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ALTERNATIVES IN SLOW FILTRATION FOR TREATMENT OF TROPICAL SURFACE WATER

By

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science of the Asian Institute of Technology, Bangkok, Thailand.

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ABSTRACT

A pilot plant consisting of series and dual media filters was operated discontinuously at a filtration rate of 0.15 m^3/m^2-h under the average raw water turbidity of 45 JTU.

The filters used were the coconut fiber - burnt rice husk series filter, burnt rice husk - sand series filter, burnt rice husk - sand and coconut fiber - burnt rice husk dual media filters.

It was found that the burnt rice husk - sand dual media filter with the discontinuous operation could produce good quality water suitable for drinking purpose in term of its clarity and bacteriological content for a period of about 2½ months. Odor and anaerobic condition prevailed in the coconut fiber - burnt rice husk series and dual media filters. Due to the high head loss build up rate, the burnt rice husk was not suitable to be used as a roughing filter medium in the series filtration system.

Preliminary study on the turbidity removal performance and head loss development of these filters operated continuously at a filtration rate of 0.15 m^3/m^2-h but slowed down during the night time (16 h) were also conducted.

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I INTRODUCTION

WHO (1973) estimated that at the end of 1970, 1.08 billion people in the rural areas of developing countries were without "reasonable access to safe water." The need for safe drinking water was greatest in Southeast Asia where 91% of the rural population lack adequate water supply. If by 1980 the number of people without adequate water supply is to be equal to the number in that position in 1971 (1.08 billion), then 297,000,000 people will have to be supplied by 1980. Thus in 1972, World Health Assembly set a target of 25% of the rural population to have reasonable access to safe water by 1980. To reach these targets, 241,000,000 people must be provided with a water supply by 1980. Therefore, it is desirable to develop a technically simple and low cost water treatment system for the rural water supply in developing countries.

In the early 1900's, before the rapid sand filtration become the accepted mode of water purification, the slow sand filter has been the accepted standard method of water treatment. The prefilters using coarse sand as filter media were used if the raw water contained high turbidity before passing through a slow sand filter for polishing the water and removal of the remaining impurities. This filtration system was used until the principle of coagulation followed by rapid sand filtration gained popularity. This is due to the advantages of less space and labour required and capability of the latter system to handle severe and sudden changes in colloidal turbidity. However, application of rapid sand filter in the tropical developing countries has certain limitation, the high operating cost and lack of skilled labour to operate it efficiently. In these countries, land and unskilled labour are readily available supplemented by the warm climate throughout the year and the availability of local materials give priority for the use of slow filtration system for treatment of the tropical surface water. HUISMAN & WOOD (1974) claimed that slow sand filtration is undoubtedly the simplest and most efficient method of treatment for many types of surface water.

In the past, studies were carried out to develop a simple, inexpensive filtering system using local materials as filter media for efficient removal of turbidity and coliform. SEVILLA (1971) reported that burnt rice husk appeared to be a potential substitute for sand in "semi-rapid" or intermediate rate filters having filtration rate of 1.25 m^3/m^2-h. This figure is higher than that of conventional slow sand filter but it is lower than rapid sand filter. For roughing filter, coconut fiber could be substituted for coarse sand as the filter medium. JAKSIRINONT (1972) showed that in polishing filters with filtration rate of 0.1 m^3/m^2-h, 80 cm of depth of media and influent turbidity range of 15 JTU to 40 JTU, the duration of run of burnt rice husk filter was 35 days. NIZAM (1975) carried out the comparative study of a combination of coconut fiber - slow sand and coconut fiber - slow burnt rice husk series filters and recorded that the latter combination was superior over a period of about two weeks of operation. THANH (1976) claimed that burnt rice husk - sand dual media filter was the potential slow filtration system producing good quality water and achieved long filter run (4 months).

This study was undertaken in a view to assess the performance of slow filtration system in a discontinuous operation. The filtration rates of all the slow filters were set at 0.15 m^3/m^2-h and operated for 8 hours (8:00 AM - 4.00 PM) and stopped for 16 hours during the night time. Due to the operation of the filters, the effects of the bio-layer in the filter was therefore the main consideration.

Purpose of Research

The purpose of this study was to determine:-

(1) The efficiencies of coconut fiber-burnt rice husk (series) filter, burnt rice husk-sand (series) filter, burnt rice husk-sand (dual media) filter and coconut fiber-burnt rice husk (dual media) filter in terms of turbidity and bacteriological removals in the long period of operation.

(2) The effects of the bio-layer in these discontinuously operated filters with raw water average turbidity of 50 JTU and the filtration rates of 0.15 m^3/m^2-h.

(3) The feasibility of the discontinuous operation of the slow filters for 8 hours a day.

(4) The physical performances, the turbidity removal and head loss development of the filter which were operated at 0.15 m^3/m^2-h for 8 hours and then at lower water (0.03 m^3/m^2-h) for 16 hours.

Scope of Research

The study was carried out in two phases.

Phase I

(a) To study the feasibility of the discontinuous operation of the slow filters in terms of turbidity and coliform removal in long period of operation. The filtration rate was set at 0.15 m^3/m^2-h for all the slow filters while that of roughing filter was 0.4 m^3/m^2-h. The turbidity of raw water up to 150 JTU was used in this study. Sieve analysis on stock sand was also conducted to determine the effective size and coefficient of uniformity.

(b) To study the effects of the bio-layer in the filters by measuring the D.O. content, the total coliform, faecal coliform and faecal streptococcus contents in the treated water with multiple tubes and plate count techniques.

Phase II

This study has been undertaken with the ultimate aim to find out the turbidity removal efficiency and head loss development of the filters which were operated continuously with filtration rate of 0.15 m^3/m^2-h for 8 hours (8:00 AM - 4:00 PM) and then with filtration rate of 0.03 m^3/m^2-h during the night time (4:00 PM - 8:00 AM).

II LITERATURE REVIEW

Filtration is the process by which water is separated from the suspended and colloidal impurities it contains. The content of microorganisms is materially reduced and changes in the chemical characteristics of the water are brought about by passing it through a porous substance, sand or granular materials.

HUISMAN (1974) described that in slow sand filtration the water is passed by gravity downward through a layer of fine sand, effective size between 0.15 and 0.35 mm with filtration rate between 0.1 to 0.4 m^3/m^2-h, which is so small that only after an extended of service, a few weeks to a few months and more, cleaning is necessary. With the filter bed composed of fine grains, suspended and colloidal matter from the raw water are retained in the very top of the filter bed. The clogging here must be removed and the filter restored to its original capacity by scrapping off this top layer of dirty sand to the depth varying from one to few centimeters. In rapid filters, the water flows through a bed of sand, which having effective size varies from 0.6 to 2 mm. The filtration rate is between 5 and 15 m^3/m^2-h, which is so high that a rapid clogging of the filter bed results, necessitating cleaning after one to a few days of operation. By the use of coarse sand, the impurities penetrate the filter bed to great depths. Cleaning process is backwashing, reversing the flow of water which expands and scours the grains and carries the accumulated impurities to waste. Frequently, rapid filters are used with pretreatment, flocculation and sedimentation, which remove most of the impurities in raw water before it reaches the filter. The few that reached the filter-bed are removed in their coagulated state and the finer flocculi forming a film on the sand particles. The further particulate impurities will adhere to this film and carried out insignificant bacterial purification due to the high filtration rate. A similar film builds up on the grains of a slow sand filter, and the slow filtration rate, the bacterial action established significant contribution to the overall treatment process. Thus slow filters are also called 'biological filters'.

Purification in a Slow Sand Filter

HUISMAN & WOOD (1974) claimed that the slow sand filter with its purification process will improve simultaneously the physical, chemical and bacteriological qualities of the delivered water.

The average time for the raw water remaining above the filter bed, waiting its downward passage through the medium varies from 3 to 12 hours. The heavier particles settle the lighter ones coalesce, so becoming more amenable for subsequent removal. Algae will grow with the presence of sunlight, carbon dioxide and nutrients from water, and form oxygen. Although algae can assimilate most of the inorganic impurities, care must be taken to prevent heavy algae growth which will clog the filter bed and reduced the filter run.

On the surface of the sand bed, 'Schmutzdecke' or biological layer is formed by organic matter, which traps most of the impurities as water pass. The slimy and gelatinuous layer consists of thread like algae and numerous other forms of life, planktons, diatoms, protozoa, rotifers and bacteria. Most of the biological activities take place in this layer - dissimilation and assimilation of living organisms. Simple organic salts are then formed and nitrogenous compounds are broken down and nitrogen is oxidized. At this stage, some colour is removed, and a large portion of inert suspended particles are mechanically strained out.

The water having passed through the layer, enters the filter bed. The mechanical straining action takes place with adsorption which further separated finer colloidals, bacteria or viruses from the water. The straining action is dependent on pore size of the bed while adsorption is attributed to electrical forces, chemical bonding and molecular activity, which is a complex process and not yet fully understood.

Between the grains are the pores of open spaces, which are about 40% of the total volume of the bed. The water velocity is slowed down by these pores as it enters them, and as a result of millions of minutes sedimentation basins are formed in which smallest particles settle onto the nearest sand grain before the continuation of the downward water flow. Therefore, every particle in the water is in contact with the surfaces of the sand grains, to which the absorption and adhesion take place. The surfaces become coated with a sticky layer, prevent the larger particle to penetrate. The living coating continues through about 40 cm of the bed, different life form predominating at different depths, with the greatest activity taking place near the surface, where food is most plentiful.

As a result the raw water after the passage through about 40 to 60 cm of the filter medium, become virtually free of all suspended solids, colloids microorganisms and complex salts, containing only some simple inorganic salts in solution. Not only has practically every harmful organism has been removed but also the dissolved nutrients that might encourage the subsequent growth of bacteria or slimes.

Effects of Algae on Filters

HUISMAN & WOOD (1974) noted that certain types of algae can have beneficial or harmful effects on the working of a biological filter, depending on a variety of conditions.

The property of algae most significant to the water purification process is the ability to build up cell material from simple minerals such as water, carbon dioxide, nitrates and phosphates. The photosynthesis may be described by the relationship:

$$n(CO_2) + n(H_2O) + \text{energy} \longrightarrow (CH_2O)_n + n(O_2) \qquad \ldots\ldots\ldots \quad (1)$$

The energy that required for their metabolism is derived from the oxidation of organic matter. When algae die off and their material is liberated to be consumed by the bacteria of the filter bed:

$$(CH_2O) + n(O_2) \longrightarrow n(CO_2) + n(H_2O) + \text{energy} \quad \ldots\ldots\ldots \quad (2)$$

The relative magnitude of these two reversible reaction governs the growth, constancy and decline of the algae population.

In tropical areas, reaction (1) predominates, increasing the oxygen and decreasing the CO_2 content. The rise in oxygen content is an advantage, but the lowering of CO_2 content may cause bicarbonate to dissociate into carbonate and CO_2.

$$Ca\ (HCO_3)_2 \longrightarrow CaCO_3 + CO_2 + H_2O$$

The lowering of the bicarbonate content will decrease the temporary hardness and insoluble carbonate will precipitate, thus contributing to the clogging of the filter. As the growth of algae continues and increase in volume, it will hinder the downward movement of the water and require frequent removal of the algae from the filter media surface, hence require a larger labour force.

