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The decade of roughing filters — development of a rural water-treatment process for developing countries

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ABSTRACT: Slow sand filtration applied as surface water treatment is particularly effective in improving the bacteriological water quality. However, efficient application of the treatment process requires water of low turbidity, hence pre-treatment of the surface water is usually necessary. Chemical flocculation combined with sedimentation is often inapplicable, because rural water supplies in developing countries generally face serious operational problems with chemical water treatment. Prefiltration is a simple and efficient alternative treatment process. This paper presents the concept, field experience and promotion of horizontal-flow roughing filters as a viable pre-treatment process. Roughing filters combined with slow sand filters present a reliable and sustainable treatment process, particularly appropriate for developing countries.

La décade des préfiltres—développement d'un système de traitement d'eau pour les zones rurales du tiers monde

RESUME: L'emploi de la filtration lente sur sable comme traitement des eaux de surface est particulièrement approprié pour améliorer la qualité bactériologique des eaux. Cependant, une application efficace du procédé exige une eau de basse turbidité et, de ce fait, un prétraitement de l'eau de surface. La floculation chimique en combinaison avec la sédimentation est souvent inapplicable vu qu'un traitement chimique pose en général de sérieux problèmes aux systèmes ruraux d'alimentation en eau dans les pays en voie de développement. La préfiltration est un procédé de traitement alternatif simple et efficace. Ce document présente la conception du procédé, les expériences sur place et la promotion des préfiltres à flux horizontal comme procédé viable de prétraitement. La préfiltration à flux horizontal en combinaison avec la filtration lente sur sable est un procédé sûr et éprouvé, ainsi que particulièrement approprié dans les zones rurales de pays en voie de développement.

INTRODUCTION

In developing countries, a large number of people are forced to use surface water, water drawn from polluted rivers, irrigation canals, ponds, and lakes. This surface water, however, is a carrier of many infectious and tropical diseases and therefore ought usually to be treated prior to consumption. The main target of any water treatment is the removal or inactivation of disease-causing organisms (pathogens), such as harmful bacteria, viruses, protozoal cysts, and worm eggs. Disinfection — usually by application of chlorine – and slow sand filters are the two most widely used treatment processes for bacteriological water-quality improvement.

Slow sand filtration (SSF) is regarded as a particularly appropriate technology [1] for developing countries. The SSF technology is described in many publications; the most recent for this type of application is presented in IRC's Technical Paper No. 24 [2]. As surface water usually requires to be pre-treated prior to SSF application, roughing filters have received considerable attention in the past decade. Studies on the design and performance of prefilters to cope with highly turbid surface water were conducted at different institutes. After a brief review of prevailing technical problems in rural water treatment, the development and world-wide promotion of the horizontal-flow roughing filter (HRF) technology will be presented hereafter. Figure 1 gives an overview of IRCWD's HRF project activities during the last decade.

THE CRUX IN RURAL WATER TREATMENT

Disinfection efficiency and SSF performance are strongly influenced by the turbidity of the water to be treated. Turbidity mainly reflects the amount of solids and colloids present in the water. A large number of the micro-organisms are attached to the surface of these solids, which act as a shelter. Hence, the chemical disinfection will be impaired in turbid water. Organic solid or dissolved matter using the disinfectant for oxidation processes will further reduce the efficiency of chemical disinfection. Consequently, adequate water disinfection is only possible with water of

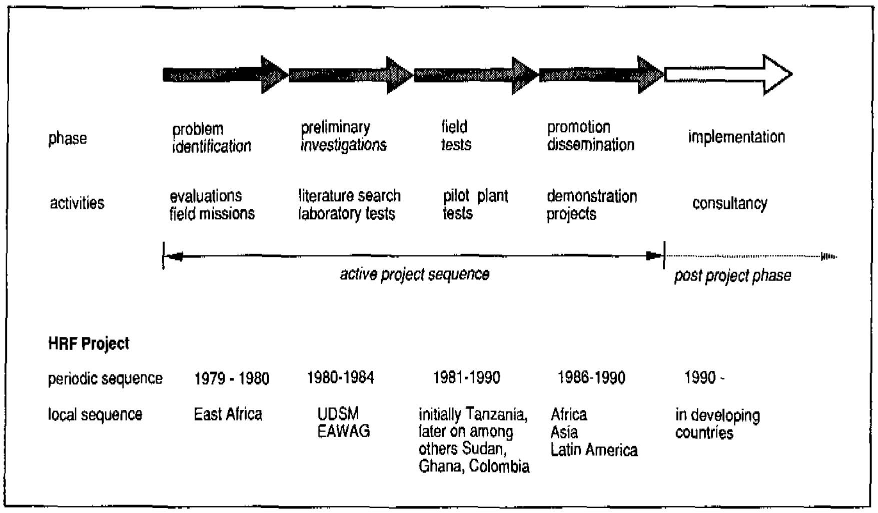

Fig. 1. HRF project phases.

low turbidity or virtually free of solid and organic matter.

SSF also requires a relatively clear water. Reasonable filter operation can be expected with raw-water turbidities below 20–30 NTU. The solid matter of water with higher turbidities will rapidly clog the top of the sand bed and interfere with the biological processes located in this part of the filter. The filter resistance will increase drastically, calling for filter cleanings at short intervals of a few days or weeks. Such an operation will considerably impair the biological filter activities and greatly reduce the bacteriological quality of the treated water. Therefore, only raw water of low turbidity will enable SSF to produce a good-quality water quality that is safe for consumption.

Pre-treatment of surface water for the reduction of turbidity or solid-matter concentration is therefore required for both discussed treatment processes, i.e. chlorination and SSF. Sedimentation, possibly preceded by chemical flocculation, is applied as a solid removal process. Plain sedimentation will remove the settleable and part of the suspended solids. Particles smaller than 20 μm will hardly be separated, although this fraction might represent the bulk of solids in a surface water. In such situations, sedimentation is enhanced by the addition of chemicals that destabilize the suspension and induce flocculation of the solids.

A reliable use of chemicals in rural water supplies in developing countries is, however, extremely difficult and often bound to fail. The chemicals must frequently be imported and therefore require foreign currency often scarce in developing countries. Apart from the availability of chemicals, transportation poses another problem, generally pertinent to developing countries. The adequate supply of chemicals to remote rural treatment plants is often difficult and unreliable. The dosage of chemicals depends on the raw-water quality and therefore needs careful supervision. The sensible dosing equipment is exposed to the aggressivity of the chemicals which can attack and damage the installations. Finally, chemical water treatment requires skilled personnel, often not available in rural areas. These factors question a reliable and successful application of chemicals in rural water supply schemes of developing countries. Numerous malfunctioning or abandoned water treatment plants supposed to use chemicals endorse this statement.

Consequently, chemical flocculation, a process reacting sensitively to water-quality changes and therefore difficult to operate, generally consitute an inappropriate technology for the considered situation. Similarly, a safe and reliable chlorination of the water remains a target difficult to attain under rural conditions in developing countries.

In contrast to chemical water treatment, SSF offers the great advantage of being safe and stable, simple and reliable. Operation is easily handled by local staff at village level and does not depend on the external inputs. SSF is essentially a self-reliant technology largely reproducible with local resources. However, even SSF requires efficient and reliable pre-treatment processes for turbid surface water. Pre-filtration can close this gap.

