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ON

APPLICATION OF SLOW FILTRATION FOR SURFACE WATER TREATMENT IN TROPICAL DEVELOPING COUNTRIES

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I INTRODUCTION

An adequate safe water supply has always been recognized as a major factor in raising the health standards of any village community and its beneficial effects in the reduction of morbidity and mortality, especially among children and infants, is well established. At the same time, to realize the full health benefits of a water supply, improved sanitation and home hygiene are necessary adjuncts. In addition to health improvements, the provision of water supply and sanitation in rural areas is also likely to have secondary effects on productivity, migration from villages, village institutions and social conditions, agricultural and economic development. The provision of a water supply, therefore, can be viewed as only one component of a broader programme of rural development. In spite of this recognition, adequate supplies of safe water for their daily needs are beyond the reach of the vast majority of people in developing countries, constituting more than two-thirds of humanity. Ignorance, poverty and disease comprise a vicious circle that seriously hampers development. More specifically, lack of skilled manpower, inadequate capital, inappropriate technology, insufficient community participation, improper or nonexistent institutional infrastructures for programme planning and implementation, and shortage of managerial skill are factors that either singly, or more often in combination, account for the poor achievement of developing countries in the provision of basic sanitary services for their populations.

The introductory part of this report reviews some important aspects of rural water supply systems in developing countries in general and in Thailand in particular, and also discusses alternative treatment systems for the provision of safe water to rural populations.

1.1 Rural Water Supply in Developing Countries of Asia[1]

1.1.1 Overview of Water Supply Problem in Rural Areas

At present, water supply and sanitation services in the developing countries of Asia are generally poor and the staggering population increases expected in the future will inevitably lead to a worsening of existing conditions unless a far greater level of investment is made in this sector. Rural areas have received less attention than urban areas in Asian developing countries and, although about 80 percent of the population live there, they have been provided with much lower levels of water supply and sanitation services.

1/ Pescod, M.B. (1976) Criteria for Improving Rural Water Supply Systems in Asia, Paper prepared for the United Nations Centre for Natural Resources, Energy and Transport (U.N. Water Conference), New York and presented at the ESCAP Regional Preparatory Meeting in Bangkok, July 1976.

Table 1.1 presents selected data taken from a special subject paper on "Community Water Supply and Sewage Disposal in Developing Countries, 1970", prepared by the World Health Organization (WHO) [1] on the basis of a survey of 91 WHO Member States. More than one third of the total population in developing countries of WHO Member States live in the South East Asia (SEA) and Western Pacific (WP) Regions of WHO. In these two regions, only about 10 percent of the rural population in 1970, or less than 8 percent of the total population, had reasonable access to safe water [2]. Over the period from 1970 to 1980, the Second U.N. Development Decade [3], the average increase in rural population in the SEA and WP Regions of WHO was estimated to be approximately 25 percent, equivalent to an annual growth rate of approximately 2.3 percent.

The target of increasing the proportion of population provided with reasonable access to safe water to 25 percent in rural areas of developing countries over the Second U.N. Development Decade (1971-1980) represents an increase in population served of 210 percent over the population served in 1970 in the SEA and WP Regions of WHO. Taking into consideration the concurrent increase in rural population of 195 million in these two regions, the 1980 rural water supply provision target of 172 million does not accommodate the additional demands for water let alone make up any backlog. Inevitably, the overall proportion of the rural population in these regions, as well as the total number of rural people, with reasonable access to safe water in 1980 will be less than in 1970.

To meet the 1980 targets for rural water supply, large investments will be necessary and Table 1.2 summarizes the estimates of costs for developing countries in the SEA and WP Regions of WHO. It can be seen that, while the total investment for rural water supply in the decade to 1980 for all the developing countries of WHO Member States is not unreasonable compared with the annual investment in 1970, for the SEA and WP Regions the comparison is absurd. Continued investment over the decade at the 1970 rate in these regions would result in a shortfall of U.S.$816 million from the estimated total investment required and this suggests that the target is far beyond the resources of the countries concerned.

The scale of the problem of providing water supply and sanitation to rural communities in Asia is very large. Although settlements originally develop where there is a water supply, the high population

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[1] World Health Organization (1973) Special Subject: Community Water Supply and Sewage Disposal in Developing Countries, 1970, World Health Statistics, v. 6, no. 11, pp. 720-783.

[2] As defined in footnote 3 in Table 1.1.

[3] Off. Rec., World Health Organization (1971), no. 193, pp. 31.

Table 1.1 - Asian Region Developing Countries - Estimated Population and Rural Water Service Data

	1970 (Million)	1980 (Million)	Approximate Increase (%)
World Population 1/	3590		
Population in WHO Member States 1/	2780		
Population in Developing Countries of WHO Member States 2/	1721	2281	30
Population in Developing Countries in South East Asia and Western Pacific Regions of WHO 2/	964	1264	30
Rural Population in Developing Countries of WHO Member States 2/	1249	1547	25
Rural Population in Developing Countries in South East Asia and Western Pacific Regions of WHO 2/	768	963	25
Rural Population in Developing Countries of WHO Member States with reasonable access to safe water 2/3/	173	414 4/	140
Rural Population in Developing Countries in South East Asia and Western Pacific Regions of WHO with reasonable access to safe water 2/	77 5/	241 4/	210
Rural Population in Developing Countries in South East Asian Region of WHO with reasonable access to safe water: 2/	61	218 4/	260
Bangladesh	30	24	-
Burma	3	7	130
India	25	137	450
Indonesia	-	33	-
Mongolia	-	0.2	-
Nepal	0.01	3	30000
Sri Lanka	0.09	3	3000
Thailand	3	10	230
Rural Population in Developing Countries in Western Pacific Region of WHO with reasonable access to safe water: 2/	16	22 4/	40
Fiji	0.05	0.1	100
Khmer Republic	2	2	-
Republic of Korea	7	5	-
Laos	1	0.07	-
Malaysia	0.06	2	3000
Philippines	5	8	60
Republic of Viet-Nam	0.6	4	600
Western Samoa	-	0.04	-

1/ Source: World Health Organization (1971) Water Supply, Sewage and Waste Disposal, Basic Paper WHO/EH/71.2 prepared for the United Nations Conference on the Human Environment, Stockholm, 1972.

2/ Source: World Health Organization (1973) World Health Statistics, v. 26, no. 11, pp. 720-783.

3/ Reasonable access to safe water in rural areas defined as implying that the housewife or members of the household do not have to spend a disproportionate part of the day in fetching the family's water needs, in the form of treated surface waters or untreated but uncontaminated water such as from protected boreholes, springs and sanitary wells.

4/ Targets for the Second U.N. Development Decade to 1980.

5/ Excluding Indonesia, Mongolia, Singapore and Western Samoa.

Table 1.2 - Estimated Investment in Rural Water Supply Necessary to Meet Second U.N. Development Decade Goal of Serving 25 Percent of Population [1]

[4]	Total Investment to 1980 (U.S.$ Million[3])	Increased Population Served (Million)	Approximate Per Caput Cost (U.S.$)	Annual Investment in 1970 for Water Supply [2] Construction (U.S.$ Million)
To Serve Rural Population in Developing Countries of WHO Member States	3196	274[5]	12	217
To Serve Rural Population in Developing Countries in South East Asia and Western Pacific Regions of WHO	1296[6]	172[7]	8	48
To Serve Rural Population in South East Asia Region of WHO:	1244	163[8]	8	44
Burma	24	4	6	-
India	900	112	8	38
Indonesia	132	33	4	0.1
Mongolia	8	0.2	8	-
Nepal	50	3	15	0.1
Sri Lanka	63	3	21	0.2
Thailand	74	7	10	1
To Serve Rural Population in Western Pacific Region of WHO:	52	8[9]	6	4
Fiji	0.6	0.08	7	0.2
Malaysia	12	2	7	-
Philippines	17	3	5	3
Rep. of Viet-Nam	22	3	7	-
Western Samoa	0.2	0.04	7	0.2

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[1] Source: World Health Organization (1973) World Health Statistics, v. 26, no. 11, pp. 720-783.

[2] Including external, national and local capital, material and labour.

[3] Assumed to be 1970 U.S.$.

[4] Provide reasonable access to safe water, as defined in footnote 3 to Table 1.

[5] From Table 1.1, this figure should be 241.

[6] Excluding Bangladesh, Khmer Republic, Rep. of Korea, Laos, Singapore.

[7] From Table 1.1, this figure should be 164.

[8] From Table 1.1, this figure should be 157.

[9] From Table 1.1, this figure should be 6.

growth rate in all Asian developing countries results in greater demands being made with time on often underdeveloped water resources. High population densities in rural areas increase the danger of epidemics of waterborne diseases through lack of proper sanitation. The situation in developing countries of Asia will get worse in the future unless family planning programs achieve the success which has evaded them in the past. If the present population growth rate continues, the investment demands of even modest goals of rural water supply and sanitation will be prohibitive and yet new systems will be unable to meet the requirements of future population increases, without making any impression on a large backlog of unserviced population. Investments for this sector would require a disproportionate share of national budgets for any noticeable progress to be made and this would raise the problem of establishing priorities in national development planning. The competition for funds between projects contributing directly to economic development and those concerned with social service is very real in Asian developing countries.

1.1.2 Constraints to Progress

Numerous are the constraints which have limited past progress in improving rural water supply and sanitation. These constraints can be grouped into three categories: administrative, financial and technological. Although most countries rate limitations of finance as the primary constraint, it would appear that institutional problems are paramount in most countries. Technological constraints do exist but they are intimately tied to and have a bearing on the financial implications of a country's rural water supply and sanitation programme and are also closely related to institutional factors. Inevitably, overlaps exist among these categories of constraints but the breakdown is convenient for the purposes of discussion.

Administrative Constraints

The lack of a sufficiently high priority being given to the need for improving rural water supply and sanitation has been a principal factor limiting past achievements in this sector. In the absence of national policies for rural water supply and sanitation only piecemeal efforts have been attempted in most Asian developing countries. Inclusion of a policy for rural water supply within the overall national water policy seems to be a precondition of progress in this sphere. There is a strong need for evaluation of the existing situation and future requirements in rural areas of many countries and precise data are prerequisite to the development of a national policy. Too often, decisions on water source and supply systems have been left to individual agencies, or even individuals, without guidance from a national plan. Formulation of a national plan for rural water supply, perhaps with regional ramifications, will allow decisions to be taken within a framework designed to optimize the use of finances, resources and manpower.

There has been a fragmentation of responsibility and authority in water supply and sanitation in many countries in Asia. Institutional structures involving many agencies have built up and now there is a reluctance on the part of agencies responsible for the sector to give up their authority. Proliferation of agencies always gives rise to problems of coordination of efforts and this is a major cause of poor selection of communities to be serviced and inappropriate system installation in many countries. It would appear sensible to reduce the number of agencies, where many government departments are involved in rural water supply and sanitation, or at least to have one of them act as the primary agency responsible for development of national policies and plans and coordination of activities of the other agencies. Normally, such an agency would need to be strengthened and have adequate manpower and resources to carry out its task.

Whatever the institutional arrangement, there is a need to ensure adequate vertical links between the policy makers and planners at the national level and the villagers at the local level. In most cases in Asia, there has been no consideration of social need, local traditions, or the mentality and skills of villagers, and certainly no involvement of villagers, in the planning and decision-making processes. In addition to the necessity of getting local beneficiaries involved in the early stages of development of a project, a local support structure is also essential to bring about efficient implementation and operation of schemes and the absence of this has led to the failure of many completed projects in Asia in the past. The costs of establishing and maintaining such a structure are significant but essential to the success of major rural water supply and sanitation programmes, and Governments in Asia must be prepared to commit themselves to a continuing responsibility for rural systems operation.

One of the biggest problems in administering rural water supply and sanitation programmes in Asia is the acute shortage of trained manpower in most countries. Agencies responsible for rural projects are notoriously short of qualified staff and this often limits the scope of their activities, both in terms of the type of project they will undertake and the number of projects they can handle. There has been little commitment on the part of Governments to training needs in general. At the sub-professional level, there has often been no training available for maintenance personnel, plant operators and village health workers, resulting in a complete absence of information, health education and technical skills at the local level.

Financial Constraints

Rural water supply is relatively costly on a per caput basis because advantage cannot be taken of the economies of scale which are possible in urban systems, as a result of the dispersed nature of the rural population. At the same time, the income of rural dwellers in Asian developing countries is small, making their ability to pay for water supply and sanitation very low even when there is willingness to pay. In spite of this situation, however, it is essential that villagers be encouraged to pay the maximum amount possible for a water supply services and this should normally cover the costs of operation and maintenance. If there is to be any chance of catching up with the backlog of rural water supply service, as well as meeting future demands of population growth, every effort must be made to make national budget allocations for this sector go further. Contributions from the beneficiaries will take some of the burden off the central budget, where this has been supporting operation and maintenance of systems, and will tend to ensure the continued operation of completed systems, where the central budget has not formerly being applied to these expenditures.

In many Asian countries, existing funds for rural water supply are already in excess of the ability of responsible agencies to handle them. Serious staff shortages and absence of a suitable administrative framework are causing serious difficulties in many departments. Shortage of qualified personnel in Government agencies in most countries is not only a reflection of inadequate training opportunities but is also due to the low salaries paid, by comparison with the private sector.

Technological Constraints

In all Asian countries, groundwater is the preferred source for rural water supply because it does not normally require treatment and is usually the least costly but, unfortunately, it is not available in all areas. Surface waters are normally polluted, and naturally highly turbid in tropical regions, and require treatment before supply. Water distribution in rural areas of Asia is usually by means of very simple systems and public stand pipes or hand pumps are more prevalent than house connections. The level of technical expertise in rural areas is very low and all parts of the supply system must be simple to operate and maintain.

Quite often in Asia, design criteria from developed countries have been adopted for rural water supply in developing countries, where the people have very different social and cultural habits. Perhaps the most basic design criterion is the quantity of water which should be supplied to a rural community. Since the cost of supply system depends very much on water consumption, this fundamental decision is one of the most important in dictating the rate at which rural communities can be served with future budget appropriations. Also, because water use is closely related to convenience of the supply, it is a decision which should be taken in conjunction with the decision on form of distribution. A national policy should provide guidelines on what level of convenience, and its associated water consumption, is consistent with the country's rural water supply situation. The duration of service is another factor affecting water consumption and the economics of system design. Many village water supply systems in Asian countries have been designed on the assumption of 12- or even 24-hour service but in practice have operated only 4 to 6 hours per day. Judicious choice of distribution system and duration of service would allow significant savings in costs if minimum consumption objectives were incorporated into system design. A policy of constructing rural systems which are spartan in their provisions but reliable in service appears to be necessary in Asia if the present water supply situation is to be markedly improved in the future.

Water quality is another fundamental design criterion which affects system costs. Many developing countries in Asia have adopted the WHO International Drinking Water Standards [1] as their criteria for rural water supply and have applied these rigidly. However, it is recognized that a much improved quality water which is convenient and acceptable to villagers is preferable to an absolutely safe water which villagers reject in favour of their traditional contaminated supply.

Development of economic and technologically sound systems suited to local conditions depends on such optimization through research and field testing of feasible processes.

In general, technological constraints are not seriously inhibiting the implementation of rural water supply and sanitation programmes the way financial and administrative constraints are retarding progress. Overcoming technological problems and improving the appropriateness of the technology of rural systems could have a major effect on costs and, therefore, on the extent to which future investments would meet the needs of the rural population in Asia.

1.2 Rural Water Supply in Thailand

The 1970 census in Thailand reported a population of 36.8 million, of which 85 percent were rural. Communities of less than 5000 people are regarded as villages and there are 50,000 such villages in the country. Rural population annual growth rate is estimated to be about 3 percent but there are signs that family planning programmes are having an effect in reducing this, perhaps to 2.5 percent by 1977. It has been estimated that, in 1972, 10.6 percent of the rural population had access to safe water from piped supplies or protected wells with handpumps. This figure is expected to increase to 25 percent by 1980, in conformity with the declared global targets for the Second Development Decade of the United Nations.

Thailand has a centralized system of Government and, administratively, the country is divided into four regions: north, north-east, central and south. There are 72 Provinces (Changwats) which are di-

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1/ WHO (1971) International Standards for Drinking Water, Third Edition, Geneva.

vided into Districts (Amphers) and each of these has 8 to 10 Sub-districts (Tambols). Each sub-district comprises 5 to 10 villages (Muhbans). The district capitals and larger sub-districts have municipal bodies and other sub-districts Tambol Councils.

The National Economic and Social Development Board (NESDB) is responsible to the Prime Minister for the overall development plan of the entire country on a Five-Year Plan basis. At the national level, the responsibility for rural water supply and sanitation is shared by several agencies. The Department of Public Health Promotion in the Ministry of Public Health, the Department of Public Works in the Ministry of Interior, the Department of Mineral Resources in the Ministry of Industry and the Accelerated Rural Development Office (ARD) in the Ministry of Interior have responsibility for villages with population between 500 and 5000. Villages having population below 500 are looked after by the Department of Medical and Health Services in the Ministry of Public Health and the Department of Local Administration in the Ministry of Interior. Added to these are the Department of Community Development in the Ministry of Interior, the Royal Irrigation Department in the Ministry of Agriculture & Cooperatives and the Border Patrol Police Service of the Ministry of Interior, which also play minor roles in rural water supply and sanitation.

In April 1966, the Government started the "Community Water Supply Project" to be completed in five years (1966-71), which had the objective of providing safe water to the entire rural population. By the end of 1970, almost three million people had benefited from this programme, representing about 10 percent of the rural population. The Second National Plan recognized the need for increased investment in potable water supply throughout Thailand but at the end of the Plan period it was admitted that potable water schemes for smaller villages were still inadequate. Only 0.8 percent of the total outlay of the Second Plan was allocated to water supply and sanitation for rural areas, while 1.1 percent was allocated for urban water supply and sanitation. At the end of the Third National Plan (1972-1976), it is expected that about 5.3 million (15 percent) rural people will have access to safe water, representing an additional 2.2 million people. In this Third National Plan, the share of water supply and sanitation investment for rural areas was 1 percent of the total outlay, half that allocated to urban areas. However, there has been a progressive increase in spending on rural water supply and sanitation in recent years: US$4 million in 1970, US$4.67 million in 1972 and US$6.1 million in 1974. As evidence of the Government's intentions of promoting the development of rural areas, the budget allocated to the principal Departments involved in rural water supply and sanitation in the Third Five-Year Plan has been raised to 1165 million Baht 1/, from 509 million Baht in the Second Five-Year Plan. Considering that provision of

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1/ Current exchange rate approximately 20.15 Baht = US$1.

about US$58 million has been made in the Third Plan (1972-1976) to cover 2.2 million population of the rural community, it is estimated that an additional US$150 million will be needed to cover 25 percent of the 41.7 million population by 1980. An expenditure of US$1000 million will be necessary in addition to the Third Plan provision to provide safe water to the entire rural population by 1980.

The present general policy of the Government is to provide tubewells equipped with handpumps, and to construct sanitary wells fitted with handpumps. This is to be supplemented by piped water supply systems, wherever feasible. The contribution of the people to water supply schemes is significant and, in many cases, has been more than 50 percent of the capital cost, with the balance being made up by the Government. The difficulty, however, in many schemes is in maintaining public handpumps in good order. It is estimated that 50 percent of the pumps are out of order. Action is being taken by the Government to ensure better maintenance. Another difficulty that rural water supply in Thailand is facing is lack of qualified personnel for the provision of technical services. Manpower distribution in the community water supply programme in 1970 is given in Table 1.3. It can be seen that the intermediate level (sanitarians and technicians) and primary level (sanitary inspectors and operators) staffing is not enough and has to be increased by 40 to 60 percent if the target of 25 percent coverage of the rural population with safe water by 1980 is to be achieved. There is also a need to change the attitude of high level personnel (sanitary and civil engineers) *vis-à-vis* the real problems of rural communities. In general, their urban orientation and cosmopolitan experience give them a strong preference for city life and they are loath to leave metropolitan centres to serve in remote rural areas.

Table 1.3 - Manpower Distribution in Water Supply Programme in Thailand [1]

Categories	Number	Ratio to Total Population
High Level	124	1: 250,000
Intermediate Level	2375	1: 13,000
Primary Level	5800	1: 5,000

In Thailand, the approach towards the provision of safe water for rural communities is generally good. Thailand is, relatively, more affluent than other developing countries in South-East Asia and the people are in a better position to contribute towards water supply

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[1] World Health Organization (1974), Regional Office for South-East Asia, *Report on Rural Water Supply, Thailand*, EH/SEARO/74.10

schemes. However, special efforts should be made for increased allocation of Government funds to achieve the target set for the future. Budget provision should be managed by the local authorities for the maintenance and operation of water supply systems. The involvement of as many as six agencies in the rural water supply programme is a major factor retarding its development. An amalgamation of several agencies would reduce the expenditure on establishment, and ensure better use of technical and administrative manpower, supplies and equipment. A possibility worth considering is whether it might be feasible for the entire rural water supply programme to become the responsibility of one single department, covering investigation, planning, design and implementation of both piped and handpump supplies. Educational training in health and sanitation for rural people is essential in the implementation of a successful water supply programme.

1.3 Alternative Treatment Systems

An effective water supply system should provide water to the greatest number of people at the lowest cost, in a steady and reliable manner. Functional design of systems should be directed by these principles for effective operation of water supply systems in developing countries. Complex and expensive methods of water supply are inappropriate for many rural areas. High cost technology imposes high demands for operation and maintenance on local organization and skills, and in many rural areas the population is unable to make use of the technology available.

Groundwater offers an ideal source of water for villages and small communities. Shallow depth groundwater, if suitably protected from surface contamination, is often of high quality and an available good supply can be provided without complex or costly technology. Deep groundwater shares the same characteristics, except that there can be more confidence in its quality, but greater costs are involved in its exploitation. This is because it has to be lifted further and may be harder to reach, especially if an impermeable layer has to be penetrated as in the case of confined aquifers. Development of deep groundwater is a technical enterprise which requires careful planning, skilled implementation and cautious supervision by specially trained manpower.

Of all the alternative sources of water for domestic supply, deep groundwater usually provides the best quality water; in most cases it is potable without treatment but sometimes simple treatment, such as sand filtration or chlorination, may be added. The good bacteriological quality of groundwater is due to the filtering action provided by soil layers through which it must pass, and to the lack of oxygen and nutrients which makes it an unfavourable medium for the growth of pathogenic bacteria. As a result of slow filtration through the soil, the physical quality of groundwater is also good; deep groundwater is generally colourless and of low turbidity. The chemical quality of groundwater varies, in accordance with the geological formations (minerals) in the area, some of which are dissolved during the water movement through the soil. In some instances, the mineral content of water affects water palatability and may also occasionally present a health hazard.

