. This section introduces two such systems and discusses their suitability along with the existing design principles.

8.1 Direct Filtration

8.1.1 Principles

Direct filtration has been defined by the American Water Works Association (AWWA) as "the treatment system in which filtration is not preceded by sedimentation" (Culp, 1977). Filters for direct filtration thus differ little in construction from those used for conventional treatment. The primary differences in the operation of the two systems are related to solids storage capacity and backwash requirements.

Direct filtration was first explored during the early 1900's, but these attempts were not successful because of the rapid clogging of the sand beds and subsequent accumulation of headloss. The development of coal-sand filters has made it possible to store greater amounts of floc within the filter bed without excessive headloss, and this modification has increased the feasibility of the direct filtration process. Further advances in filter design, and the availability of a wide selection of chemical coagulants, have resulted in a variety of filtration systems being designed in which coagulating chemicals are employed, where the flocculation basin is either eliminated or reduced in size, and the sedimentation basin is not utilized. Such processes thus have only screening, rapid mixing, coagulation and flocculation prior to filtration. All suspended solids and flocs formed are deposited in the filter, which is usually a multi-media, granular bed containing coal, sand, and perhaps other constituent media.

Chemical destabilization prior to filtration appears to be essential for improved water quality. Sometimes a 30-60 minute contact basin is placed between the flocculation and the filter. If a turbidity surge occurs, settling will reduce the turbidity to an acceptable level for direct filtration. The contact basin does a very poor job of turbidity removal when the turbidity is low, but a surprisingly good job when the turbidity is high (Mueller & Conley, 1981). In effect, the contact basin provides a reasonably uniform influent to the filter even though the raw water quality changes drastically. Hence, the contact basin is a practical way of coping with turbidity surges of short duration. For water with medium turbidities, a contact time of about 30 minutes is required when treating cold water, as compared with 10 minutes during the warm season (Sweeney & Prendiville, 1974). A similar conclusion was also drawn by Hutchison & Foley (1974).

A prevalent misconception is the level of turbidity in the raw water that can be treated successfully by direct filtration. Dense turbidity plays a minor role in clogging filters. Light, gelatinous flocs formed by the reaction of the coagulant with the raw water play the major role. If the turbidity, which is mainly colloidal, can be destabilized with a small dose of coagulant or polymer or a combination of the two, a properly designed filter can handle relatively turbid water (Wagner, 1983).

Wagner & Hudson (1982) have devised a simple filter paper test for determining the efficacy of direct filtration for any particular raw water.

The status of direct filtration has been reviewed in various documents (AWWA Filtration Committee, 1980; Culp, 1977; Gavin & FitzPatrick, 1981; King & Amy, 1979; Logsdon, 1978; Logsdon et al., 1980; McCormick & King, 1980; Tate & Trussell, 1980; Wagner & Hudson, 1982). The Asian Institute of Technology has also conducted a pilot-scale study for rational design purposes (Liang, 1982; Vigneswaran & Liang, 1982).

The AWWA Filtration Committee's report (1980) on a worldwide survey of seventy operating and pilot direct filtration plants indicates that waters with less than 40 units of color, turbidity consistently below 5 units (FTU), iron and manganese concentrations of less than 0.3 mg/L and 0.05 mg/L respectively, and algal counts of up to 2000 ASU/ml appear to be perfect candidates for direct filtration. Turbidity and color removals are consistently attained in this process. By efficient post-chlorination, bacteria and virus removal problems can be overcome. Most of the literature favors the use of dual- or mixed-media in direct filtration (Gadkari et al., 1980; King & Amy, 1979). For raw water with a turbidity of 25 units, the filter run might be one-fifth as long as for a conventional plant (Mueller & Conley, 1981). Experience from the Toronto plant on Lake Ontario, Canada, indicates that the length of the filter run is approximately inversely proportional to the alum dose (Hutchison & Foley, 1974).

Direct filtration flow schemes of importance are indicated in Fig. 24 (King & Amy, 1979). Further details on operational characteristics of the process can be found from AWWA Filtration Committee (1980); Culp (1977); Hutchison & Foley (1974); King & Amy (1979); McCormick & King (1980; 1982).

8.1.2 Design Principles

Since optimum design parameters depend greatly on the nature of the water to be treated, pilot studies are required to determine the appropriate type of coagulant and coagulant-aid, and the media composition, size and depth. Some guidelines are given below.

** Filter media : Can be single-, dual- or mixed-media, but usually dual- and mixed-media are preferred in direct filtration. One research (Gadkari et al., 1980) recommends dual-media with bituminous coal or anthracite coal. An excellent multi-media filter bed might consist of (Culp, 1977):

:: 41 cm of -4 to +14 mesh coal, specific gravity of 1.48;
:: 20 cm of -9 to +18 mesh coal, specific gravity of 1.62;
:: 20 cm of -30 to +40 mesh san, specific gravity of 2.4; and
:: 8 cm of 40-80 mesh garnet, specific gravity of 4.2.

Culp (1977) also suggests a typical dual-media bed as follows:

:: 64 cm of -4 to +20 mesh coal, specific gravity of 1.55; and
:: 28 cm of -20 to +50 mesh sand, specific gravity of 2.4.

This dual-media bed can produce the same quality of effluent as a mixed-media bed containing three or four media, but the chemical dosages will be higher.

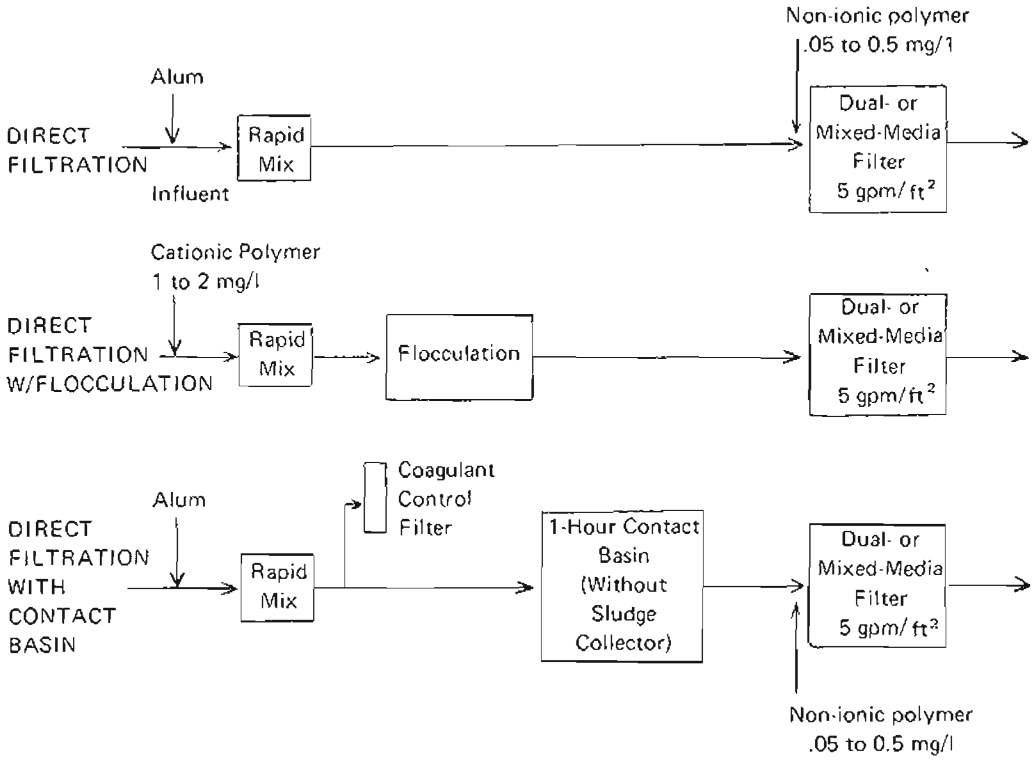


Fig. 24 : Direct Filtration Flow Schemes (1 gpm/ft^2 = 2.444 m^3/m^2·h)

Recent trends appear to favor deeper filters than are normally associated with conventional filtration (King & Amy, 1979). The finest media possible should be selected to minimize chemical dosages. Within reasonable limits, coarse filter beds or beds containing fewer grains can produce the same quality filtrate as finer beds, but more polymer is required. Fine filter media are supported on a gravel bed. This is preferred to direct support on bottoms equipped with mechanical strainers or nozzles, which are not recommended (Culp, 1977).

** Flocculants : The type of flocculant is the most important parameter and should be experimentally evaluated first. Alum has been utilized with success in many installations. Dosages of 5-10 mg/L can be effective for direct filtration of waters of various turbidities (Adin et al., 1979).