THE MULTIPLE FILTER APPROACH

Filtration is a more effective process for solid removal due to the large filter surface area available for sedimentation, adsorption and chemical and biological activities. Sound water treatment concepts start with the separation of coarse matter, usually easy to achieve, and end with the removal or inactivation of small solids and micro-organisms generally more difficult to separate. Figure 2 shows an approximate relationship between particle size and solids classification. It also illustrates the main application areas for different treatment processes. Water containing impurities of different sizes has to undergo a step-by-step treatment. In a first step, coarse matter, possibly present in surface water, is removed by screens, and settleable solids are retained by sedimentation tanks. In a second stage, pre-filters, known

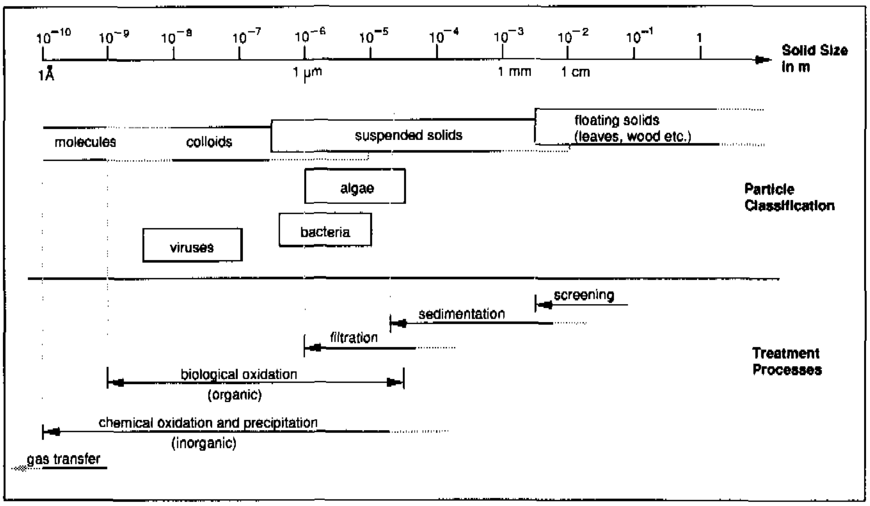

Fig. 2. Particle size and treatment process.

as roughing filters, separate the fine and light particles classified as suspended solids.

Roughing filters usually consist of filter materials that successively decrease in size. The bulk of solids is separated by the coarse filter medium, while the subsequent medium and fine filter media have more of a polishing function. Roughing filters are able to reduce turbidity to a level that allows a sound and efficient SSF operation. SSF as the final treatment stage will substantially reduce the number of the micro-organisms present in the water, retain the last traces of solid matter and oxidize organic compounds dissolved in the water.

In other words, roughing filters mainly act as physical filters and are applied to retain the solid matter. SSF are biological filters used to improve, in particular, the bacteriological water quality. Both filter types are of an equal technical level and their operation is characterized by a high process stability. They make full use of natural purification processes, and do not require chemicals to support or supplement the treatment scheme. Therefore, roughing filtration combined with SSF presents an appropriate process scheme for rural water treatment in developing countries.

ROUGHING FILTERS

The filter medium of roughing filters is composed of relatively coarse (rough) material ranging from 25 mm to 4 mm in size, installed in layers of different fractions. Gravel is usually used as filter material. The design and mode of application of roughing filters vary considerably. The different filter types can be classified according to their location within the water supply scheme, and with respect to the flow direction. There is therefore a distinction between intake and dynamic filters, which form part of the water intake structure, and the actural roughing filters, which are integrated in the water-treatment plant. Roughing filters are further subdivided into down-, up- and horizontal flow filters. Figure 3 illustrates the layout of intake and dynamic filters, whereas Fig. 4 presents the main features of the three roughing filter types.

Intake and dynamc filters are installed next to small and narrow river beds. Part of the river water, impounded by a small weir, is diverted either into a filter box or into a small canal where a subsurface filter is installed. The river water is filtered through different gravel layers, the top layer being of finest size. These two filters therefore act mainly as surface filters.

Intake and dynamic filters are not only designed for continuous solids separation, but also to protect the treatment plants from shock loads of high solid concentration. Such peaks rapidly clog the filter and thereby interrupt the flow of highly turbid water to the treatment plant, especially when high filtration rates of approximately 10 m/h are applied to a top layer of relatively fine gravel of about 1–2 mm in size. Intake and dynamic filters are cleaned manually by scouring, normally every week, the top of the filter bed with a shovel or a rake. The accumulated solids are resuspended and washed back to the river. In order to safeguard the SSF from a sudden silt load, these two filters should preferably be used with relatively clear rivers reacting with short turbidity peaks during rainfall. Alternatively, they might be used as a first pre-treatment step in combination with roughing filters to reduce the solid load of highly turbid water.

Roughing filters are designed to treat surface water of high turbidity over prolonged periods. The water is filtered by a sequence of normally three filter fractions. Due to the deep penetration of the solids into the filter medium, roughing filters act, in contrast to intake and dynamic filters, as space filters and therefore possess a large silt storage capacity. In vertical-flow roughing filters, the available height of the filter medium is limited to about 1.0–1.5 m due to structural constraints. Hence, the total length of a three-stage vertical-flow filter will amount to a maximum of 4.5 m.