Iron removal is a problem most commonly met with in underground waters having high CO_2 content, low pH and zero dissolved oxygen. Tropical underground waters are often chalybeate in nature and many areas have well waters of this type. If the iron content is too high, the supplied water will not be acceptable to the community and they will use contaminated sources which taste better. Iron removal can be achieved when the water is aerated as it trickles down through trays of gravel, with subsequent sand filtration. Here again, the complicated mechanical and electrical equipment of rapid filters are a disadvantage in rural areas.

Recent developments in water treatment have been mainly in the area of improving the rapid sand filtration method. However, it should be realized that the older and unchanged slow sand filtration system does have certain advantages and should be retained in the chain of development of low-cost technology for rural communities in developing countries. It is a single process with the greatest range of effects on water properties and can achieve good results by a method that is simple to construct and operate. Where suitable qualities of sand are not available it is possible to develop and use other local materials, such as rice husk, coconut husk, pea gravel, etc.

The conventional approach to the solution of many rural water supply problems consisted of adapting scaled-down versions of hardware and technology commonly adopted in the urban situation. In technologically developed countries which also had the advantage of a better economy, this adaptation process did not create any special problems. However, when the same technique was extrapolated to the relatively undeveloped regions, it was seen that these solutions were seldom successful.

For rural areas of developing countries, slow filtration seems to be the most suitable single treatment process for surface water and may be very efficient when combined with chlorination (and sedimentation if necessary). It is less complicated, can suffer more abuse and still produce high-grade water and, where land area is not a limiting factor, usually requires less investment. One problem in applying slow filtration to turbid surface waters in tropical regions is that the suspended silt quickly blocks the filter. However, a slow filter can be maintained in good working condition in spite of excessive turbidity (particularly inorganic turbidity) which causes rapid clogging of the filter surface, necessitating frequent cleaning. Where the raw water source contains high amounts of turbidity and algae, pre-filters (coconut fibre or pea gravel) can be used to remove most of the turbidity and algae before the water passes through a slow sand filter (or burnt rice husk filter) for polishing and removal of remaining impurities.

1.4 Purpose of the Study

This study was not initiated to consider the administrative or financial problems of providing potable water supply to rural communities but was limited to technological considerations. Nor was it the intention to study a broad range of technological alternatives, but rather to concentrate on a specific aspect of the problem. The emphasis was entirely on the technological aspects of utilizing surface waters for potable supply in Asian villages and the ultimate aim was to provide an acceptable water as cheaply as possible using simple treatment systems.

The specific purposes of this first phase of study was to conduct the following investigations:

(i) Performance of a slow sand/burnt-rice husk filter and its ability to function in combination with a coconut fibre filter (series-filter system).

(ii) Performance of a dual-media filter (coconut fibre in the upper layer and burnt-rice-husk in the lower layer, in the same filter box) with a view to evaluating the advantages and disadvantages of this system compared with the series-filter system.

(iii) Performance of dual-media filters, made of burnt-rice-husk or coconut fibre overlying sand.

The method of investigation was to assess the influence of raw water turbidity and filtration rates on the quality of treated water (turbidity, coliform removal) and the duration of filter runs based on the observation of head-loss development.

II EXPERIMENTAL INVESTIGATION

This study was a continuation of the exploratory phase which has already been described in the Progress Report to the WHO International Reference Centre for Community Water Supply [1], March 1976. It was intended to divide this follow-up study into two stages,(Stage A: raw water turbidity level at 50 JTU, and Stage B: raw water turbidity level at 100 JTU), with the emphasis on the duration of filter run and the bacteriological quality of the effluent.

2.1 Source of Raw Water

The raw water source is a canal (klong) near the Regional Engineering Research Centre of the Asian Institute of Technology, Bangkok. Under normal conditions, the turbidity of this surface water ranged from 25 to 50 JTU. Fluctuations in turbidity were particularly marked during rainy days when runoff from the surrounding area carried silt and soil into the canal. Under these conditions a turbidity of up to 150 JTU could be temporarily recorded. To maintain raw water turbidity at higher levels for experimental purposes, an artificial intake system was designed. Raw water was drawn from the canal by means of a 10-hp centrifugal pump. The pump played a double role, both supplying water to the filters and returning a portion of this water back to the intake area, creating turbulence and scouring the muddy bottom to induce higher levels of turbidity for experimental needs. The intake system arrangement is shown in Fig. A1 in Appendix A.

2.2 Filter Systems

Two systems of filters were designed for the experimental study of series-filtration and dual-filtration and the filters were coded for ease of reference. The series-filtration system consisted of two identical pre-filters (R_1 and R_2) mounted on a 3.20 m-high wooden frame and packed with coconut fibre. When stage A (at raw water turbidity level of 50 JTU) was studied, one of these filters (R_1) was coupled with two burnt-rice-husk filters (F_1 and F_2) and the other (R_2) with two sand filters (F_3 and F_4), making four polishing filters. This arrangement, represented in Fig. 2.1, allowed the study of two different filtration rates at the same time, both in the sand filters and the burnt-rice-husk filters.

The pre-filters (R_1 and R_2) were made of 0.32 cm-thick galvanized iron sheets and measured 1 m x 1 m x 2 m each. The internal depth of each box was the sum of the following depths, starting from the top:

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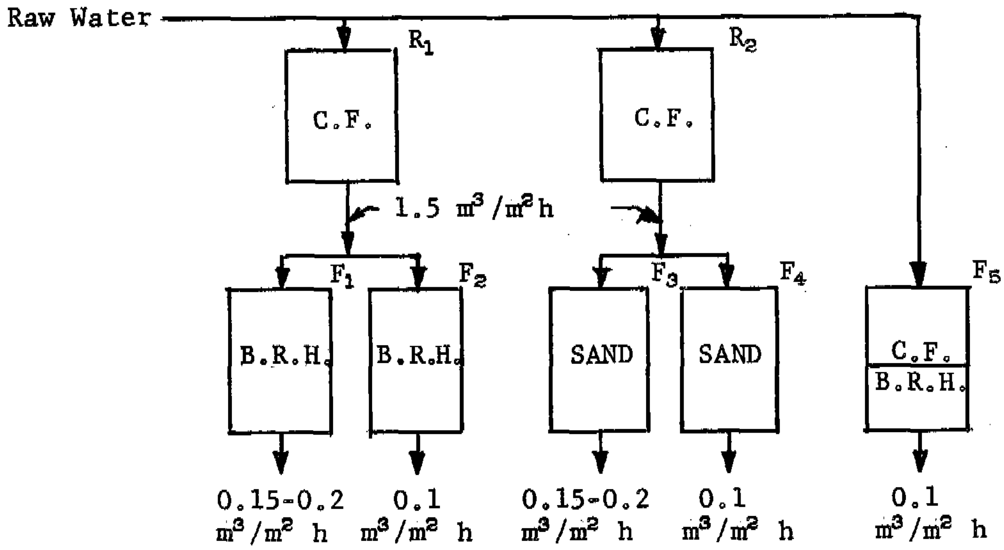
[1] Progress Report on "Application of Slow Filtration for Surface Water Treatment in Developing Countries (Phase 1), WHO-IRC, March 1976.



C.F. = Coconut Fibre; B.R.H. = Burnt Rice Husk

Fig. 2.1 - Flow Diagram of Series-Filtration and Dual-Filtration Systems at Raw Water Turbidity Level of 50 JTU

Freeboard above supernatant water level	0.30 m
Supernatant water	0.80 m
Coconut fibre	0.80 m
Crushed stone underdrain	0.10 m

The four polishing filters (F_1, F_2, F_3 and F_4) were of the same configuration, each being made of three 1 m-long, 1.54 m I.D. concrete sewer pipes. The arrangement in each filter box was as follows:

Freeboard above supernatant water level	0.70 m
Supernatant water	1.20 m
Sand/Burnt rice husk	0.80 m
Crushed stone underdrain	0.30 m

The dual-filtration system (F_5) consisted of one single filter box, of the same design as the other four polishing filters, which was filled with coconut fibres overlying burnt rice husks. The internal depth of the dual-media filter was as follows:

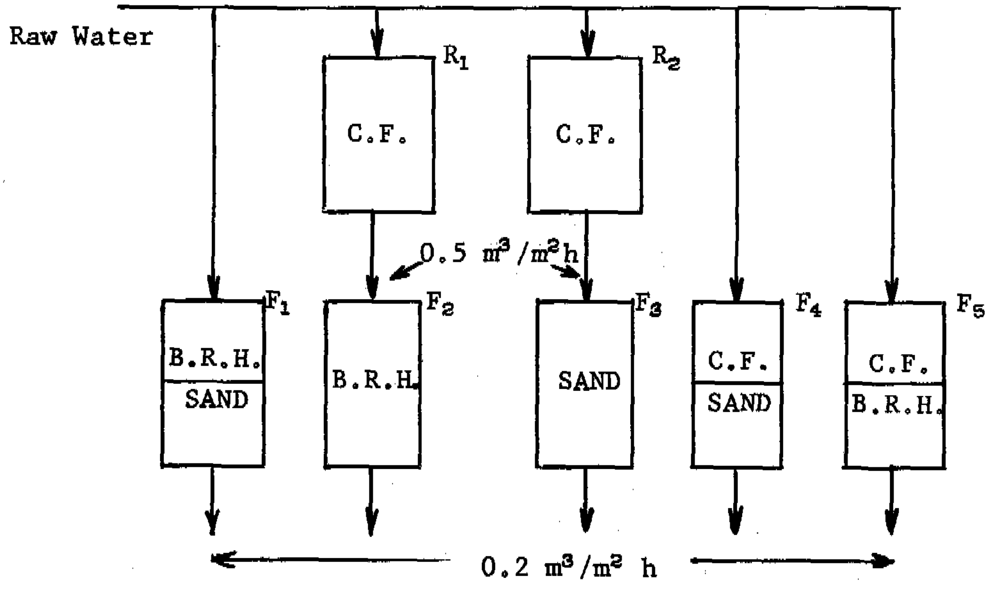
Freeboard above supernatant water level	0.10 m
Supernatant water	1.20 m
Coconut fibre	0.80 m
Burnt rice husk	0.60 m
Crushed stone underdrain	0.30 m

Filtration rates for the series-filtration and dual-filtration systems are also indicated in Fig. 2.1.

In the later stage of study (at raw water turbidity of 100 JTU), F_1 and F_4 were transformed into dual-media filters, containing burnt rice husk and sand in F_1 and coconut fibre and sand in F_4, making three dual-filters in total, with F_5 packed with coconut fibre and burnt rice husk. The series-filtration consisted of the two roughing filters (R_1 and R_2) packed with coconut fibre as already described. The pre-filter R_1 was coupled with the burnt-rice-husk filter F_2 and R_2 with the sand filter F_3. The layout of the filter systems in this stage of study is shown in the flow diagram of Fig. 2.2. All filtration rates were maintained at 0.2 m^3/m^2-h.

In this later stage of study, a minor change was made in the internal arrangement of the dual-media filter boxes, whereas the series-filtration system remained unchanged. The internal depth of each dual-media filter was as follows:

Freeboard above supernatant water level	0.70 m
Supernatant water	0.60 m
Top layer of burnt rice husk/coconut fibre	0.80 m
Bottom layer of sand/burnt rice husk	0.60 m
Crushed stone underdrain	0.30 m



C.F. = Coconut Fibre; B.R.H. = Burnt Rice Husk

Fig. 2.2 - Flow Diagram of Series-Filtration and Dual-Filtration Systems at Raw Water Turbidity Level of 100 JTU

The reduction of the supernatant water head from 1.20 m to 0.60 m was designed to minimize the development of anaerobic conditions in the dual-media filter. This important phenomenon will be discussed in more detail in the section on "Experimental Results".

The entire experimental unit is shown in Fig. 2.3. Design details of the filters are given in Fig. A2, A3 and A4 in Appendix A.

2.3 Filter Controls

Two 1.5 m x 1.5 m x 1 m galvanized-iron "reserve" tanks were provided to store raw water before delivery into the filters, as shown in Fig. 2.3. A 40 rpm blade-mixer was provided in the first tank to render the raw water homogeneous before discharge into the second tank, from which water was pumped directly to the dual-media filters by a 0.5 HP-centrifugal pump, and to the two roughing filters (R_1 and R_2) by a 2.5 HP-piston pump.

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

2.4 Filter-Media Characteristics

Coconut fibres, before being used, were soaked in water for at least 24 hours and rinsed 3 or 4 times to remove organic colour originating in the fibre structure.

From the results of sieve analyses, presented in Fig. 2.4, burnt rice husks were found to have a relatively high non-uniformity coefficient (U = 5.8) compared with sand (U = 2.3), but the effective size was almost the same in both cases ($E = 8.3 \times 10^{-2}$ cm for sand and 9×10^{-2} cm for burnt rice husk). For the purposes of this study, stock sand and stock burnt rice husk were used so that the relatively high expense of careful grading was avoided. Burnt rice husk is composed of about 90 percent silicon dioxide, 6-7 percent oxides of magnesium, calcium and iron and the remaining 3-4 percent is organic matter 1/. Its specific gravity is approximately 2.3 and its density is 7.45 to 7.61 kg/m^3.

2.5 Under-Drainage System

The bottoms of the five filters F_1, F_2, F_3, F_4 and F_5 were de-

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1/ WILLIAMS, F.H.P. and SOMPONG, S. (1971) Some Properties of Rice Husk Ash, Geotechnical Engineering, Vol. 2: 75-81.

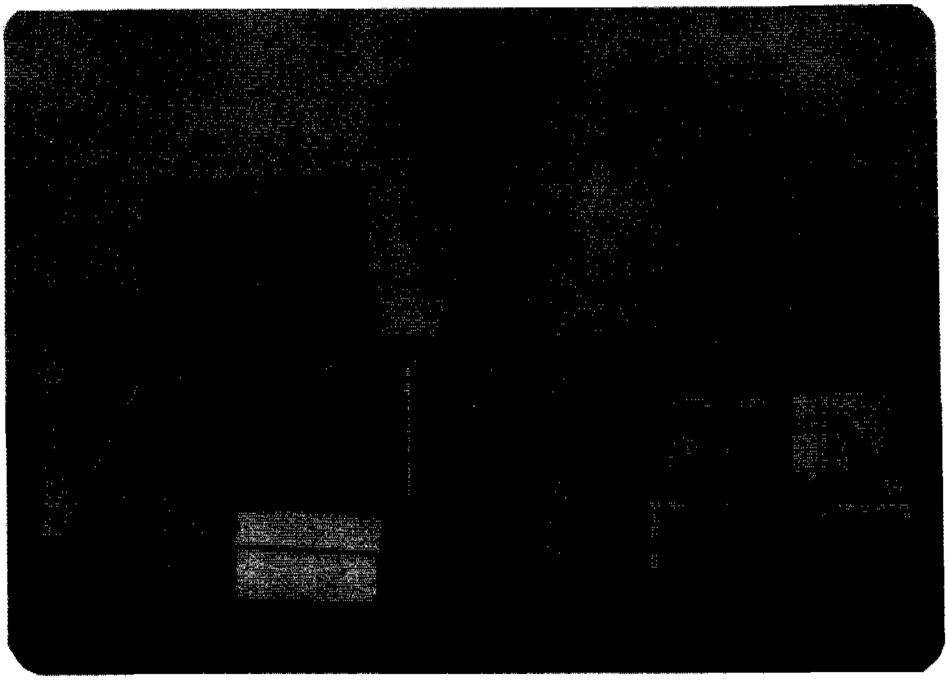


Fig. 2.3 - Experimental Pilot System

R_1 & R_2 : Roughing Filters

F_1 to F_5: Different Filters

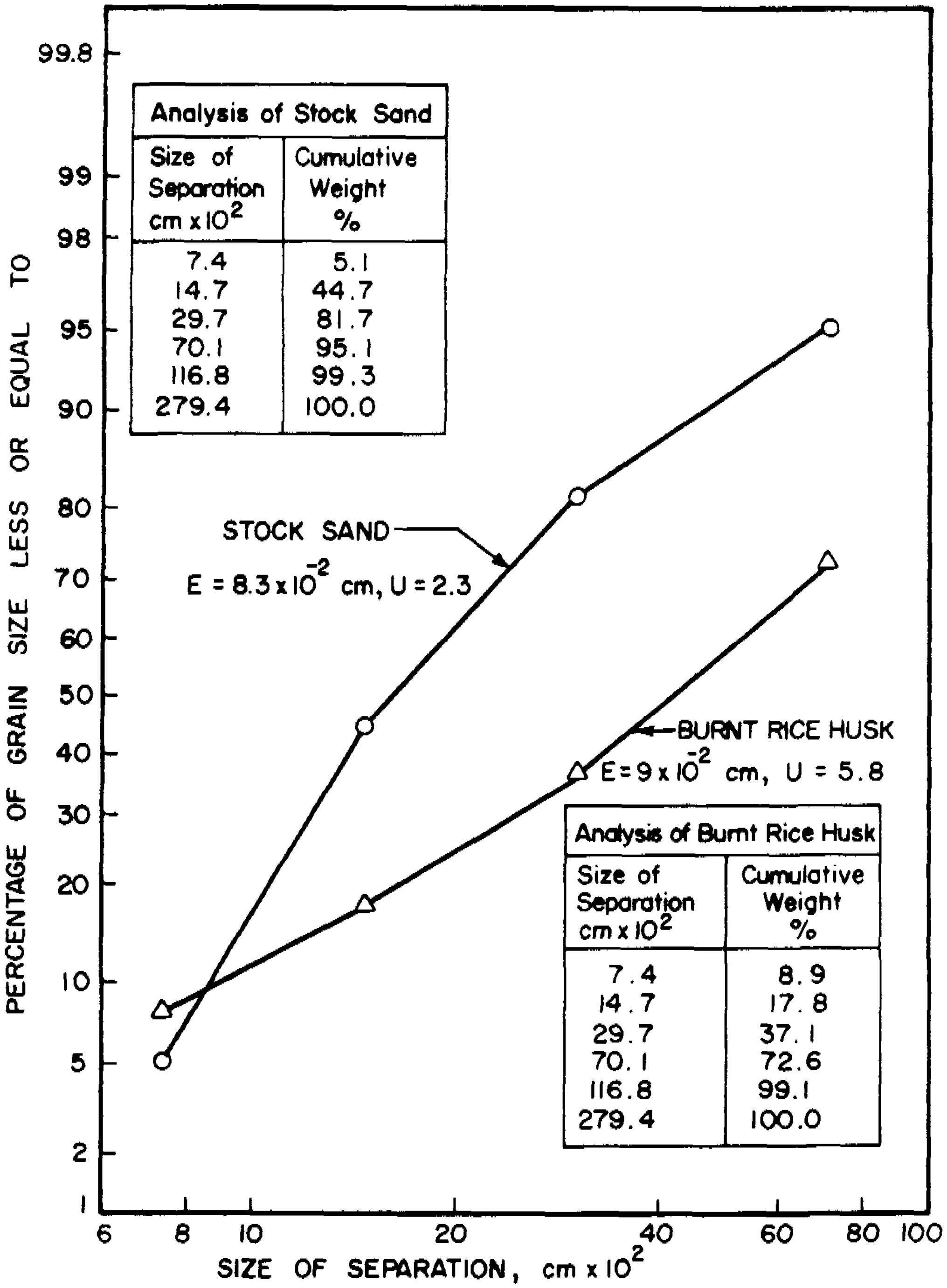
RT: Reserve Tank

MT: Mixing Tank

P_2 : Pump for Roughing Filters

P_3 : Pump for Dual-Media Filter

P_1 : Intake 10 hp-Centrifugal Pump (not shown)



Analysis of Stock Sand	
Size of Separation cm x 10^2	Cumulative Weight %
7.4	5.1
14.7	44.7
29.7	81.7
70.1	95.1
116.8	99.3
279.4	100.0

Analysis of Burnt Rice Husk	
Size of Separation cm x 10^2	Cumulative Weight %
7.4	8.9
14.7	17.8
29.7	37.1
70.1	72.6
116.8	99.1
279.4	100.0

Fig. 2,4 Sieve Analysis of Stock Sand and Burnt Rice Husk.

signed with a 1:25 slope providing easy flow for the treated water to leave the underside of the filters. Between the bottom of these filters and the filter beds lay three 10-cm layers of crushed stone with gradings of 6.4-12.7 mm, 12.7-19.1 mm and 19.1-25.4 mm. This arrangement was provided to prevent the filtering medium from entering and chocking the drainage waterways. The under-drainage system of the roughing filters (R_1 and R_2) was made of a 10-cm layer of crushed stone with grading of 12.7-25.4 mm.

2.6 Filter Cleaning

A filtration run was interrupted when the bed resistance (sand and burnt rice husk) had increased to such an extent that the outlet regulating valve was fully open. The headloss measurement was also an indication of blocking development and imminence of the end of a run.

To clean the roughing filter beds, water was completely drained off from the filter box and coconut fibres were manually removed and discarded. New coconut fibre stock, previously soaked in water for 24 hours, was used to repack the filters. It was also experienced that the used medium after washing could be reused a second time but must then be discarded. An additional amount of coconut fibre previously soaked in water for 24 hours was used to compensate for the loss of fibres during the washing operation and to maintain a constant filter depth. However, in this experimental study it was found to be preferable to refill the roughing filters with new coconut fibre stock (without affecting the performance of filters) for reasons of simplicity of operation and elimination of the rewashing process. Similar operations were applied for the handling of coconut fibres in the dual-media filter.

The cleaning of sand and burnt rice husk filter beds was carried out by manually scraping off the surface layer to a depth of 1-2 cm in the case of sand and 2-3 cm in the case of burnt rice husk since it was observed that the suspended solids and colloidal matter were deposited to a greater depth in the latter medium due to the porous nature of the burnt rick husks. Cleaning of the bed in the dual-media filter was achieved by scraping off the biological layer to a depth of only 1 cm or less because the penetration of suspended particles into this type of filter was less than in the other types of filter system mentioned.

III EXPERIMENTAL RESULTS

3.1 Synopsis of the Exploratory Phase of Study [1]

The exploratory filtration study was conducted to provide a rational approach in determining the range of reasonable operating conditions for a long-term filtration study of different filter systems. The main conclusions from that preliminary study were:

(i) The coconut fibre pre-filter removed sufficient turbidity from raw waters with turbidity up to 150 JTU to produce an effluent acceptable for subsequent treatment by sand or burnt-rice-husk filters. The head loss build-up in the pre-filter was insignificant and the duration of filter run was relatively long.