Growth of small algae (diatoms) may be found in the contribution that filamentous species make to the formation of an active 'Schmutzdecke' which is mentioned before, enhancing straining and adsorbing action. However, blooms of such algae can caused rapid clogging of the bed, shortened filter runs, resulting in operational problems and poor performance. Therefore the effects of algae on slow sand filters is to be taken into consideration when adopted it as water purification process.

Hydraulic of Filtration

HUISMAN & WOOD (1974) stated that the laminar flow conditions may be assumed to prevail throughout the filter bed, because of the small rate of downward flow of the water.

According to Darcy's law

$H = (V_f/k) \times h$ is the resistance offered by a clean filter-bed

where,
- h = thickness of the bed
- V_f = the filtration rate
- k = coefficient of permeability m/h

The value of k can be estimated theoretically by the following formula:

$$k = 150\ (0.72 + 0.028T)\ \frac{P^3}{(1-P)^2}\ \phi^2\ d_s^2 \quad \text{m/h}$$

in which,
- T = temperature in degree celsius (^oC)
- P = porosity (ratio of volume of pores to total volume of filter medium)
- ϕ = shape factor
- d_s = specific diameter of sand grains, mm

The shape factor,

$$\emptyset = \frac{\text{Surface area of sphere}}{\text{surface area of average grain of the material}}$$

$\emptyset \leq 1$, the less the spherical grains the smaller will be.

Table 2.1 - Shape Factor of Various Kinds of Each Grains

	Spherical	Nearly Spherical	Rounded	Worn	Angular	Broken
$\emptyset$	1.00	0.95	0.90	0.85	0.75	0.65

The specific diameter d_s, which is not very restricted in slow sand filtration:

$$d_s = d_{10}\,(1 + 2 \log U) = \emptyset\, d_{10}$$

where d_{10} is the size of sieve opening through which 10% of the material will just pass and U is the coefficient of uniformity, which is d_{60}/d_{10}. When U is large, the sand is less uniform.

For a sieve with mesh width s, will pass grains up to a volumetric d, which may be larger or smaller than s depending on the shape of the sieve openings. Usually, square woven wire screen with ratio d/s = 1.05 to 1.2 is used.

For ellipsoidal grains d = 1.10 s, so the formula used for calculating the coefficient of permeability becomes

$$k = 150(0.72 + 0.028T)\,\frac{P^3}{(1-P)^2}\,\emptyset^2\,(1{+}2 \log U)^2\,(1.10s_{10})^2$$

$$= 180(0.72 + 0.028T)\,\frac{P^3}{(1-P)^2}\,\emptyset^2\,(1{+}2 \log U)^2\,S_{10}^2$$

in which s_{10} is the clear sieve opening that would pass 10% of the material

Thus, from Darcy's law with fine grained filtering material, the thickness of the filter bed should be kept minimum as the desired effluent quality will permit and avoid high rates of flow.

During filtration, head loss will increase when the impurities deposited in and upon the surface layer of the bed and reduced the pore space. The head loss rate cannot be readily calculated, and must be found by experimenting with the particular water, filter medium and the operating conditions. Generally, at the beginning of ripening period, the overall resistance will build up slowly from the initial (theoretical) value of a clear sand bed, but at a later phase of filter run it will increase very sharply. In normal design, the permissible had loss should not exceed 1 to 1.5 m and sand bed is from 0.6 to 1.2 m.

Factors Affecting Filtrate Quality

The following factors will influence filtrate quality

i) the properties of the applied water,
ii) filtration rate, and
iii) the composition of filter bed.

The climatic condition also affects effluent quality, in tropical areas where the range of variation in temperature is very small, the effects of temperature on effluent quality are negligible.

The Properties of Applied Water

ASCE MANUAL No. 19 stated that filtrability is the most importance property of the applied water. It is related to the nature, size concentration and adhesive qualities of the suspended and colloidal impurities in the water. The higher the filtrability is the greater the clarity of filtrate will be.

ROBERT (1964) suggested that if the turbidity of influent is less than 25 JTU, flocculation and sedimentation may be omitted in the filtration system. However, influent with low oxygen level or high in oxygen demand is not suitable for slow filtration because of the anaerobic reaction and taste and odor problems will result.

HUISMAN & WOOD (1974) said that the turbidity range 10 to 50 mg/l (SiO_2) of water will give longer filter runs, and better treatment efficiency. Pretreatment may be used when the applied water quality fluctuates widely and frequently.

The Effects of Filtration Rate

HUDSON (1956) reported that the penetration of suspended matter into the bed seems to be directly proportional to the filtration rate. Filters operated under unsteady flow conditions cannot produce good water. HUDSON (1958) noted that higher filtration rates shorten the filter runs. More than twice as much turbidity in the effluent of a filter operated at 4 gpm rate can be expected as in the effluent from one operated at 2 gpm rate.

CLEASBY & BAUMANN (1961) suggested that the filtration rate was a function of the type of applied water, and that deposition of materials within the pores of the filter resulted in a linear head loss development.

SECALL & OKUN (1966) concluded that the effect of filtration rate on filtrate quality was also a function of media grain size and porosity. Higher filtration rate has less effect on the sand than on the anthracite filter because sand has smaller size porosity than that of anthracite. JAKSIRINONT (1972) claimed that the duration of a run at any constant depth of media (coconut husk fiber) at a filtration rate of 1.25 m^3/m^2-h was twice than that at filtration rate of 2.5 m^3/m^2-h. At same length of filter runs and constant filtration rate, filter efficiency increases with greater bed depth.

HUISMAN & WOOD (1974) noted that straining efficiency in a slow sand filter is independent of flow rate and a decrease in sedimentation efficiency accompanying a higher filtration rate is likely to have little influence on the turbidity of the final effluent. The biological activity is time-dependent and higher filtration rates will lower the constant period between water and the purifying microorganisms. A breakthrough of organic matter into the effluent may occur if the velocity of flow is too high. They also claimed that the effluent quality depends largely on the grain size of the filtering medium but not on filtration rate.

The Composition of Filter Bed

The properties of the filter bed that affect the efficiency of the filter include the size and shape of the grains; the porosity of the bed; the arrangement of grains; the depth of the bed; and the head loss through the bed. In general, filter efficiency increases with smaller grain size, lower porosity, and greater bed depth. Because of smaller grain size and lower porosity, the coarse-to-fine filter is more efficient than a fine-to-coarse filter.

HUISMAN & WOOD (1974) noted that effluent quality depends largely on the grain size of the filtering medium. Filter sand should not normally be finer than necessary, otherwise the filter runs will be unduly short. In traditional slow sand filters, the depth of the filter bed is 0.6 to 1.2 m. The flow in slow sand filter is obeyed Darcy's law.

$$H = (V_f/k) \times h$$

where,
H = bed resistance
V_f = filtration rate
k = coefficient of permeability m/h
h = depth of bed
and k = f(porosity, sphericity, size and temperature)

If depth h increases, bed resistance H also increases and velocity of flow and rate of filtration decreases at the same time.

HUDSON (1958) concluded that if filtration rate and media characteristics remain the same, the greater depth of bed will produce better quality of effluent.

Mathematically,

$$n_q = f(d),\ Q,V,T = \text{constant}$$

where,
n_q = efficiency of removal
d = depth of bed
Q = flow rate
V = media character
T = temperature

JAKSIRINONT (1972) recorded that two-stage filters using coconut husk fiber of 40 to 80 cm in depth as roughing filter and burnt rice husk of the same range of depth as polishing filter, with filtration rates of 0.1 to 2.5 m^3/m^2-h and maximum duration of runs of 250 hr (more than 10 days) can produce effluent quality which meets WHO (1971) recommended standards for drinking water in terms of turbidity, color, taste and odor.

THANH and PESCOD (1976) reported the cost estimation of different slow filter systems as shown in Table 2.2 and the application of slow filtration for surface water treatment in tropical developing countries. From the Table 2.2, the dual media filter system has the lower cost than the series filter system regarding the capital cost and operating cost. They also suggested that the dual media filter consisting burnt rice husk and sand is the best slow filtration system for treatment of tropical surface waters in rural areas.

Table 2.2 - Comparative Initial Costs and Operating Costs of Different Filter Systems

Items	Alternative A	Alternative B	Alternative C	Alternative D
Capital Cost Baht (฿)	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 Serves	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

Alternative A : Coconut fiber-burnt rice husk (series)
Alternative B : Coconut fiber-burnt rice husk (dual media)
Alternative C : Burnt rice husk-sand (dual media)
Alternative D : Burnt rice husk-sand (series)

฿1.00 = U.S.$0.05

III EXPERIMENTAL INVESTIGATION

Raw Water Source

The raw water was the canal (klong) water near the Regional Engineering Research Center of the Asian Institute of Technology. Under normal conditions the turbidity of the water was low, at an average of 30 JTU. High turbidity was recorded in the rainy days due to the surface runoff from the surrounding areas, which carried silt and soil into the klong. In normal days, the increase in turbidity up to 150 JTU could be induced by the turbulence in the muddy bottom to meet the study requirement. The turbulence was created by the portion of the supplied water which was pumped by a 10 hp centrifugal pump (P_1 in Fig. 3.1). The intake system layout is shown in Fig. A1 in Appendix A.

Pilot Plant Set-Up

The layout of the plant, as shown in Fig. 3.1 was composed of:

- Reserve tanks
- Pumping units
- Filtration units

Reserve Tanks

Two galvanized iron tanks (R_1T) each having a volume of 1.0 m^3 (1m x 1m x 1m) were used to receive water from the klong for the supplying of raw water to the roughing filters (R_1 and R_2) filled up by the centrifugal pump P_1 before it was started in the next day which was the required step of the operation of a centrifugal pump to achieve good suction.

Pumping Units

In Fig. 3.1, the 10 hp centrifugal pump P_1 was used to supply raw water to the reserve tanks. A 2.0 KW piston pump P_2 of capacity 100 l/min was used to pump the water from the reserve tank up to the roughing filters. The 1.0 hp centrifugal pump P_3 was served as the standby pump. A 5.24 cm ϕ bypass pipe was used to control the output of the pumps P_2 and P_3.

Filtration Units

The filtration units consisted of two systems of filters, the series filters (R_1-F_1 and R_2-F_2) and the dual media filters (F_3 and F_4) as shown in Fig. 3.4. Table 3.1 presents the components of the series filters and dual media filters.