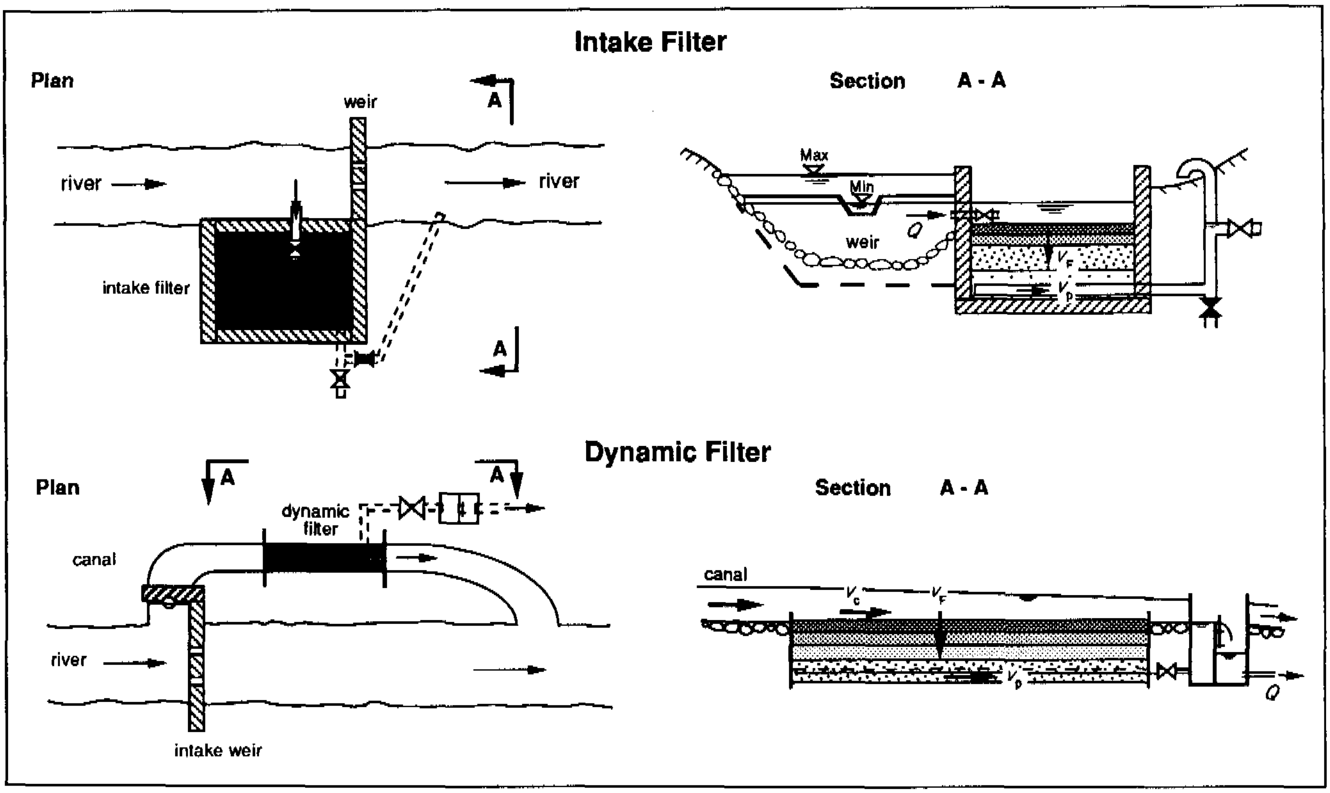

Fig. 3. Layout of intake and dynamic filters.

Alternatively, the filter length of horizontal-flow roughing filters is theoretically unlimited, but varies in general between 5 and 9 m. Roughing filters are operated at filtration rates ranging from 0.3 to 1.5 m/h. Up- and down-flow roughing filters can cope with raw-water turbidities of 50–150 NTU, whereas horizontal-flow roughing filters can handle even short turbidity peaks of 500–1000 NTU on account of their comparatively long filter length. The filters are cleaned periodically by a fast filter drainage and, if necessary, manually by removing, washing and reinstalling the filter material.

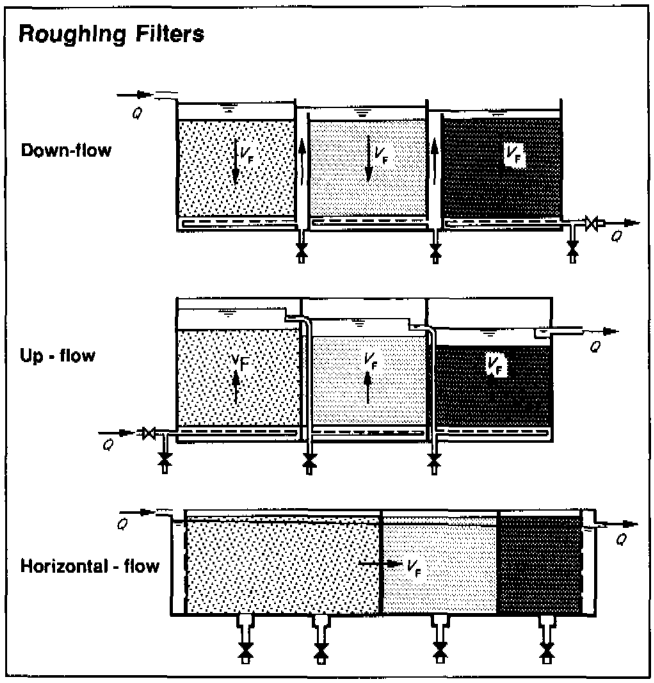

Fig. 4. Layout of roughing filters.

Recently, another pre-filter type called pebble matrix filter has been studied in the laboratory. The down-flow filter consists of a large (approximately 50 mm in size) pebble layer filled half-way with sand (specific diameter 0.4–1.0 mm). Kaolin clay suspensions of up to 5000 mg/l were reduced by the filter to below 25 mg/l. The laboratory-scale filter achieved filter runs of up to 116 h, with head-losses not exceeding 1.5 m. The filter column was cleaned by drainage and backwash process. It is planned to field test this filtration technology in different developing countries in order to assess its suitability as a pre-treatment method for highly turbid surface water [3].

An overview of the pre-treatment methods and current experience is presented in an IRC publication [4]. Further design details and guidelines on roughing filters are also summarized in a training document [5], published by the World Bank. The different pre-treatment methods are currently field tested in parallel in Cali, Colombia, where CINARA (Centro Inter-Regional de Abastecimiento y

Remoción de Agua) investigates, in collaboration with IRC (International Water and Sanitation Centre, The Hague) and other international technical institutions and supporting agencies, possibilities to optimize and simplify the pre-treatment processes [6].

THE HRF TECHNOLOGY

In the past decade, horizontal-flow roughing filtration (HRF) has received greater attention than any other pre-filtration technique. The comprehensive development of the HRF technology through research, laboratory and field tests, and successful application of the treatment process has also enhanced the development of other types of roughing filters. IRCWD has been strongly involved in the development and promotion of the HRF technology since 1982 (see also Fig. 1). This long-term engagement enabled a world-wide dissemination of the treatment process. The conceptional layout, development, field experience, process limitation, and promotion of the HRF technology is presented hereafter.

HRF CONCEPT AND DESIGN

Simplicity of the installation, reliability of the treatment as well as sustainability in operation and maintenance are basic requirements for rural water-treatment schemes in general, and in particular also for new pre-treatment processes. A horizontal-flow rectangular sedimentation tank meets these critieria. However, its efficiency in solid matter removal is limited to easily settleable solids. Particles to be separated have to reach, within a certain period, (e.g. the detention time), the bottom of the sedimentation tank located at a depth of 1.50 m or more. Hence, the settling properties of the particles greatly determine the solid-removal efficiency of the tank. This efficiency increases greatly when the same tank is filled with filter material. The settling distance is now reduced from 1.50 m to a few mm. The turbid water flows through the pore system of the filter and is in extensive contact with the filter medium during its flow. In the small pore system, the suspended solids settle on the upper surface of the filter material.

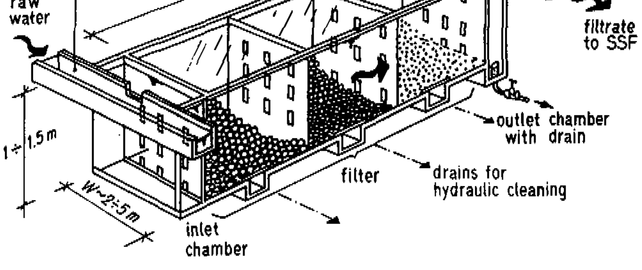

Fig. 5. Main features of a horizontal-flow roughing filter (HRF).

Apart from improved solid-removal efficiency, operational aspects were also decisive in the design of the new pre-treatment process. Long filter runs of 2–3 months or more, similar to those required for sound SSF operation, have to be attained by the filter even during high-turbidity periods. The provision of a large silt-storage capacity is therefore required. A small filter resistance is an additional operational criteria to avoid pumping whenever possible.