(ii) In general, the burnt-rice-husk filter and the sand filter in the series-filtration system and the dual-media filter (coconut fibre-burnt rice husk in the same box) performed well at filtration rates of 0.1 and 0.2 m^3/m^2h, resulting in suitably long filter run durations as well as acceptable effluent turbidities. Moreover, it was observed that the final treated water turbidity was relatively independent of raw water turbidity at flow rates in the range 0.1-0.6 m^3/m^2h but head loss development increased with increasing raw water turbidity and filtration rates. It was considered advisable to rely on the head loss rate as the main parameter controlling the length of filter runs.

The preliminary study confirmed the potential of series-filtration and dual-filtration systems for treatment of turbid tropical surface waters, and justified the long-term filtration study emphasizing the biological effectiveness of this form of treatment and the bacteriological quality of the filtered water.

3.2 Stage A: Long-Term Filtration Study at Raw Water Turbidity Level 50 JTU

This part of the study extended from November 1975 to March 1976, when the raw water turbidity varied between 25 and 45 JTU and no artificial turbulence was resorted to. As a result of the exploratory phase, filtration rates of 0.1 to 0.2 m^3/m^2h were maintained in the slow filters. The quality, in terms of turbidity, of the raw water and effluents from roughing filters and slow filters, was monitored daily. Head loss build-up in the slow filters was recorded regularly because it served as a criterion in concluding a filter run. Records of head loss

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[1] Progress Report on "Application of Slow Filtration for Surface Water Treatment in Developing Countries (Phase 1), WHO-IRC, March 1976.

development in the roughing filters were also kept for reference. The bacterial contents of the raw water and the final treated waters were determined in the forms of total coliforms, faecal coliforms and Streptococcus faecalis. All analyses were carried out according to Standard Methods [1]. Detailed data are tabulated in Appendix B Tables B1 to B5 and the major results presented in the next sections.

3.2.1 Performance of the Series-Filtration System

As previously described, the series-filtration system consisted of two identical tanks serving as roughing filters (R_1 and R_2) to pre-treat raw water to remove most of the gross turbidity for subsequent treatment by slow filters. One of the roughing filters (R_1) was connected to two burnt-rice-husk filters (F_1 and F_2), and the other (R_2) to two sand filters (F_3 and F_4). Figs. 3.1 and 3.2 illustrate the performance of the series-filtration system and the results of the roughing filters will be discussed first, followed by presentation of results on the slow filters.

Roughing Filters

Both roughing filters were operated at a filtration rate of 1.5 m^3/m^2h. Fig. 3.2a shows the variations of turbidity in the raw water and in the effluent from the roughing filters. The values plotted represent averages of 5-day values. It was observed that the effluent turbidity from the two roughing filters did not show significant differences and so average values have been herein reported. Raw water turbidity varied from 25 to 45 JTU during 108 days of continuous operation, while the mean value of turbidity in the effluent from the pre-filters was about 12 JTU, denoting a 63 percent removal efficiency. It can also be seen that, during the first 48 days of operation, the turbidity of the water produced by the roughing filters was relatively stable and independent of the raw water turbidity. As operation progressed and clogging became more important, the roughing filters gradually lost their stability and their performance became raw water turbidity dependent.

Head loss development is an important parameter in filtration since it announces the conclusion of filter runs. Fig. 3.1a records the head loss build-up across the roughing filter beds. It can be seen that the total head loss after 108 days of continuous operation was 85 cm in the roughing filter R_1 and 75 cm in R_2, averaging 80 cm for both roughing filters. During the first 30 days of operation, head loss development in the coconut filter bed was insignificant. From the 31st day onward, head loss build-up increased gradually at a rate of approximately 1 cm/day, if linear extrapolation is applied. For a head

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[1] Standard Methods for the Examination of Water and Wastewater, AWWA, WPCF (1971).

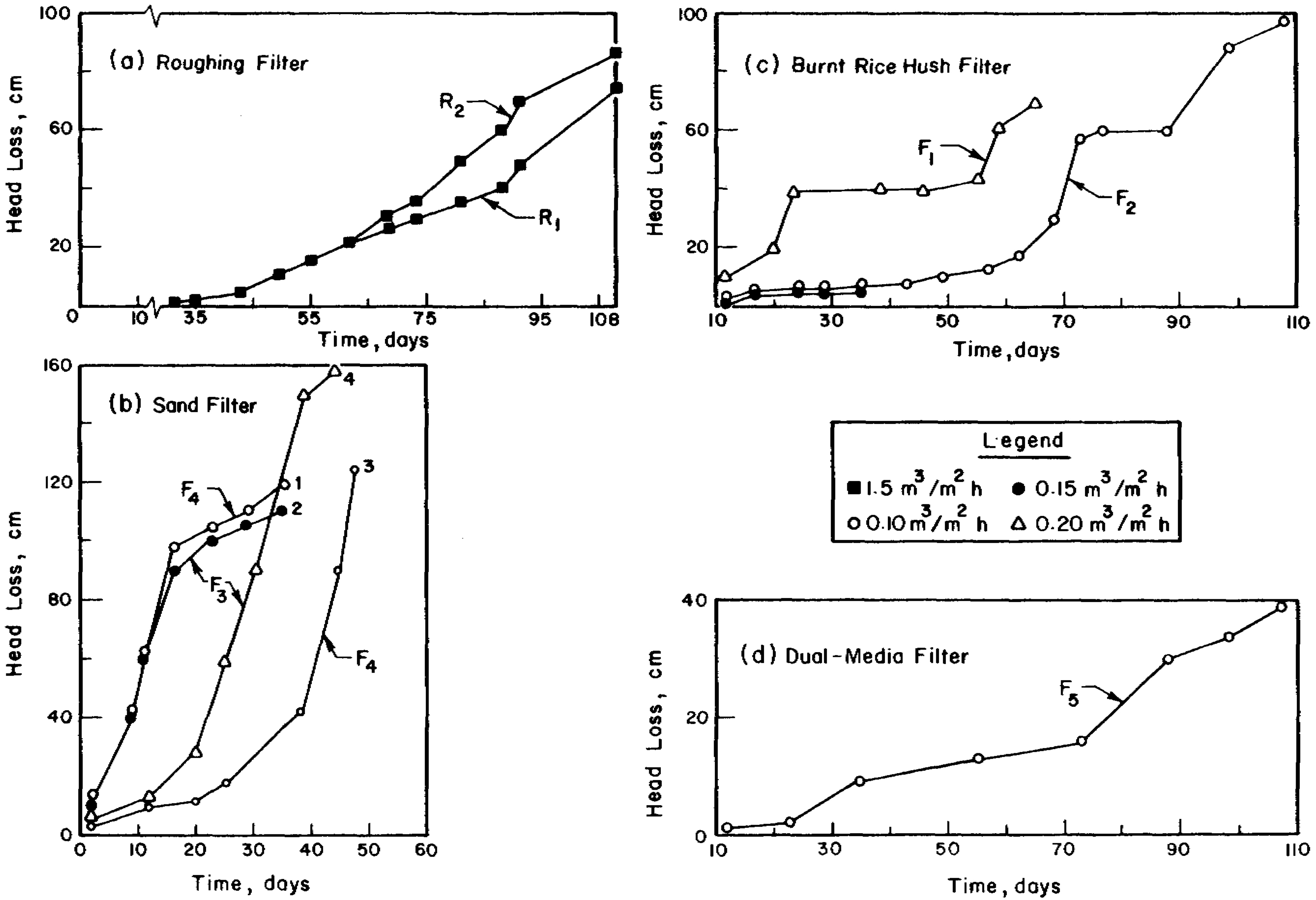


Fig. 3.1 Head Loss Development in Different Filters.

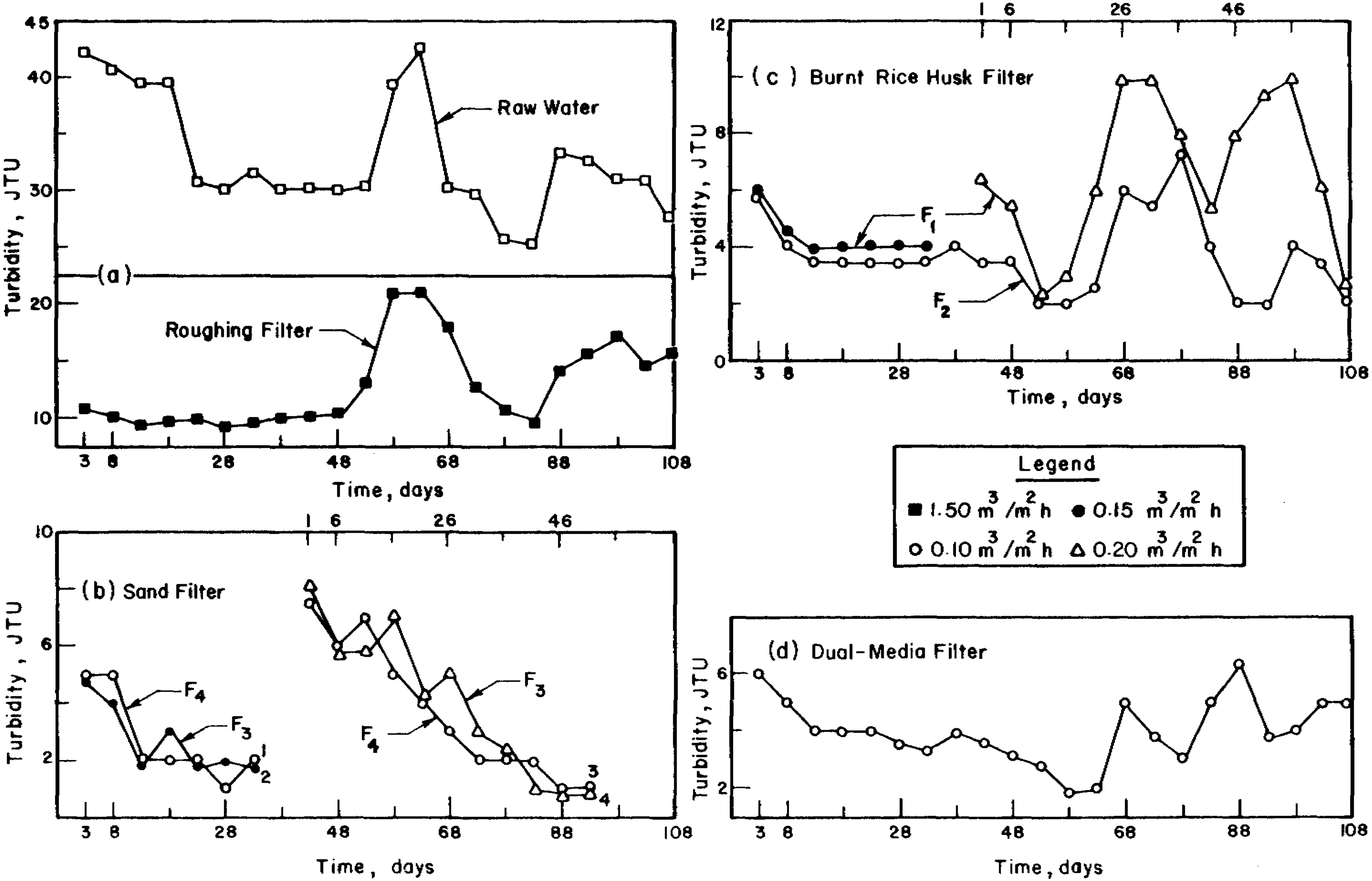


Fig. 3.2 Turbidity of Raw Water and Effluents of Different Filters.

loss limit of 1.2 m and continuous filtration rate of 1.5 m^3/m^2h, the interval between recharges of new coconut fibres would be of the order of 4 months. One important conclusion that can be drawn from this study of coconut fibre filters is their considerable potential to tolerate raw water turbidity changes and still produce an effluent satisfactory for subsequent treatment by slow sand and burnt-rice-husk filters.

Sand Filters

At the start of this stage of study, two filtration rates (0.15 and 0.1 m^3/m^2h) were maintained in two sand filters F_3 and F_4, respectively. Curves 1 (for F_4) and 2 (for F_3) of Fig. 3.1b illustrate the head loss development in both sand filters. It can be seen that head loss curves followed a similar path in both filters and, after 35 days of operation, reached levels of 1.10 to 1.20 m indicating the end of filter runs. After scraping 1 cm off the top of the sand layer, the two filters were allowed to operate again, this time at filtration rates of 0.2 m^3/m^2h for F_3 and again at the same filtration rate of 0.1 m^3/m^2h for F_4. Curves 3 and 4 in Fig. 3.1b show head loss development across the sand bed for F_4 and F_3, respectively, and it can be seen that head loss rate was slower at the filtration rate of 0.1 m^3/m^2h than at 0.2 m^3/m^2h, resulting in a relatively longer filter run. There was, however, a discrepancy between head loss curves for the same filtration rate of 0.1 m^3/m^2h, as shown in curves 1 and 3 of Fig. 3.1b. It was believed that this was due to the cleaning process of the sand surface. A carefully controlled scraping of the "biological layer" will result in a smooth slope of head loss curve and as a result, a longer filter run could be achieved. However, as a general observation, at flow rates of 0.1 and 0.2 m^3/m^2h head loss averaged 3 cm/day which gave a filter run of approximately 40 days of continuous filter operation, if linear extrapolation is applied for a total permissible head loss of 1.20 m. These results were in close agreement with the prediction from the exploratory phase.

In terms of treated water quality, the effluent turbidity from the sand filters was relatively good (2 to 8 JTU) at flow rates of 0.1-0.2 m^3/m^2h, as it can be seen from Fig. 3.2b. It is also worthwhile mentioning that the turbidity of the final treated water was of little importance in the conclusion of a filter run, as previously mentioned in the exploratory study, and the performance of filters was independent of filtration rate, at least within the range under study.

As already mentioned, emphasis was given to the microbiological aspects of the slow filters in this part of study. Figs. 3.3a and 3.3b report the results of MPN tests of raw water and effluents from the slow sand filters, respectively. It was observed that, in general, the bacteriological quality of the treated water improved when the biolayer was formed but, unfortunately, the maximum head loss build-up occurred at the same time, forcing the conclusion of the filtration run. To remedy this situation, it is suggested that during

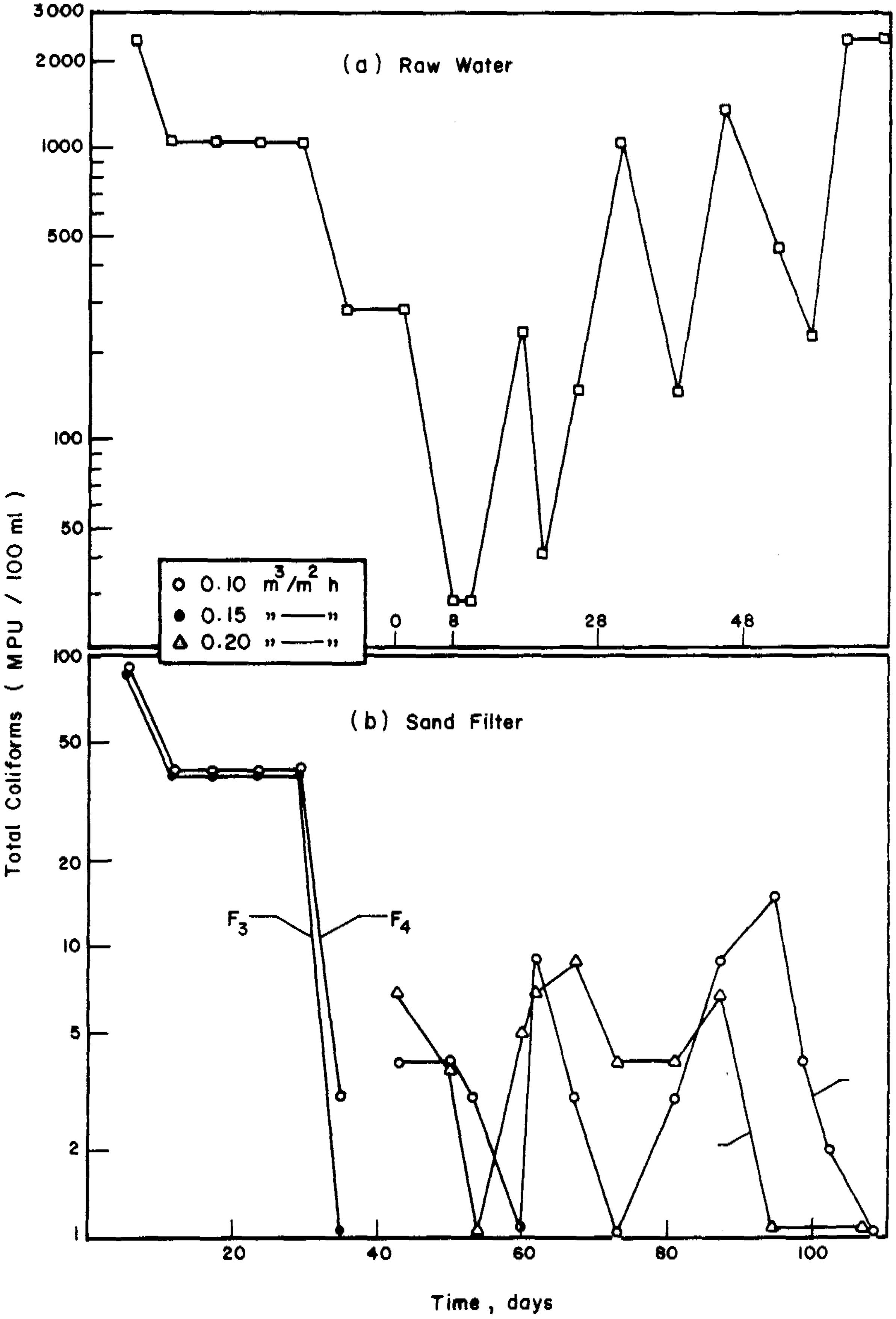


Fig. 3.3 Results of MPN Tests for Total Coliforms

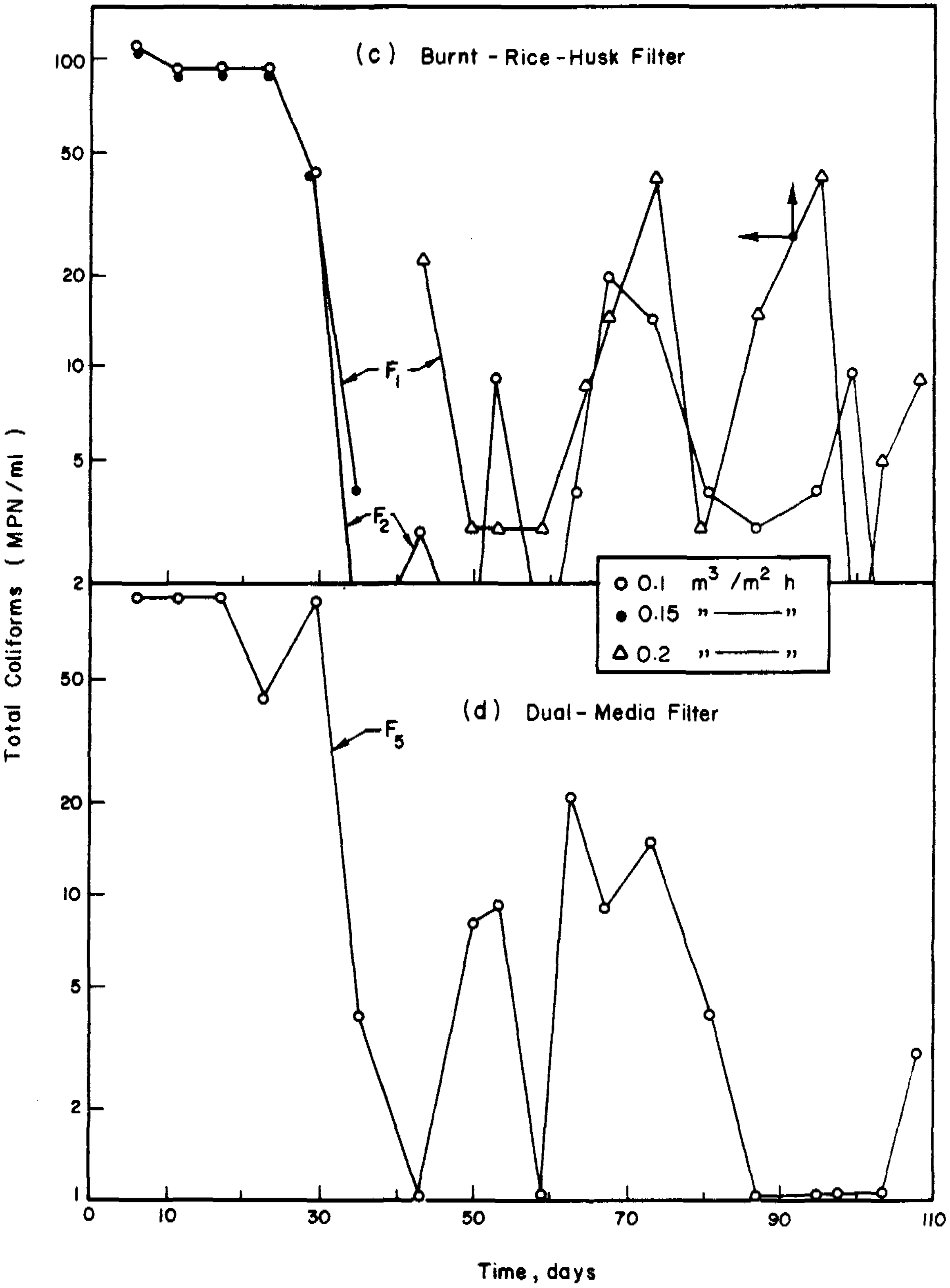


Fig. 3.3 (Cont'd) Results of MPN Tests for Total Coliforms

the ripening period, recycle of treated water may be an appropriate way of minimizing the rapid head loss development in the sand bed. As a result of this practice possible stabilization of the biological layer might bring about coliform removal in a more efficient way.

If the WHO International Drinking Water Standards[1/] were rigidly adopted as criteria for rural water supply, it is apparent that the final treated water would not meet the requirements, at least with regard to the coliform count. However, considering the present situation in many rural communities, where water from polluted surface sources is carried over long distances and used directly, any significant improvement in service and water quality could be expected to have a beneficial impact on health. This does not mean that reasonable efforts should not be made to supply a good quality safe water, but costly attempts to meet international standards are unnecessary and wasteful in Asian developing countries. Another important quality criterion to consider in village water supply is acceptability and the success or failure of a project depends on this. If an acceptable quality could be preserved with simple continuous treatment and source protection, the risk of transmission of water-borne disease will have been markedly reduced even if final disinfection is not incorporated to provide absolute safety. In other words, a much improved quality water which is convenient and acceptable to villagers is preferable to an absolutely safe water which villagers reject in favour of their traditional contaminated supply.