However, more recently it is apparent that a carefully selected cationic polymer may have considerable advantages in some situations (King & Amy, 1979). At least in one case, a cationic polymer provided a better performance than an alum or anionic polymer in increasing the length of filter runs (Chapman & Benoit, 1980). Polyelectrolyte doses for uncolored water may frequently vary from 0.05 to 1.0 mg/L when used as primary flocculants (essentially cationic), and may be less when used in addition to alum for the treatment of organic-contaminated water (Adin et al., 1979). The general range of the cationic polymer dosage used as the primary coagulant is 0.1-5 mg/L (Culp, 1977). More discussions on flocculation prior to direct filtration can be found from Adin et al. (1979); Treweek (1979).

** Rapid Mixing : The rapid mixing process for direct filtration usually does not differ much from that used for conventional plants. Some engineers extend the time for mechanical rapid mixing in direct filtration plants up to as much as 5 minutes (Culp, 1977), which is longer than that used in most conventional plants.

If settling is omitted and if a properly designed rapid mix is provided, then usually there is no reason to include flocculation. Rather than spending money on flocculation, improvement of the rapid mixing, provision of finer filter media, or an increase in the depth of the filter media may be better (Culp, 1977).

** Filtration Rate : 10-15 m^3/m^2-h (constant-rate operation). A rate of 12 m^3/m^2-h is usually adopted. Filter influent and effluent piping should be designed for flows of 24 m^3/m^2-h.

** Backwash Method : Any conventional washing procedure can be used. The usual backwashing rate is 37.5-60 m^3/m^2-h. In the case of dual-media and multi-media filters, the backwashing rate should be chosen in such a way as to minimize the intermixing of media. Details are given elsewhere (Baumann, 1978; Kawamura, 1975). The total backwash water volume can be reduced by a combined air-water backwash method.

** Filter Run Length : Filter-run length depends on the raw water characteristics, the coagulant dose, the mixing energy input for floc formation (extent of pre-treatment), the media size, the filtration rate, etc. As a guideline for design, the design parameters should be chosen in such a way that the filter run is at least 12 hours.

8.1.3 Economics

Cost data for direct filtration in the U.S.A. have been reported by Culp (1977); Logsdon et al. (1980); McCormick & King (1980); Monscvitz et al. (1978); Mueller & Conley, (1981); Tate et al. (1977).

Culp (1977) states that the capital cost saving in direct filtration could be as high as 30%, and that a saving of 10 to 30% in chemical cost could be achieved. The costs for polymer may be higher than in conventional plants, but these costs are more than offset by the lower costs for the coagulant. Monscvitz et al. (1978) report that to add sedimentation to one water treatment plant in Las Vegas would require more than 50% additional capital expenditure. Tate et al. (1977) also report capital cost savings of approximately 30% for the Utah Valley water treatment plant. When the 72-mgd (272,500 m^3/d) Toronto water treatment plant was doubled in capacity by adopting direct filtration, the cost saving was $4.8 million (or 35%) as compared with conventional treatment (Tredgett, 1974). Similarly, studies in Virginia, U.S.A., indicate (McCormick & King, 1980) that the use of direct filtration for waters of less than 10 NTU should result in savings of 10 to 30% in total annual costs. All in all, information collected by Logsdon (1978) indicates that the elimination of sedimentation basins can yield a capital cost saving of 20-30%.

It should be noted (Logsdon, 1978) that the capital savings from omission of settling basins can be slightly offset by reducing the length of the filter runs. Cost comparisons of conventional and direct filtration plants should be made on the basis of designs that permit optimum economy for each mode - rather than assuming fixed filter-run lengths for both modes.

Figs. 25 and 26 (Logsdon et al., 1980) show the estimated curves for total capital costs and O&M costs respectively. Fig. 27 (Mueller & Conley, 1981) expresses capital costs per m^3/d of water treated, using an index number to permit cost comparison. An interesting fact arising from this Figure is that, the smaller the plant, the more the direct filtration process should be given preference over the conventional system. For instance, at a capacity of 200 m^3/d, direct filtration is nearly three times cheaper, and at a capacity of 500 m^3/d, it is twice as cheap. In each instance, the capital cost includes an allowance for the equipment, its installation, and its foundations and housing. Intake structures, filtered water storage, high-service pumps and distribution systems are excluded.

Clark & Morand (1981) reached a similar conclusion when they compared the three treatment options available for small water supply systems, namely (i) conventional treatment (flocculation, sedimentation, filtration), (ii) direct filtration, and (iii) package treatment plants. Costs for annual operation and maintenance and capital costs over a range of specific flow levels were calculated, and cost equations developed. Total production costs for the three treatment alternatives are plotted versus plant capacity in Fig. 28, which assumes that the average flow is 70% of the designed or capacity flow. All of the costs have been standardized with 1979 as a base year. It can be seen that in the production range below 2 mgd (7,600 m^3/d), package treatment represents a lower-cost alternative for water treatment than does conventional or direct filtration. With plant capacities over 7,600 m^3/d, direct filtration is significantly cheaper than the other two methods.

The 60-mgd (227,100 m^3/d) direct filtration plant for the City of Springfield, Massachusetts, U.S.A., could bring about a saving in construction costs of US$ 10 per 1,000 m^3 of capacity, as compared with conventional treatment (Sweeney & Prendiville, 1974).

8.1.4 Applicability

Direct filtration can be successfully used for low-turbid water in developing countries because of its lower capital and operational cost. It does not involve any sophisticated equipment, although it requires skilled operators for close monitoring of filters. Attention should be paid to the possibility of poor bacteriological quality of the filtrate as a result of treating badly polluted raw water.

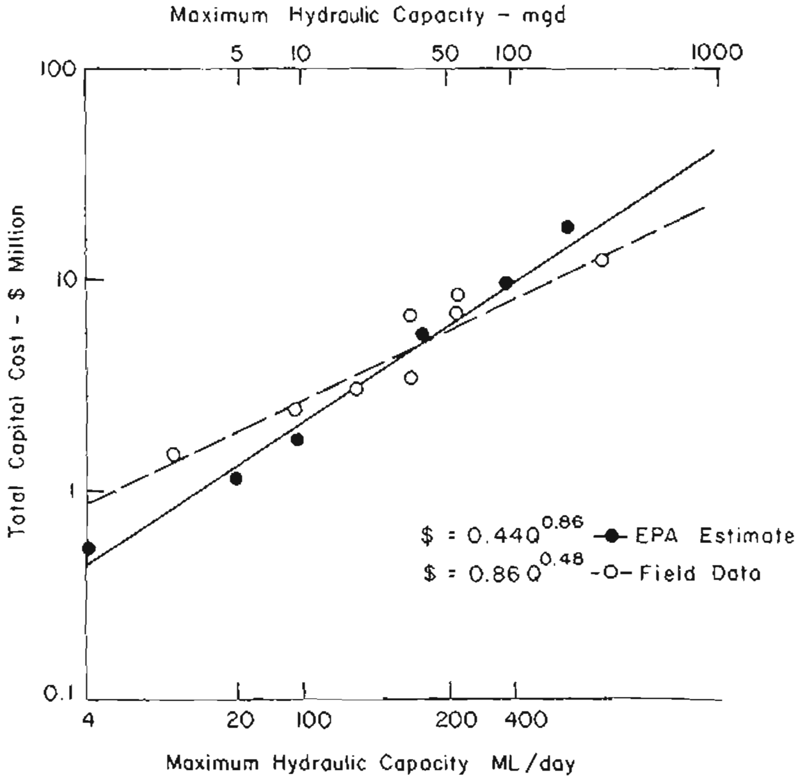


Fig. 25 : Total Capital Cost of Direct Filtration
(Q : Maximum Plant Capacity in mgd)