All these requirements are met by HRF's, the main features of which are illustrated in Fig. 5. HRFs have the simplest layout of all roughing filters. The raw water runs from the inlet compartment in horizontal direction through a series of differently graded filter material separated by perforated walls. The water level in the filter is controlled by an outlet weir or pipe, and kept beneath the filter surface to prevent the growth of algae. Type and amount of solids present in the raw water determine the filtration rate, the length and the media size of the different filter compartments. Filtration rates in the order of 0.5–1.5 m/h applied to coarse and graded filter material of 4–20 mm in size and 5–9 m total length, keep the total filter resistance small, i.e. normally below 30 cm.

The shallow filter box eases the construction of HRFs, which do not require mechanical equipment for their operation. The high process stability of the filter prevents operational breakdowns. HRF operational and maintenance is possible at village level — an important criterion for the sustainability of the technology.

HRF DEVELOPMENT

The combination of HRF with SSF is in fact not a new treatment concept. The first known horizontal-flow gravel filter used in a public water supply was constructed by John Gibb at Paisley, Scotland in 1804 [7]. The treatment plant consisted of three concentric rings arranged around a central clear water tank. The water flew from the outer ring, used as a settling basing, in a horizontal direction through the inner rings filled with gravel and sand, respectively, and was finally collected by the central clear water tank. This was an application of gravel filters prior to sand filters. Many other filter installations constructed in Great Britain in the last century followed this example. Down-flow roughing filters were used as pre-treatment in Europe. The Puech-Chabal filter was, until the first decades of this century, one of the best-known and extensively applied filters in France [7].

As time passed, the roughing filters were converted virtually into rapid or mechanical filters. Coagulation in conjunction with sedimentation and, more recently, with direct filtration replaced the pre-filter technology. Thus, the respective knowledge and experience with this treatment process gradually vanished and had to be rediscovered. In the

Table 1. Exampes of roughing filters in artificial groundwater recharge plants

Plant	Country	River	Suspended solids (mg/l) Mean	Max.	Filter length (m)	Filtration rate (m/h)
Dortmund	W. Germany	Ruhr	8	20	50–70	10
Aesch	Switzerland	Birs	7	40	15	5–8
Graz	Austria	Andritzbach	5	20	10	4–14

early 1960s, the water works of Dortmund, Germany, constructed horizontal-flow roughing filters for an artificial groundwater recharge plant [8]. Other water works in Europe (e.g. in Switzerland and Austria) followed the example of Dortmund with modified designs. Salient data of such plants are given in Table 1.

European rivers usually have a low turbidity and filter operation is stopped during the short periods of high turbidity, i.e. during heavy rainfall. The continuous supply of water to the consumer is guaranteed by the use of the aquifer's storage capacity.

Permanent or seasonally high turbidity is a characteristic of tropical rivers. In the absence of an aquifer, surface-water treatment plants have to maintain operation throughout the year. A reliable water supply is required especially during the rainy season when the risk of epidemic outbreaks of diarrhoeal diseases increases as a result of washed-off faeces not properly disposed.

Motivated by the simplicity of the HRF technology, different institutions embarked on laboratory and field studies in order to assess the potential of HRFs to reduce highly turbid surface water to a turbidity level required by SSF. This marked the beginning of HRF introduction to developing countries.

LABORATORY TESTS

Studies on the design and performance of HRF for the treatment of highly turbid and silted surface water were conducted at the Asian Institute of Technology (AIT), Bangkok, Thailand, at the University of Dar es Salaam (UDSM), Tanzania and by the International Reference Centre for Waste Disposal (IRCWD) at the Swiss Federal Institute for Water Resources and Water Pollution Control (EAWAG), Duebendorf, Switzerland.

In 1977, AIT carried out respective laboratory tests on a 5-m-long pre-filter composed of seven gravel layers. The different gravel fractions, which ranged in size from 5 to 18 mm, were installed with the finest filter medium at the centre of the filter. In spite of the good results reported by AIT [9], no reasonable arguments justify the installation of the smallest gravel fraction in the centre of the filter. Nevertheless, three water-treatment plants applying the AIT pre-filter design were constructed in combination with SSF units. The treatment plants were monitored for approximately half a year. The recorded data [10] reveal a good performance of the pre-filters. This enabled SSF filter runs of several months. These investigations were, however, not continued and therefore marked the end of the project in Thailand.

After evaluating the operational problems with SSF plants in Tanzania, the UDSM embarked on filtration tests in 1980. Laboratory tests were first conducted with vertical-flow roughing filters, revealing short filter runs of a few days only. Subsequently, the HRF design was developed as presented in Fig. 5. The concept was tested in the laboratory with a 15-m-long open channel filled with three gravel fractions of 16–32, 8–16, 4–8 mm in size at different filtration

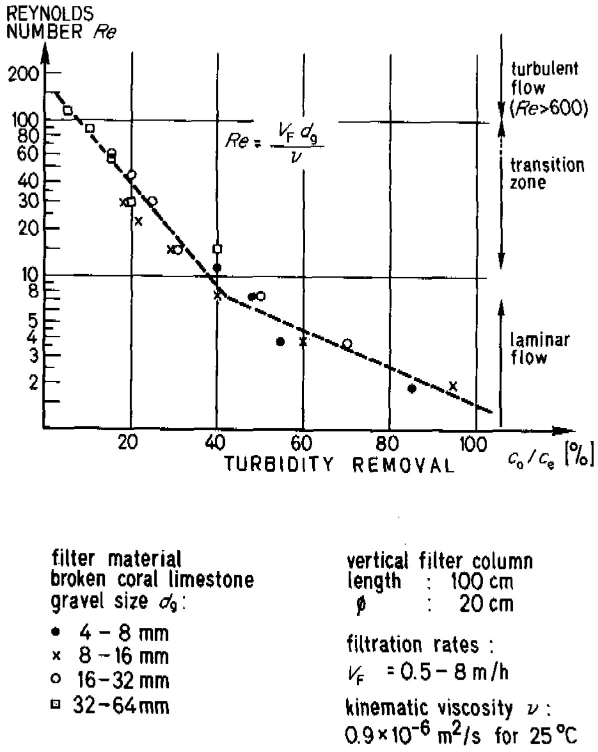

Fig. 6. Influence of flow conditions on filter efficiency.

rates ranging between 0.5 and 8 m/h. The laboratory tests clearly indicated the sensitivity of the filter performance with respect to flow conditions in the filter as illustrated in Fig. 6. Significant solids removal efficiency is only achieved under laminar flow conditions since sedimentation is the predominant process in roughing filtration.

Field tests were carried out to assess the practical applicability of the HRF—SSF treatment combination. Figure 7 summarizes the filter resistance development — an operational key parameter — for different SSF fed with either untreated river water or with water pretreated by HRF. The investigations indicated that HRF combined with SSF could be a viable process scheme for turbid surface-water treatment [11].

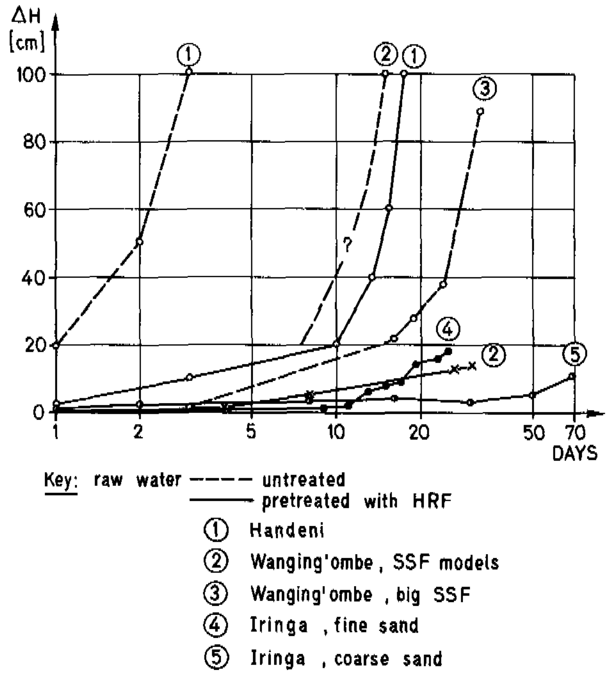

Fig. 7. Filter resistance development for different SSF in Tanzania.