Analyses for faecal coliforms and <u>Streptococcus faecalis</u> have also been carried out on the treated water. From Figs. 3.4b and 3.5b it can be noted that these two kinds of microorganisms were absent or negligeable in the treated water. This is not only true for the slow sand filters under study but also for the burnt-rice-husk filters and the dual-media filters, as can be seen from Figs. 3.4 and 3.5. In conclusion, it is appropriate to say that the treated water is safe for drinking purposes as far as faecal coliforms and <u>S. faecalis</u> are concerned.

<u>Burnt-Rice-Husk Filter</u>

Rice constitutes the staple food in many Asian countries and burnt-rice-husk is generally available as a waste product after combustion of the raw husk at rice mills. The low density of the compacted burnt rice husk, coupled with small pore size and high permeability make the material suitable as a filter medium for village water supply.

As a part of this study, two burnt-rice-husk filters,

1/ WHO (1971) International Standards for Drinking Water, Third Edition, Geneva.

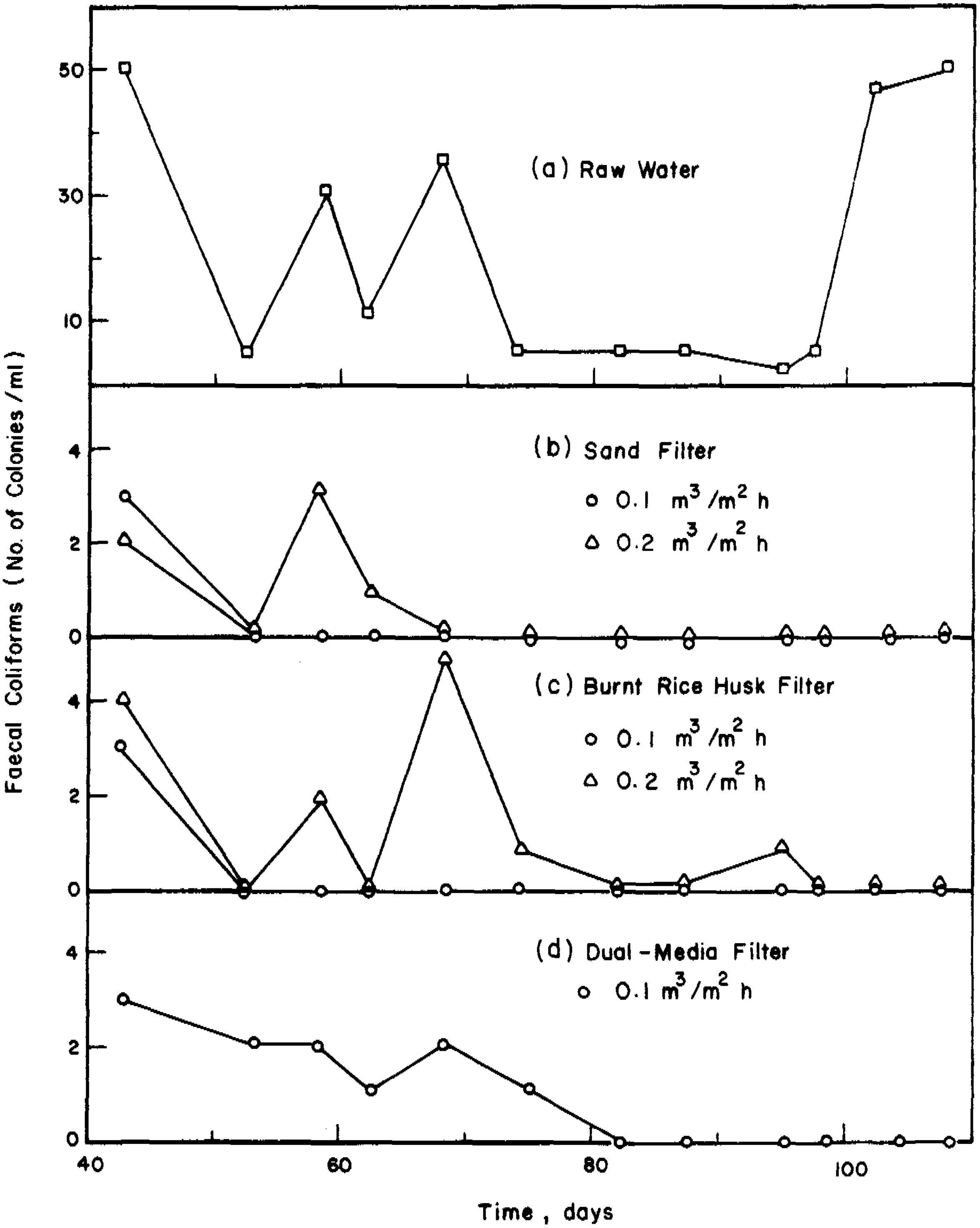


Fig. 3.4 Results of Faecal Coliform Plate Count Tests

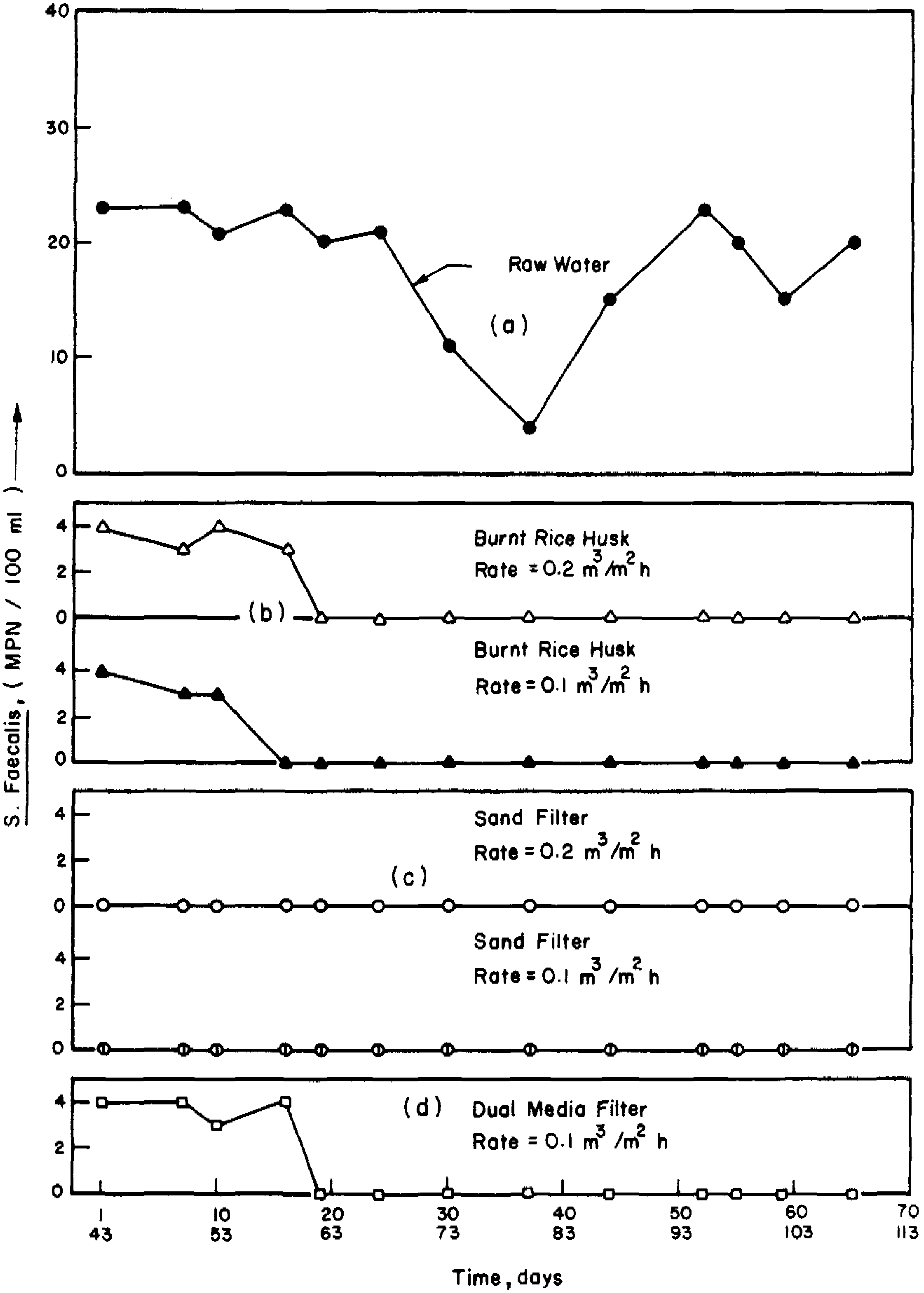


Fig. 3.5 Results of Streptococcus Faecalis MPN Tests

F_1 and F_2, were allowed to operate at filtration rates of 0.15 and 0.1 m^3/m^2h, respectively. These flow rates had also been applied for the sand filters, as previously described, for the purposes of performance comparison between sand and burnt-rice-husk filters. Fig. 3.1c records the head loss development in both burnt-rice-husk filters, and it can be seen that there was no difference in the rate of head loss build-up at filtration rates of 0.1 and 0.15 m^3/m^2h, which was very slow even after 35 days of continuous operation. The operation of filter F_1 was then discontinued and subsequently restarted at the filtration rate of 0.2 m^3/m^2h after scraping off about 2 cm of the top layer of burnt rice husk. However, filter F_2 continued to operate at the filtration of 0.1 m^3/m^2h, and developed a head loss of 97 cm after 108 days of continuous operation, averaging a head loss rate of 0.9 cm/day. This indicates that a run duration of 4½ months could be contemplated at a continuous filtration rate of 0.1 m^3/m^2h. Head loss development across the filter bed at a flow rate of 0.2 m^3/m^2h was faster with an average rate of 1.03 cm/day for continuous operation of about 4 months. Therefore, in this study the burnt-rice-husk filters performed better than sand filters in terms of head loss development at filtration rates between 0.1 and 0.2 m^3/m^2h.

In general, burnt-rice-husk filters produced water with an acceptable quality (2-10 JTU) for the rural population, at filtration rates of 0.1 to 0.2 m^3/m^2h, as can be seen from Fig. 3.2c. With regard to this aspect, burnt-rice-husk filters and sand filters are very competitive in their performance.

From the microbiological point of view what has been said for sand filters could be applied in the case of burnt-rice-husk filters. Fig. 3.3c reports the results of MPN tests representing the number of coliform microorganisms in the treated water from the burnt-rice-husk filter as filtration progressed. Considering the number of coliform microorganisms in the raw water and the situation where the rural population has been using unsafe waters for decades, it may be stated that the final treated water could be considered suitable for the purposes of village community needs, requiring a certain relaxation of WHO standards for drinking waters. Moreover, negligeable numbers of faecal coliforms and S. faecalis in the treated water and, as filtration progressed their absence in the treated water (indicated in Figs. 3.4c and 3.5c), provide a degree of security against epidemic outbreaks.

3.2.2 Performance of Dual-Media Filtration System

The dual-media filter consisting of 80 cm of coconut fibre overlying 60 cm of burnt rice husk was supplied with raw water at a filtration rate of 0.1 m^3/m^2h during the whole study of filter operation. Fig. 3.1d shows the head loss build-up in this filter as time progressed. It can be seen that the development of head loss across the filter bed occurred smoothly, with a very low build-up rate up to 70 days and then a gradual increase at an average rate of 0.7 cm/day. If linear extrapolation and a maximum head loss of 1.20 m are applied in this situation, a continuous filter run of 7 months duration could be expected. Hence, in this study it was found that the dual-media filter gave longer filtration runs than the series-filter for the same raw water. This may have been a result of the coconut fibres overlying the burnt rice husk bed not only serving as pre-treatment to remove the gross turbidity in the raw water, but also distributing the remaining smaller particules uniformly over the burnt-rice-husk layer for further polishing filtration. As a result of this action, particles of impurity could penetrate deeper into the polishing bed resulting in slower development of head loss throughout the system and a better quality treated water. Fig. 3.2d illustrates the quality of the treated water from the dual-media filter. Effluent turbidity, ranging from 2 to 6 JTU during the whole course of continuous operation (108 days), could be considered to be suitable for rural consumption.

The dual-media filter did not completely remove total coliforms, as can be seen from Fig. 3.3d. However, the same observation also applies to the sand filter and the burnt-rice-husk filter. In addition, as filtration progressed, faecal coliform and S. faecalis concentrations were negligible or nil in most cases as shown in Fig. 3.4d and 3.5d, suggesting that the treated water could be served to rural communities.

An unacceptable odour was noted in the effluent from the dual-media filter after 3 months of continuous operation. Concomitant tests on dissolved oxygen in the effluent (shown in Table 3.1) revealed the absence of this parameter in spite of the excellent clarity of the water. The development of anaerobic conditions can be explained as having been due to the extended detention time of the water in the filtration unit, which was 29 hours at a filtration rate of 0.1 m^3/m^2h for a total water depth of 2.9 m. It is believed that organic matter in the raw water was deposited in the filter bed and incurred depletion of dissolved oxygen in the water during its degradation process. In practice it would be necessary to conclude a filtration run as soon as odour occurred and proceed to filter cleaning. Also shown in Table 3.1 are the results of the dissolved oxygen content in filtered waters from the series-filtration units (sand and burnt rice husk). Short residence time of water in the roughing filter (coconut fibre), helped by aeration between the roughing filter and the polishing filter, prevented the occurrence of anaerobic conditions in the final treated water.

3.2.3 Conclusions from Stage A Study

The long-term filtration study at a raw water turbidity level of about 50 JTU was intended to assess the performance of series-filtration and dual-filtration systems in the range of flow rates from 0.1 to 0.2 m^3/m^2h. The main conclusions of this study are:

(i) The coconut fibres, through their physical configuration, were revealed to be a potential filtering medium to remove

Table 3.1 - Dissolved Oxygen Content in Raw and Filtered Water (Stage A: Raw Water Turbidity Level 50 JTU)

Run Duration, Days	Date	Influent Water, I	R_1 & R_2 @ 1.5 m^3/m^2 h	F_1 @ 0.15 m^3/m^2 h	F_2 @ 0.1 m^3/m^2 h	F_3 @ 0.15 m^3/m^2 h	F_4 @ 0.1 m^3/m^2 h	F_5 @ 0.1 m^3/m^2 h
6	20/11/75	7.4	6.2	5.2	5.4	5.4	5.6	5.5
11	25/11/75	7.8	6.8	5.4	5.4	5.3	5.3	5.6
17	1/12/75	7.6	6.2	5.4	5.5	4.8	5.1	5.2
23	7/12/75	8.2	6.2	5.4	5.5	4.8	4.9	5.6
29	13/12/75	7.8	6.3	6.0	6.0	5.8	5.8	5.7
35	19/12/75	6.5	5.5	5.5	5.5	5.0	6.0	5.5
39	23/12/75	-	-	Cut off and restarted @ 0.2 m^3/m^2 h	-	End and restarted @ 0.2 m^3/m^2 h	-	-
43, 1*	27/12/75	7.0	5.5	6.0	6.0	5.0	5.5	5.5
50, 8	3/ 1/76	7.0	6.0	5.4	5.5	4.9	5.6	5.8
53,11	6/ 1/76	6.5	6.1	5.5	5.7	5.2	5.1	3.5
98,56	20/ 2/76	5.2	3.8	3.3	3.4	End	3.4	0
101	23/ 2/76	4.0	4.0	2.0	3.0	End	3.5	0
103	25/ 2/76	4.5	3.5	3.0	3.1	End	3.6	0
105	27/ 2/76	4.1	3.0	2.9	3.9	End	3.2	0
108	1/ 3/76	4.3	2.4	3.7	4.0	End	3.3	0

Legend:

R_1 & R_2	:	Coconut fibre roughing filters
F_1 & F_2	:	Burnt rice husk filters (series-filters)
F_3 & F_4	:	Sand filters (series-filters)
F_5	:	Dual media filters (coconut fibre + burnt rice husk)

* Run starting for F_1, F_2, F_3 and F_4

sufficient turbidity from raw waters and produce an effluent acceptable for subsequent treatment by sand and burnt-rice-husk filters. At a filtration rate of 1.5 m^3/m^2h, the head loss build-up rate was approximately 1 cm/day, suggesting a continuous filtration duration of 4 months for a permissible head loss of 1.2 m.

(ii) At filtration rates of 0.1 and 0.2 m^3/m^2h, a polishing sand filter in series following the coconut fibre filter developed a head loss rate of 3 cm/day indicating a continuous filtration duration of about 40 days. During continuous operation, the final effluent turbidity was relatively good, ranging from 2 to 8 JTU, which is considered acceptable for village needs. A polishing burnt-rice-husk filter in series with the coconut fibre filter showed a net superiority over the sand filter in terms of filtration duration. At the same above-mentioned flow rates, a continuous filter run of about 4 months could be contemplated, with the burnt-rice-husk filter producing the same good clarity of water.

(iii) The dual-media filter (coconut fibres and burnt rice-husk in the same box) exhibited better performance than the series-filtration system as far as turbidity removal and filtration duration are concerned. At a filtration rate of 0.1 m^3/m^2h, the dual-media filter could achieve 7 months of continuous operation, producing throughout a clear water. However, it was noted that after 3 months of continuous filtration, anaerobic conditions prevailed in the filter unit and a bad odour developed in the filtered water, jeopardizing the acceptability of this filtration mechanism. To overcome this problem in practice the filter run would have to be curtailed after about 3 months of continuous operation and the dual-media filter cleaned. If this is done, it is appropriate to say that the coconut fibre-burnt rice husk series-filter and the dual-media filter are competitive in their performance and both systems are capable of producing clear water for a period of about 3 months of continuous operation.

(iv) From the microbiological standpoint, neither series-filters nor dual-media filters could completely remove coliform bacteria from the raw water. This deficiency would tend to limit the application of these simple systems in the provision of treated water to rural populations if the bacteriological international drinking water standards are strictly applied. However, it is suggested that a much improved quality water which is convenient and acceptable to villagers is preferable to an absolutely safe water which villagers reject in favour of their traditional contaminated supply. In many rural situations, acceptability is a more important criterion than bacterial quality, as indicated by the coliform standard, and the W.H.O. international drinking water standards should be applied with discretion. The series filters and dual media filters significantly improved the bacterial quality of the raw water, as the efficient removal of faecal coliforms and S. faecalis proved, and would provide a high degree of health protection to rural people now exposed to unprotected water supplies.

3.3 Stage B: Long-Term Filtration Study at a Raw Water Turbidity Level of 100 JTU

As already mentioned in the Experimental Investigation Section, this stage of study included two series-filters (F_2 and F_3) and three dual-media filters (F_1, F_4 and F_5), all operated at a filtration rate of 0.2 m^3/m^2h. In the series-filter system, the coconut-fibre roughing filter R_1 was coupled with the burnt-rice-husk F_2, and the coconut-fibre roughing filter R_2 with the sand filter F_3. In the dual-media filter system, the filter F_1 was packed with burnt rice husk overlying sand; F_4 was filled with coconut fibre spread on sand; and F_5 was packed with coconut fibre shredded over burnt rice husk. This experimental design was intended to provide an overall picture of the performance of different types of filters in supplying village water supply needs.

This part of study was carried out between March and June 1976 (the hot season in Thailand), when raw water turbidity was at a level of 30 JTU. For the purposes of this study, artificial stirring of the muddy canal bottom was applied, using the device already described, to maintain the turbidity of the raw water at a level of about 100 JTU. All the parameters included in the Stage A study were also examined in this study. The results obtained are here presented in the form of graphs and detailed data are tabulated in Tables C1 to C3 in Appendix C.

3.3.1 Performance of Series-Filter System

In this part of the study, both roughing filters were operated at 0.5 m^3/m^2h. In spite of wide fluctuations in raw water turbidity, as shown in Fig. 3.7a, the behaviour of the coconut fibre filters was remarkably consistent, exhibiting considerable potential to absorb turbidity "shock loading" and produce an effluent relatively constant and satisfactory for subsequent slow-filtration treatment by sand and burnt-rice-husk. Fig. 3.7a also shows that the average turbidity in the effluent of the roughing filters ranged from 10-30 JTU, for a raw water turbidity range of 40-140 JTU, denoting an overall turbidity removal of 75 percent. At this filtration rate and during 40 days of continuous filtration run, the turbidity of the water produced by the roughing filters was relatively independent of raw water turbidity. This was also observed in the Stage A study at the lower raw water turbidity level. It was believed that the performance of roughing filters would become raw water turbidity dependent as continuous operation progressed.

Fig. 3.6a records the head loss build-up across the roughing filter beds. It can be seen that the head loss after 40 days of continuous operation was only 20 cm, at a rate of about 0.5 cm/day. If linear extrapolation is applied for a maximum head loss of 1.20 m a continuous filtration run of 8 months duration at a filtration rate of 0.5 m^3/m^2h could be contemplated. This compared with a duration of 4 months in the case of the study at a lower level of raw water turbidity but at higher filtration rate.