The series filters set-up is shown in Fig. 3.1 and 3.2, two roughing filters (R_1 and R_2) were placed on a 1.40 m high wooden stand and connected to two polishing filters (F_1 and F_2). The connection was R_1-F_1 and R_2-F_2, formed two series filters. The influent of the dual media filters was supplied from the R_2 roughing filter outlet just above the

Table 3.1 - Components of the Series and Dual Media Filters

	Roughing filter	Polishing filter	Dual media filter
Material	0.32 cm thick galvanized iron	1.54 m I.D. concrete sewer pipe	1.54 m I.D. concrete sewer pipe
Height	2 m	3 m	3 m
Surface area(m^2)	1.0	1.87	1.87
Media	R_1 : coconut fiber R_2 : CF-BRH	F_1 : BRH F_2 : Sand	F_3 : BRH-Sand F_4 : CF-BRH
Depth of Media	R_1 : 0.8 m (Phase I) R_2 : 0.1-0.7 m	F_1 : F_2 : 0.8 m	F_3 : F_4 : 0.8-0.6 m
	R_1 : 0.4 m (PhaseII) R_2 : 0.2-0.2 m	F_1 : F_2 : 0.8 m	F_3 : F_4 : 0.8-0.6 m
Supernatant	0.8 m (Phase I) 1.2 m (Phase II)	0.6 m	0.6 m
Crushed stone underdrain (grading)	0.1 m (12.7-25.4 mm)	0.1 m (6.4-12.7 mm) 0.1 m (12.7-19.1 mm) 0.1 m (19.1-25.4 mm)	0.1 m (6.4-12.7 mm) 0.1 m (12.7-19.1 mm) 0.1 m (19.1-25.4 mm)
Freeboard above supernatent water	0.3 m	0.7 m	0.7 m

CF = Coconut fiber; BRH = Burnt rice husk

surface level of the filtering medium. The constant water level in each filter, which was above the filter bed was held by an overflow pipe, 5.24 cm ϕ PVC pipe. The water from the roughing filters was supplied through perforated distributors each having ten 0.5 cm openings to the polishing filters and dual media filters (see Fig. 3.2). Each filter was equipped with rotameter and gate valve to control and measure the filtration rate. The headloss across the filter bed was measured by monometer.

Filter Media Characteristics

Mill shredded coconut fiber before being placed in filter was soaked in water for at least 24 hours and washed to remove the organic colour and impurities.

Sieve analysis results of burnt rice husk and stock sand are presented in Fig. A4. in Appendix A and their characteristics were summarized in Table 3.2. The effective size of the burnt rice husk was 0.90 mm

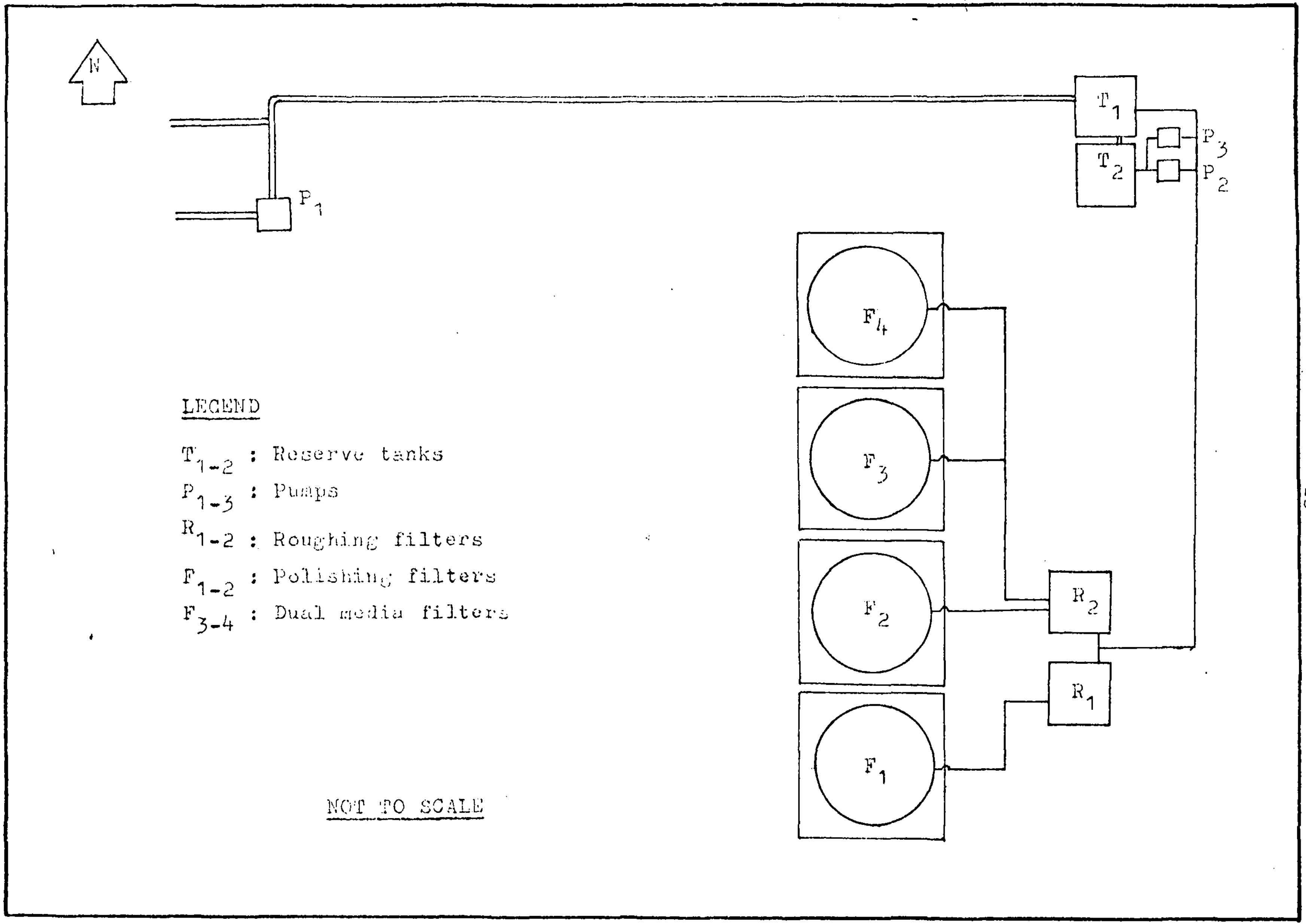


Fig. 3.1 - Plan View for Pilot Plant Set-Up

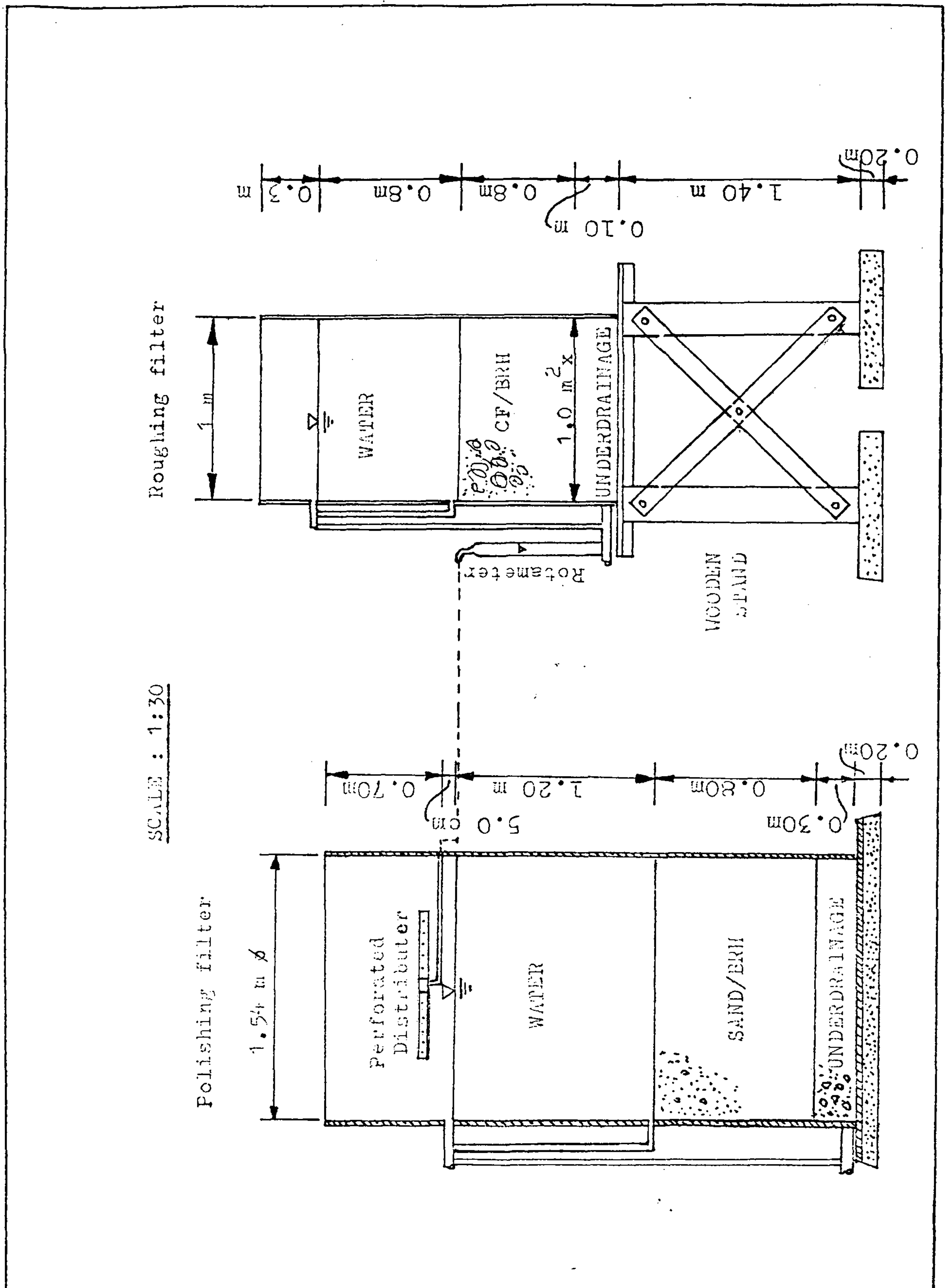


Fig. 3.2 - Series Filter Set-Up

Table 3.2 - Filter Media Characteristics

Media	Shape	E, mm	U	Sp. Gr.	Charge	Remarks
Sand	Rounded/oval/ granular	0.55	1.86	2.65	Negative	Silica-SiO_2 insoluble in acid but sometimes soluble in alkali
Burnt rice husk	Cellular, Crystalline silica	0.90	5.8	2.30	Probably negative	SiO_2 = 90% Mg, Pe and Ca = 6-7% organic matter =3-4% has adsorptive power as activated carbon

E = Effective Size
U = Uniformity Coefficient
Sp.Gr. = Specific Gravity

with uniformity coefficient of 5.80 while effective size of stock sand was 0.35 mm and its uniformity coefficient was 1.86.

Underdrainage System

The bottom of the four filters F_1, F_2, F_3 and F_4 were designed with a 1:25 slope for easy drainage of the treated water. The underdrainage was composed of 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. The underdrainage system of the roughing filters, R_1 and R_2 was made of 10 cm layer of crushed stone with grading of 12.7 ~ 25.4 mm.

Experimental Design Parameters

Independent Variables - The following were the independent variables:

(1) Raw water quality: turbidity, pH, temperature, alkalinity, dissolved oxygen content, total coliform, faecal coliform, faecal streptococcus contents.

(2) Filtration rate.

(3) Size, type and depth of media.

Among the parameters, the raw water quality was uncontrollable.

Dependent Variables - The evaluation of the filters performance was based on the following dependent variables:

(1) Head loss in filters.

(2) Removal efficiencies of turbidity, faecal coliform, faecal streptococcus and total coliform.