In 1982, extensive filtration tests were conducted by IRCWD at EAWAG's laboratory over a period of 2 years. A model suspension of kaolin was used to investigate the mechanisms taking place in HRF and to elaborate design guidelines for HRF. A semi-empirical filtration model was developed and used as an efficient design tool for the evaluation of different filter layouts. The results of the research are presented in a scientific paper [12], whilst the more-practical aspects of HRF implementation are compiled in the design, construction and operation manual [13]. An important result obtained by the laboratory tests reveals that the filter efficiency is hardly influenced by the surface properties of the filter medium as shown in Fig. 8. Hence, any inert, graded, insoluble and mechanically resistant material can be used as filter medium. This aspect could represent an essential economic factor in the implementation of HRF. Another important phenomenon observed during the filtration tests was the possibility of filter regeneration by drainage. At a drainage rate of 60–90 m/h, the solid matter accumulated in the filter is flushed to the filter bottom and out of the filter if adequate drainage facilities are provided. Filter efficiency and filter resistance are thereby restored.

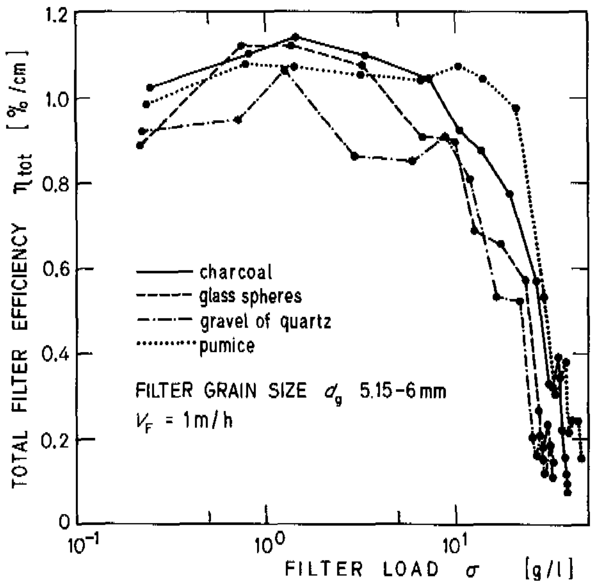

Fig. 8. Filter efficiency in correlation to filter load for different filter material.

FIELD EXPERIENCE

The HRF design guidelines derived from the laboratory tests, conducted under strictly controlled conditions, had to be tested under field conditions. The HRF technology was exposed to different types of raw water, to inadequate filter operation, and to different socio-cultural behaviours during the field test phase (see also Fig. 1).

Filter efficiencies had to be monitored on a regular basis. However, local water-quality laboratories were often not available so that IRCWD had to design some simple and sturdy field test methods. The equipment for turbidity, filtrability, settleable solids and suspension stability were packed into a field test kit and provided to each of the pilot plants. The filtrability test replaces the analysis of suspended-solids concentration, for which a well-equipped laboratory is required. A specific volume of water to be analysed is filtered by gravity through a filter paper and the filtered water volume recorded in function of time. Neither chemicals nor energy are required for the different analyses. Only filter papers as consumables have to be supplied. The applied test methods are described in [13].

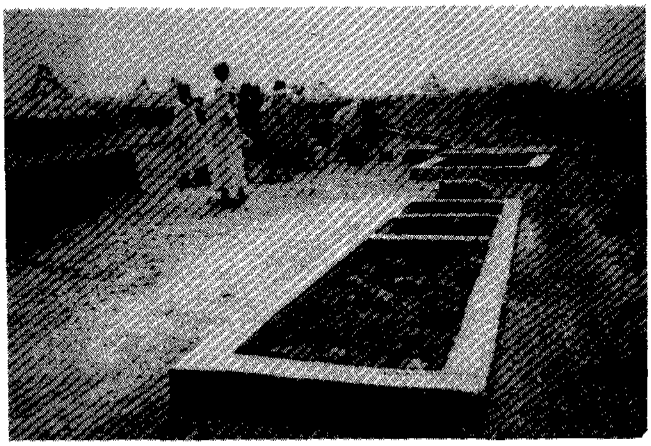

Fig. 9. Water treatment plant of the Blue Nile Health Project showing HRF, SSF, clear water tank and handpump.

Some practical experience gained from pilot plants are presented hereafter.

Blue Nile Health Project, Sudan. The rural population of the Gezira/Managil irrigation draws its water from small irrigation canals with a high bacteriological contamination. Besides malaria, diarrhoeal diseases and bilharzia are predominant in this region. The surface water supplied by the Blue Nile is further characterized by high turbidities reaching a thousand and more turbidity units during the rainy season. Small water supply schemes, operated by gravity and consisting of an HRF and SSF unit, a clear water tank and a handpump, as illustrated in Fig. 9, were constructed to supply villages of 200–500 inhabitants. Part of the HRF filter medium has been replaced by broken burnt bricks since gravel and stones are scarce in the project area located in an alluvial zone. Figure 10 summarizes the turbidity reduction of three plants using different filter material for the HRF. The comparable efficiency is similar for all three plants, thereby confirming IRCWD's respective laboratory results. Turbidity is reduced to approximately 5–10 NTU and substantial improvement of the bacteriological water quality is recorded. In the raw water, *E. coli* counts of 200 to several 1000/100 ml are reduced to 10–30/100 ml in the treated water [14,15]. The treatment plants were not operated at optimal conditions as the float valves for a smooth raw-water supply were purposely set out of operation by some of the caretakers. In order not to lose control over the treatment plant and consequently their social influence, they run the filters in batch charges by operating the inlet valves more or less at random. Nevertheless, 30 filter plants are in operation now, and their performance is reported to be good. The water-quality improvement achieved is a step towards better health conditions for the farmers in these irrigation schemes.