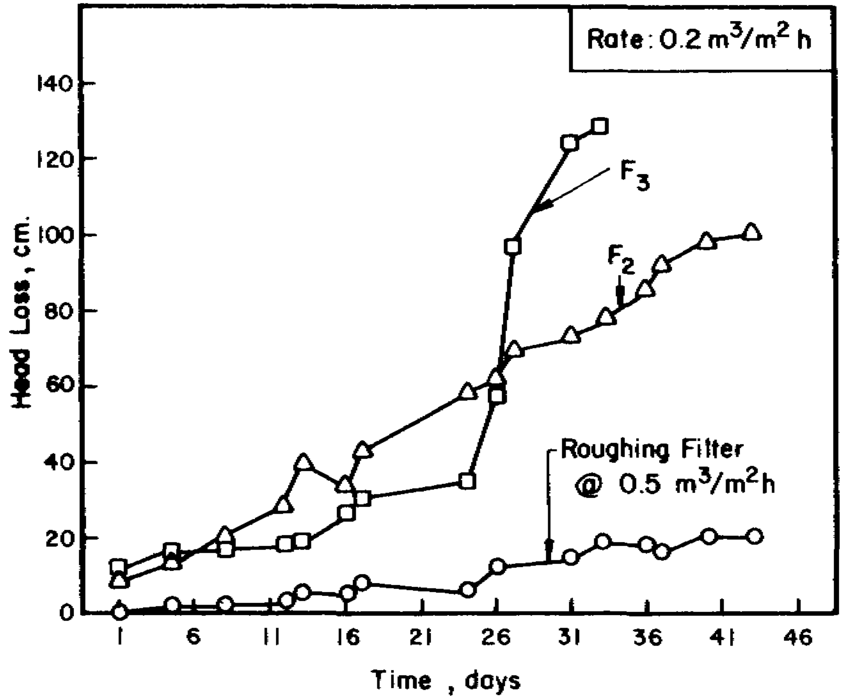


Fig. 3.6 a Head Loss in Series-Filter Systems

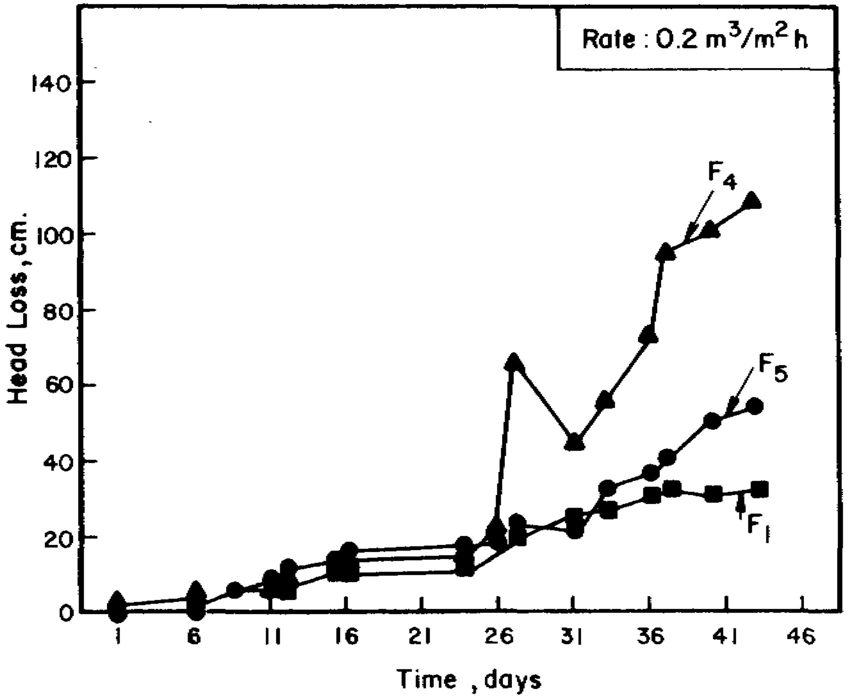


Fig. 3.6 b Head Loss in Dual - Media Filters

Legend

○ Roughing Filter

△ Burnt Rice Husk Filter (F_2)

□ Sand Filter (F_3)

● Coconut Fiber + Burnt Rice Husk (F_5)

▲ Coconut Fiber + Sand (F_4)

■ Burnt Rice Husk + Sand (F_1)

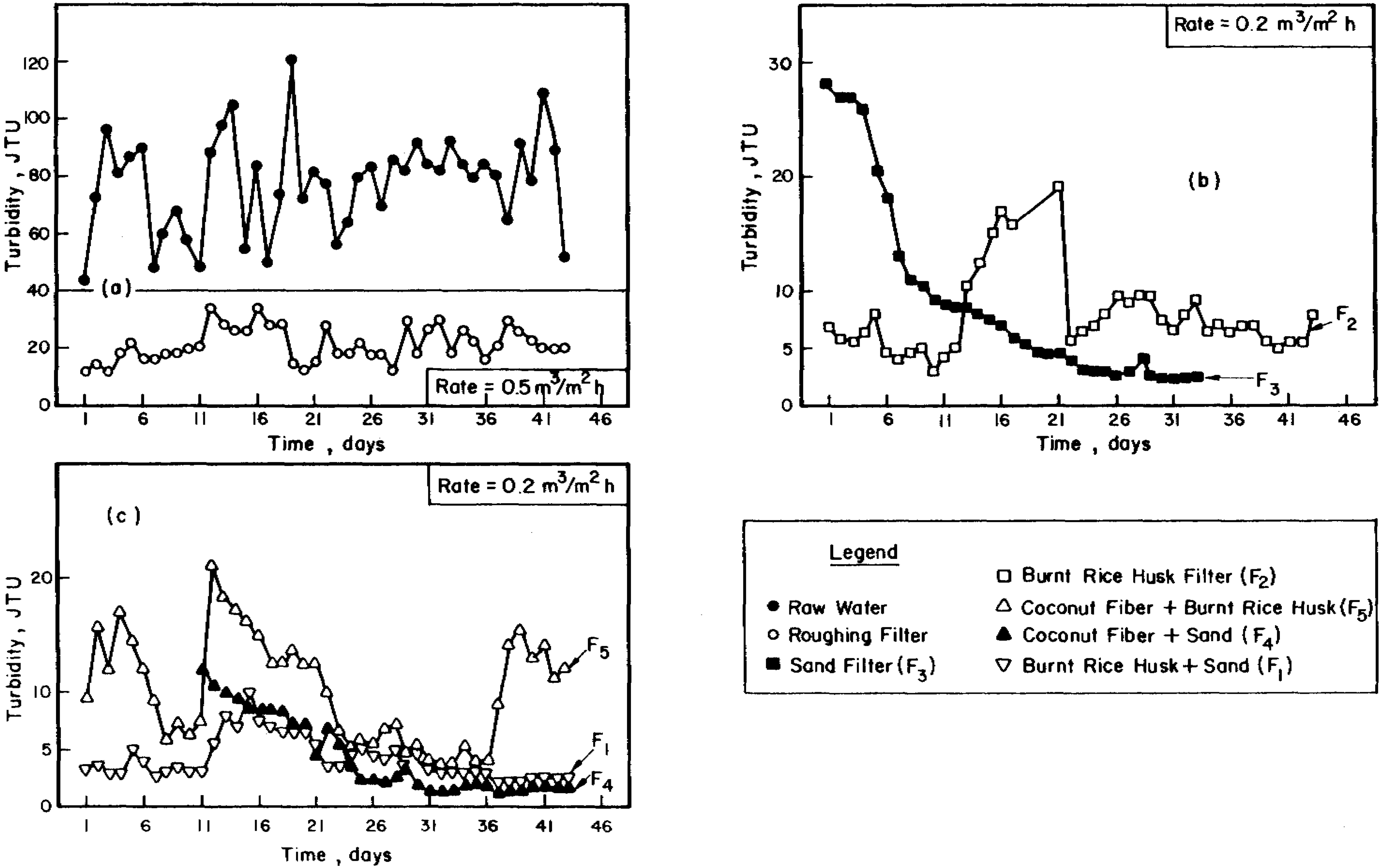


Fig. 3.7 Turbidity of Raw Water and Effluents of Different Filters.

Also shown in Fig. 3.6a is the head loss build-up in the sand and burnt rice filters of the series-filtration system. Sand filters developed a gradual head loss at the rate of 1.12 cm/day which was disrupted after 24 days of operation. The run was terminated after one month of filter operation. Turbidity removal varied inversely with head loss build-up and, after about 10 days of filtration, pure water was obtained. It is evident that if the problem of rapid head loss build-up in the sand bed could be overcome, the sand filter would constitute an excellent treatment technique for tropical surface waters. Combining the results of the stage A study with those obtained in this part of study, it could be concluded that the sand filter in the series-filtration system is not suitable for the purposes of village community water supply because of the need for frequent cleaning and the inconvenience of short filter runs when raw water turbidity is relatively high.

For the same level of raw water turbidity and at a filtration rate of 0.2 m^3/m^2h, the burnt-rice-husk filter in the series-filtration system developed head loss at a lower rate than the sand filter. The head loss rate was approximately 2.3 cm/day, indicating a continuous filtration duration of 50 days, which is half of what was achieved in the stage A study (at raw water turbidity level 50 JTU). In Fig. 3.7b, it can be seen that the water produced from the burnt-rice-husk filter was, in general, of acceptable quality for village needs in terms of turbidity, except in some circumstances of excessive turbidity in the raw water during rainy days when runoff from the surrounding area carried silt and soil into the canal.

The results of MPN tests, shown in Fig. 3.8, indicated that neither a sand nor a burnt-rice-husk filter in a series-filtration system could completely remove coliform bacteria. Removal of faecal coliforms and S. faecalis was better in the sand than in the burnt-rice-husk filter and, towards the end of the ripening period, the treated water could be considered safer for village community needs. However, both filters produced a treated water much safer than the raw water.

3.3.2 Performance of Dual-Media Filtration System

It has already been mentioned in the stage A study discussion that the dual-media filter F_5, consisting of coconut fibres over burnt-rice-husk in the same filter box, was an excellent water treatment system. The performance of this same filter was again assessed, but at a higher level of raw water turbidity and a higher flow rate. Variations in the combination of different media to form dual-media filters (e.g. burnt-rice-husk - sand for F_1, coconut fibre - sand for F_4) were also examined in this part of the study in an attempt to look into a wider range of alternatives for treatment of tropical surface waters to cope with the needs of village community water supply.

In terms of head loss development in filter beds, the three dual-media filters followed a similar path of low head loss build-up at

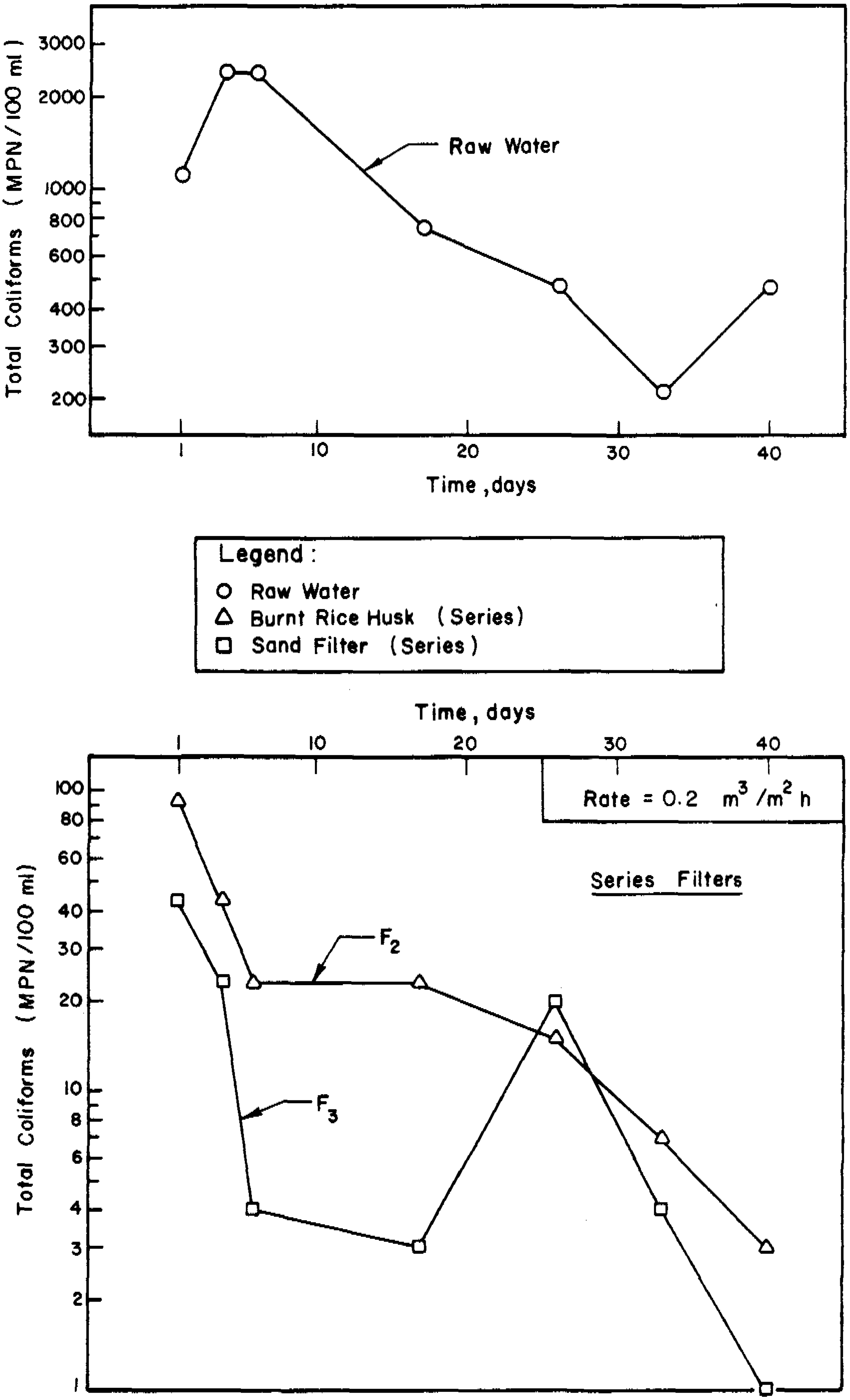


Fig.3.8 Results of MPN Tests for Total Coliforms

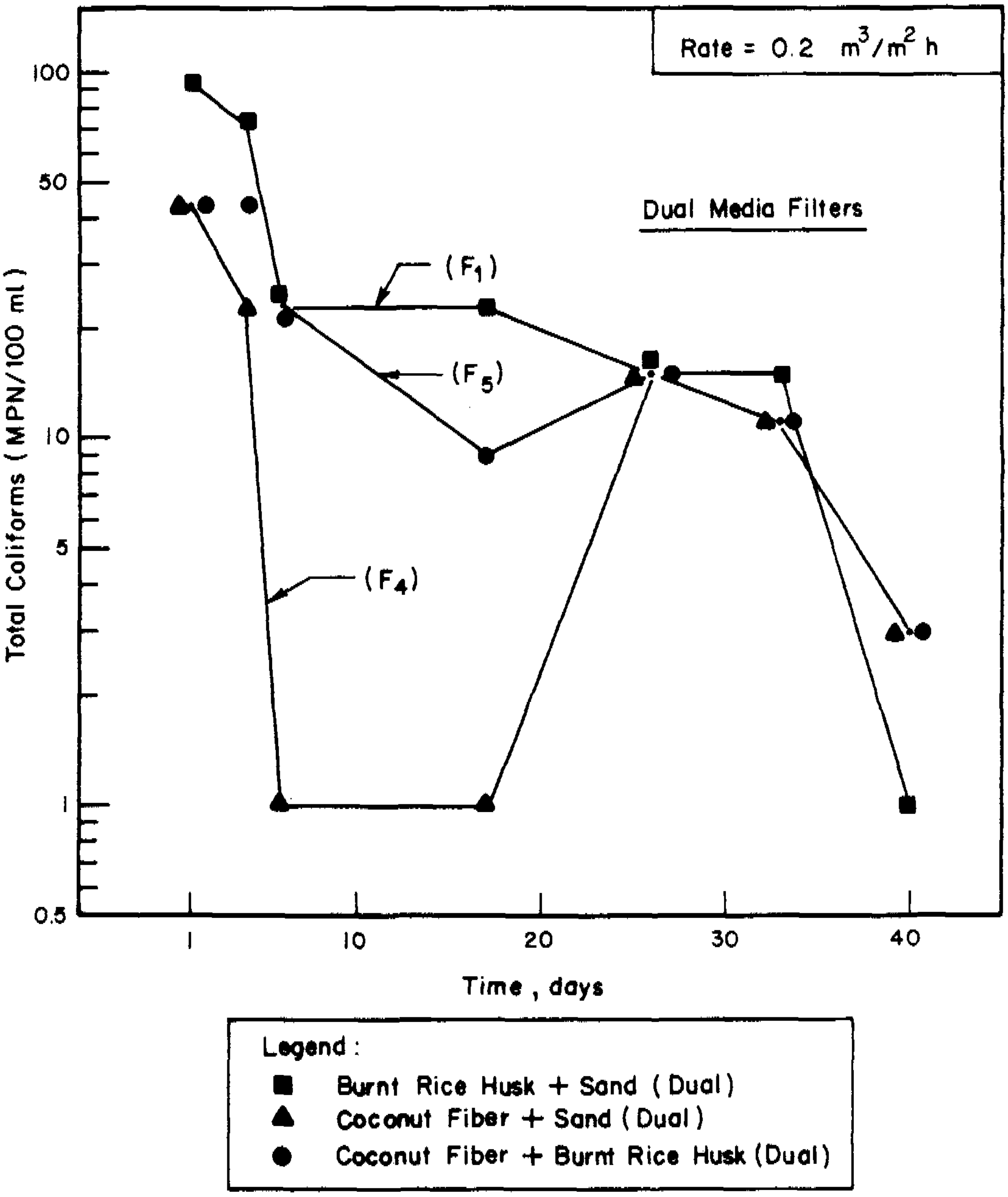


Fig. 3.8 (Cont'd) Results of MPN Test for Total Coliform

the beginning of operation, as can be seen in Fig. 3.6b. After 26 days of continuous operation, the filter F_4 (coconut fibre - sand) showed a breakthrough in head loss forcing the shutdown of the unit after about 45 days of filtration duty. On the other hand, the water produced from this type of filter was of very good clarity and constant quality. At this stage, it is appropriate to bring up a general comment on the performance of the sand filter coupled with coconut fibre in a series-filter system or dual-filter system. In both cases, this filter arrangement is not attractive for village community water supply as far as head loss build-up is concerned. The filter has a rapid rate of head loss resulting in short filter runs, which are not convenient for village needs because of the need for frequent filter cleaning. However, this type of filter can produce a good quality and relatively safe water.

If the combination of coconut fibre and sand is not practically attractive, the dual-media filter F_1 made up of burnt-rice-husk overlying sand seems to be a reliable alternative for tropical surface water treatment. This filter developed a slow rate of head loss, as recorded in Fig. 3.6b. After 40 days of continuous operation the head loss only reached 40 cm (about 1 cm/day). If linear extrapolation is applied for a permissible head loss of 1.2 m, a continuous filtration run of 4 months could be contemplated. Added to this, the quality of the treated water in terms of turbidity was excellent, as can be seen in Fig. 3.7c. Removal of coliform organisms, faecal coliforms and S. faecalis was gradual, as shown in Figs. 3.8, 3.9 and 3.10 respectively, reaching the limits of safety at the end of a ripening period.

The dual-media filter F_5 (coconut fibre and burnt-rice-husk) exhibited a head loss rate of 1.8 cm/day after 26 days of continuous operation. The total run duration could be estimated to be approximately 2½ months if a total head loss of 1.2 m was permitted. Recorded turbidity in the treated water, as shown in Fig. 3.7c, was not stable as in the cases of filters F_1 and F_4 but still fluctuated within the limits of acceptability for village needs. It can be seen in Fig. 3.8 that removal of coliform organisms could not be completely achieved, as already observed in previous cases. However, the reduction of faecal coliforms and S. faecalis was quite substantial, as shown in Figs. 3.9 and 3.10, as filtration time advanced and this suggests that a reasonable degree of health protection for village communities could be provided by these systems.

The objection to this type of filter (coconut fibre and burnt-rice-husk in the same filter box) was the development of a disagreeable odour in the treated water after a long period of operation, as can be seen in Table 3.2. This situation has already been mentioned for the same kind of filter when the study at raw water turbidity level 50 JTU was carried out but the phenomenon did not occur for any other filter type.