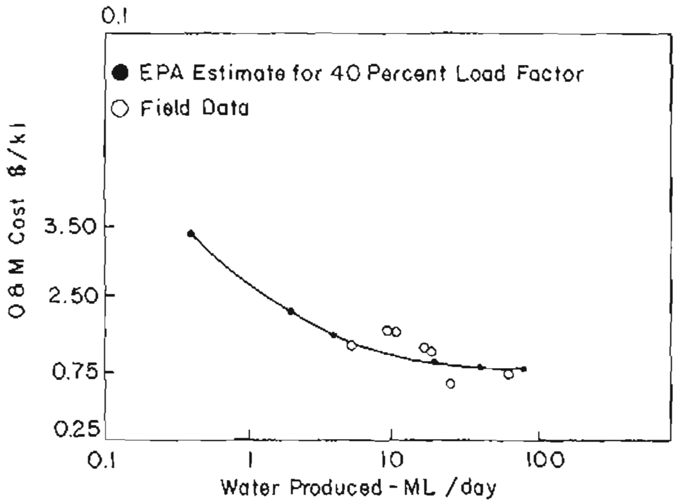


Fig. 26 : Operation and Maintenance Cost of Direct Filtration

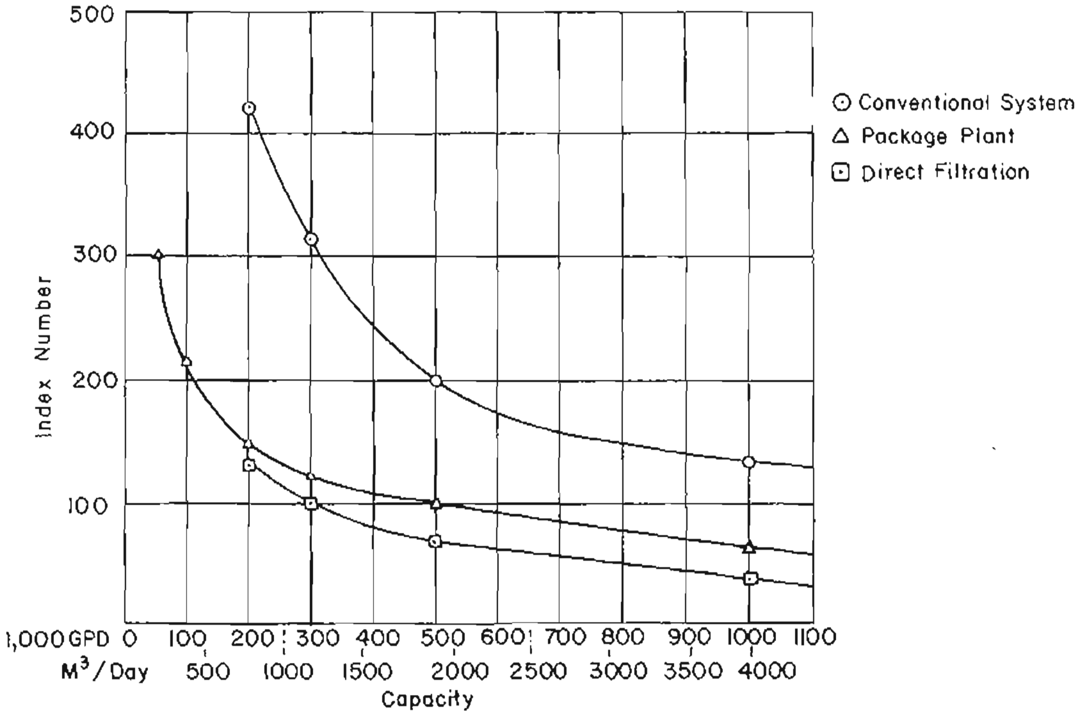


Fig. 27 : Systems Cost Comparison

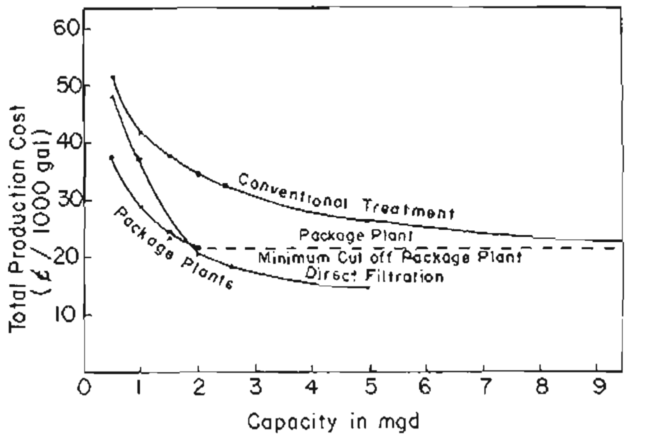


Fig. 28 : Comparison of Package Plants, Direct Filtration and Conventional Treatment

8.1.5 Advantages

++ Direct filtration processes are normally found to be efficient and cost-effective with raw water of relatively high quality (with turbidity less than 25 NTU).

++ Direct filtration requires only that the colloids in raw water be destabilized into a small filterable floc. It is unnecessary to produce a settleable floc, which is more difficult to filter and far more expensive both in terms of chemicals and plant operation. Thus, a shorter flocculation time is required to form small flocs, and this reduces the power cost.

++ The key benefit of direct filtration is cost savings. The omission of large sedimentation basins results in lower plant construction costs - and possible savings on land cost.

++ Likewise, a reduction in operational and maintenance costs is obtained because less equipment is involved.

++ Consequently, there is a substantial reduction in chemical dosages, of about 20-30%. This also results in decreased sludge production and thus less maintenance.

++ The operation and maintenance of a direct filtration plant become simpler and easier, as compared with operating and maintaining a conventional plant.

++ Direct filtration is more effective than conventional treatment in dealing with upsets in the coagulation process because of the shorter detention time before filtration.

8.1.6 Disadvantages

-- The use of polyelectrolytes, used in most cases as sole flocculant, may cause mudball formation in the filter bed, which necessitates frequent backwashing.

-- Due to the elimination of the sedimentation process, the backwashing of the filter becomes more frequent. Also, since all the impurities are removed in the filter, more suspended solids are retained in the pores of the filter media, which requires a large amount of backwash water. Some of the experiences indicate that the backwash water used in direct filtration is as high as 6% of the water volume produced (Culp, 1977). Therefore this shortcoming has to be taken into cost calculations before selecting an appropriate alternative.

-- Due to the shorter retention time between the application of coagulants and filtration and the greater loading applied to the filter, a significant amount of contaminated water enters the distribution system before the problem is discovered.

-- For the same reason, more operator's vigilance is required. The chance of operational error is also greater than with the conventional treatment method. In order to mitigate this effect, continuous monitoring of effluent turbidity at each filter is a must (Logsdon, 1978).

-- In the treatment of raw water containing a high concentration of coliform organisms, the reliability of public health may be reduced.

8.1.7 Application Status

== Canada. As early as 1964, direct filtration was used in Toronto, when an existing plant with the maximum capacity of 72 mgd (272,520 m^3/d) on Lake Ontario was converted to direct filtration (Hutchison & Foley, 1974; Tredgett, 1974). The use of alum plus polyelectrolyte when needed, followed by filtration through a dual-media filter with 18" (46 cm) of coal and 12" (30 cm) of sand produces high-quality effluent (less than 0.3 FTU). There is little change in the effluent turbidity for the filtration rates of 2.4-7.2 gpm/sq.ft (5.9-17.6 m^3/m^2-h). Diatoms in the raw filter have a marked influence on the length of the filters, but this problem can be overcome by using a coarse medium (such as coal) in the dual-media filters. During the algae off-seasons, this coarse coal filter requires a greater level of operational skill on the part of the plant operator. As of 1976, seven direct-filtration plants existed in Ontario, and plans were underway for the construction of up to six additional plants to serve localities on Lake Ontario, Lake Huron and Lake Superior (Hutchison, 1976).

Case histories of direct-filtration plants in Canada are described by Hutchison & Foley (1974).

== U.S.A. Diatomaceous earth and granular media direct filtration has been used at a number of full-scale plants with capacities from less than 1 mgd (3,780 m^3/d) to above 100 mgd (378,000 m^3/d). Generally, diatomaceous earth plants are smaller, in the order of 1 to 10 mgd (Logsdon, 1978). Biggest plants include a 200-mgd (757,000 m^3/d) plant at Las Vegas, Nevada, constructed in 1971, a 60-mgd (227,100 m^3/d) plant for the City of Springfield, Massachusetts, and a 30-mgd (113,550 m^3/d) plant at Duluth, Minnesota, completed in late 1976. After several years of operation, the plant at Duluth demonstrated that the process can be an effective and efficient means of providing a high-quality finished water when proper design and operation parameters are adhered to (Hagar & Elder, 1981).

At the Springfield plant, raw water is conducted to the headworks of the conditioning basins. A channel running down the center of the conditioning structure feeds fourteen sets of basins, seven sets on each side. Each set of basins consists of two rapid-mix chambers in series, followed by two slow-mix chambers. A detention time of 30 minutes, believed conservative, is provided in the conditioning basins. Alum or iron salts may be used as the prime coagulants. The filter media consist of 24" (61 cm) of 1.0-1.1 mm effective size anthracite coal and 12" (30 cm) of 0.45 mm effective size silica sand. It also operates at a filtration rate of 12.5 m^3/m^2-h (Sweeney & Prendiville, 1974).