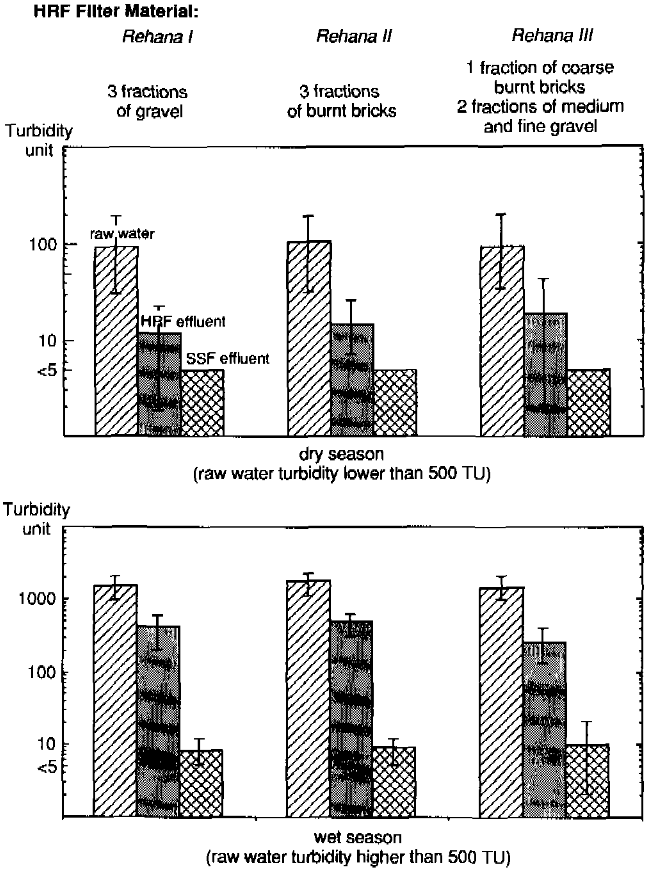

Fig. 10. Turbidity reduction (mean ±SD) with different HRF filter materials in the Blue Nile Health Project's treatment plants.

Jinxing, China. In cooperation with the Zhejiang Health and the Anti-Epidemic Station, two pilot plants were constructed in the Zhejiang Province in 1989. Jinxing, which is one of them, treats water from a canal grossly contaminated by small-scale industry and heavy navigation. The treatment plant of 240 m^3/day capacity has two lines, each consisting of a small tilted plate settling tank, a HRF and an SSF unit as shown in Fig. 11. Turbidity of the canal water is relatively low, ranging between 20 and 90 NTU. The HRFs operated at a high filtration rate of 1.7 m/h still drastically reduce turbidity, which is further decreased by SSF as shown in Fig. 12. The two HRF units are cleaned by drainage every 40 days. After 5 months of operation, head-loss in the SSFs was recorded to be only 31 cm [16]. The remarkable operational experience with the first HRF–SSF schemes in China is now attracting the interest of the local authorities.

Mafi Kumase, Ghana. SSF operation is not only impaired by high turbidities originating from inorganic solid matter, but also by high algae concentrations. The field tests of the Mafi Kumase also demonstrate the potential of HRF for algal removal. The population of this Ghanian village has suffered under guinea worm and bilharzia. These diseases originated from a shallow lake used as a water supply

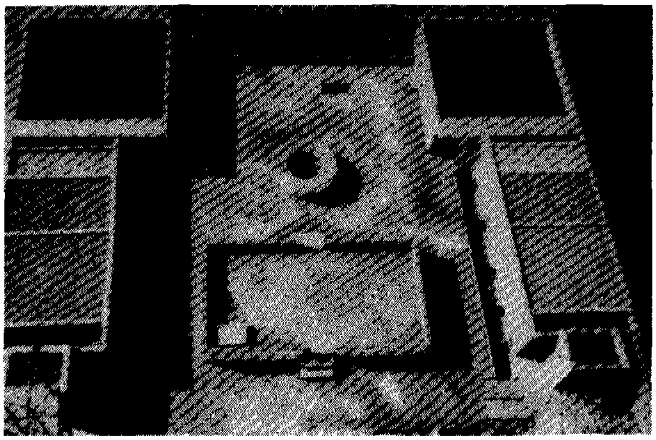

Fig. 11. Aerial view of Jinxing Water Treatment Plant showing the two treatment lines (tilted plate settling tank, HRF and SSF) clear water tank and sand-washing facility.

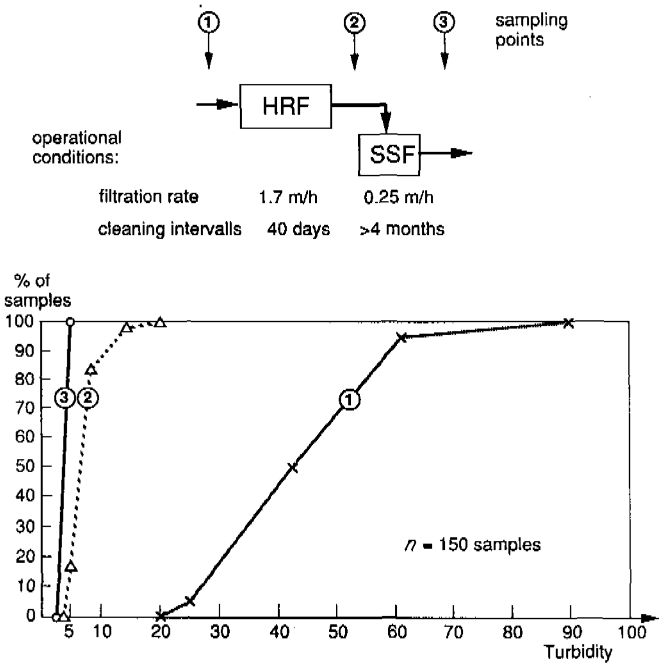

Fig. 12. Operational conditions and turbidity reduction of Jinxing Treatment Plant.

source. Under local expertise [17], the community constructed, in a self-help project, an HRF–SSF treatment plant. The lake virtually acts as an efficient sedimentation tank and also as a potential reactor for biomass production. In this case, the HRF technology is used to reduce the algae concentration. A grab sample illustrated in Fig. 13 indicates the efficiency of HRF and SSF for algae separation. The algae counts found in the SSF effluent are partly explained by the organotrophic regrowth in the treated water. Nevertheless, practical experience shows that the SSF units have to be cleaned every 4–6 months only. The HRF–SSF process combination reveals its potential also for the treatment of algae loaded surface water.

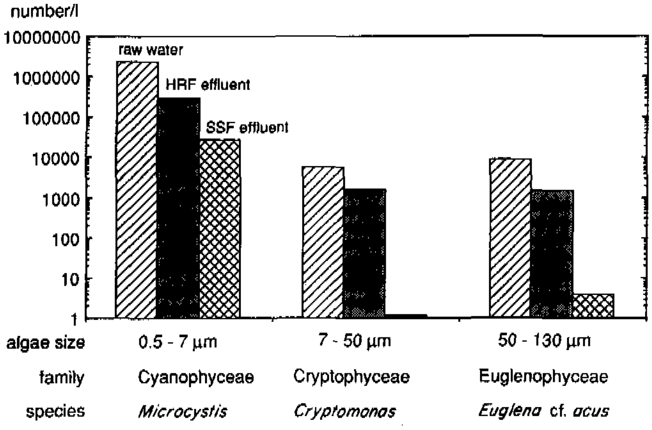

Fig. 13. Algae removal by Mafi Kumase Treatment Plant (filtration rates: HRF, 1.5 m/h; SSF, 0.25 m/h).

La Javeriana, Colombia. The treatment plant of La Javeriana in Cali, Colombia, is a good example of the multiple filter approach. The treatment process scheme consists of an intake filter, two HRF and two SSF units. The respective filtration rates amount to 4.7, 1.2 and 0.15 m/h. The performance of the treatment plant with a capacity of 260 m^3/day has been extensively monitored by CINARA [18]. The variation of the different water-quality parameters and their respective reduction by the different treatment stages is summarized in Table 2. Figure 14 illustrates the gradual reduction of turbidity, apparent colour and faecal coliforms through the different treatment stages. The gradual improvement of these three parameters is an indication of the development of biochemical processes in the different filters. The applied natural purification processes improve the bacteriological water quality by three or four orders of magnitude and also significantly reduce the intense colour of the raw water.