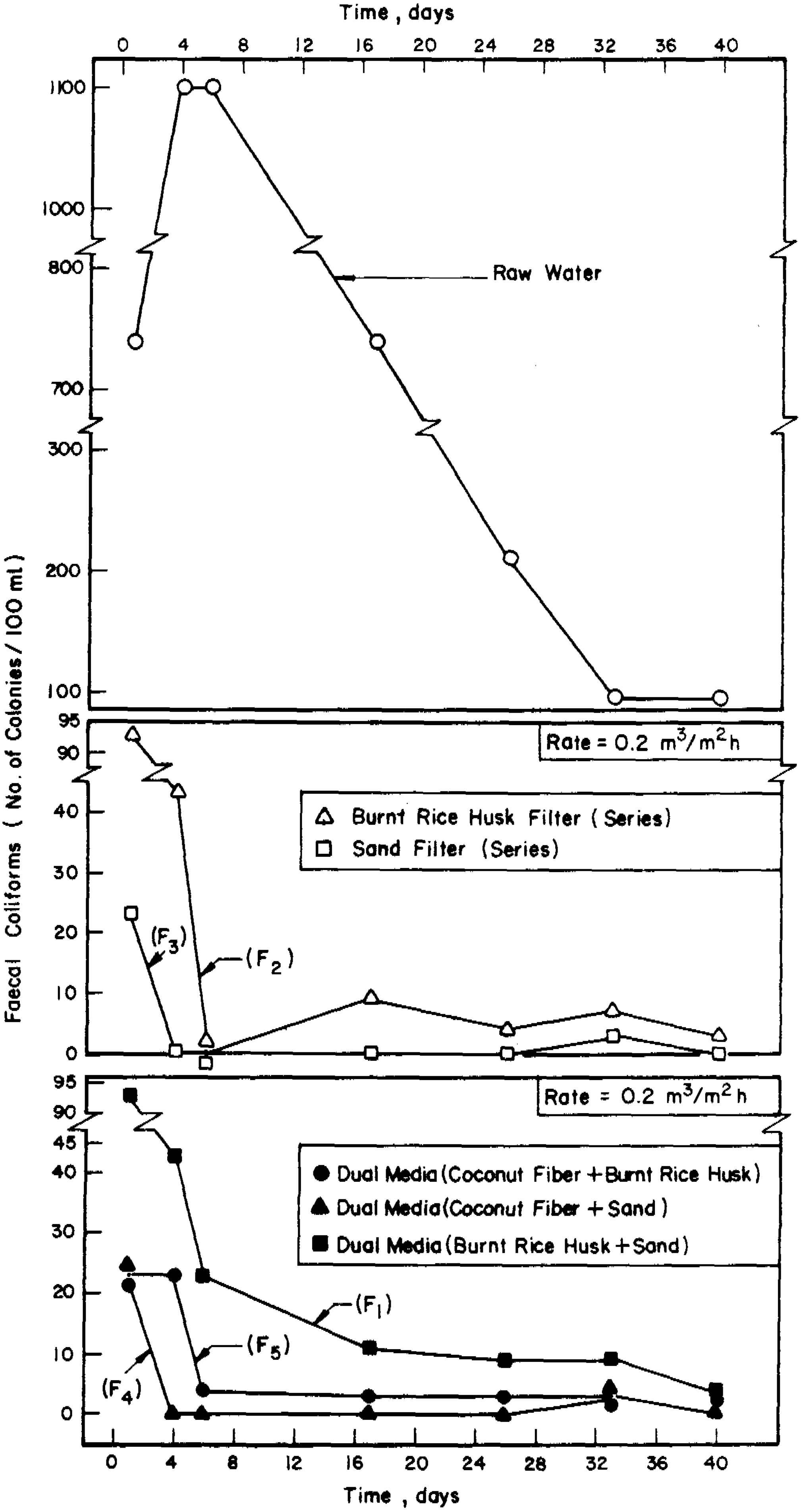


Fig. 3.9 Results of Faecal Coliform MPN Tests

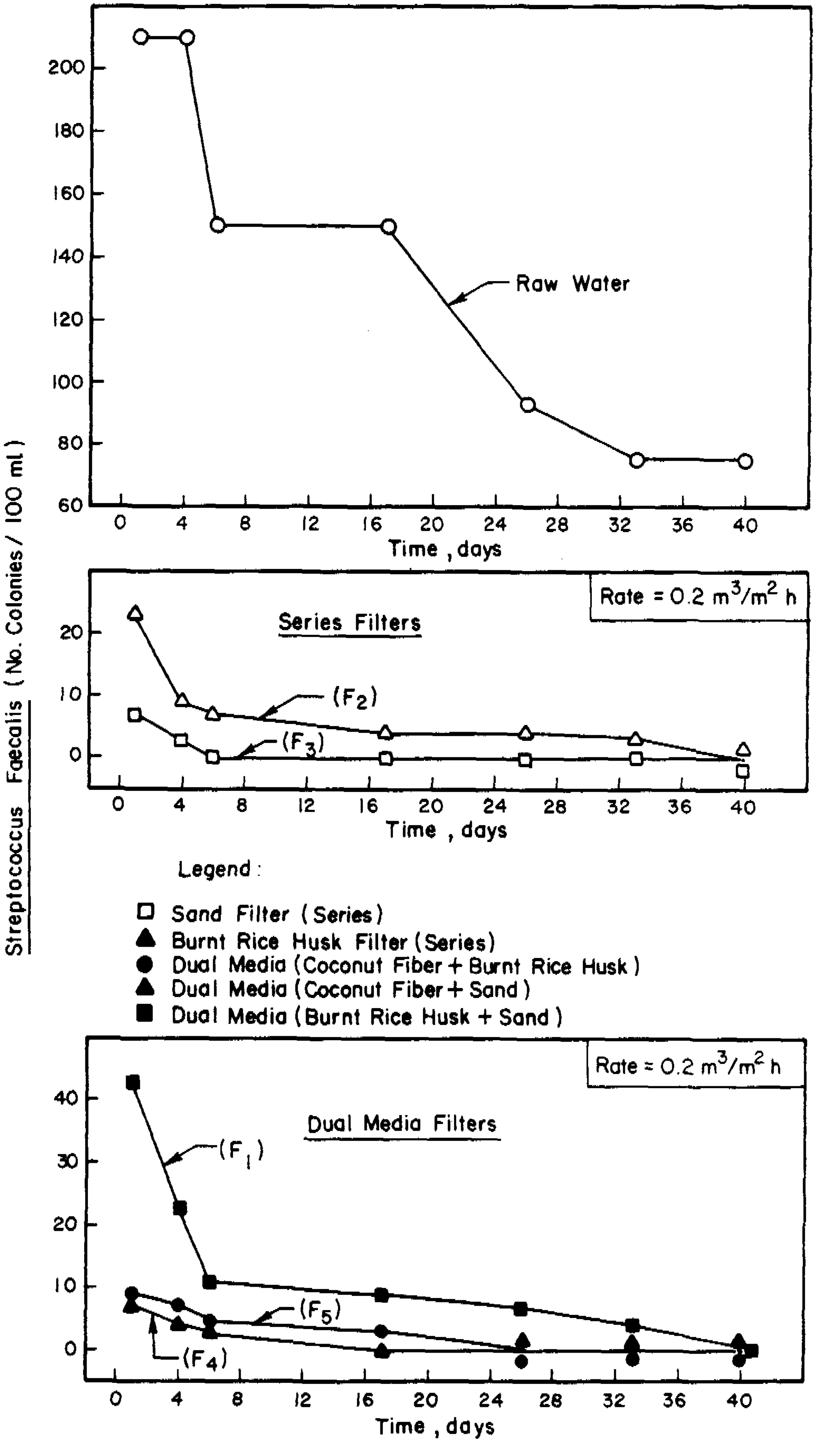


Fig. 3.10 Results of Streptococcus Faecalis MPN Tests

Table 3.2 - Dissolved Oxygen Content in Raw and Filtered Water
(Stage B: Raw Water Turbidity Level 100 JTU)

Run Duration, Days	Date	Influent Water, I	R_1 & R_2 @ 0.5 m^3/m^2 h	F_1 @ 0.2 m^3/m^2 h	F_2 @ 0.2 m^3/m^2 h	F_3 @ 0.2 m^3/m^2 h	F_4 @ 0.2 m^3/m^2 h	F_5 @ 0.2 m^3/m^2 h
1	26/4/76	6.7	3.9	4.1	4.0	-	3.4	2.1
4	29/4/76	5.3	4.0	4.7	4.1	4.6	3.1	2.7
5	30/4/76	6.8	4.6	4.3	4.8	3.5	-	3.0
12	7/5/76	5.2	4.6	4.1	4.5	-	-	2.9
24	19/5/76	5.8	4.5,2.4	4.8	4.0	3.1	3.7	3.2
26	21/5/76	4.6	4.3,3.7	4.5	4.3	4.9	3.7	3.0
31	26/5/76	6.4	4.5,3.6	4.9	4.7	3.8	3.4	2.5
33	28/5/76	6.1	4.2	4.5	4.5	-	3.5	0.6
38	2/6/76	5.2	5.1,2.4	4.6	4.4	3.6	3.3	0
40	4/6/76	5.4	4,2.5	3.6	4.5	3.6	3.3	0

Legend: R_1 & R_2 : Coconut fibre roughing filters
F_1 : Dual media filters (burnt rice husk + sand)
F_2 : Burnt rice husk filters (series, polishing)
F_3 : Sand filters (series, polishing)
F_4 : Dual media filters (coconut fibre + sand)
F_5 : Dual media filters (coconut fibre + burnt rice husk)

3.3.3 Conclusions from Stage B Study

In this stage of study, attempts have been focused on the assessment of performance of series-filtration and dual-filtration systems in response to raw water turbidity level 100 JTU and flow rate 0.2 m^3/m^2h. The important points which come out from this part of the study can be summarized as follows:

(i) Coconut fibres proved to be a reliable medium in prefilters for removal of gross impurities from highly turbid surface waters. At a filtration rate of 0.5 m^3/m^2h, head loss through the filter bed was slow to build-up and a long filtration run was achieved. Another characteristic of coconut fibres as a pre-filter is their capacity to tolerate turbidity fluctuations in the raw water and still produce an adequate effluent for subsequent polishing filtration by sand or burnt rice husk. These results added to those reported previously in the stage A study confirmed the remarkable quality of coconut fibres for the pre-treatment of highly turbid surface waters in the tropics.

(ii) In terms of length of filter run, burnt-rice-husk demonstrated a net superiority over sand as a polishing filter. The burnt-rice-husk filter could be kept in continuous operation for about two months at a filtration rate of 0.2 m^3/m^2h and raw turbidity level of 100 JTU, while sand filter operation had to be disrupted after 30 days, the head loss development being at its maximum. Nevertheless, although the sand filter had a shorter filtration run than the burnt-rice-husk filter, the quality of its treated was more consistent and superior. The same applied in the stage A study at a raw water turbidity level of 50 JTU.

(iii) The dual-media filter consisting of coconut fibre and sand produced a very good quality water but this arrangement is not suitable for village water supply because of short filter runs requiring frequent filter cleaning. A combination of coconut fibre and sand, either in the series-filtration system or the dual-media filtration system, is not practically suitable for the treatment of highly turbid tropical surface waters, at least under the present experimental conditions.

(iv) The dual-media filter consisting of burnt-rice-husk and sand produced a good quality water and simultaneously developed a slow rate of head loss, so that a long filter run could be achieved before cleaning would be necessary. A duration of approximately four months can be expected.

(v) In this part of the study at the higher turbidity raw water level (100 JTU), the dual-media filter consisting of coconut fibre and burnt-rice-husk demonstrated its potential for treatment of tropical surface waters for village community water supply. At a flow rate of 0.2 m^3/m^2h, this filter developed a relatively low rate of head loss and could be kept in continuous operation for a period of about 2½ months, producing acceptable water quality for village consumption. However, the disadvantage of this dual-media filter arrangement resides in the production of an unpleasant odour resulting from the prevailing anaerobic conditions forcing premature shutdown of the unit.

(vi) With regard to the microbiological aspects of water quality, all the treated waters still contained relatively high numbers of total coliform organisms, rendering them unsuitable for village domestic consumption if bacteriological international drinking water standards are rigidly applied. However, the removals of faecal coliforms and S. faecalis were quite substantial.

IV APPRAISAL OF DIFFERENT FILTER SYSTEMS

4.1 Treatment Alternatives for Tropical Surface Waters

From the results of this investigation, it is considered important to bring the efficient treatment alternatives for tropical surface waters into relief and to make a trade-off among these alternatives. Considering the range of turbidity in the raw water under study (which also reflects the quality of many tropical surface waters), four alternative systems could be favourably considered, as shown in the diagram of Fig. 4.1.

Alternative A is a series-filter system composed of coconut fibre as a roughing filter and burnt rice husk as a polishing filter. It has already been demonstrated that coconut fibre, through its fibrous configuration, exhibited remarkable potential in retaining impurities in water and also absorbing turbidity "shock loading" to produce a relatively consistent effluent satisfactory for subsequent polishing treatment. At a raw water turbidity level of about 100 JTU and filtration rate of 0.5 m^3/m^2h, the average turbidity in the effluent of the coconut fibre filter was about 25 JTU, showing an overall turbidity removal of 75 percent. At this filtration rate, head loss development through the filter bed was slow and, as a result, a continuous filtration run of about 8 months could be contemplated, if linear extrapolation for a maximum head loss of 1.2 m is applied. The burnt-rice-husk filter in this system plays the role of a polishing filter, and removes the residual turbidity in the effluent from the roughing coconut fibre filter to produce a final water acceptable for village consumption. The length of operation of the burnt-rice-husk filter depends upon flow rates and, to some extent, the turbidity of raw water. On the basis of the results obtained, there is reason to believe that, at a raw water turbidity level of about 100 JTU and filtration rate of 0.2 m^3/m^2h, a continuous filter run of 2-3 months could be expected. It is logical to anticipate that a longer duration, perhaps about four months, could be achieved at a lower level of raw water turbidity.

Alternative B is a dual-media filter consisting of coconut fibres compactly spread on a bed of burnt rice husk. Recorded results on performance of this type of filter indicated that the length of filter run depended upon raw water turbidity and filtration rate. At a turbidity level of about 50 JTU in the raw water and filtration rate of 0.1 m^3/m^2h, a continuous filter run of seven months could be extrapolated. At a higher level of turbidity, of about 100 JTU, and filtration rate of 0.2 m^3/m^2h, only a 2½ months run duration was obtained. It has been observed that, in spite of the acceptable quality of treated water in terms of turbidity and the relatively long filter run, a disagreeable odour was detected after a long period of filter operation. It is suggested, therefore, to adopt a filtration rate to hinder the occurrence of this odour, which can be detected organoleptically or by

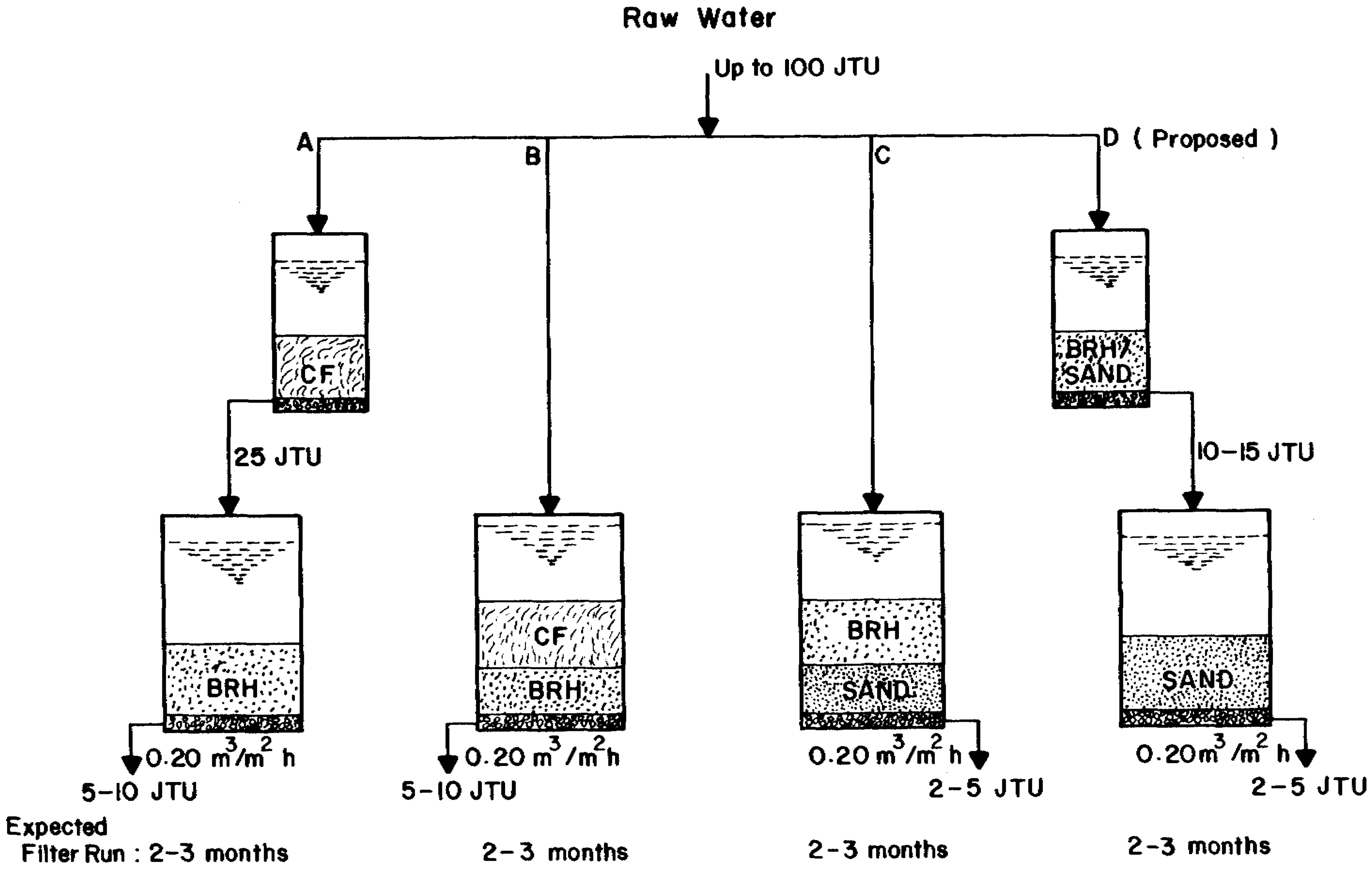


Fig. 4.1 Treatment Alternatives for Tropical Surface Waters

dissolved oxygen determination. Based on the results of this study, it is pertinent to adopt a filtration rate of 0.2 m^3/m^2h for a raw water turbidity level of about 100 JTU, and a continuous filter run of 2 to 3 months could be expected. In practice, operation would be disrupted at the first sign of odour in the system.

Alternative C is also a dual-media filter consisting of a burnt-rice-husk bed overlying a sand bed. This combination of filter media proved to be a reliable water treatment system for village community water supply. Head loss rate was relatively slow giving a fairly long filtration period. The treated water was of excellent clarity and no odour was detected during the period of 43 days of continuous operation. However, this type of filter is inconvenient in operation due to the cleaning process involving removal of the whole burnt-rice-husk bed before the top layer of the sand bed can be removed. This mode of cleaning is troublesome and time-consuming. On the other hand, it is counterbalanced by the lower height to reach by comparison with the series-filter system, which may make the cleaning operation easier. On the basis of the findings of this study, a series-filter system using the media of alternative C could also be designed. The roughing filter could consist of either burnt-rice-husk or coarse sand, and the polishing filter would be fine sand, represented as alternative D in Fig. 4.1. However, a higher construction cost will be incurred if this treatment alternative is adopted. It is proposed that further investigations are necessary before a valid conclusion can be reached on this last alternative.

There is a need to apply the WHO International Drinking Water Standards with discretion as far as rural water supply is concerned. Considering the present situation in many rural communities where water from polluted surface sources is used without treatment, any improvement in facilities and water quality would have a beneficial impact on health. This policy does not necessarily mean that reasonable efforts should not be made to supply a good quality safe water, but costly attempts to meet international standards are inappropriate and wasteful. Acceptability is another important criterion to consider in village water supply. If an acceptable quality could be preserved with simple continuous treatment and source protection, the risk of transmission of water-borne disease will have been markedly reduced even if final disinfection is not incorporated to provide absolute safety.

4.2 Trade-Off Between Different Filter Systems

In order to make a judicious choice of filtration system to be adopted in a given circumstance, it is appropriate to delineate the trade-off among different filter systems and, more specifically, between series-filtration and dual-media filtration systems. From the operational point of view, the series-filtration system and the dual-media system have their own advantages and disadvantages. More power is needed to lift raw water to a higher head in the case of the series filter but the cleaning process can be carried out separately in the roughing filter and polishing filter without disturbing the whole system. It is advisable to apply an uniform distribution of the effluent from the roughing filter over the surface of the polishing filter, otherwise shorter filter runs would result. In the dual-media filter, the coconut fibre, or any other material playing the same role, has to be removed from the filter box before the burnt rice husk or sand can be cleaned, which is time-consuming and requires labour. However, the advantage of the dual-media filter is that less power is used in pumping raw water to the filter.

Both series-filter and dual-media filter systems are likely to have applications depending upon local conditions in villages and economic considerations. A detailed cost estimation of different filter systems is presented in Appendix D and Table 4.1 summarizes total initial cost and monthly running costs of these systems. It should be noted that cost estimates do not include the construction cost of a storage tank. These estimates show that the initial costs incurred in the construction of the series-filter system is 25 percent higher than in the case of the dual-media filter system. This is because of the extra construction cost of the roughing filter box and the capital cost of a pump with higher power rating. However, the monthly operating costs are not significantly different between the two systems or between one treatment alternative and another and represent an average cost of 5 Baht/month per person, using either gasoline or electricity.

In conclusion, from an economic point of view it is more attractive to choose a dual-media filter system than a series-filter system. Out of the four treatment alternatives suggested, alternative C, which is a dual-media filter consisting of burnt rice husk and sand, seems most appealing and has the greatest potential for treatment of tropical surface waters in rural areas.

Table 4.1 - Comparative Initial Costs and Running Costs of Different Filter Systems

Items		Alternative A CF-BRH (Series)	Alternative B CF-BRH (Dual)	Alternative C BRH-SAND (Dual)	Alternative D BRH-SAND (Series)
Capital cost, Baht [1] (฿)		20,260	15,260	15,260	20,260
Operating cost, ฿/month	gasoline	1,200	1,365	1,088	1,148
	electricity	1,088	1,144	1,032	1,036
Population served		250	250	250	250
Operating cost, ฿/cap-month	gasoline	4.80	5.50	4.40	4.60
	electricity	4.40	5.20	4.10	4.15
Operating cost, ฿/family of 5/month	gasoline	24	27	22	23
	electricity	22	26	21	21

CF = Coconut Fiber BRH = Burnt Rice Husk

[1] Current Exchange Rate Approximately 20.15 Baht = U.S.$1.