The plant at Las Vegas operates at a filtration rate of 5 gpm/sq.ft (12.2 m^3/m^2-h), and the filter media consist of 20" (51 cm) of 0.60-0.70 mm effective size anthracite and 10" (25 cm) effective size silica sand (Spink & Monscvitz, 1974; Monscvitz et al., 1978). Odor problems occur in two distinct periods - the spring and the fall - due to algal blooms. Activated carbon is added in the mixing chamber immediately ahead of the filters to remedy this problem (Spink & Monscvitz, 1974). Problems were initially encountered due to the inefficiency of the system in plankton removal without flocculation (Monscvitz et al., 1978)

== Australia. The direct-filtration plant serving Sidney, at a capacity of 800 mgd (3,028,000 m^3/d), is the largest facility of this kind in the world. It adopts a filtration rate of 5.4 gpm/sq.ft (13.2 m^3/m^2-d), and the media include a total of 3 ft (0.9 m) of 1.0 mm coal and 0.6 mm sand (Walder et al., 1975).

The status of application of direct filtration in developing countries is reported below.

== Amman, Jordan. During March and April 1981, bench-scale and pilot filter studies were carried out on the water of East Ghor Main Canal in the Jordan Valley near Amman, Jordan. The turbidity of the water applied to the filter during the test period was 62 NTU. The most effective pilot filter run was with a filter medium of 85 cm of anthracite of 1.4-mm effective size and 1.57 uniformity coefficient over 26 cm of sand of 0.67-mm effective size and 1.05 uniformity coefficient. The filtration rate was 3.2 mm/s (11.7 m^3/m^2-h). It is thought that direct filtration can cut the chemical consumption cost by 70-80% (Wagner & Hudson, 1982).

== West Africa. Direct filtration can offer an economic advantage in West Africa, owing to the economy of low alum dosage. The most striking examples are in Bamako, Mali, and Kano, Nigeria, (Wagner & Hudson, 1982). Both pay a high price for acquiring alum and hauling it to the treatment plant. The price of alum in Kano is over US$ 400/tonne, and in Bamako it is over US$ 700/tonne.

The alum dose at the time of the testing at Kano was 20 mg/L to treat water of turbidities in the range of 20-24 NTU. The water at Kano has turbidities of 30-40 NTU at its peak, and is clear during much of the year. The average alum dose during the wet season is 26 mg/L, whereas in the dry season it is 15 mg/L.

Both these water sources have been shown to be good candidates for direct filtration, and both cities are proceeding toward pilot filter testing. The effluents produced by the bench-scale work are well below the WHO turbidity limit of 5 NTU.

== Bombay, India. Investigations (Gadkari et al., 1980) have been carried out to explore the possibility of adopting direct filtration in the master plan of water supply for Greater Bombay. Two filters with different media arrangements (dual media and coarse media) were used in this study as presented in Table 19. Since the turbidity range of this water is on the high side, the average filter run in both the filters was short (7 to 10 hours). This phenomenon was also observed when the water turbidity was of the order of 10 JTU, which contradicts the above statement from the worldwide survey.

Table 19: The Operation Parameters of Pilot-Scale Filters

Parameter	Values
1. Filter Media Filter I (dual media)	Bituminous coal Size: 1-1.2 mm Depth: 15 cm Specific gravity: 1.35 Quartz sand E.S. = 0.65 mm U.C. = 1.3 Depth: 75 cm Specific gravity: 2.65
Filter II (coarse medium)	Quartz sand E.S. = 0.8 mm U.C. = 1.3 Depth: 90 cm
2. Filtration Rate	1.66-2.66 gpm ft^2 (4.6-6.6 m^3/m^2-h)
3. Backwashing	High-rate water backwash at 12-20 gpm/ft^2 (30-50 m^3/m^2-h) for a period of 3-5 min.
4. Filter-Run Length	Filter run is terminated when: a) The total headloss exceeds 180 cm, or b) the turbidity of effuent exceeds 3 JTU, or c) break-through of flocs through the filter is noticed in the filtrate

It is concluded that for relatively high-turbid waters (100-150 JTU), direct filtration preceded by alum flocculation is not a practical proposition, since the filter runs are short. But with low-turbid waters (less than 10 JTU) and for optimum filter runs, the alum requirements are only 30-40% of the optimum alum dose determined by the jar test. In direct filtration of plain settled water, when the alum dosage is at 20-40% of the jar test dose, there is a 140%-increase in the length of filter runs for a dual-media filter.

== Brasilia, Brazil. A new direct filtration plant is being designed with filtration rates as high as 24-29 m^3/m^2-h (Wagner, 1983).

== Hongkong. A water treatment plant adopting direct filtration is being constructed for Hongkong. Facilities for coagulation and flocculation are provided in cases where they are needed.

8.1.8 Conclusions on Direct Filtration

Information is available to indicate that:

** A number of water treatment plants of conventional design can operate in the direct filtration mode in order to achieve substantial savings in chemical costs and in reduced sludge handling. This is a very important advantage for developing countries, and the one that should not be overlooked.

** Direct filtration can handle waters with a turbidity as high as 40 NTU.

** The area of land required for a direct filtration plant is usually substantially smaller than that for a conventional plant.

For these reasons, direct filtration is a potentially attractive alternative technology for adoption in developing countries. There are many situations in such countries where disinfection alone will not produce water of adequate safety, but where the cost of full-range treatment would be prohibitive. In such a case, as King & Amy (1979) have suggested, full consideration should be given to the direct filtration process. Wagner (1983) also agrees with this advocation, and states that an investigation into this possibility should have top priority in the design of new plants as well as in upgrading existing plants.

In order to implement the concept of direct filtration, some problems should be solved.

** Since the primary workload has been transferred from the sedimentation basin to the filter, the importance of the filter is magnified, and thus the selection of appropriate filter bed conditions becomes a crucial question. A dual-media filter is usually required, and this may pose a constraint on the search for suitable media.

** The operator of a direct filtration plant must be more alert, since the water passes through this system very quickly. Changes in influent water quality - or chemical feed failures - must be recognized immediately to prevent sub-standard water from entering the clear well.

** Shorter residence time also means less contact time for disinfection. A properly baffled clear well could be designed to provide adequate contact for disinfection of filtered water.

8.2 Contact-Flocculation Filtration

8.2.1 Principles

Contact-flocculation filtration is a water clarification process whereby the raw water is applied directly to the filter without prior clarification by flocculation and sedimentation. The flocculation occurs during the contact of raw water and flocculant with the filter medium, and the whole solids separation process occurs in the filter bed. Details on the operational characteristics of the process can be found from Adin & Rebhun (1974). A general outline of the process is given below.

Filter Media and Flow Direction

The fine-to-coarse media arrangement used in conventional sand filtration is not suitable for contact-flocculation filtration, because the majority of particles are removed at the top layer of the filter bed. This results in rapid clogging. A coarse-to-fine media arrangement can be accomplished either by operating the filter in an upwards direction or by having a dual-media filter bed arrangement.

Upflow filtration poses some technical problems. Dual-media filter beds constructed of upper layers of coarse particles of low density and lower layers of fine particles of high density are suitable for the contact-flocculation filtration process since the entire bed is used in efficient filtration action. The reason is that coarse particles or flocs are removed by the upper layer of coarse media and fine particles are removed by the bottom layer of the fine media. A coarse-media filter is another alternative for contact-flocculation filtration.

Raw Water Quality

Since the entire solid removal takes place within the filter itself, waters with low turbidity range are the most suitable candidates for contact-flocculation filtration.

Chemicals

In contact-flocculation filtration, flocculation occurs in the filter bed. Therefore, commonly used alum may contribute to a large fraction of the sludge produced. For example, raw water containing 10 mg/L of suspended solids may require an alum dose of 25 mg/L, which will produce a sludge of which more than 50 per cent may be the precipitate of aluminum hydroxide. When polyelectrolytes are used as the sole flocculants, they are applied in small doses (usually in the 1 mg/L range), and the sludge produced is composed almost entirely of solids which originated in the raw water (Shea et al., 1971). Therefore, polyelectrolytes are suitable flocculants for contact-flocculation filtration and are added just ahead of the filter.

Filtration Rate and Filter Bed Depth

The values of these parameters are decided based on the raw water characteristics, the required effluent quality, and the filter-run length. As a guideline, one could use the values that are used in dual-media filters.

8.2.2 Applicability

Contact-flocculation filtration is suitable only for low-turbid waters.

8.2.3 Advantages

++ The unit operations used in contact-flocculation filtration consist of a chemical holding tank and a filter unit. This process eliminates the sedimentation and flocculation processes. Therefore, large capital and operational cost savings can be achieved.