Aesch, Switzerland. In the early 1970s, nine HRF units and one SSF basin were designed for the artificial groundwater recharge plant in Aesch. The plant, with a minimum capacity of 17300 m^3/day, started operation in 1976 and apparently worked without operational problems in the first years. However, the recharge wells started to silt up for different reasons, thereby endangering the long-term use of the plant. Possibilities for the conversion of the exisiting 15-m-long and 16.8-m-large HRFs filled with uniform gravel ranging in size between 50 and 80 mm and operated at filtration rates of 5–8 m/h, had to be elaborated as part of the rehabilitation study. A pilot plant consisting of two HRF units and three up-flow roughing filters, was installed for this purpose. The field tests proved that the shorter 6.6-m-long test filters filled with three gravel fractions (see Fig. 5) had a greater suspended solids removal efficiency than the

Table 2. Water-quality improvement by the different treatment stages for the treatment plant La Javeriana, Cali [18]. (Number of samples = 24–26; suspended solids concentration and apparent colour recorded with HACH test kit DREL 5)

	Raw water	Intake filter	Effluent of HRF	SSF
Turbidity (NTU)	22±17.2	12±9.5	4.4±3.0	2.6±1.9
Suspended solids (mg/l)	49±41	27±19	11±7	7.5±4.9
Apparent colour (CU)	132±113	79±53	34±20	22±17
Faecal coliforms (/100 ml)	4800±2400	2400±1600	295±300	3.9±6.6

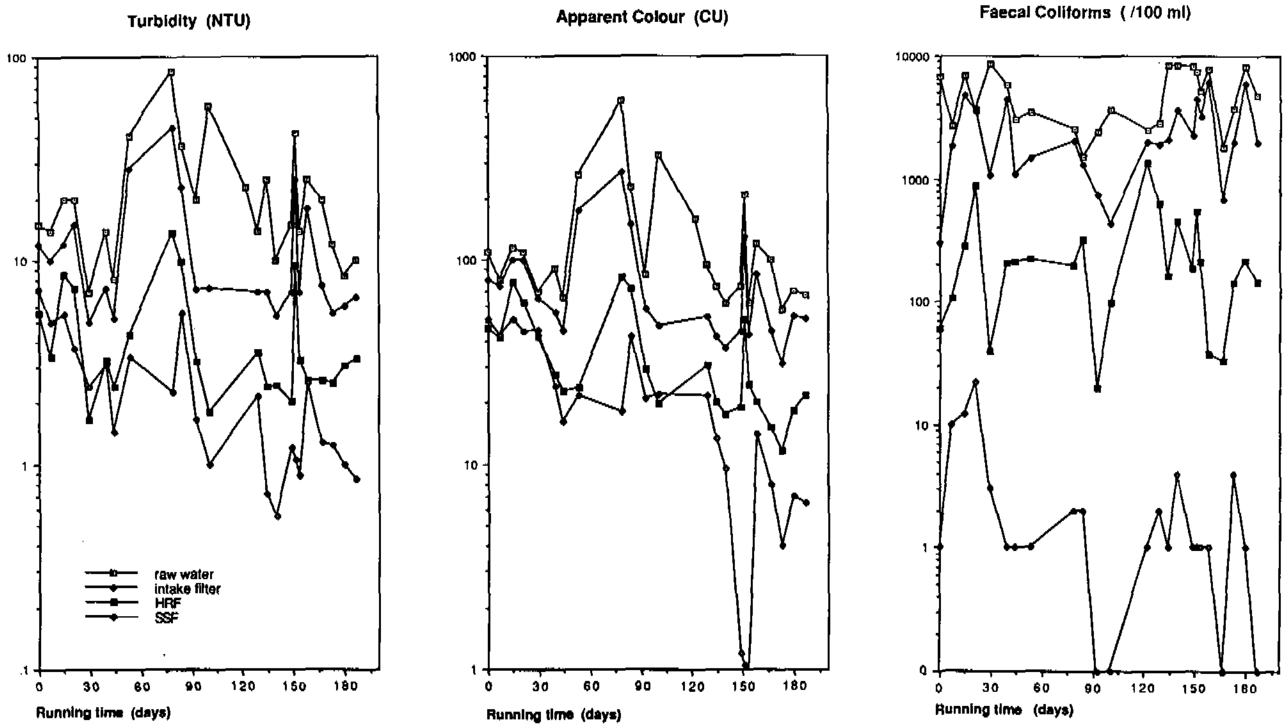

Fig. 14. Reduction in turbidity, apparent colour and faecal coliforms by the different treatment stages at La Javeriana Treatment Plant.

old HRFs (see Fig. 15). The new HRF layout would even allow an increase in the plant's capacity by a factor of 2 (increase of the filtration rate from 2.3 to 4.6 m/h) without a significant reduction in solids-removal efficiency. However, filter-cleaning aspects constitute another criterion for the selection of the pre-treatment system. Under the given situation, up-flow roughing filters allowing a filtration rate of 0.4 m/h to meet the minimum plant capacity will probably be installed as they showed higher performance in solids removal and hydraulic filter cleaning. The experience of Aesch also exemplifies that industrial countries can benefit from the development of appropriate technologies for developing countries.

LIMITS OF THE HRF TECHNOLOGY

'Filtration is more an art than a science' is a saying which implies that the implementation of this technology is limitless. On the contrary, the HRF technology also has limitations. First of all, HRF is predominantly designed for rural water supplies. The treatment process requires relatively large installations and can therefore hardly be applied in large urban water-supply schemes.

HRFs operate at relatively small filtration rates asking for large installations and consequently higher specific construction costs per m^3 design capacity. The initial costs will be higher than those required for the construction of floccu-

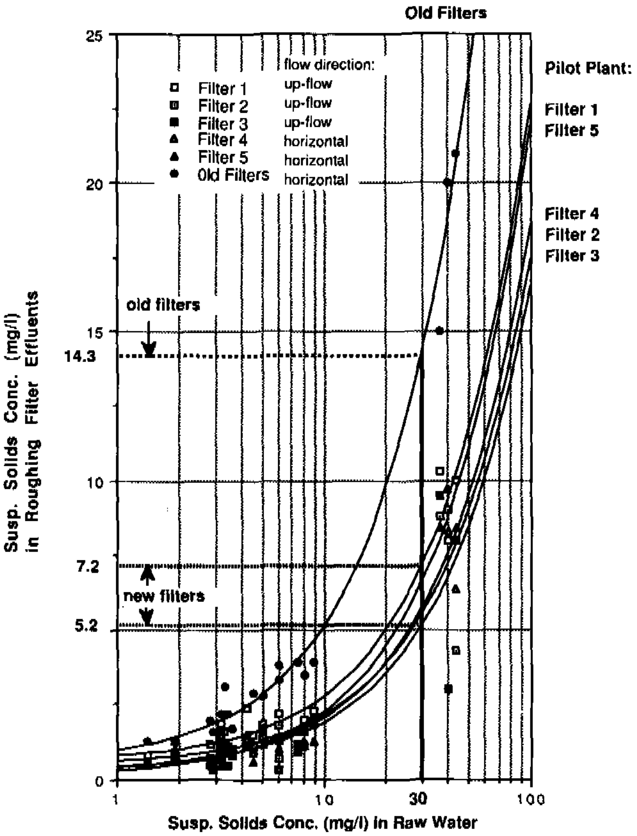

Fig. 15. Reduction of suspended solids by roughing filters in Aesch.

lation/sedimentation tanks. However, the operation and maintenance costs will be lower for the HRF option, which is an important factor with respect to the economical sustainability. Construction costs can be saved by minimizing the filter length, which, however, calls for hydraulic filter cleaning at shorter intervals.