(3) Duration of filter run. The run length was concluded when at least one of the following criteria was fulfilled:

(a) Development of 0.8 m headloss in roughing filter
(b) Development of 1.2 m headloss in polishing filter
(c) Development of 0.6 m headloss in dual media filter
(d) Final treated water turbidity was more than 25 JTU
(e) Bad odor or zero D.O. content was detected from the effluent

Schedule of Study

The experiment was carried out into two phases. In the phase I, the filters were operated discontinuously with filtration rate of 0.15 m^3/m^2-h for the slow filters and 0.4 m^3/m^2-h for the roughing filters. In the phase II, the filters were operated continuously but with very slow flow rate in the night time (the off period in phase I) from 4:00 P.M. to 8:00 A.M. Phase I was designed to investigate the feasibility of the discontinuous operation of the slow filters regarding their performance in term of turbidity removal, filter run and bacterial removal. Phase II was to find out the turbidity removal efficiency and head loss development of the filters. In either case the pumps were operated only 8 hours a day, from 8:00 A.M. to 4:00 P.M. Summary of the schedule of study are shown in Fig. 3.3a and 3.3b.

Experimental Procedure and Sample Analysis

In Table 3.4 is the summarized of the tests and methods performanced in this study. They were carried out according to "Standard Method" proposed by APHA et al. (1971), except the measurement of headloss and filtration rate.

Table 3.4 - Test Measurements on the Performance of Filter

Component	Interval between Measurement	Method of Measurement
Turbidity	8 h	Hatch Turbidimeter
Temperature	8 h	Thermometer
pH	8 h	pH-meter
Alkalinity	3 or 4 days	Titration
MPN	3 or 4 days	Multiple tubes
Faecal coliform	3 or 4 days	Plate count
Faecal streptococcus	3 or 4 days	Multiple tubes
Filtration rate	8* h	Rotameter
D.O.	8 h	Standard method
COD total	7 days	Titration
BOD_5	7 days	Standard method
Sand	-	Sieve analysis
Head loss	8 h	Manometer

* Adjusted every 8 hr

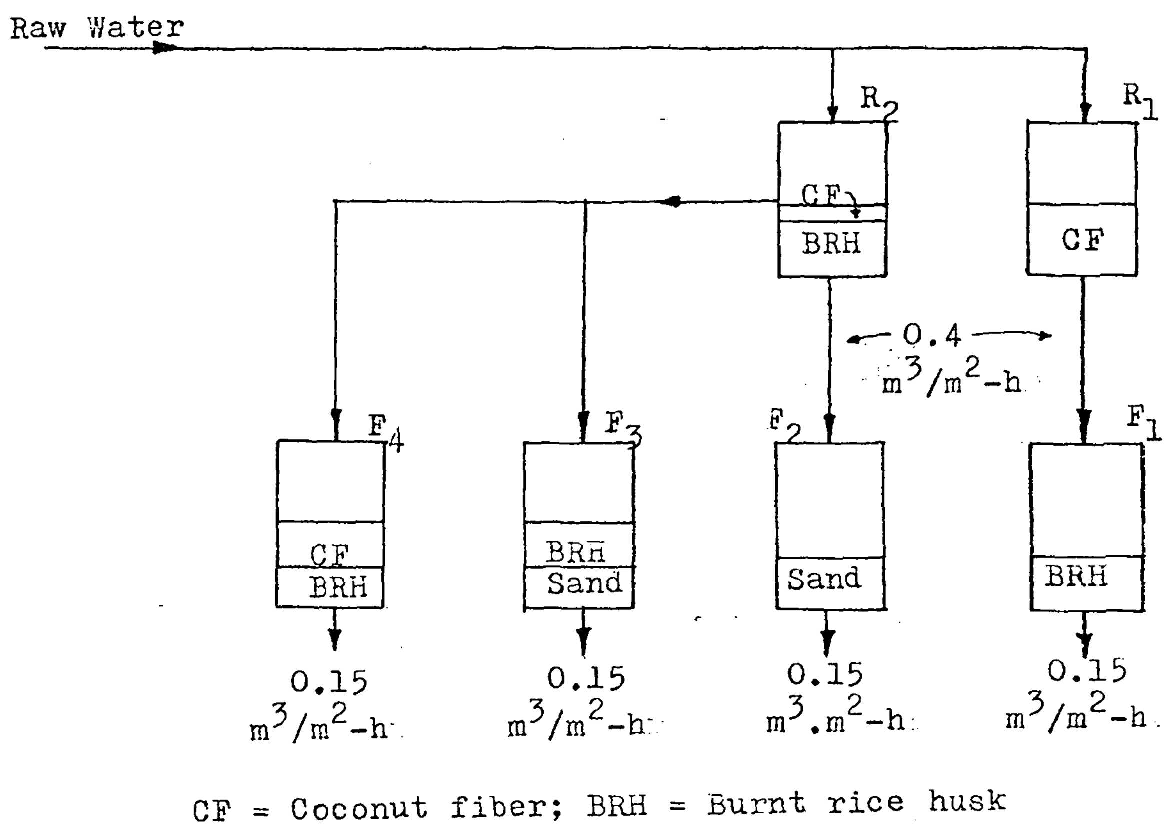
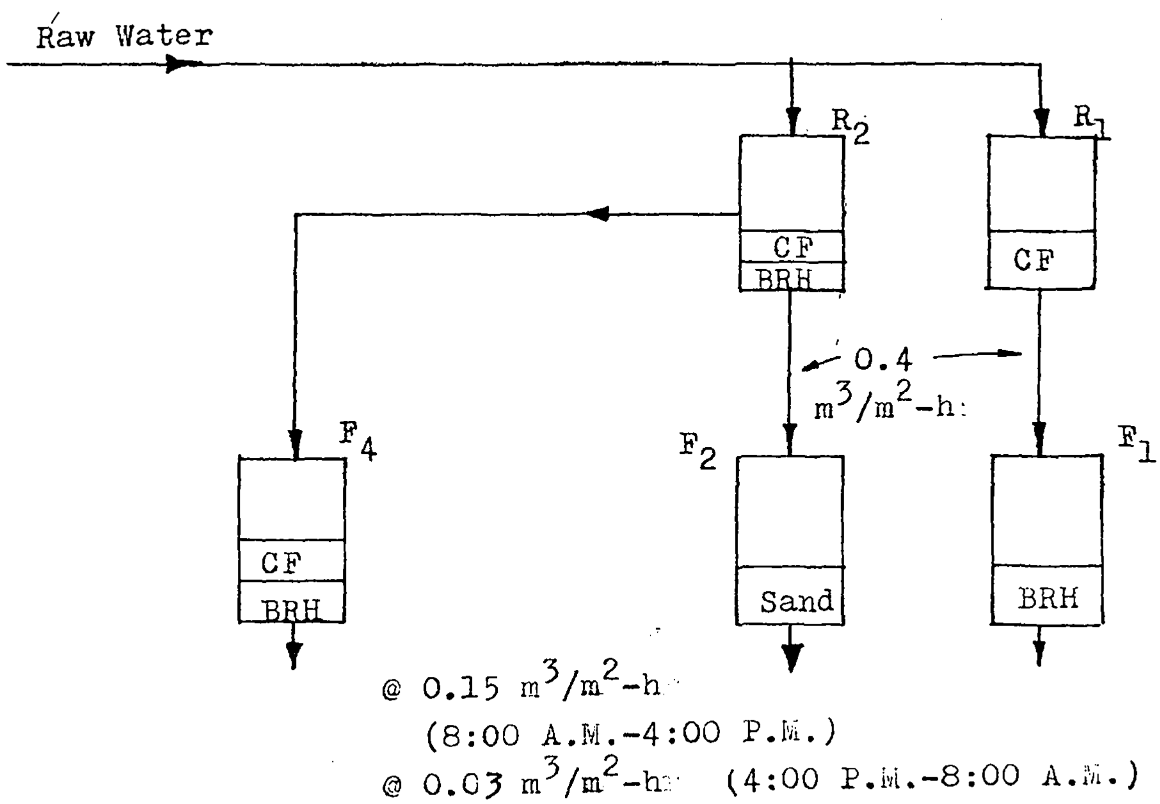


Fig. 3.3a - Flow Diagram of Series-Filtration and Dual Media Filtration Systems in Phase I



CF = Coconut fiber; BRH = Burnt rice husk

Fig. 3.3b - Flow Diagram of Series-Filtration and Dual Media Filtration Systems in Phase II

Fig. 3.4 - Experimental Pilot Plant

R_1 & R_2 : Roughing Filters

F_1 & F_2 : Polishing Filters

F_3 & F_4 : Dual Media Filters

P_1 : Pump for Reserve Tank - 10 hp Centrifugal Pump

P_2 : Pump for Roughing Filters

P_3 : Stand-by Pump for Roughing Filters

RT : Reserve Tank

Control Operation

In phase I, the discontinuous operation of filters, all the gate valves were opened to maintain designed filtration rates from 8:00 A.M. to 4:00 P.M., then closed for 16 hours from 4:00 P.M. to 8:00 A.M. The pumps were also operated for only 8 hours in day time. In phase II, the operation was changed by open the gate valves in the series filtration units from 4:00 P.M. to 8:00 A.M. to allow very low flow of water which was designed to maintain the constant water head in the polishing filters and continuous running of the water through the filter bed. The day time operation was the same as in phase I.

Cleaning and Maintenance

The rotameters were covered with black rubber sheets to prevent the penetration of sunlight which give birth to algae. They were cleaned after each run. The pumps were cleaned and oiled once a month.

The media in roughing filters and in dual media filter were removed manually after the runs were concluded. The cleaning of polishing media was carried out by manually scrapping off the surface layer to a depth of 1-2 cm in the case of sand bed, and 2-3 cm in the case of burnt rice husk bed since it was believed that the impurities in raw water were deposited to a greater depth in the latter filtering media due to its porous nature. At the time of cleaning, water level in the polishing and dual media filters was maintained below the surface of the filter bed. After cleaning, water level was kept high to overflow so that partially burnt rice husk with ashes, dust in sand float up and drained out by a 5.24 cm ϕ siphons.

IV PRESENTATION AND DISCUSSION OF RESULTS

The study was carried out from June 1976 to November 1976 with two types of operation system as mentioned in the previous chapter. Discussion and comparison on the findings are supplemented by the data and results presented in the forms of tables and graphs.

Phase I - Discontinuous Operation

The variation of turbidity in raw water is shown in Fig. 4.1a. The turbidity ranged from 11 JTU to 150 JTU having an overall mean of 45.6 JTU over the test period from August 1976 to October 1976. High turbidity and low alkalinity occurred during the rainy days due to the drainage of soil and clay with the surface runoff into the klong. The pH of raw water ranged from 6.9 to 7.6 and the differences in pH between the filtered water and raw water was insignificant. The temperature of raw water ranged from 23.5°C to 34.0°C, higher values were obtained in the mid-day. The differences in temperature of the filtered water and raw water was negligible. The DO contents of all the filters effluents and raw water are recorded in Table 4.1 and their characteristics are summarized in Table 4.2.

Performance of the Series-Filtration System

The series-filtration system consisted of two identical tanks as roughing filters (R_1 and R_2) to remove most of gross turbidity for subsequent treatment by polishing filters (F_1 and F_2). Roughing filter R_1 was connected to burnt rice husk polishing filter F_1, and roughing filter R_2 was connected to sand polishing filter F_2. The filtration rate of the polishing filters was 0.15 m^3/m^2-h while that of roughing filters was controlled at about 0.4 m^3/m^2-h just to maintain the constant head of the supernatant water in the polishing filters. The detention time of water in the polishing filters was 31.3 hours, and 20.2 hours for roughing filters. These was due to the off-period of 16 hours had been applied. As previously mentioned, the system was operated from 8:00 a.m. to 4:00 p.m. and then stopped from 4:00 p.m. to 8:00 a.m.