8.2.4 Disadvantages

-- The polyelectrolytes, used as the sole flocculants in contact-flocculation filtration have to be imported in most cases, which increases the operational costs.

-- Since the entire solids removal is within the filter itself, a shorter filter run may result. This would increase the frequency and degree of backwashing, hence the operational cost.

-- This process would necessitate highly skilled personnel for close supervision of the plant, since the detention time of this process is very short, of the order of 10 minutes.

8.2.5 Application Status

An upflow filter system known as a contact clarifier (Fig. 20) was developed by Mints (1962). Experiences in many municipal water treatment plants in Russia indicate that this system can be used for purifying waters having turbidities up to 150 mg/L (Mints, 1962).

The design parameters of this filter system are summarized in Table 20.

Table 20: Design Parameters of Contact-Flocculation Filtration

Parameters	Values
Filter Medium	
Sand size	0.9 – 1.1 mm
Depth	2 – 2.6 m
Filtration Rate	5-6.25 $m^3/m^2 \cdot h$
Inlet Arrangement	A manifold-lateral pipe system at the filter bottom distributes the incoming flow in an upward direction.
Outlet Arrangement	Filtered water is collected through the collection troughs above the top of the sand.
Coagulant Used	Alum; 30% less than the conventional filter system.

The turbidity and color reduction in this filter system was the same as that of the conventional system, whereas the removal of microorganisms was less. The filter-run time was about twice that of the conventional system.

It has been reported that superfilters employing contact flocculation are being used in Brazil. Operational problems have occurred in Costa Rica where superfilters have been installed. The underdrain systems were not properly designed, and consequently there were inefficient distribution of backwash water, excessive rates of backwashing, loss of media, and clogging of inlet pipes to the filter. The two filter chambers are enclosed, so it is difficult to monitor their performance.

8.3 Conclusions

Table 21 summarizes the design criteria of direct filtration and contact-flocculation filtration. From the above discussions, direct filtration appears to be an economical solution to treat the low-turbid water. This method can easily be applied in developing countries as it does not require any special equipment. The only limitation of its applicability in developing countries is that it requires close supervision by skilled personnel.

Contact-flocculation filtration, although it involves low construction costs, requires polyelectrolytes as flocculants and close supervision by skilled personnel. Polyelectrolytes in most instances have to be imported from developed countries. Therefore, the process may be feasible only in major urban centers in developing countries, particularly for treatment of water intended for industrial use.

Table 21: Summary of Design Parameters for Direct and Contact-Flocculation Filtration Units.

Parameters	Conventional Treatment	Direct Filtration	Contact-Flocculation Filtration
1) Filter Type	Generally conventional single media filter	Dual-, mixed- or coarse-media filter	Dual-media or coarse-media (upflow filter is also suitable)
2) Filtration Rate	5 m³/m²·h	Can be operated two or three times higher filtration rate	Can be operated two or three times higher filtration rate
3) Filter Media Specifications		Depends on the filter types (summarized in earlier tables)	Depends on the filter types (summarized in earlier tables)
4) Cleaning Procedure		Air-water backwash (since all the solids are removed in the filter only)	Air-water backwash (since all the solids are removed in the filter only)
a) Cleaning Frequency		high	higher
b) Backwash Water Requirement		high	higher
5) Filter-Run Length		Short (as a guideline, a minimum filter run length of 12 hours is recommended)	Shorter (as a guideline, a minimum filter run length of 12 hours is recommended)
6) Raw Water Characteristics	Medium turbid water with proper pre-treatment	Low turbid waters	Low turbid waters
7) Capital Cost	High	Low	Lower

Table 21: (Cont'd)

Parameter	Conventional Treatment	Direct Filtration	Contact-Flocculation Filtration
8) Operational & Maintenance Costs	High	30% less than conventional treatment	Still less
9) Chemical Cost	High	30% less than conventional treatment	Still less
10) Skilled Labor		More skilled labor is necessary for closer supervision of plant and effluent characteristics	More skilled labor is necessary for closer supervision of plant and effluent characteristics
11) Sludge Disposal	Significant	Sludge is only produced in the filter back-wash *Less problem	Sludge is only produced in the filter backwash *Less problem

9. FILTER BACKWASH METHODS

In a filter operation, suspended solids get clogged in the filter bed. This phenomenon leads to a development of headloss in the filter unit. When the headloss reaches the maximum allowable limit, or when the effluent quality deteriorates below the required quality level, the filter run should be stopped and the bed should be cleaned. This filter cleaning operation is done by the filter backwash method.

Various methods of backwashing exist. They include:

a. High-rate backwash with water alone;
b. Low-rate backwash with water alone;
c. Water backwash with surface-wash auxiliary;
d. Water backwash with air auxiliary; and
e. Backwashing with the effluent from other units.

An additional method is to take washwater from the high-pressure distribution systems. This method wastes energy, but results in low installation costs. A pressure-reducing valve is normally required so as not to blow out the filter.

9.1 Choice of Backwash Method.

The past experiences in the filter backwashing show that the choice of a backwash method partly depends on the type of the filter media used. The different factors influencing the backwash effectiveness in a filter unit are:

a) Media Size : Coarse media will behave differently, depending on the backwashing method employed.

b) Media Shape : Rounded grains are generally thought to be easier to clean than angular or flat grains.

c) Media Density : Denser material needs higher velocities to suspend it in the upflow.

d) Water Quality : Different waters behave differently in mudball formation and in the attachment of particles to the grains.

e) Coagulant Used : The amount and type of coagulant used: metallic coagulants or polyelectrolytes change the adhesiveness of the film formed around the grains. Weak and strong flocs will also behave differently with regard to ease of backwashing.

The first four backwashing methods listed above have been used extensively. The last one looks more promising for application in developing countries due to its low capital and operational costs. Therefore, the first four methods are only summarized in Table 22, which indicates their design criteria and applicability, whereas the last method will be discussed in detail.

Table 22: Recommended Design Values of Various Backwash Methods

Parameters	High-Rate Water Backwash	Low-Rate Water Backwash		Water Backwash with Air Auxiliary		Water Backwash with Surface-Wash Auxiliary
		Air Scour Followed by Low-Rate Water Backwash	Simultaneous Air & Low-Rate Water Backwash, Followed by Low-Rate Water Backwash	Air Scour Followed by High-Rate Water Backwash	Simultaneous Air & Low-Rate Water Backwash, Followed by High-Rate Backwash	
1. Backwash Rate	> 37.5 m^3/m^2-h	18 m^3/m^2-h	15-18 m^3/m^2-h	> 18 m^3/m^2-h		15-18 m^3/m^2-h
2. Pressured Backwash Water	2.5-5 Kg/cm^2	2.5-5 Kg/cm^2	2.5-5 Kg/cm^2	2.5-5 Kg/cm^2	2.5-5 Kg/cm^2	0.25-0.5 Kg/cm^2
3. Air Scour Rate	–	27 m^3/m^2-h	18-27 m^3/m^2-h	27 m^3/m^2-h	36-46 m^3/m^2-h	–
4. Surface Wash Rate	–	–	–	–	–	10-12 m^3/m^2-h
5. Pressure of Surface Scour Water	–	–	–	–	–	1.5-4 Kg/cm^2
6. Porosity Range During Expansion	0.68-0.7	–	–	–	–	*This type of filter backwashing is used, when mudball formation occurs on the top of filter bed.
7. Expansion of Medium	80-100%	Low	Low	High	High	
8. Time of Washing	3-6 min.	3-6 min.	2-3 min.	3-4 min.	2-3 min.	
9. Time of Air Scour Application	–	3-6 min.	2-3 min.	3-4 min.	2-3 min.	
10. Amount of Washwater needed	High	Low	Low	High	High	High
11. Efficiency of Cleaning Action	Low	Fair	Good	Good	Good	

Table 22: (Cont'd)

Parameters	High-Rate Water Backwash	Low-Rate Water Backwash		Water Backwash with Air Auxiliary		Water Backwash with Surface-Wash Auxiliary

11. Efficiency of Cleaning Action	Low	Fair	Good	Good	[illegible]	

Table 22: (Cont'd)