APPENDICES

APPENDIX A

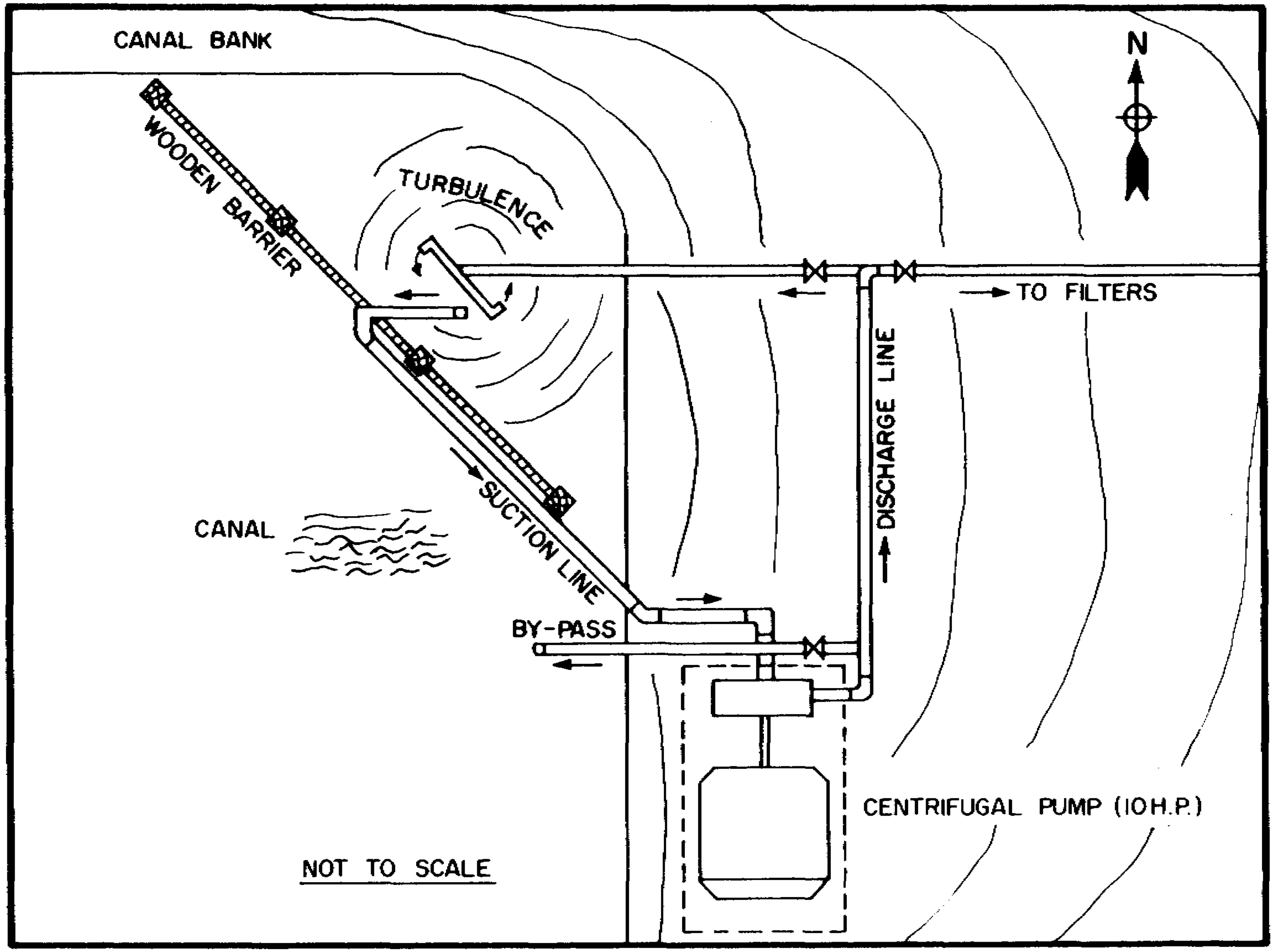


FIG. A-1 INTAKE SYSTEM

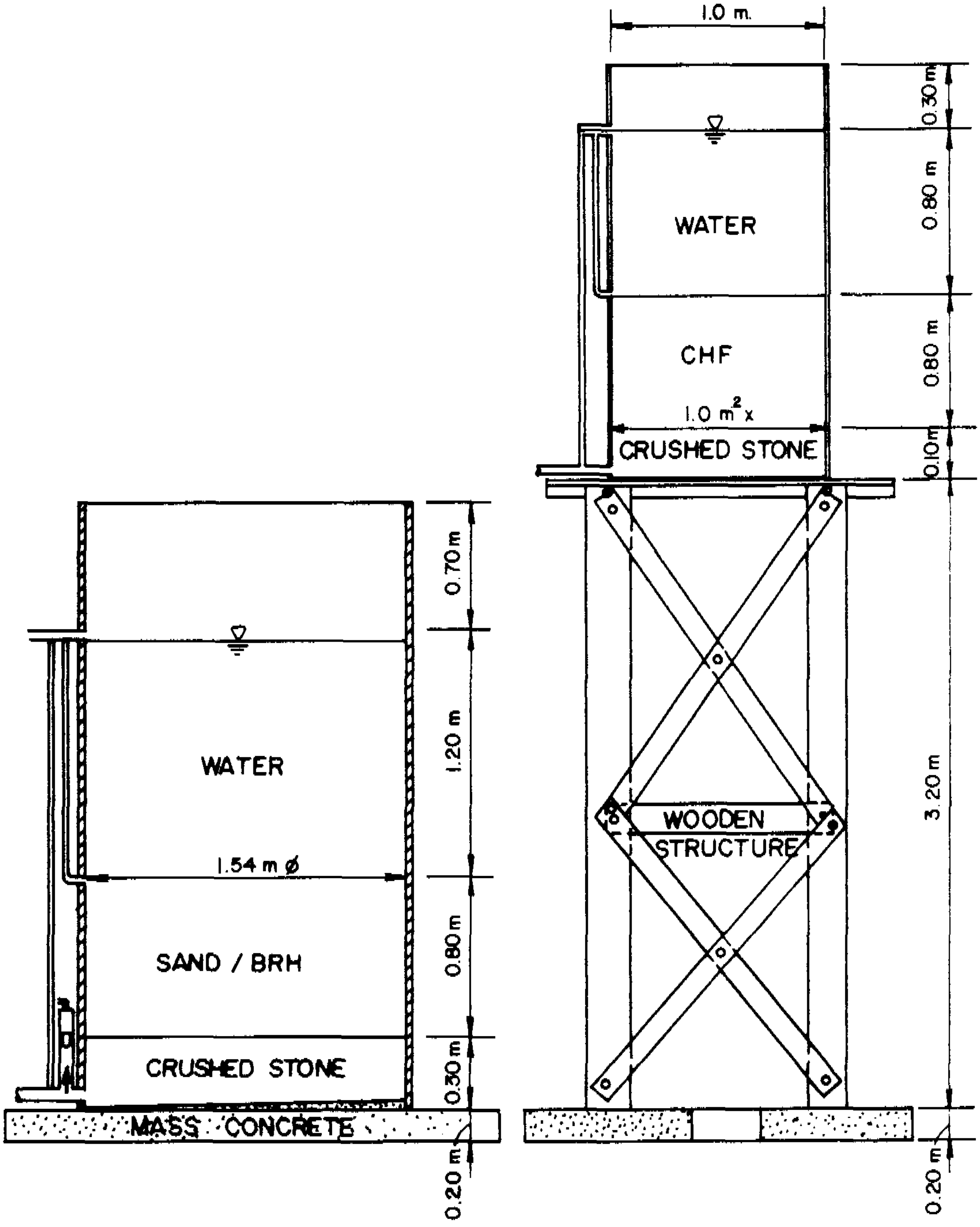
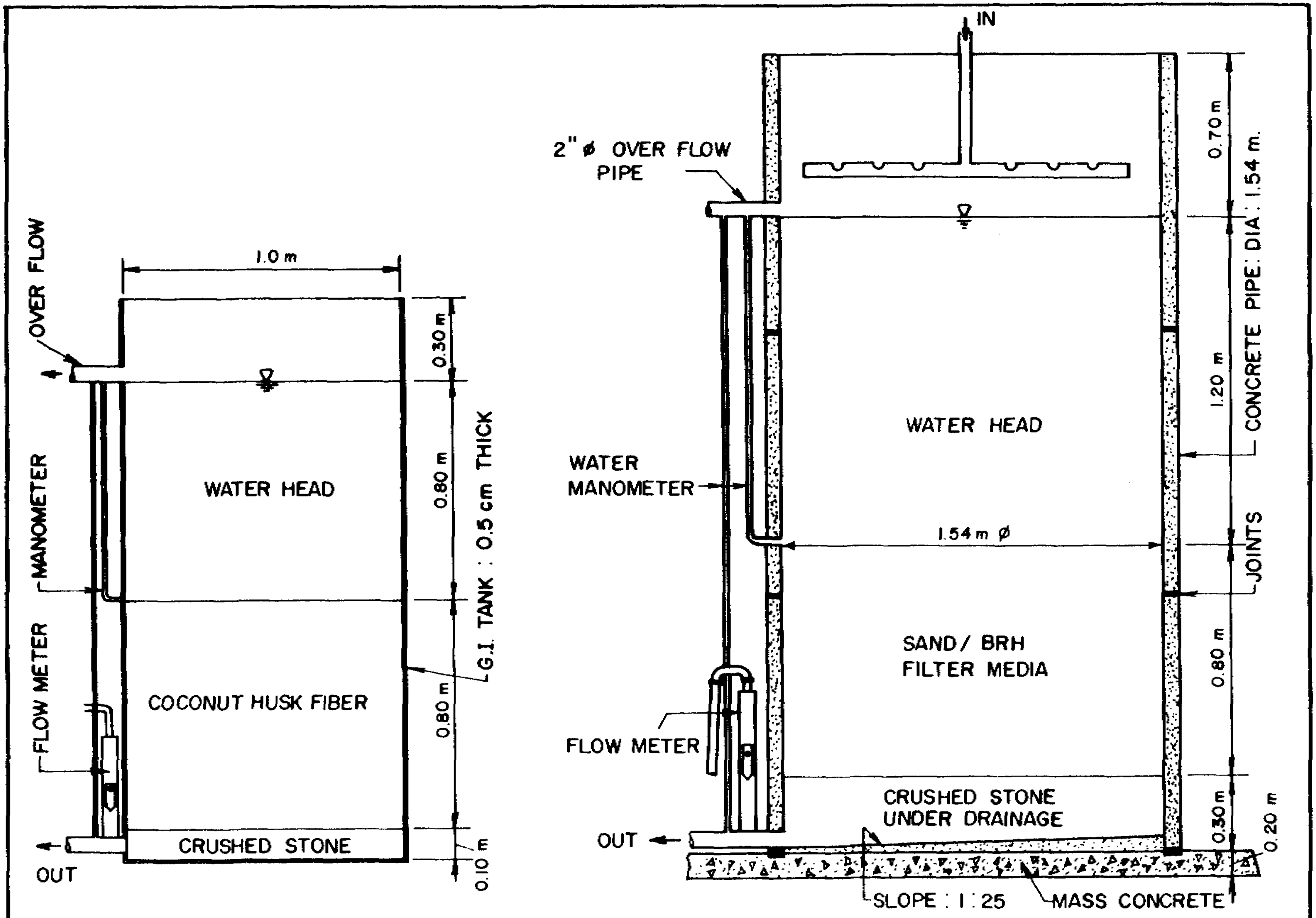


FIG. A-2 SERIES FILTER SET-UP



ROUGHING FILTER (TYPICAL)
SCALE 1:50

POLISHING FILTER (TYPICAL)
SCALE 1:50

FIG. A-3 TYPICAL DETAILS OF SERIES FILTER

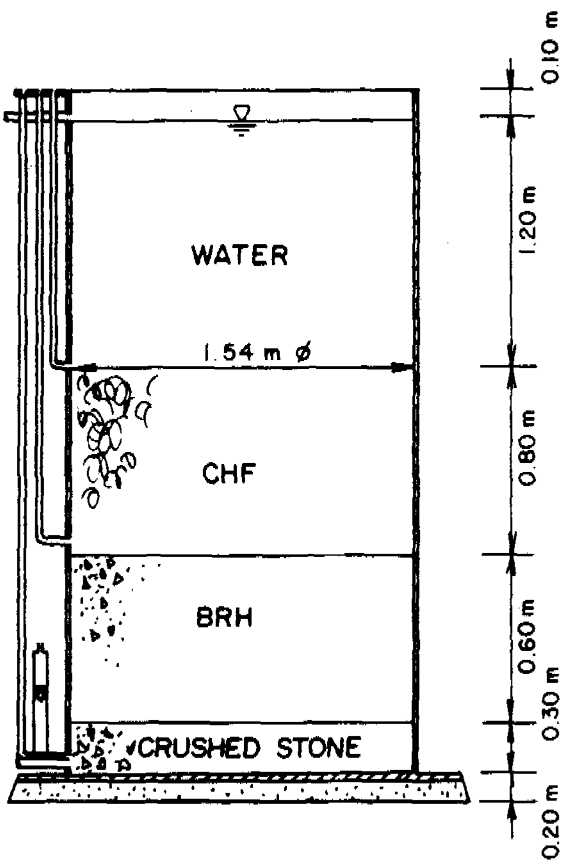


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FIG. A-4 DUAL-MEDIA FILTER

APPENDIX B

Table B1 - Head Loss in Filters (cm) (Stage A: Raw Water Turbidity 50 JTU)

Run Duration, Days	Date	R_1 & R_2 @ 1.5 m^3/m^2 h	F_1 @ 0.15 m^3/m^2 h	F_2 @ 0.1 m^3/m^2 h	F_3 @ 0.15 m^3/m^2 h	F_4 @ 0.1 m^3/m^2 h	F_5 @ 0.1 m^3/m^2 h
1	15/11/75	-	-	-	10.0	8.0	-
6	20/11/75	-	-	-	23.0	28.0	1.0
9	23/11/75	-	1.0	1.0	40.0	38.0	1.6
11	25/11/75	-	2.0	2.0	58.0	69.0	2.0
14	28/11/75	-	2.5	2.5	73.0	75.0	2.0
17	1/12/75	-	3.0	3.5	87.0	93.0	2.0
20	4/12/75	-	3.0	3.5	94.0	98.0	3.0
23	7/12/75	-	3.5	3.5	100.0	104.0	4.0
26	10/12/75	-	3.8	3.7	101.0	107.0	4.0
29	13/12/75	-	4.0	4.0	104.0	111.0	4.5
32	16/12/75	-	4.2	5.0	106.0	115.0	5.5
35	19/12/75	2.0	5.0	6.5	110.0	120.0	7.5
37	21/12/75	3.0	Shut off	6.5	End	End	7.5
40	24/12/75	4.0	-	7.0	-	-	8.0
43, 1*	27/12/75	5.0	1.5	8.0	4.0	5.0	8.5
46, 4	30/12/75	8.0	2.0	9.5	6.0	7.0	9.0
49, 7	2/ 1/76	11.0	2.0	10.0	6.5	7.5	10.0
52,10	5/ 1/76	14.0	5.0	11.0	8.5	8.5	11.0
55,13	8/ 1/76	16.0	6.0	12.0	10.5	10.0	11.5
58,16	11/ 1/76	18.0	6.5	12.5	11.5	11.0	11.5
62,20	15/ 1/76	22.0	19.0	17.0	27.0	12.0	12.5
65,23	18/ 1/76	27.0	39.0	21.5	41.0	14.0	15.0
68,26	21/ 1/76	30.0,28.0	-	30.0	59.0	17.5	15.0
70,28	23/ 1/76	33.0,29.0	-	50.0	64.0	25.0	15.0
73,31	26/ 1/76	35.0,30.0	24.0	57.0	89.0	48.0	15.0
74,32	27/ 1/76	40.0,30.0	15.0	57.0	109.0	-	17.0
75,33	28/ 1/76	42.0,30.0	22.0	58.0	125.0	71.0	17.0
76,34	29/ 1/76	44.0,30.0	28.0	63.0	133.0	24.0	25.0
77,35	30/ 1/76	46.0,32.0	22.0	64.0	140.0	24.0	23.0
79,37	1/ 2/76	-	32.0	59.0	149.0	33.0	24.0
81,39	3/ 2/76	50.0,36.0	43.0	49.5	160.0	42.0	25.0
83,41	5/ 2/76	54.0,39.0	28.5	58.5	End	47.5	28.0
84,42	6/ 2/76	56.0,40.0	30.0	60.0	-	53.0	28.0
88,46	10/ 2/76	60.0,40.0	38.0	61.5	-	89.0	30.0
89,47	11/ 2/76	64.0,44.0	45.0	65.0	-	101.0	32.0
90,48	12/ 2/76	66.0,46.0	55.0	65.0	-	118.0	24.0
91,49	13/ 2/76	70.0,48.0	39.0	75.0	-	126.0	26.0
98	20/ 2/76	85.0,56.0	45.0	89.0	-	End	33.0
101	23/ 2/76	85.0,56.0	63.0	94.0	-	-	34.0
105	27/ 2/76	85.0,64.0	-	-	-	-	-
108,66	1/ 3/76	85.0,75.0	68.0	97.0	-	-	37.0
		Shut off	Shut off	Shut off			Shut off
Run length, days		108.0	66.0	108.0	39.0	49.0	108.0

Table B1 - Continued.

Legend: R_1 & R_2 : Coconut fibre roughing filters

F_1 & F_2 : Burnt rice husk filters (series, polishing)

F_3 & F_4 : Sand filters (series, polishing)

F_5 : Dual media filter (coconut fibre + burnt rice husk)

* Run starting for F_1, F_3 & F_4

Table B2 - Turbidity of Raw Water and Effluents of Different Filters (Stage A: Raw Water Turbidity Level 50 JTU)

Run Duration, Days	Date	Influent Water, I	R_1 & R_2 @ 1.5 m^3/m^2h	F_1 @ 0.15 m^3/m^2h	F_2 @ 0.1 m^3/m^2h	F_3 @ 0.15 m^3/m^2h	F_4 @ 0.1 m^3/m^2h	F_5 @ 0.1 m^3/m^2h
1	15/11/75	44.0	10.0	5.6	5.4	4.8	4.9	5.9
2	16/11/75	47.0	11.0	5.7	5.4	4.7	4.7	6.1
3	17/11/75	43.0	12.0	5.8	5.3	4.6	4.8	5.9
4	18/11/75	40.0	10.0	5.8	5.2	4.7	4.8	5.6
5	19/11/75	42.0	11.0	5.8	5.3	4.2	4.3	5.8
6	20/11/75	46.0	13.0	5.7	5.4	4.2	4.3	5.7
7	21/11/75	40.0	13.0	5.8	5.4	4.3	4.3	5.9
8	22/11/75	46.0	9.0	5.9	4.8	4.8	4.9	5.9
9	23/11/75	40.0	8.0	3.8	3.9	3.2	2.6	4.2
10	24/11/75	38.0	9.0	3.6	3.8	3.1	2.5	4.1
11	25/11/75	37.0	9.0	3.2	3.2	3.1	2.1	4.0
12	26/11/75	39.0	9.0	3.3	3.4	3.0	2.8	4.1
13	27/11/75	38.0	9.5	3.2	3.5	2.6	2.6	4.2
14	28/11/75	32.0	9.0	3.1	3.1	2.2	1.5	4.0
15	29/11/75	38.0	8.5	3.2	3.2	1.1	1.2	4.1
16	30/11/75	39.0	8.0	4.3	3.4	1.5	2.2	4.4
17	1/12/75	36.0	8.0	4.2	3.2	1.3	1.8	3.8
18	2/12/75	40.0	11.0	3.5	3.8	4.0	2.8	4.1
19	3/12/75	42.0	11.0	3.8	3.2	4.0	2.9	4.0
20	4/12/75	36.0	10.0	3.8	3.2	3.2	3.0	4.1
21	5/12/75	33.0	10.0	3.9	3.1	2.7	3.2	4.0
22	6/12/75	32.0	9.0	3.9	3.2	2.6	1.5	3.8
23	7/12/75	33.0	10.0	4.0	3.2	2.8	1.6	3.9
24	8/12/75	32.0	10.0	4.0	3.2	1.7	1.7	3.8
25	9/12/75	31.5	9.0	4.0	3.3	1.6	1.5	3.6
26	10/12/75	30.0	9.0	4.0	3.2	2.5	1.5	3.7
27	11/12/75	30.0	9.0	3.8	3.2	1.4	1.4	3.6
28	12/12/75	29.0	9.0	3.4	3.2	2.3	1.4	3.8
29	13/12/75	28.0	9.0	3.4	3.2	2.3	1.4	3.9
30	14/12/75	29.0	8.0	3.3	3.2	2.2	1.3	2.9
31	15/12/75	29.0	9.0	3.2	3.3	2.5	1.5	2.3
32	16/12/75	33.0	9.0	3.2	3.5	2.6	1.6	3.3
33	17/12/75	34.0	9.0	3.3	3.2	1.1	2.3	4.0
34	18/12/75	33.0	8.0	3.4	3.1	1.1	2.4	3.5
35	19/12/75	39.0	9.5	5.0	4.2	1.9	1.6	3.2
36	20/12/75	31.0	9.0	Cut off	4.3	End	End	4.1
37	21/12/75	33.0	9.0	Cut off	4.3	End	End	4.0
38	22/12/75	26.0	9.0	Cut off	4.2	End	End	3.8
39	23/12/75	29.0	8.5	Start at 0.2 m^3/m^2h	4.2	Start at 0.2 m^3/m^2h	Start at 0.1 m^3/m^2h	3.7

Table B2 - Continued

Run Duration, Days	Date	Influent Water, I	R_1 & R_2 @ 1.5 m^3/m^2h	F_1 @ 0.15 m^3/m^2h	F_2 @ 0.1 m^3/m^2h	F_3 @ 0.15 m^3/m^2h	F_4 @ 0.1 m^3/m^2h	F_5 @ 0.1 m^3/m^2h
40, 1*	24/12/75	30.0	8.5	Start at 0.2 m^3/m^2h	4.2	Start at 0.2 m^3/m^2h	Start at 0.1 m^3/m^2h	3.7
41, 2	25/12/75	29.0	8.5	"	4.3	"	"	3.6
42, 3	26/12/75	33.0	9.5	"	4.2	"	"	3.5
43, 4	27/12/75	32.0	9.0	6.5	3.8	8.2	7.8	3.5
44, 5	28/12/75	31.0	10.0	6.5	3.6	8.0	8.0	3.5
45, 6	29/12/75	29.0	9.5	6.5	3.7	7.0	6.5	3.5
46, 7	30/12/75	34.0	10.0	6.5	3.8	7.0	6.0	3.6
47, 8	31/12/75	33.0	10.0	6.5	3.8	7.0	5.5	3.5
48, 9	1/ 1/76	30.0	13.0	4.8	3.7	6.8	5.5	3.4
49, 10	2/ 1/76	25.0	10.0	1.8	2.8	7.0	7.5	2.7
50, 11	3/ 1/76	24.0	9.0	1.9	2.7	5.8	5.9	2.8
51, 12	4/ 1/76	26.0	9.0	1.8	2.6	5.3	5.6	2.6
52, 13	5/ 1/76	24.0	8.5	1.9	2.5	7.4	7.3	2.3
53, 14	6/ 1/76	32.0	14.0	1.8	1.6	7.7	7.4	4.2
54, 15	7/ 1/76	32.5	15.0	1.9	1.7	8.9	7.8	2.4
55, 16	8/ 1/76	38.0	20.0	4.5	1.8	7.4	6.9	1.7
56, 17	9/ 1/76	35.0	21.0	2.7	1.7	7.5	4.7	1.5
57, 18	10/ 1/76	38.0	22.0	2.8	1.8	7.4	5.2	1.6
58, 19	11/ 1/76	37.0	23.0	2.8	1.7	7.5	5.0	1.7
59, 20	12/ 1/76	37.5	25.5	3.8	1.7	8.2	7.5	1.5
60, 21	13/ 1/76	39.0	24.0	4.1	1.5	8.2	5.5	1.6
61, 22	14/ 1/76	49.5	18.5	5.2	1.4	3.0	7.5	1.6
62, 23	15/ 1/76	47.0	32.0	5.0	2.2	4.7	5.7	1.7
63, 24	16/ 1/76	47.0	25.0	5.6	2.2	4.5	4.4	2.2
64, 25	17/ 1/76	41.0	23.0	5.8	2.8	4.4	4.3	2.0
65, 26	18/ 1/76	40.0	21.0	5.7	2.9	6.5	5.0	1.5
66, 27	19/ 1/76	38.5	25.0	10.2	7.2	9.2	7.2	7.0
67, 28	20/ 1/76	31.0	19.0	11.0	7.7	4.2	3.8	5.5
68, 29	21/ 1/76	28.0	17.5	-	6.2	3.7	3.3	4.7
69, 30	22/ 1/76	27.5	14.0	12.0	6.4	3.7	3.4	4.2
70, 31	23/ 1/76	26.5	13.5	9.2	5.3	3.6	3.3	4.1
71, 32	24/ 1/76	31.0	11.5	9.4	5.6	3.7	3.2	4.0
72, 33	25/ 1/76	37.0	10.5	10.2	5.3	3.8	3.2	4.1
73, 34	26/ 1/76	27.5	14.0	8.9	5.2	2.8	3.3	3.4
74, 35	27/ 1/76	28.0	14.0	11.0	6.0	2.7	4.5	3.5
75, 36	28/ 1/76	25.0	14.0	10.0	7.1	2.7	3.2	3.6
76, 37	29/ 1/76	27.5	13.0	9.5	7.2	2.6	2.7	3.5
77, 38	30/ 1/76	25.0	12.0	8.7	7.7	2.1	2.8	3.4
78, 39	31/ 1/76	27.0	11.0	6.8	7.6	2.0	2.4	3.2
79, 40	1/ 2/76	26.0	11.0	6.5	7.4	2.0	2.2	3.0
80, 41	2/ 2/76	24.0	9.5	5.5	7.0	1.7	2.0	2.7