Roughing Filters

The roughing filters were operated at 0.4 m^3/m^2-h filtration rate. The variation of turbidity in the effluent of the roughing filters showed no significant difference as seen in Fig. 4.1a. There is discontinuity of the time-turbidity curve in the 11th day, because of the pump failure resulting in no data being obtained for that day.

The turbidity in the effluent from the coconut husk fiber roughing filter R_1 ranged from 10 JTU to 54 JTU with an arithmetic mean of 25.8 JTU in the first 23 days of operation revealing a 59% of turbidity removal efficiency. From 24th day to 67th day, the turbidity ranged from 0.7 JTU to 40 JTU with a mean of 8.9 JTU and 76.4% of removal efficiency. For the

Table 4.1 - Dissolved Oxygen Content in Raw and Filtered Water

Run Duration Days	Date	Raw Water	R_1 @ 0.4 m^3/m^2-h	F_1 @ 0.15 m^3/m^2-h	R_2 @ 0.4 m^3/m^2-h	F_2 @ 0.15 m^3/m^2-h	F_3 @ 0.15 m^3/m^2-h	F_4 @ 0.15 m^3/m^2-h
1	22-8-76	3.4	0.7	0.5	0.1	1.1	0.5	1.8
2	23-8-76	3.6	0.5	0.5	0.7	1.0	1.3	1.9
3	24-8-76	4.0	0.1	0.4	0.6	0.9	1.3	1.8
5*	26-8-76	3.6	3.6	0.8	2.1	1.5	1.2	0.9
7	28-8-76	5.2	4.6	0.6	3.3	2.3	0.9	0.5
8	29-8-76	3.4	4.0	0.5	3.2	2.4	0.8	0.5
10	31-8-76	5.0	4.0	0.7	3.0	2.0	1.0	0.5
12	2-9-76	4.0	2.5	0.6	1.0	2.4	0.5	0.4
13	3-9-76	4.5	1.4	0.5	1.2	0.8	0.5	0.4
14	4-9-76	5.0	1.0	0.4	1.1	0.6	0.5	0.4
15	5-9-76	4.5	0.9	0.4	0.8	0.9	0.5	0.2
16	6-9-76	5.5	1.1	0.5	1.1	2.0	0.5	0.3
17	7-9-76	3.3	3.0	0.5	1.0	1.3	0.7	1.2
18	8-9-76	4.8	1.9	0.6	0.8	1.5	0.6	0.4
19	9-9-76	5.6	2.8	1.8	1.2	1.0	0.6	0.4
20	10-9-76	5.0	3.0	1.8	1.0	1.0	0.7	0.4
21	11-9-76	5.5	2.0	1.8	1.0	1.2	0.8	0.3
22**	12-9-76	5.9	1.2	1.8	1.1	1.4	1.1	0.3
23	13-9-76	5.8	1.1	1.8	1.2	1.4	1.1	0.8
24	14-9-76	5.5	1.0	1.6	1.0	1.0	1.1	0.6
25	15-9-76	3.9	1.2	1.4	0.8	1.2	1.0	0.5
26	16-9-76	4.2	1.0	1.4	1.0	1.3	1.0	0.5
27	17-9-76	6.0	1.1	1.4	1.1	1.5	1.1	0.5
28	18-9-76	3.5	1.1	1.5	0.9	1.2	0.9	0.4
29	19-9-76	5.8	1.0	1.4	0.8	1.2	0.8	0.5
30	20-9-76	5.4	1.0	1.6	0.8	1.2	0.7	0.4
31	21-9-76	3.9	0.4	2.1	0.7	1.1	0.7	0.4
32	22-9-76	3.7	0.3	2.0	1.2	1.8	0.7	0.5
33	23-9-76	5.5	0.3	2.1	0.8	2.2	1.6	0.8
34	24-9-76	3.1	0.4	1.9	0.5	1.3	0.8	0.8
35	25-9-76	5.3	0.4	1.8	0.7	1.4	0.7	0.2
36	26-9-76	5.3	0.4	1.4	0.6	1.0	1.2	0.2
37	27-9-76	5.1	0.9	2.0	0.4	1.7	1.7	0.2

Cont'd/

Legend
* Replaced new coconut fiber in R_1
** Odor detected in F_4 effluent in 22nd day

Continued

Run Duration days	Date	Raw Water		R_1 @ 0.4 m^3/m^2-h		F_1 @ 0.15 m^3/m^2-h		R_2 @ 0.4 m^3/m^2-h		F_2 @ 0.15 m^3/m^2-h		F_3 @ 0.15 m^3/m^2-h		F_4 @ 0.15 m^3/m^2-h	
		M	E	M	E	M	E	M	E	M	E	M	E	M	E
38	28- 9-76	3.0	3.7	0.6	0.4	1.7	2.0	1.5	0.4	0.7	1.5	2.0	1.6	0.2	0.1
39	29- 9-76	1.4	2.9	0.1	0.3	2.1	1.9	0.6	0.5	0.6	0.9	1.7	1.6	0.1	0.1
40	30- 9-76	2.3	3.6	0.0	1.4	1.9	2.5	0.4	0.6	0.6	1.6	1.6	2.6	0.1	0.1
41	1-10-76	3.0	3.5	0.1	1.4	1.8	2.0	End				1.6	2.4	0.0	0.0
42	2-10-76	2.0	3.6	0.1	0.1	1.6	1.4	-		-		1.6	1.6	Shut off	
44	4-10-76	2.4	4.0	0.0	0.5	1.2	1.3	-		-		1.0	0.9	-	
45	5-10-76	2.4	4.2	0.1	0.2	0.6	0.6	-		-		0.9	0.8	-	
46	6-10-76	3.0	3.9	0.1	0.2	0.5	0.4	-		-		0.9	0.8	-	
47	7-10-76	2.5	4.0	0.3	0.2	0.3	0.2	-	0.9	-	2.2	0.9	1.0	-	
48	8-10-76	2.6	4.3	0.1	0.2	0.4	0.3	-	0.8	-	2.1	0.9	1.1	-	
49	9-10-76	2.4	5.0	0.1	0.3	0.4	0.3	0.4	0.8	1.2	2.1	1.0	0.9	-	
50	10-10-76	2.5	4.2	0.0	0.0	0.3	0.4	0.3	0.7	0.9	1.3	0.9	0.8	-	
51#	11-10-76	2.6	4.2	0.0	0.0	0.4	0.3	0.3	0.8	0.7	0.9	0.9	0.9	-	
52	12-10-76	2.9	5.8	0.0	0.5	0.7	0.9	0.2	1.0	0.7	1.0	0.7	0.8	-	
53	13-10-76	4.9	3.9	0.0	0.5	0.2	0.6	0.2	0.6	0.9	0.8	0.7	1.0	-	
54	14-10-76	4.2	4.2	0.0	0.3	0.6	0.3	0.6	1.3	1.1	1.3	0.9	0.7	-	
55	15-10-76	3.1	3.6	0.0	0.2	0.6	0.3	0.5	1.1	1.0	2.3	0.9	1.0	-	
56	16-10-76	2.8	3.9	0.0	0.1	0.6	0.2	0.4	0.9	0.6	0.8	1.0	1.1	-	
57	17-10-76	2.8	4.9	0.0	0.1	1.1	0.5	0.7	0.5	0.6	0.4	0.9	1.0	-	
58	18-10-76	4.4	3.9	0.0	0.2	0.3	0.5	0.7	0.5	0.6	0.4	0.9	0.7	-	
59	19-10-76	5.4	5.6	0.0	0.2	0.4	0.2	0.9	0.9	0.7	1.5	0.8	1.1	-	
60	20-10-76	3.9	4.5	0.0	0.2	0.4	0.2	0.7	0.7	1.0	2.0	0.5	0.8	-	
61	21-10-76	3.3	4.4	0.0	0.3	0.4	0.2	0.9	0.9	0.7	1.3	0.9	0.8	-	
62	22-10-76	3.5	3.7	0.0	0.7	0.3	0.2	1.3	1.3	1.3	1.3	0.8	0.7	-	
63	23-10-76	3.8	4.0	0.0	0.2	0.3	0.2	End		Shuf off		0.8	0.7	-	
64	24-10-76	5.4	5.6	0.0	0.4	0.2	0.2	-		-		0.8	0.7	-	
65	25-10-76	4.2	5.0	0.0	0.1	0.2	0.2	-		-		0.5	0.4	-	
66##	26-10-76	3.7	4.0	0.0	0.1	0.0	0.0	-		-		1.0	0.8	-	
67	27-10-76	5.3	4.3		Shut	off		-		-		0.6	1.2	-	
68	28-10-76	5.0	5.2	-		-		-		-		0.5	1.0	-	
69	29-10-76	4.0	5.0	-		-		-		-		0.6	0.6	-	
70	30-10-76	4.1	5.2	-		-		-		-		0.4	0.6	-	
71	31-10-76	3.9	5.1	-		-		-		-		0.4	0.6	-	
72	1-11-76	3.5	4.9	-		-		-		-		0.7	0.8	-	
												End			

<u>Legend</u>

- \# Odor detected in R_1 effluent in 50th day
- \## Odor detected in F_1 effluent in 66th day
- M Morning
- E Evening
- R_1 Coconut fiber roughing filter
- F_1 Burnt rice husk filter (series)
- R_2 Coconut fiber-burnt rice husk (10/70 cm) dual media roughing filter
- F_2 Sand filter (series)
- F_3 Burnt rice husk-sand dual media filter
- F_4 Coconut fiber-burnt rice husk dual media filter

Table 4.2 - Characteristics of Raw Water and Filtered Water in Brief (Phase I)

Test Period August-November 1976	Raw Water	R_1 @ 0.4 m^3/m^2-h	F_1 @ 0.15 m^3/m^2-h	R_2 @ 0.4 m^3/m^2-h	F_2 @ 0.15 m^3/m^2-h	F_3 @ 0.15 m^3/m^2-h	F_4 @ 0.15 m^3/m^2-h
Physical							
Temperature °C	23.5 ~ 34.0	23.0 ~ 35.0	25.0 ~ 32.0	23.0 ~ 35.0	25.0 ~ 32.0	26.0 ~ 32.0	
Turbidity JTU	11 ~ 150	0.7 ~ 54.0	0.2 ~ 10.0	0.6 ~ 29.0	0.2 ~ 11.0	0.6 ~ 48.0	0.2 ~ 16.0
Chemical							
Alkalinity mg/1 $CaCO_3$	60 ~ 174	68 ~ 174	84 ~ 186	78 ~ 184	80 ~ 187	76 ~ 186	80 ~ 186
pH	6.9 ~ 7.6	7.0 ~ 7.5	7.1 ~ 7.7	7.0 ~ 7.5	7.2 ~ 7.7	7.2 ~ 7.7	7.1 ~ 7.6
COD_T mg/1	13 ~ 26	10 ~ 20	2 ~ 4.5	20 ~ 32	10 ~ 24	2 ~ 13	6.5 ~ 15.0
D.O. mg/1	6.0 ~ 1.4	4.6 ~ 0.0	2.1 ~ 0.0	3.3 ~ 0.2	2.4 ~ 0.4	2.6 ~ 0.4	1.9 ~ 0.0
Bacteriological							
Total coliform, MPN/100 ml	2400 ~ 460	460 ~ 93	150 ~ < 3	460 ~ 75	150 ~ < 3	460 ~ 9	460 ~ 93
Faecal strepto-coccus MPN/100 ml	460 ~ 43	210 ~ 15	75 ~ < 3	150 ~ 4	43 ~ < 3	75 ~ 4	93 ~ 4
Faecal coliform colories/ml	136 ~ 6	16 ~ 0	1 ~ 0	20 ~ 0	1 ~ 0	2 ~ 0	1 ~ 0