Parameters	High-Rate Water Backwash	Low-Rate Water Backwash		Water Backwash with Air Auxiliary		Water Backwash with Surface-Wash Auxiliary
		Air Scour Followed by Low-Rate Water Backwash	Simultaneous Air & Low-Rate Water Backwash, Followed by Low-Rate Water Backwash	Air Scour Followed by High-Rate Water Backwash	Simultaneous Air & Low-Rate Water Backwash, Followed by High-Rate Backwash	
12. Applicability	Single- & multi-media filters	Single-media filters only	Single-media filters only	Single- & multi-media filters	Single- & multi-media filters	Single-media filters
13. References:–	1. Cleasby et al. (1977) 2. AWWA (1971) 3. Weber (1972) 4. Amirtharajah (1977)	1. Cleasby et al. (1977) 2. Barnes et al. (1981)	1. Cleasby et al. (1977) 2. Barnes et al. (1981) 3. Simonds (1963) 4. Jung & Savage (1974) 5. Degremount (1979) 6. Cleasby et al. (1975)	1. Cleasby et al. (1977) 2. Barnes et al. (1981) 3. Delholm (1956)	1. Degremount (1979)	1. Baylis (1959) 2. Cleasby et al. (1977) 3. AWWA (1971) 4. Fair et al. (1968)

9.2 Backwashing with Effluent from Other Filter Units

9.2.1 Principles

In this method of backwash which results in "inter-filter backwashing" filters, the filter units of a treatment plant have to be interconnected as shown in Fig. 29 (Valencia, 1977). The effluent from the interconnected units are collected by a single drainage channel, and the filter effluent outlet is located at a higher level than that of the washwater trough of the individual units. So, one cleans a particular unit by closing the inlet and opening the drainage outlet of this particular unit. The water level in the unit is thus lowered, and a positive head (H_b) is created in this unit which reverses the direction of the flow through the filter bed. The backwashing will start with the effluent from the adjoining units that provides the upward flow. Once the filter cleaning operation is finished, the outlet (drainage) is closed and the inlet of this unit is opened to resume the filtration process.

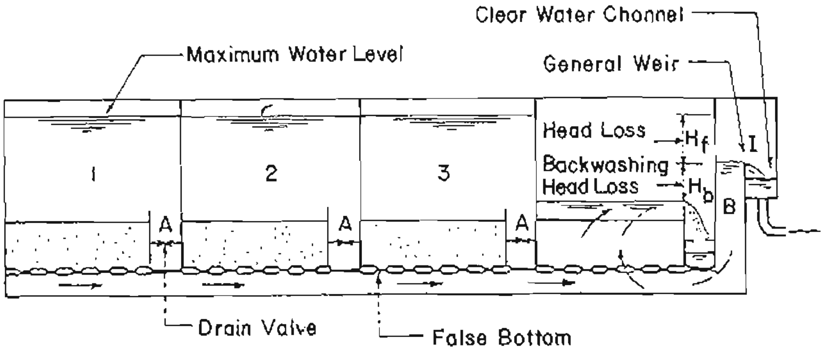


Fig. 29 : Backwashing of One Filter with the Flow of the Others

9.2.2 Design Criteria

Schulz & Okun (1983) briefly describe the design principles as presented below.

The head available for backwashing (H_b) is the difference in elevation between the effluent weir and the gullet lip in the filter. To obtain sufficient head for backwashing, the depth of the filter box must be substantially greater than for conventional filters. The filter box for the plant in Cali, Colombia, has a depth of 6 m, compared with a depth of about 3 m in conventional filters. Also, filter bottoms must be designed with much lower headlosses than conventional filters - only 20-30 cm of headloss compared with about 1-1.4 m for conventional filters.

The filter bottom can be locally produced from concrete beams with plastic tube orifices inserted along the beam, as shown in Fig. 30. The spacing of the orifices dictates the headloss in the system. As long as the underdrain systems are interconnected, the backwash velocities will be low enough in the plenum, so that the wash water distribution will be fairly uniform. Therefore, by increasing the depth of the water over the filter beds to about 1.5-2.5 m, limiting the headloss in the underdrain system to about 20-30 cm, interconnecting the underdrain system, and using dual-media filter beds, the backwashing headloss can be made sufficient to produce the desired expansion of the filter media.

Inter-filter washing filtration units can be designed either with unrestricted or restricted declining flow rate. A filter system using restricted declining flow rate is shown in Figs. 31-33. The filter units are connected by common influent and effluent channels. The outlet weir controls the water level in the effluent channel, and therefore regulates the filtration and backwash rates. During the filtration cycle (Fig. 32), the headlosses in filtration (H_f) dictate the water level in the clear water channel. The difference in water level (H) between the clear water channel and the interconnecting flume is controlled by the sluice gate, which sets the rate of filtration. During the backwash cycle (Fig. 33), the same gate is used to change the head available for backwashing (H_b), and thus the rate of rise of washwater. To change from a filtration to a backwash mode and vice versa, only two gates are used : (1) the gate located at the inlet side of the filter, which controls the opening and closing of the inlet channel and drain, and (2) the gate located at the outlet side of the filter, which regulates the filtration and washing rates.

The following precautions must be taken into account in designing this mode of backwash (Arboleda, 1974):

** So that one filter may be washed with the flow of the others, the total production of the plant must be at least equal to the wash-water flow needed to clean one filter.

** Thus, the filter units must supply enough water for the required backwash rates. A minimum of four filter units, capable of working at a rate one-third higher, is necessary to minimize the peak flow produced when one unit is out of service for washing.

** The filters must be so designed that one may be taken out of service for repairs without interruption of the normal operation of the others.

** The underdrain must be specially designed to produce low headloss. This is feasible because the filters are completely open at the bottom, and the wash-water flow rate is therefore very low.

9.2.2 Applicability

This system can be used for both single- and multi-media filters. But it requires four or more filter units to operate effectively.

9.2.3 Advantages

++ Backwashing is automatically controlled, and this simplifies the operation. Also as a result, it is impossible for the plant operator to manipulate the filtration, either by accident or intention. This prevents any sudden rate increases or detriment to filtrate quality.