Filter regeneration by fast drainage is not yet fully explored. Depending on the efficiency of hydraulic filter cleaning, manual cleaning by removing the filter material, washing it and then refilling it into the filter box must therefore be foreseen after several years of filter operation. Substantial volumes of settleable solid matter should be separated by sedimentation tanks or intake and dynamic filters prior to the application of HRF. Cleaning of these installations is usually easier than the removal of large amounts of solids from HRFs. Furthermore, solids separation by roughing filters might be hindered by high suspension stability likely in the presence of humic acids. In such a situation, the treatment efficiency should be assessed by pilot-plant tests.

HRF PROMOTION

In 1986, the IRCWD-managed HRF project had entered in its last phase, which involved the promotion and dissemination of the HRF technology (see also Fig. 1). New technical approaches are often difficult for rural inhabitants to understand and their advantages difficult to believe. Demonstration projects on a 1 to 1 scale helped to overcome these difficulties and to gain more practical experience. Local authorities and institutions willing to introduce the HRF and, in some cases, also the SSF technology were identified. SSF plants requiring rehabilitation by the addition of HRFs or new treatment schemes were selected as demonstration projects. Under the technical assistance of IRCWD, local staff designed the treatment plants which were usually constructed as self-help projects by the communities. The monitoring of the HRF/SSF plants was facilitated by the

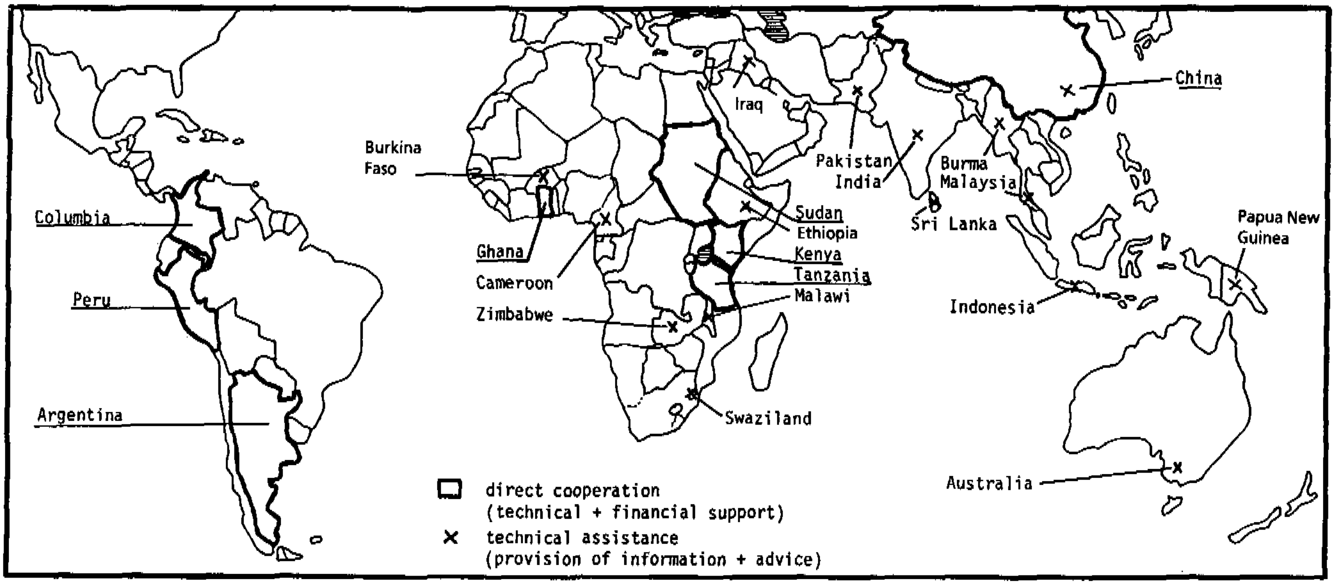

Fig. 16 Geographical distribution of the HRF demonstration projects.

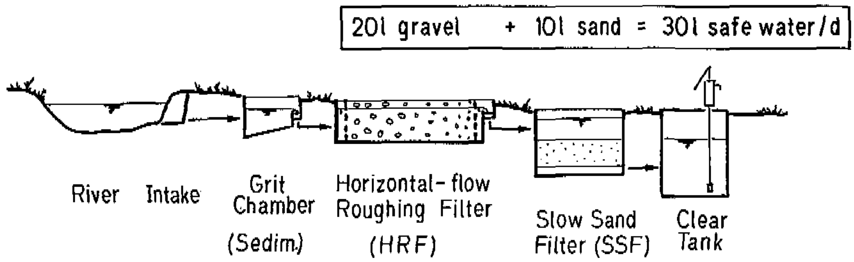

Fig. 17. Scheme of a self-reliant water treatment plant.

provision of a field test kit described under the heading 'Field Experience'. The HRF technology has spread to more than 20 countries (see Fig. 16) in the past 4 years.

According to IRCWD's information, over 60 HRF plants have been constructed during this period. This not only enabled the development of local HRF expertise, but positive experience with the treatment process convinced the cooperation partners who now strongly identify with the HRF technology.

IRCWD also acted as an information pool. New approaches and designs developed by the local engineers were collected and the information passed on to other cooperation partners through an HRF Filter Newsletter. Several institutions carried out studies on the HRF process in the form of M.Sc. theses [e.g. 19–23] and further consolidated this technology. Additional comprehensive field studies are under way to compare the HRF technology with other pretreatment processes [6]. All these activities contribute to keeping the HRF technology in the technical press, a vital medium for the dissemination of information.

FINAL REMARKS

The provision of safe water remains a challenge, particularly in developing countries facing increasing economic, institutional and socio-cultural problems. Under such conditions, self-reliant, substainable and community-based water supplies will be less affected. Slow sand filtration meets these criteria and is therefore recognized as a particularly appropriate technology for developing countries. In the past, however, slow-sand-filter operation was often hampered by inadequately pre-treated turbid surface water. Over the last decade, roughing filtration was rediscovered and is now used for its simple and efficient process.

Horizontal-flow roughing filtration received special attention due to its simplicity in construction and reliability in operation. Horizontal-flow roughing and slow sand filters are characterized by their high process stability, ease of operation and remarkable efficiency. Treatment schemes like the one illustrated in Fig. 17 make utmost use of local resources and are therefore reproducible under various conditions. Twenty litres of gravel and 10 litres of sand used as filter material are able to transform contaminated turbid surface water into 30 litres of quality drinking water, a water volume often applied as design value for the daily per-capita demand in water distribution schemes using public standposts. A large number of demonstration projects in many developing countries are proving the viability of the promoted treatment concept. This experience is to be used in the next decade — the implementation decade of roughing filters — for the benefit of those still lacking a safe and reliable water supply.

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