Legend

R_1 = Coconut fiber roughing filter F_1 = Burnt rice husk filter (series)

R_2 = Coconut fiber-burnt rice husk (10/70 cm) dual media roughing filter

F_2 = Sand filter (series) F_3 = Burnt rice husk-sand dual media filter

F_4 = Coconut fiber-burnt rice husk dual media filter

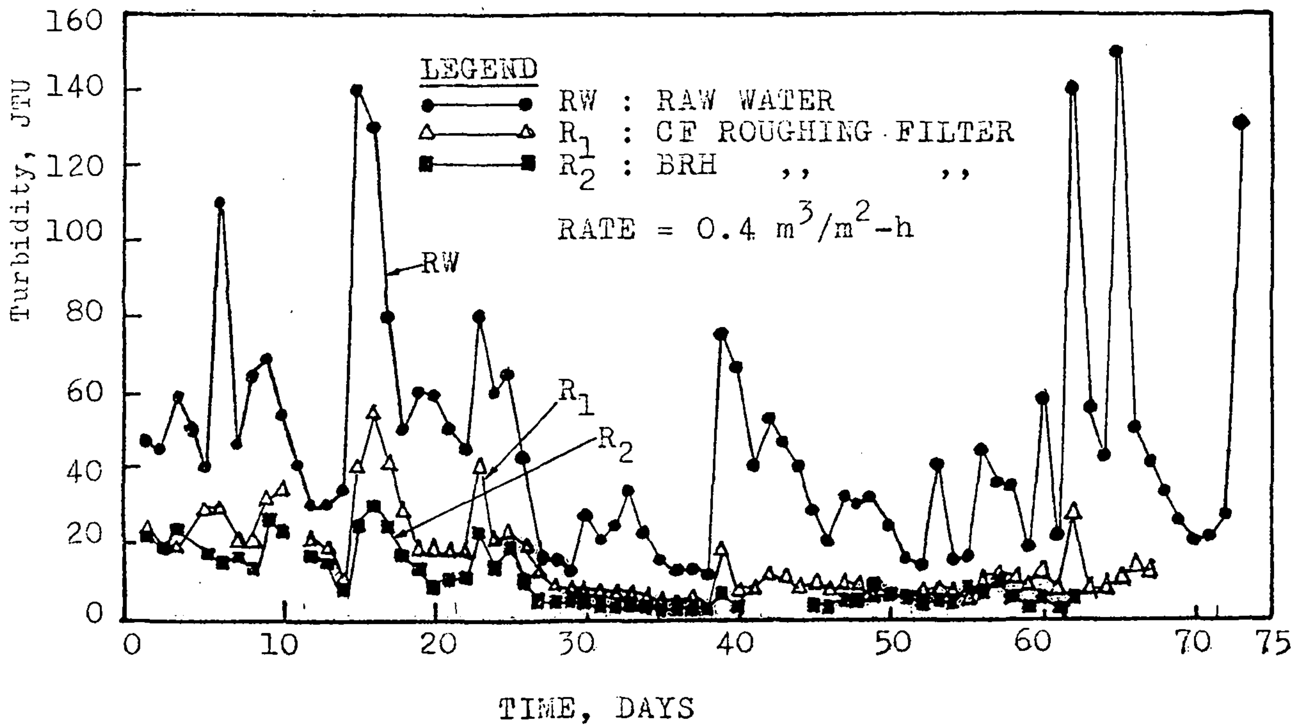


Fig. 4.1a Turbidity of Raw Water and Roughing Filters

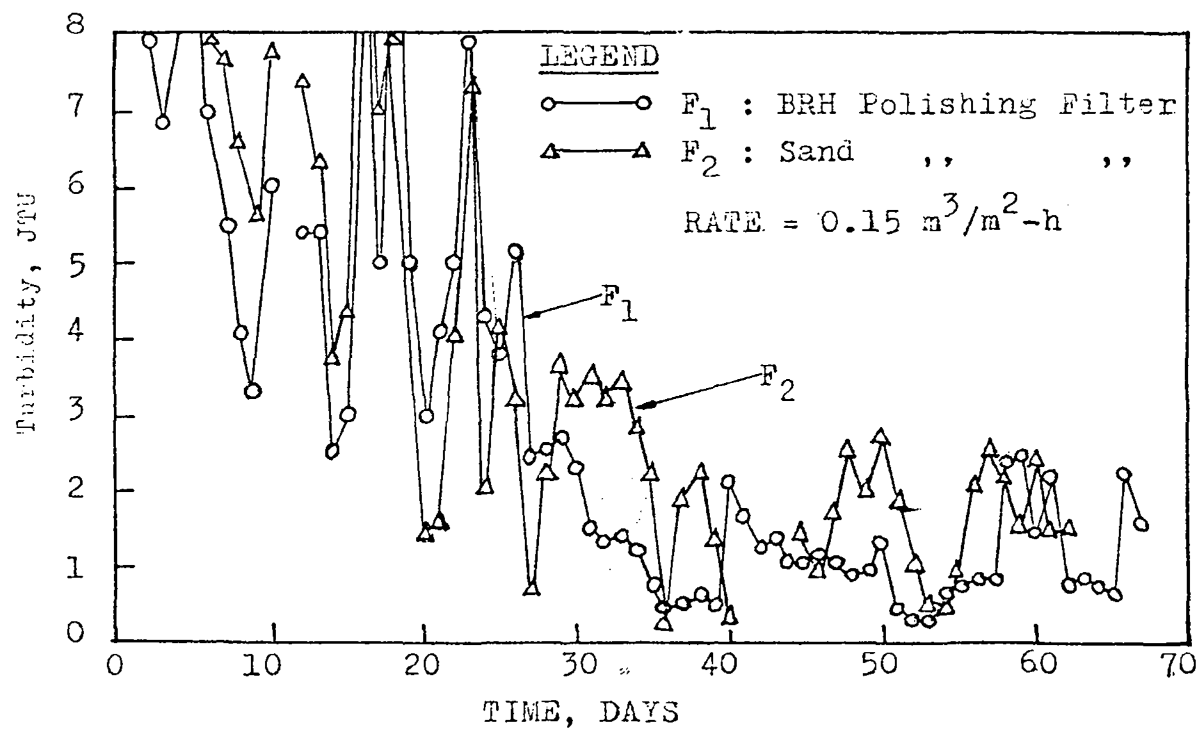


Fig. 4.1b Turbidity of Polishing Filters

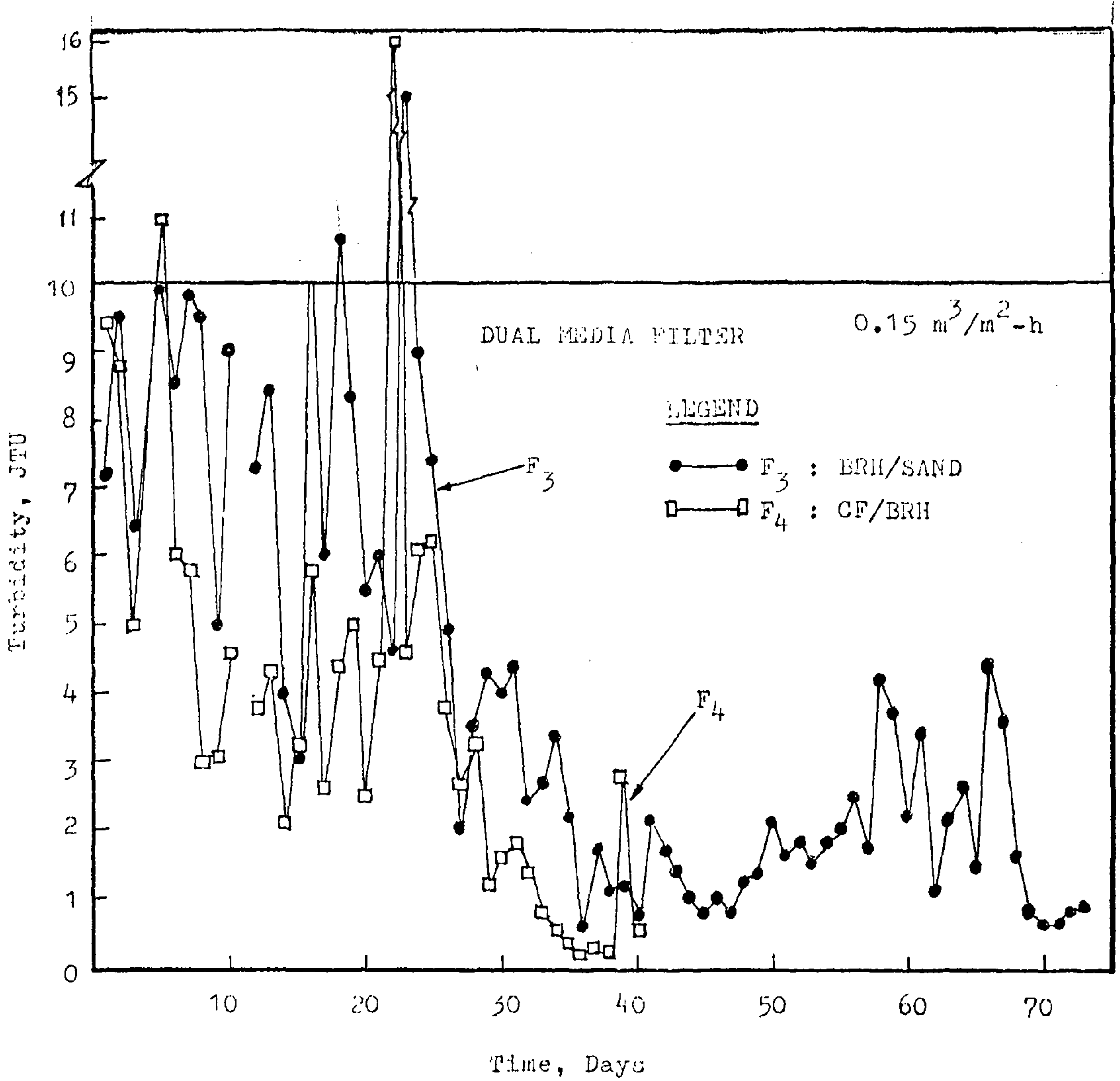


Fig. 4.1c - Turbidity of Dual Media Filters

overall period, the turbidity ranged from 0.7 JTU to 54 JTU with an overall mean of 14.3 JTU, denoting a 68.6% of turbidity removal efficiency (see Table A6). The R_1 filter run was terminated in the 68th day due to the strong odor being detected from the effluent, although the head loss was only 8 cm at that time. The odor was first detected in the 50th day and no D.O. content was recorded at the same time. It showed that the anaerobic condition was developed in the filter bed. The anaerobic condition prevailed in the filter and production of strong odor in the effluent affecting the subsequent slow burnt rice husk filter, which turned the polishing filter bed into anaerobic and forced the conclusion of the run of the slow filter in the 68th day.