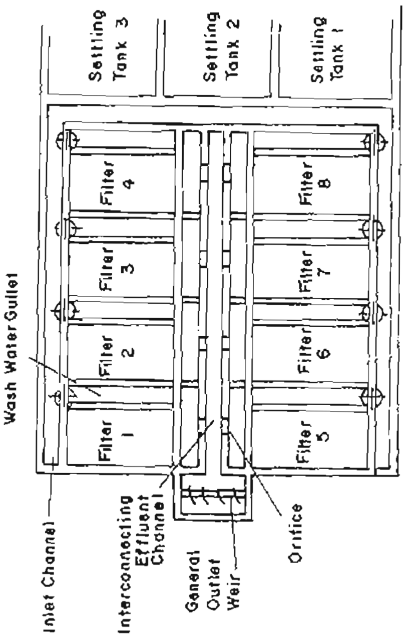


Fig. 31 : Plan of Battery of Interfilter-Washing Filters

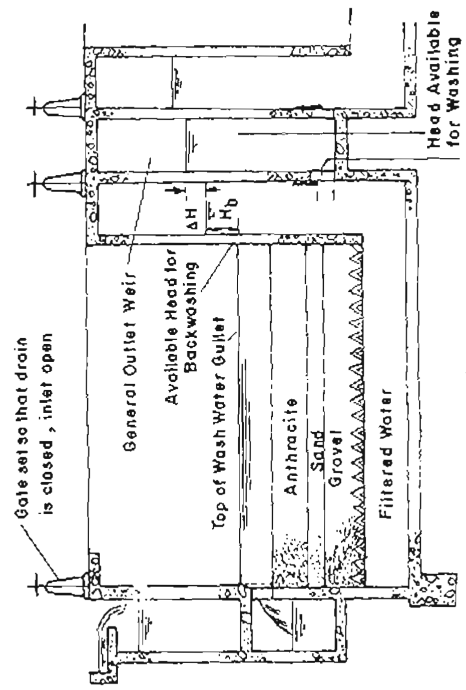


Fig. 33 : Water Levels During Backwashing

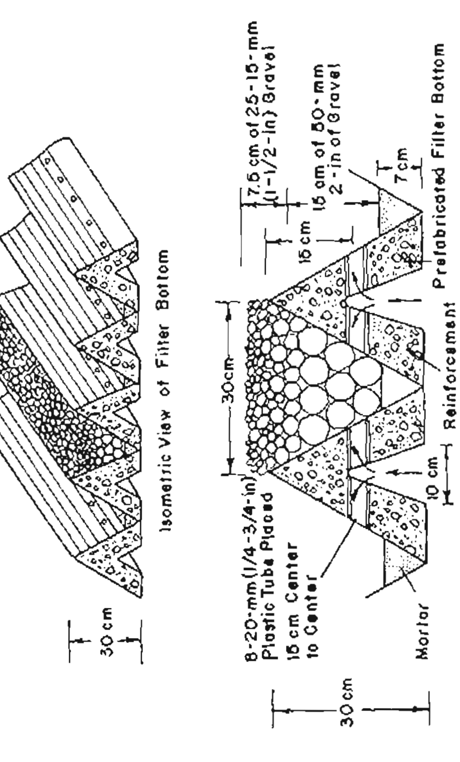


Fig. 30 : Low Head Loss Filter Bottom that can be Fabricated Locally

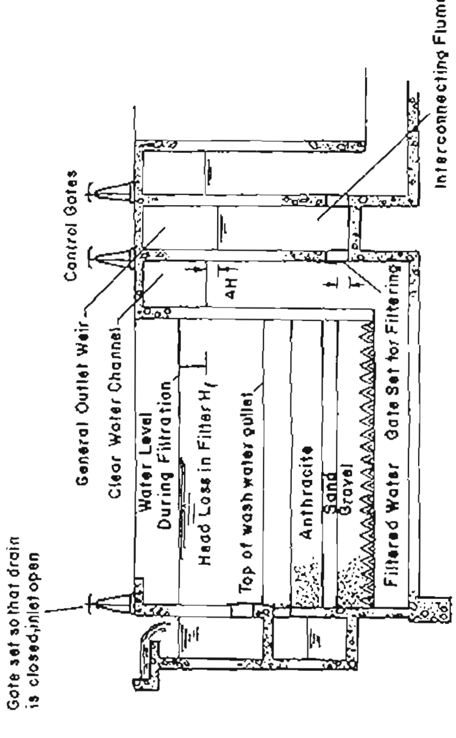


Fig. 32 : Water Levels During Filtration

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9.2.4 Disadvar

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filter unit ha
construction co

9.2.5 Applicat

Filter backwashing
time, and later was suc
(Valencia, 1977). Filter
plants in Latin America,
Monterey, Mexico (24 m
as well as in Peru,
Valencia, 1977).

++ Filters operated in this mode are easier to build than conventional filters. Only two valves are needed for filter control; the entire system can be designed with concrete channels or box conduits; and it is possible to eliminate the elaborate piping, valves and control systems common to conventional filtration schemes (Schulz & Okun, 1983). There is no need for headloss gauges (since the headloss is evident to the operator, who can observe the water level in the filters), flow-rate controllers, washing equipment, or pipe gallery. Capital and maintenance costs can therefore be considerably reduced.

++ There is a minimum of mechanization. As a result, the system is simple in design, operation and maintenance.

++ The backwash water is applied to the bed using the head development in the unit, so one does not need to pump water into the bed. This leads to a reduction in the capital and operational costs.

++ When one filter is taken out of service for backwashing, the filtration rate variations are slow and smooth. Once the headloss is fixed, the washing starts very slowly, and therefore a sudden expansion of the bed is prevented.

9.2.4 Disadvantages

-- For a proper cleaning operation one requires higher headloss (55-80 cm). To create this headloss in the unit, the height of the free board of the filter unit has to be increased. This leads to an increase in the construction cost of the filter unit.

9.2.5 Application Status

Filter backwashing with this method has been practiced in Australia for a long time, and later was successfully used in more than 100 installations in the U.S.A. (Valencia, 1977). Filters of this kind have also been operating satisfactorily in large plants in Latin America, including those serving the cities of Mexico City (24 m^3/s), Monterey, Mexico (24 m^3/s), Rio Grande, Brazil (6 m^3/s), Cali, Colombia (4 m^3/s), as well as in Peru, Bolivia and the Dominican Republic (Schulz & Okun, 1983; Valencia, 1977).

10. CONCLUDING REMARKS

A wide range of non-conventional water filtration technologies exist to offer various advantages when adopted in developing countries. Although discussed under separate, arbitrarily classified headings, these options are interrelated, and can be used in combination for greater benefits. For instance, the design for rapid filtration can be greatly simplified by adopting three concepts: declining-rate filtration, dual-media filter beds, and inter-filter backwashing. By incorporating these three technologies in a simple design, it is possible to eliminate most of the equipment in conventional filter designs, equipment that would have to be imported in most developing countries, and would quite often create problems in operation and maintenance. Moreover, construction costs for this kind of design can be as much as 60% cheaper than the cost of conventional designs, and at the same time operation and maintenance costs are also considerably reduced - without any detrimental effects on filtrate quality (Schulz & Okun, 1983).

Other possibilities of combining different unit operations include (i) coarse-media or dual-media filtration operating at high rates, (ii) upflow filtration operating at high rates, (iii) dual-media or coarse-media filtration with a declining rate, and (iv) direct filtration on coarse media or dual media with high rates. No filtration technology can be considered as a panacea, nor can it accomplish something that cannot be done with conventional treatment. In addition, none of these technologies occur spontaneously. Only with extensive research and with the development of supportive technologies (such as those in filter media and flocculants) do they become viable. The reviewed options simply deserve due consideration, when and where conventional filtration is not affordable or not practical.

Among the filtration technologies reviewed, declining-rate filtration and direct filtration are probably the most economically promising ones for developing countries. Unfortunately, the latter may impose a constraint due to the fact that alum is unlikely to be used as the only flocculant in this process - and in fact it is unlikely that it will be in used modern treatment systems, which tend to use higher filtration rates and want to reduce their sludge disposal problems. The use of polyelectrolytes either alone or in combination with alum in water filtration has therefore become inevitable. The next constraint would be the training of competent, skilled operators who understand the process and handle it efficiently.

As suggested (King et al., 1975), for high-rate filtration certainly, but the point also has general validity, attention should be given to the optimization of the total system rather than the individual unit processes. The entire system should be handled as a single entity to arrive at the optimum and most economical solution for each case. Only in this way can the most cost-effective solution to the water treatment problem be developed. Therefore, the reader should be aware of the fact that this review has not adopted a holistic approach, but has dealt rather with only a part of the overall work in water treatment.

In any case, pilot studies for feasibility assessment and subsequent rationale design work are necessary. General methodology for pilot-plant design and testing is well presented by Adin et al. (1979). Although this kind of study incurs a cost and may be time-consuming, it is a good investment in the long run. In this respect, developing countries can benefit greatly from the experience of the West, where the technologies have been established. The fundamentals of the processes are now more clearly understood, and full-scale data are now better and better known, which means that planners and designers in developing countries can be more confident in this new venture. The essential purpose of this review is to help promote this confidence by giving some basic information - and a bird's eye view of the relevant information and data. The authors hope that the discussion presented here will kindle some interest in those who are involved in supplying clean water at an affordable cost to that half of humanity which does not have safe water near home.

ABOUT THE AUTHORS

S. Vigneswaran is Assistant Professor at the Environmental Engineering Division, Asian Institute of Technology (AIT), Bangkok. He received his B.Sc. degree (Hons.) from the University of Peradeniya, Sri Lanka, Master of Science at AIT in 1978, and Docteur Ingenieur from the University of Montpellier, Montpellier, France, in 1980. He teaches the courses related to process design aspects in water and wastewater treatment, and his specialized research work is water treatment.

C. Visvanathan is, at the time of this writing, a graduate student at the Environmental Engineering Division, AIT. He obtained his B. Tech. in Chemical Engineering from the Indian Institute of Technology, Madras.

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Appendix A

IMPORTANCE OF LABORATORY-SCALE (OR PILOT-SCALE) STUDIES IN DESIGNING FULL-SCALE FILTERS

The particle removal mechanism by a filter is physico-chemical in nature, and it has been claimed that this is because a combination of the following factors are involved :

1. Straining
2. Flocculation
3. Sedimentation
4. Inert impaction
5. Diffusion
6. Brownian movement
7. Van de Walls forces
8. Electrokinetic effects.

Since the removal is complex and depends on the physico-chemical characteristics of the raw water and filtering media, it is difficult to choose appropriate media, size, depth and filtration rate without pilot-scale (or laboratory-scale) experiments with the raw water to be filtered. However, some general guidelines could be ventured to help select a filter medium size a depth and a filtration rate to minimize the number of experiments.

Figure A.1 indicates what appropriate options could be tentatively chosen, depending on the raw water turbidity. Table A.1 suggests the ranges of parameters commonly employed for different filtration technologies based on laboratory-scale experimental studies (Davis, 1983).

Media Depth

The headloss of a clean filter bed depends on the filtration rate, filter media size and shape, and the depth of the bed, and can be computed using Carman-Kozney's equation (Fair et al., 1968). But as the filtration proceeds, the influence of the bed depth is affected by the substances being removed. Strongly flocculated materials tend to clog the upper fine layers of a filter, causing a very rapid headloss. In such a case, the lower layers of sand act only as a supporting medium, and headloss considerations govern the filter run length (Davis, 1983). When a weak or non-flocculated material is filtered, the penetration of particles into the bed increases, and the bed depth is then of primary importance in determining the filter-run length (Gosh, 1958; O'Melia & Crapps, 1963). In this case, effluent quality may be the governing factor. Therefore, laboratory-scale filtration experiments are necessary to calculate the filter depth for a given size of filter medium and for a particular type of raw water to be treated.