* Starting day for F_1 , F_3 and F_4

Table B2 - Continued

Run Duration, Days	Date	Influent Water, I	R_1 & R_2 @ 1.5 m^3/m^2h	F_1 @ 0.15 m^3/m^2h	F_2 @ 0.1 m^3/m^2h	F_3 @ 0.15 m^3/m^2h	F_4 @ 0.1 m^3/m^2h	F_5 @ 0.1 m^3/m^2 h
81, 42	3/2/76	22.0	8.5	4.3	6.6	1.5	1.7	2.6
82, 43	4/2/76	27.0	8.0	6.1	5.5	1.2	1.7	7.6
83, 44	5/2/76	23.0	9.0	4.0	4.5	1.2	1.6	2.7
84, 45	6/2/76	27.5	11.5	6.4	4.4	1.0	1.3	5.6
85, 46	7/2/76	28.5	11.5	5.0	1.5	1.2	3.6	5.8
86, 47	8/2/76	30.5	12.5	7.0	1.7	1.2	2.0	7.5
87, 48	9/2/76	35.0	14.0	9.3	2.8	1.0	1.2	9.3
88, 49	10/2/76	32.5	14.0	8.5	2.6	0.9	1.2	5.7
89, 50	11/2/76	32.0	12.5	9.2	2.2	1.0	1.4	1.4
90, 51	12/2/76	38.0	16.5	7.6	1.8	1.0	1.3	8.5
91, 52	13/2/76	32.5	15.0	9.7	2.5	0.7	1.2	1.5
92, 53	14/2/76	36.0	16.5	9.6	2.6	0.8	1.5	1.6
93, 54	15/2/76	35.0	16.0	8.6	2.5	0.8	1.3	3.4
94, 55	16/2/76	33.0	15.5	8.7	1.7	0.7	1.2	1.7
95, 56	17/2/76	28.0	14.0	9.2	2.2	0.9	1.2	10.5
96, 57	18/2/76	28.0	14.5	9.4	2.0	0.8	1.2	1.0
97, 58	19/2/76	31.0	17.0	10.0	5.0	2.5	1.0	9.5
98, 59	20/2/76	30.0	17.0	10.5	4.5	End	1.7	1.0
99, 60	21/2/76	33.0	15.0	10.0	5.0	-	1.8	1.0
100, 61	22/2/76	32.0	14.5	9.5	4.3	-	1.7	8.5
101, 62	23/2/76	30.0	16.5	8.5	3.0	-	1.5	1.0
102, 63	24/2/76	27.0	13.5	8.7	2.5	-	1.7	10.0
103, 64	25/2/76	27.0	12.0	7.7	5.2	-	1.5	1.5
104, 65	26/2/76	47.0	18.5	6.5	2.0	-	1.5	3.0
105, 66	27/2/76	24.0	13.0	2.5	4.2	-	1.7	10.0
106, 67	28/2/76	26.0	16.0	1.8	3.2	-	1.7	9.5
107, 68	29/2/76	31.0	16.5	2.0	3.7	-	2.0	2.5
108, 69	1/3/76	21.0	16.5	1.6	1.5	-	1.4	2.6
			End	Shut off			End	Shut off

Legend: R_1 & R_2: Coconut fibre roughing filters

F_1 & F_2: Burnt rice husk filters (series-filters)

F_3 & F_4: Sand filters (series-filters)

F_5 : Dual media filter (coconut fibre overlying burnt rice husk)

Table B3 - Results of MPN Tests for Total Caliform on Raw Water and Filter Effluents (Stage A: Raw Water Turbidity Level 50 JTU

Run Duration, Days	Date	Raw Water I	F_1 @ 0.1-0.2 m^3/m^2 h	F_2 @ 0.1 m^3/m^2 h	F_3 @ 0.15-0.2 m^3/m^2 h	F_4 @ 0.1 m^3/m^2 h	F_5 @ 0.1 m^3/m^2 h
6	20/11/75	2400	115	115	93	93	93
11	25/11/75	1100	93	93	43	43	93
17	1/12/75	1100	93	93	43	43	93
23	7/12/75	1100	93	93	43	43	43
29	13/12/75	1100	43	43	43	3	93
35	19/12/75	280	4 End	0	0 End	4 End	4
43, 1*	27/12/75	280	23	3	7	4	0
50, 8	3/ 1/76	28	3	0	3	3	7
53, 11	6/ 1/76	28	3	9	0	0	9
59, 17	12/ 1/76	240	3	0	5	9	0
62, 20	15/ 1/76	43	9	4	7	3	21
67, 25	20/ 1/76	150	15	23	9	0	9
73, 31	26/ 1/76	1100	43	14	4	3	15
81, 39	3/ 2/76	150	3	4	4	9	4
87, 45	9/ 2/76	1400	15	3	7	15	0
95, 53	17/ 2/76	460	43	4	0	4	0
98, 56	20/ 2/76	240	0	9	End	End	0
102, 60	24/ 2/76	2400	5	0	-	-	0
108, 66	1/ 3/76	2400	9	0	-	-	3

Legend:
R_1 & R_2 : Coconut fibre filter (series roughing)
F_1 & F_2 : Burnt rice husk filters (series)
F_3 & F_4 : Sand filters (series)
F_5 : Dual media filter (coconut fibre and burnt rice husk)

* Run starting for F_1, F_3 and F_4

Table B4 - Results of Faecal Coliform Plate Count Tests for Raw Water and Filtered Water (Calories/ml)
(Stage A: Raw Water Turbidity Level 50 JTU)

Run Duration	Date	Raw Water I	F_1 @ 0.2 m^3/m^2 h	F_2 @ 0.1 m^3/m^2 h	F_3 @ 0.2 m^3/m^2 h	F_4 @ 0.1 m^3/m^2 h	F_5 @ 0.1 m^3/m^2 h
43	27/12/75	47	4	3	2	3	3
53	6/ 1/76	5	0	0	0	0	2
59	12/ 1/76	31	2	0	3	0	2
62	15/ 1/76	11	0	0	1	0	1
67	20/ 1/76	38	5	3	0	0	2
73	26/ 1/76	5	1	0	0	0	1
81	3/ 2/76	5	0	0	0	0	0
89	9/ 2/76	5	0	0	0	0	0
95	17/ 2/76	2	1	0	0	0	0
98	20/ 2/76	5	0	0	0	0	0
102	24/ 2/76	47	0	0	0	0	0
108	1/ 3/76	31	0	0	0	0	0

Table B5 - Results of Streptococcus Faecalis MPN Tests for Raw Water and Filtered Water (MPN/100 ml)
(Stage A: Raw Water Turbidity Level 50 JTU)

Run Duration	Date	Raw Water I	F_1 @ 0.2 m^3/m^2 h	F_2 @ 0.1 m^3/m^2 h	F_3 @ 0.2 m^3/m^2 h	F_4 @ 0.1 m^3/m^2 h	F_5 @ 0.1 m^3/m^2 h
43	27/12/75	23	4	4	0	0	4
50	3/ 1/76	23	3	3	0	0	4
53	6/ 1/76	21	4	3	0	0	3
59	12/ 1/76	23	3	0	0	0	4
62	15/ 1/76	20	0	0	0	0	0
67	20/ 1/76	21	0	0	0	0	0
73	26/ 1/76	11	0	0	0	0	0
81	3/ 2/76	4	0	0	0	0	0
89	9/ 2/76	15	0	0	0	0	0
95	17/ 2/76	23	0	0	0	0	0
98	20/ 2/76	20	0	0	0	0	0
102	24/ 2/76	15	0	0	0	0	0
108	1/ 3/76	20	0	0	0	0	0

APPENDIX C

Table C1 - Head Loss in Filters (cm)
(Stage B: Raw Water Turbidity Level 100 JTU)

Run Duration, Days	Date	R_1 & R_2 @ 0.5 m^3/m^2 h	F_1 @ 0.2 m^3/m^2h	F_2 @ 0.2 m^3/m^2h	F_3 @ 0.2 m^3/m^2h	F_4 @ 0.2 m^3/m^2h	F_5 @ 0.2 m^3/m^2h
1	26/4/76	0	3	9.5	12	4	0
4	29/4/76	2	4	14	15	4	3
7	2/5/76	2	4	20	16	5	5
11	6/5/76	3	6	28	17	5	8
12	7/5/76	5	7	40	17	8	11
15	10/5/76	5	9	33	26	8	14
16	11/5/76	8	9	44	30	10	14
24	19/5/76	5	11	59	34	15	16
26	21/5/76	12	20	61	56	23	18
27	22/5/76	-	22	68	95	65	25
31	26/5/76	15	25	72	130	45	22
33	28/5/76	18	28	75	140	57	33
36	31/5/76	18	28	84	End	74	36
37	1/6/76	17	28	92		95	40
40	4/6/76	20	28	99		101	51
41	7/6/76	22	32	99		125	54
		Shut off				End	Shut off
Run length, days		41	41	41	33	41	41
Head loss rate, cm/day		0.5	0.7	2.4	3.4	3.0	1.3

Legend: R_1 & R_2 : Coconut fibre roughing filters

F_1 : Dual media filter (burnt rice husk and sand)

F_2 : Burnt rice husk filter (series filter)

F_3 : Sand filter (series filter)

F_4 : Dual media filter (coconut fibre and sand)

F_5 : Dual media filter (coconut fibre and burnt rice husk)

Table C2 - Turbidity of Raw Water and Effluents of Different Filters (Stage B: Raw Water Turbidity Level 100 JTU)

Run Duration, Days	Date	Influent Water, J	R_1 & R_2 @ 0.5 m^3/m^2 h	F_1 @ 0.2 m^3/m^2h	F_2 @ 0.2 m^3/m^2h	F_3 @ 0.2 m^3/m^2h	F_4 @ 0.2 m^3/m^2 h	F_5 @ 0.2 m^3/m^2 h
1	26/4/76	42.0	13.0	3.2	6.7	28.0	-	9.4
2	27/4/76	73.0	12.5	3.4	5.3	27.0	-	16.0
3	28/4/76	97.0	12.0	2.9	5.8	27.0	-	12.0
4	29/4/76	80.0	18.0	2.8	6.1	26.0	-	17.0
5	30/4/76	86.0	21.0	5.0	8.3	21.0	-	-
6	1/5/76	89.0	16.0	3.7	4.8	18.0	-	12.0
7	2/5/76	48.0	16.0	2.8	3.9	13.0	-	9.0
8	3/5/76	60.0	17.5	2.9	4.5	11.0	-	5.6
9	4/5/76	68.0	17.5	3.0	5.0	10.0	-	7.0
10	5/5/76	59.0	18.0	3.2	3.2	9.0	-	6.0
11	6/5/76	48.0	19.5	3.0	4.2	8.9	11.0	7.5
12	7/5/76	88.0	24.0	5.7	5.3	8.5	10.0	21.0
13	8/5/76	97.0	28.0	8.0	11.0	8.4	9.5	18.0
14	9/5/76	105.0	25.0	7.0	13.0	8.3	9.0	17.0
15	10/5/76	54.0	25.0	10.0	15.0	8.2	8.0	16.0
16	11/5/76	84.0	34.0	7.3	17.0	7.0	8.4	15.0
17	12/5/76	50.0	29.0	6.8	16.0	6.0	8.5	-
21	16/5/76	74.0	28.0	5.3	19.0	4.0	8.5	-
22	17/5/76	133.0	14.0,15.0	3.3	5.6	4.2	6.4	-
23	18/5/76	72.0	12.0,14.0	3.5	6.3	3.3	6.2	4.7
24	19/5/76	82.0	14.0,15.0	4.5	7.0	3.7	4.8	6.1
25	20/5/76	77.0	28.0,24.0	4.7	8.0	3.5	2.7	5.8
26	21/5/76	56.0	18.0,22.0	4.3	9.6	4.4	2.5	6.5
27	22/5/76	64.0	18.0,19.0	4.0	9.0	5.0	2.2	7.0
28	23/5/76	79.0	21.0,23.0	4.5	9.6	5.2	2.6	7.4
29	24/5/76	83.0	15.0,16.0	3.2	9.7	4.0	3.7	4.1
30	25/5/76	71.0	18.0,17.0	4.1	7.2	2.7	1.6	4.8
31	26/5/76	86.0	13.0,11.0	2.9	6.2	2.4	1.2	2.7
32	27/5/76	82.0	23.0,37.0	2.7	8.7	End	1.5	2.8
33	28/5/76	92.0	18.0	2.9	9.1		1.3	5.1
34	29/5/76	84.0	24.0,31.0	2.9	6.7		1.8	3.0
35	30/5/76	79.0	19.0,26.0	2.5	6.8		2.0	3.4
36	31/5/76	83.0	12.0,22.0	2.6	6.0		1.7	8.7
37	1/6/76	78.0	10.0,11.0	1.7	5.6		1.2	14.0
38	2/6/76	65.0	17.0,26.0	1.8	6.8		1.3	16.0
39	3/6/76	91.0	13.0,20.0	1.8	6.2		1.6	13.0
40	4/6/76	77.0	12.0,16.0	1.8	5.3		1.5	14.0
41	5/6/76	109.0	24.0,17.0	2.2	6.0		1.6	11.0
42	6/6/76	89.0	22.0,15.0	2.1	6.1		1.9	12.0
43	7/6/76	51.0	16.0,22.0	2.3	8.8		2.2	9.3

Legend: R_1 & R_2: Coconut fibre roughing filters
F_1 : Dual media filter (burnt rice husk and sand)
F_2: Burnt rice husk filter (series) F_3: Sand filter (series)
F_4 : Dual media filter (coconut fibre and sand)
F_5 : Dual media filter (coconut fibre and burnt rice husk)

Table C3 - Results of MPN Tests for Total Coliforms on Raw Water and Filtered Water (MPN/100 ml)
(Stage B: Raw Water Turbidity Level 100 JTU)

Run Duration	Date	Raw Water, I	F$_1$ @ 0.2 m^3/m^2 h	F$_2$ @ 0.2 m^3/m^2 h	F$_3$ @ 0.2 m^3/m^2 h	F$_4$ @ 0.2 m^3/m^2 h	F$_5$ @ 0.2 m^3/m^2 h
1	26/4/76	1100	93	93	43	43	43
4	29/4/76	2400	73	43	23	23	43
6	1/5/76	2400	23	23	4	0	23
17	12/5/76	740	23	23	3	0	9
26	21/5/76	460	15	15	20	15	15
33	28/5/76	210	15	7	4	11	11
40	4/6/76	460	0	3	0	3	3

Table C4 - Results of Faecal Coliform MPN Tests for Raw Water and Filtered Water (MPN/100 ml)

1	26/4/76	740	93	93	23	23	23
4	29/4/76	1100	43	43	0	0	23
6	1/5/76	1100	23	0	0	0	4
17	12/5/76	740	11	9	0	0	3
26	21/5/76	210	9	4	0	0	3
33	28/5/76	93	9	7	3	3	3
40	4/6/76	93	4	3	0	0	3

Table C5 - Results of Streptococcus Faecalis MPN Tests for Raw Water and Filtered Water (MPN/100 ml)

1	26/4/76	210	43	23	7	7	9
4	29/4/76	210	23	9	3	4	7
6	1/5/76	150	11	7	0	3	4
17	12/5/76	150	9	4	0	0	3
26	21/5/76	93	7	4	0	0	0
33	28/5/76	75	4	3	0	0	0
40	4/6/76	75	0	0	0	0	0

Legend:
F$_1$: Dual media filter (burnt rice husk and sand)
F$_2$: Burnt rice husk filter (series)
F$_3$: Sand filter (series)
F$_4$: Dual media filter (coconut fibre and sand)
F$_5$: Dual media filter (coconut fibre and burnt rice husk)

APPENDIX D

COST ESTIMATION

Capital costs incurred represent the actual costs of construction of various types of filters. The cost of land is excluded in the calculation of the capital cost. Operating costs are computed on the basis of number of population served, manpower and energy (electricity, gasoline) used. Both capital and operating costs are evaluated for two alternative filters designed in order to provide continuous water supply.

A. Capital Cost of a Series-Filter System

Roughing Filter		Baht[1/]
Wooden structure and concrete foundation for wooden poles	=	1,000
Galvanized-iron tank	=	2,000
Crushed stones (฿130/m^3)	=	40
One wooden ladder	=	100
Two 0.787 cm (2 in) gate valves (฿250/each)	=	500
		3,640
Contingency 10%	=	360
Construction cost of a roughing filter	=	4,000

Polishing Filter		Baht
Cement for floor foundation (฿30/bag, 5 bags)	=	150
Three 1.54 m ϕ concrete sewer pipes (฿1,000/piece)	=	3,300
Crane renting (฿1400/day)	=	1,400
Crushed stones (฿130/m^3, 0.6 m^3)	=	80
Two 0.787 cm- (2 in-) gate valves (฿250/piece)	=	500
Piping, steel bars, bricks	=	500
One wooden ladder	=	100
		6,030
Contingency 10%		603
Construction cost of a polishing filter	=	6,630

Considering that one roughing filter can supply water to two polishing filters which can afford two months of continuous and simultaneous operation, a 1-hp pump (฿3000) is required to lift water up to a level of about 6-8 m.

Finally, the construction cost of the whole series-filtration system will be: 4,000 + (6,630 x 2) + 3,000 = 20,260 Baht. This does not

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[1/] Current exchange rate approximately 20.15 Baht = U.S.$1.

include cost of rotameters for flow rate measurement which can be handled by simpler bucket techniques.

B. Capital Cost of a Dual-Media Filter System

Assuming that it requires two dual-media filters for continuous operation of two months, a 0.5 hp-pump (฿2,000) will be necessary to lift the raw water up to a level of 3-5 m. The total construction of the dual-media filter system for a continuous operation of a two-month cycle will be: (6,630 x 2) + 2,000 = 15,260 Baht.

C. Population Served

Population benefitting from water supply will be the same for both series and dual-media filtration systems. Each system has two filters operating simultaneously. At a filtration rate of 0.20 m^3/m^2h, the total volume of water produced per day (10 hours of operation, 8 hours with pumping and 2 hours without pumping) will be:

$$0.2 \times \frac{\pi}{4} (1.54)^2 \times 10 \text{ h} \times 2 \simeq 7.45/\text{day} = 7450/\text{day}$$

Assuming a water consumption of 30 ℓ per person per day in rural communities, the number of people served would be:

$$\frac{450}{30} = 250 \text{ personnes} \simeq 50 \text{ families of 5 people}$$

D. Operating Costs of Different Alternatives of Filter Systems

The following estimation is based on 2 months of continuous operation of two filters working simultaneously.

1. Alternative A Series-Filter: Coconut Fibre - Burnt Rice Husk

Quantity of coconut fibre required = 1 m x 1 m x 0.8 m
$\simeq$ 1 m^3 for 4 months

Cost of coconut fibre $\left(\frac{฿220/m^3}{4 \text{ months}}\right)$ = 55 Baht/month

Quantity of burnt rice husk for two polishing filters = $\frac{\pi}{4} \times (1.54)^2 \times 0.8 \times 2$
= 3 m^3 for 2 months

Cost of burnt rice husk $\left(\frac{฿2/m^3 \times 3m^3}{2 \text{ months}}\right)$ = 3 Baht/month (negligible)

Transportation costs of filtering materials (฿50 every 2 months) = 25 Baht/month

Salary of one operator (฿25/day) = 750 Baht/month

Salary of 2 labourers for cleaning (average 1 day/month) = 50 Baht/month

Gasoline cost: 1 hp-pump consumes (฿3.62/ℓ) about 5 ℓ/day or 2 ℓ/8 h of operation-day (฿3.62/ℓ x 2 x 30 days) = 220 Baht/month

Or electricity cost: 1 hp = 7-6 watts = 0.746 kw (฿0.60/kw) 1 hp-pump consumes 0.746 x 8 = 6 kw/day = 108 Baht/month

Pump maintenance cost ≃ 100 Baht/month

Total operating cost if using gasoline = 1,200 Baht/month

Operating cost per head ≃ 4.80 Baht/month

Operating cost per family of 5 personnes = 24 Baht/month

Total operating cost if using electricity = 1,088 Baht/month

= 4.40 Baht/cap-month

= 22 Baht/family/month

2. <u>Alternative B Dual-Media Filter: Coconut Fibre - Burnt Rice Husk</u>

Quantity of coconut fibres required for 2 filters: $\frac{\pi}{4} \times (1.54)^2 \times 0.8 \times 2$ ≃ 3 m^3/2 months

Cost of coconut fibres $\left(\frac{฿220/m^3 \times 3\ m^3}{2\ \text{months}}\right)$ = 230 Baht/month

Cost of burnt rice husk = negligible

Transportation cost of filtering materials (฿50 every 2 months) = 25 Baht/month

Salary of one operator = 750 Baht/month

Salary of two labourers for cleaning (average 1 day/month) = 50 Baht/month

Gasoline cost = $\frac{220}{1} \times 0.5$ = 110 Baht/month

Or electricity cost = $\frac{108}{1} \times 0.5$ = 54 Baht/month

Pump maintenance cost = 100 Baht/month

Total operating cost (if using gasoline) = 1365 Baht/month

= 5.50 Baht/person-month

= 27 Baht/family of 5-month

Total operating cost (if using electricity) = 1309 Baht/month

= 5.20 Baht/person-month

= 26 Baht/family-month

3. Alternative C Dual-Media Filter: Burnt Rice Husk - Sand

Cost of burnt rice husk = negligible

Quantity of sand required for 2 filters = 3 m^3 for about 10 years

Cost of sand (฿75/m^3) = 224 Baht/10 years

= 23 Baht/month

Transportation cost of sand (฿500/10 years) = 5 Baht/month

Salary of one operator = 750 Baht/month

Salary of two labourers for cleaning (average 2 days/month) = 100 Baht/month

Gasoline cost = 110 Baht/month

Or electricity cost = 54 Baht/month

Pump maintenance cost = 100 Baht/month

Operating cost (if using gasoline) = 1088 Baht/month

= 4.73 Baht/person-month

= 23.65 Baht/family-month

Operating cost (if using electricity) = 1032 Baht/month

= 4.50 Baht/person-month

= 22.40 Baht/family-month

4. Alternative D Series-Filter: Burnt Rice Husk - Sand

Cost of burnt rice husk = negligible

Quantity of sand required for 2 filters = 3 m^3/10 years

Cost of sand = 23 Baht/month

Transportation cost of sand = 5 Baht/month

Salary of one operator = 750 Baht/month

Salary of two labourers for cleaning (average 1 day/month) = 50 Baht/month

Gasoline cost (1 hp-pump) = 220 Baht/month

Or electricity cost (1 hp-pump) = 108 Baht/month

Pump maintenance cost = 100 Baht/month

Operating cost (if using gasoline) = 1148 Baht/month

= 5 Baht/person-month

= 25 Baht/family-month

Operating cost (if using electricity) = 1036 Baht/month

= 4.50 Baht/person-month

= 22.50 Baht/family-month