The head loss development of the coconut fiber roughing filter was not constant and varied with time, as shown in Fig. 4.2a. The variation of head loss rate was due to the discontinuous operation of the filter. The total head loss after 67 days of operation was 8 cm. The rate of head loss build-up was approximately 6 cm/month, if linear regression was applied. If the head loss limit of 0.8 m was used as the only criteria for the termination of the filter run, then the filter would run for about a year, at the filtration rate of 0.4 m^3/m^2-h and employing discontinuous operation method. However, after 2 months of intermittent operation of the filter R_1, anaerobic conditions prevailed in the filter bed which causing the odor in the effluent. The filter then had to be shut off and the media to be changed.

In Fig. 4.1a, it can be seen that with filtration rate of 0.4 m^3/m^2-h, the turbidity of the roughing filter R_2 effluent was better than that in the R_1. In the first 40 days of operation, the turbidity in the R_2 effluent ranged from 0.6 JTU to 29 JTU with a mean of 12.1 JTU and a 75.1% of turbidity removal. From 45th day to 62nd day, the turbidity ranged from 2.2 JTU to 10 JTU with a mean of 5.2 JTU and a 84.8% of removal efficiency. The overall turbidity removal efficiency of the roughing filter R_2 was 79.0% and it was higher than that of the roughing filter R_1.

The head loss development of the roughing filter R_2 was not uniform and fluctuated with time as shown in Fig. 4.1a. In the first 3 day, the R_2 filter bed was only the burnt rice husk and the head loss was built up to the head loss limit (80 cm). It was then shut off and scrapping off of about 10 cm of the top layer of burnt rice husk and replaced with 10 cm of coconut fiber. The rapid clogging of the burnt rice husk bed can be explained by the existence of partially burnt rice husk and ashes on the surface of the bed and the relative high filtration rate of the roughing filter. The dual media roughing filter R_2 started functioning in the 5th day with initial head loss of 20 cm as shown in Fig. 4.1a. The head loss built up to 75 cm in the 53rd day, and terminated the filter run. The top layer of coconut fiber was removed in the 54th day and replaced with new coconut fiber and then restarted the filter again, but it lasts for only 7 days and shut off due to the head loss built up to 80 cm. The analysis for total coliform, faecal coliform and streptococcus faecalis have also been carried out on the pretreated water. The results are presented in Fig. 4.2, 4.3, 4.4 and Table A3, A4 and A5. It can be noted