Fig. A-1: Rational Selection of Filtration Option Based on Raw Water Turbidity

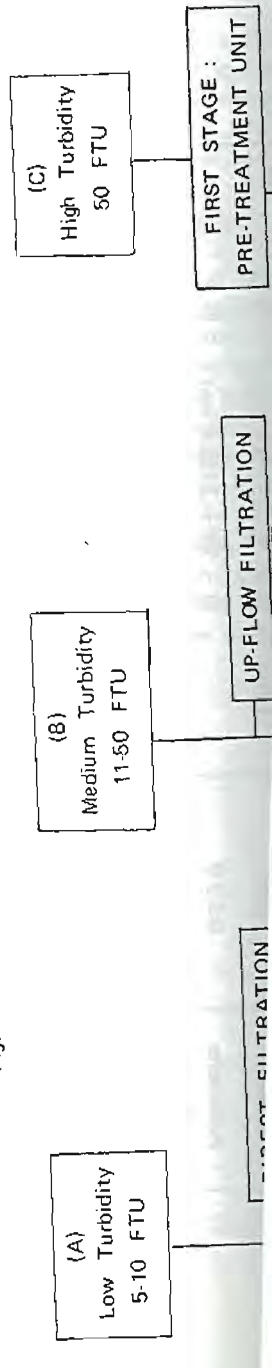
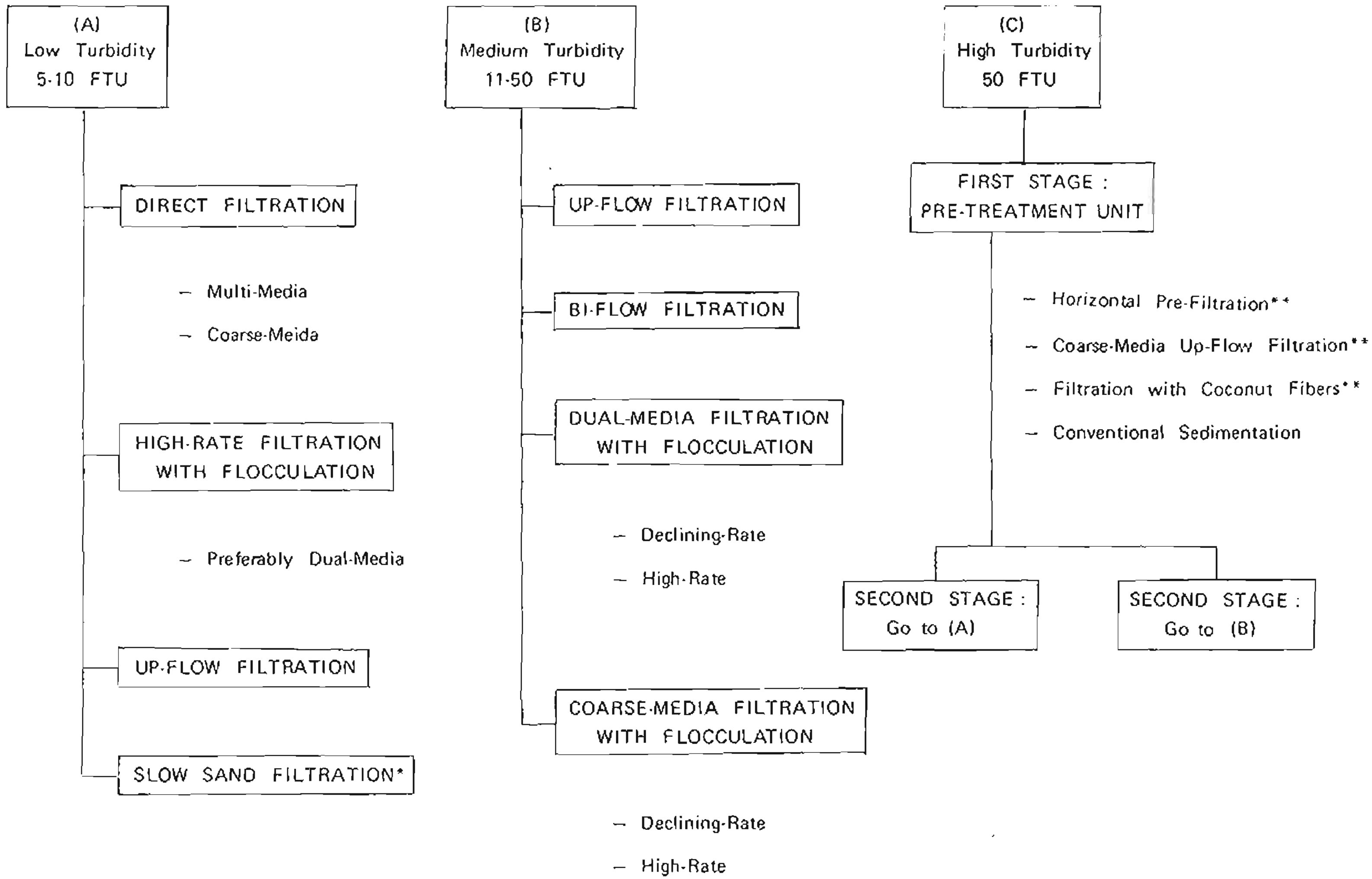


Fig. A–1: Rational Selection of Filtration Option Based on Raw Water Turbidity



* *Used only where land is sufficiently available*
** *Suitable only for small community water supply*

Table A-1: Range of Values of Design Parameters Used in Laboratory-Scale Filter: Experiments

Filtering Material	Effective Size (mm)	Uniforming Coefficient	Filter-Media Depth	Filtration rate ($m^3/m^2 \cdot h$)	Reference
Sand	0.50		24 in. (60.8 cm)	15	Hudson (1963)
Sand	0.40-0.55	1.35-1.751	24 in. (60.8 cm)	5-7.5	Segal and Okun (1966)
Sand	0.51	1.40	30 in. (76.0 cm)	5	Gosh (1967)
Sand	0.46-0.92		24 in. (60.8 cm)	7.5	Oeben et al. (1968)
Sand	0.65 and 0.77		61 cm (total)	5-7	Rimber, (1968)
Sand	0.46	1.44	24 in. (60.8 cm)	5	Wei et al. (1969)
Sand	0.35-0.65	1.2-1.6	24 in. (60.8 cm)	7.5	Deb (1969)
Anthracite Sand Granet	1.40 0.78 0.37	1.33 1.30 1.501	24 in. (60.8 cm) 9 in. (22.5 cm) 3 in. (7.5 cm)	12.5	Conley and Hsiung (1969)
Anthracite Sand	0.9-2.0 1.2-1.6		12 in. (30.4 cm) 20 in. (50.7 cm)	12	Hutchison and Foley (1974)
Coarse Sand	1.21	1.17	150 cm	5 m/h	Adin and Rebhun (1974)

Medium Grain Size

If one uses a filter medium in a broad size range, the filter will become graded after backwashing. That is, the fine portion will be lifted to the top, and the coarse portion will remain at the bottom. This creates an undesirable situation in which only the top layer actually participates in efficient filtration action. From Table A.1, it can be seen that sand used in deep-bed filters commonly has an effective size range of 0.4-1.05 mm, and a uniformity coefficient range of 1.2-1.75.

As already mentioned, dual-media and coarse-media filtration makes use of the entire bed in efficient filtration action. The commonly used media in dual-media filtration are anthracite (effective size of 1.1-2.0 mm and uniformity coefficient of 1.3-1.7) and sand. Coarse-media filtration normally employs sand with an effective size of 1.2-1.9 mm and a uniformity coefficient of 1.1-1.3.

Filtration Rate

The filtration rate of rapid sand filtration lies in a range of 5-15 m^3/m^2-h, although in exceptional cases a rate as high as 25 m^3/m^2-h can be used. An increase in filtration rate would significantly reduce the filter area, and thus the filter construction cost. On the other hand, a high filtration rate would result in inferior effluent quality and rapid headloss development. In other words, the backwashing frequency has to be increased. Hence, for a given media size and depth, an experimental run at different filtration rates with the raw water to be filtered is necessary so that the optimum rate can be determined.

From the above discussion, it is clear that the size and depth of the filter bed and the filtration rate are interrelated. In addition to the results of the experiment, the choice of these parameters would depend on various factors, such as availability and cost of filter media and of skilled labor, to say the least.

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