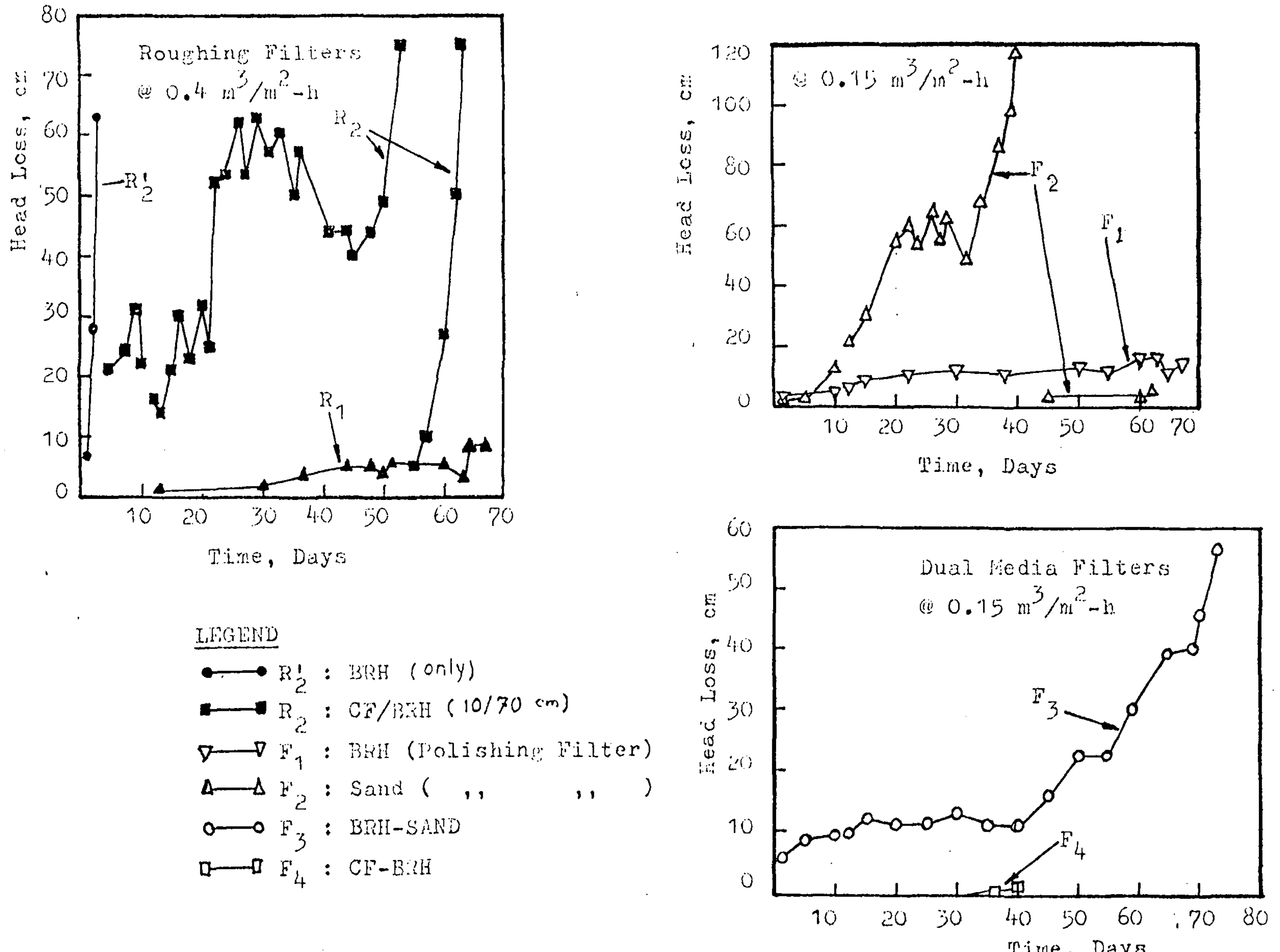


Fig. 4.2 - Head Loss Development in Different Filters

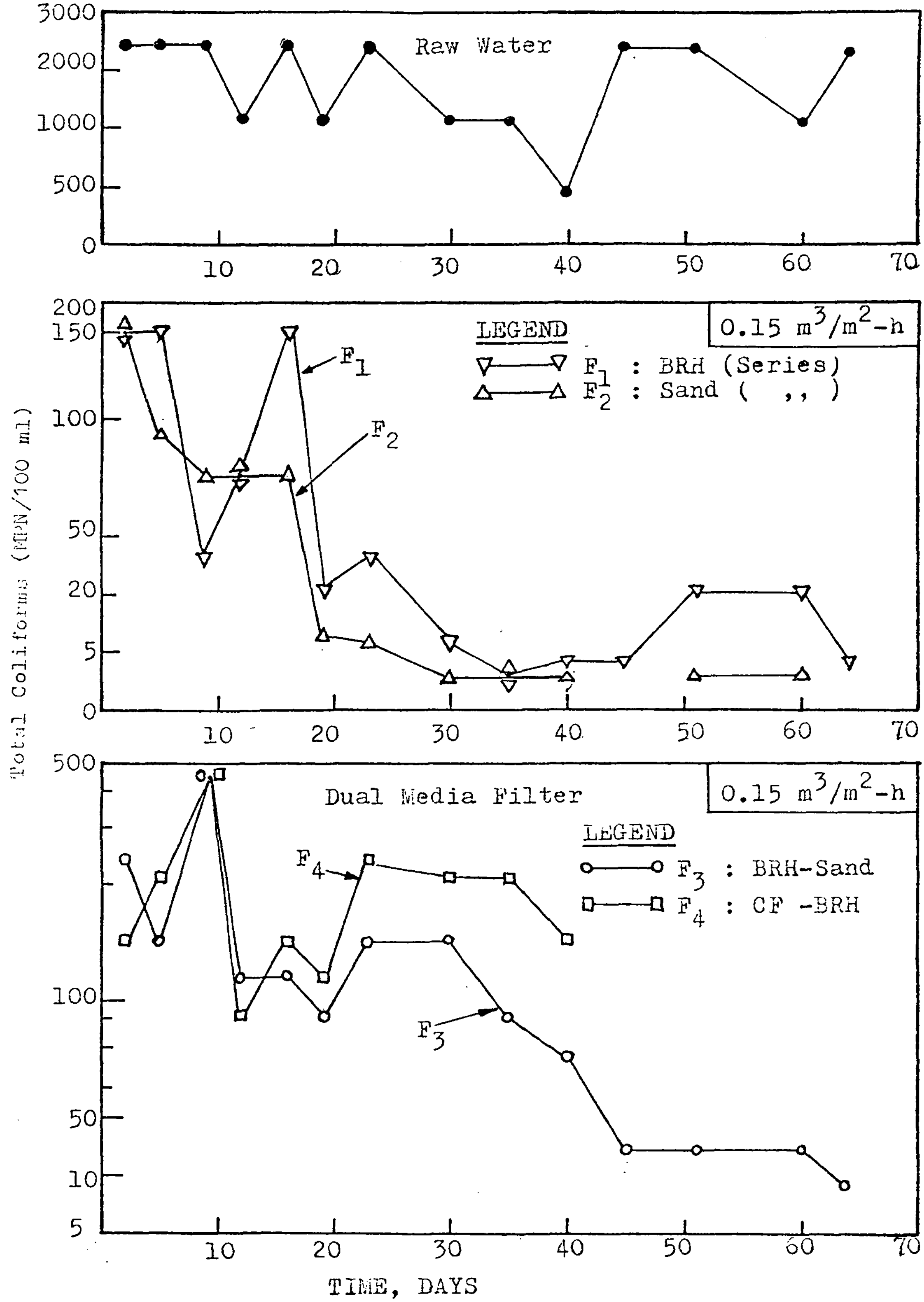


Fig. 4.3 Results of Total Coliform MPN Tests

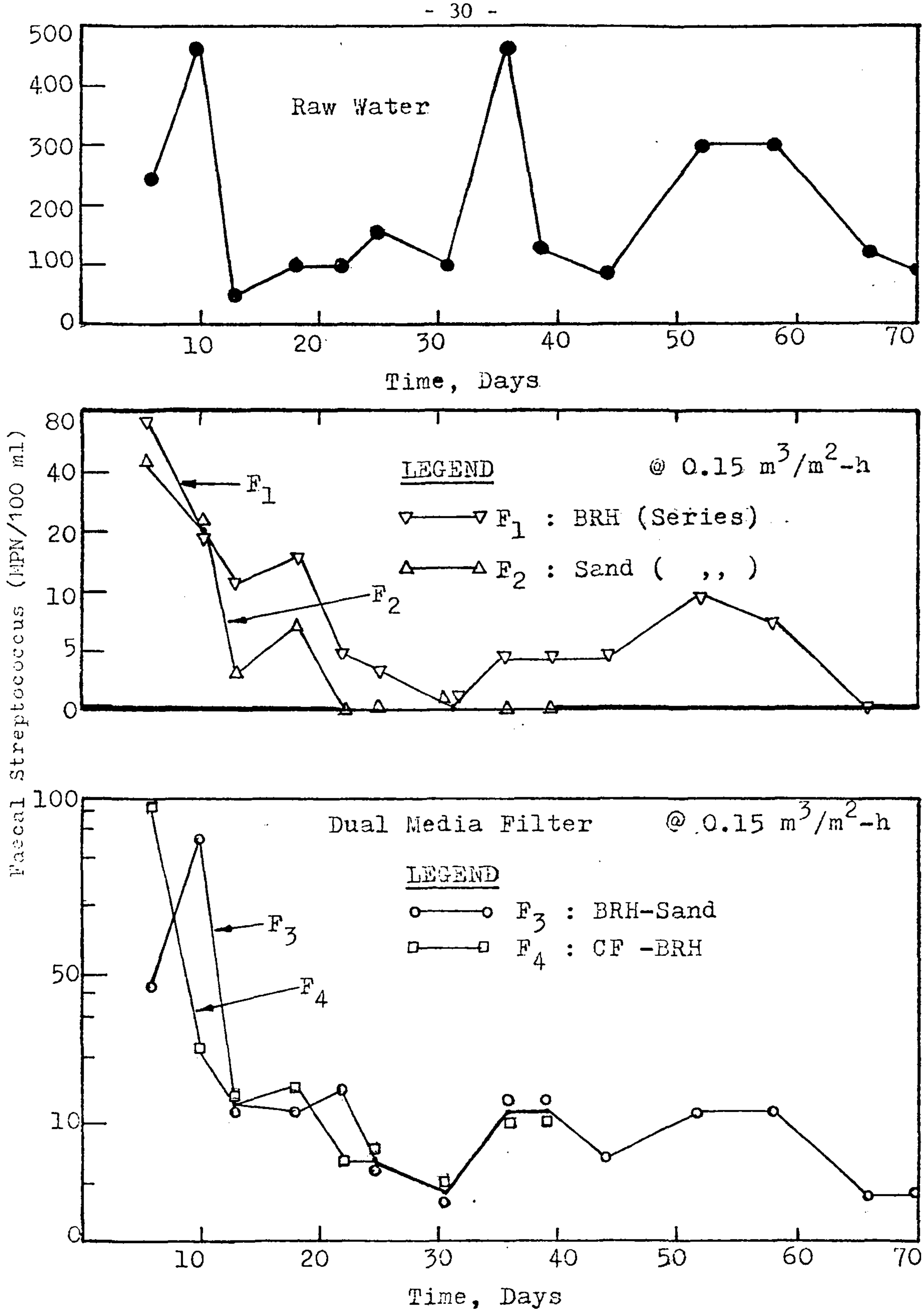


Fig. 4.4 Results of Faecal Streptococcus MPN Tests

that the roughing filters can removed more than 60% of the microorganisms in the raw water (see Table A6). Thus it can be seen that not only the roughing filters can reduce the raw water turbidity substantially, but also the microorganisms.

Table 4.1 presents the summary of the D.O. results of the raw water and filtered water, indicated that dissolved oxygen of the raw water was consumed by the bacteria and microorganisms inside the filters media. The D.O. contents in the raw water was ranged from 1.4 mg/l to 6.0 mg/l, with an overall mean of 4.2 mg/l. The D.O. in the R_1 effluent was 4.6 mg/l in the 7th day and gradually decreased to 1.0 mg/l at 30th day. Zero dissolved oxygen content and odor was detected from the R_1 effluent in the 50th and 51th day. The filter R_1 was kept on running until 66th day when odor was detected from the subsequent burnt rice husk polishing filter F_1 effluent. The anaerobic condition developed in the roughing filter R_1 bed after 50 days of operation but the condition was developed in polishing filter F_1 in the 66th day. This indicated that the development of anaerobic condition in F_1 filter bed was due to the very low D.O. influent, which was the effluent of roughing filter R_1.

The dissolved oxygen content in the effluent of the roughing filter R_2 was 3.3 mg/l in the 7th day and reduced to 1.0 mg/l at the 12th day. It then varied within ± 0.2 mg/l range at the 1.0 mg/l level until the 34th day. No anerobic condition was developed in the filter R_2 bed.

Burnt Rice Husk Filter (F_1)

The filtration rate of 0.15 m^3/m^2-h was kept constant and adjusted twice a day throughout the test period. This flow rate had also been applied for the other slow filters, sand and dual media filters (F_2, F_3 and F_4) for the comparison. In Fig. 4.2b, the head loss development across the filter bed as the operation progressed was slow with an approximate rate of 0.2 cm/day if linear regression is applied. Thus for a head loss limit of 1.2 m, the filter would operate for about a year employing the on and off operation and 0.15 m^3/m^2-h filtration rate if the head loss was the only criterion for the conclusion of filter run. The filter was shut down in the 67th day due to the odor detected in the effluent. The strong odor indicated that the filter bed was getting into anaerobic condition. This was caused by the very low D.O. effluent of the preceding coconut fiber roughing filter R_1 which was turned into anaerobic two weeks earlier. If the R_1 effluent has not affected the polishing filter bed so badly, the filter F_1 can run at least for another two months. THANH and PESCOD (1976) reported that this type of filter operated continuously at filtration rate of 0.1 m^3/m^2-h could last for about 4½ months.

The removal efficiency in terms of turbidity for the filter F_1 was 79.7% from the effluent of roughing filter. The polishing filter effluent turbidity ranged 0.2 JTU to 10 JTU with a mean of 2.9 JTU. The time turbidity curve is shown in Fig. 4.1b, the effluent turbidity was higher in the first 24 days with range of 2.5 JTU to 10 JTU and a mean of 5.9 JTU, denoting a 77% of turbidity removal efficiency, while in the period from the 25th day to 67th day, the turbidity ranged from 0.2 JTU to 5.1 JTU with an arithmetic mean of 1.4 JTU and a 84.3% of removal efficiency. The removal efficiency mentioned above was obtained by comparing the effluent of the roughing filter with the effluent of the polishing filter. The turbidity removal efficiency of the coconut fiber-burnt rice husk series filtration system was 93.7% with effluent turbidity ranged from 0.2 JTU to 10 JTU and a mean of 2.9 JTU. The high turbidity in the first 24 days as shown in Fig. 4.1b indicated that longer ripening period for the burnt rice husk filter is required.

The mean total coliform removal efficiency of the R_1-F_1 series filter was 97.2% and the total coliform in the effluent ranged from less than 3 MPN/100 ml to 150 MPN/100 ml. As shown in the Fig. 4.3 the total coliform removal of the filter performed were after 19 days of operation. This is due probably to the slow formation of the bio-layer inside the filter bed. The bacteriological performance in term of faecal streptococci removal of the filter was 93.6% and the removal efficiency was increased sharply after 18 days of operation. The effluent was free of faecal coliform (E. Coli) after 20 days of operation. In the first 20 days, the faecal coliform content was 1 colany/ml. The effluent of the series filter (R_1-F_1) was free of E. coli and contained total coliform of less than 10 MPN/100 ml after 20 days of operation showing that the final treated water could be considered suitable for the drinking purpose and meet the requirement of WHO standard for individual or small community water supplies.

The D.O. content in the effluent of the filter (as shown in Table 4.1) gradually increased in the first 18 days of operation, then maintained at the level of about 1.9 mg/l until the 41st day, and finally decreased to 0.2 mg/l at 66th day where odor was detected in the effluent which indicated the filter bed was getting into anaerobic condition.

Sand Filter (F_2)

Fig. 4.2b illustrates the head loss development across sand bed. The filter run was terminated after 40 days of operation due to the head loss reached the limit. After scrapping about 1-2 cm off the top of the sand layer in the 42nd day and then operated again in the 45th day at the filtration rate of 0.15 m^3/m^2-h and discontinuous operation, the initial head loss was 3 cm and then increased to 4 cm after 17 days (62nd day) of operation. The filter was shut down in the 62nd day due to the preceding roughing filter R_2 reached the head loss limit since it had not enough pretreated water then to maintain the supernatant water head in the sand filter. The head loss build-up rate was slower in the scrapped sand bed. The sand filter reported by THANH and PESCOD (1976) with filtration rate of 0.10 m^3/m^2-h and continuous operation were the quite similar head loss development curve as the curve of the discontinuous operated sand filter studied here. This shows that discontinuous operation of the sand filter have no effect on the filter run.

Turbidity in the effluent of sand filter (F_2) presented in Fig. 4.1b ranged from 0.2 JTU to 11 JTU with a mean of 4.6 JTU, denoting a 64.4% of removal efficiency. After the scrapping of the sand bed, the effluent turbudity ranged 0.5 JTU to 2.7 JTU with a mean of 1.6 JTU and a 69.2% of removal efficiency in the period from 45th day to 62nd day. For the R_2-F_2 series filter, the turbidity removal efficiency was 92.5% with turbidity ranged 0.2 JTU to 11 JTU. As compared to the R_1-F_1 series filter which had the efficiency of 93.7%, it can be said that the R_1-F_1 (coconut fiber-burnt rice husk) was better in term of turbidity removal as well as the duration of filter run then the R_2-F_2 (burnt rice husk-sand).

The D.O. content of the treated water ranged from 0.6 mg/l to 2.4 mg/l with an arithmetic mean of 1.5 mg/l (see Table 4.1). No odor was detected in sand filter effluent although the D.O. value was at 0.6 mg/l.

The total coliform removal efficiency of burnt rice husk-sand series filter was 97.6% which was higher than that of coconut fiber-burnt rice husk series filter. The total coliform in the effluent plotted against time curve is illustrated in Fig. 4.3. The faecal streptococci removal efficiency of the filter was 95.3%, again it was higher than that of burnt rice husk filter. The faecal coliform content was 1 colony/ml in the first 21 days and then zero from 22nd day onward. The sand filter performed well after 20 days of operation having less than 3 MPN/100 ml of total coliform and faecal streptococci and the absence of faecal coliform in the effluent. The quality of filtered water improved when the bio-layer was formed from 21st day onward and the biological activities within the sand bed had become stabilized. As shown in Fig. 4.5, the sand filter was put again into operation after the cleaning of sand bed in the 45th, the treated water was free of coliform and contained not more than 3 MPN/100 ml of faecal streptococci and total coliform.

The bacteriological performance of the burnt rice husk-sand series filter was better than the coconut fiber-burnt rice husk series filter. The effluent of the sand filter after 21 days of operation was satisfied with the bacteriological quality as recommended by WHO Drinking Water Standards.

Comparing with burnt rice husk filter, sand filter could provide a more stable performance regarding to bacteriological efficiency, but in terms of filter run, the burnt rice husk filter provided longer service and required less cleaning of the filter bed. The discontinuous operation of these two series filter had effect on the coconut fiber-burnt rice husk series filter but not the burnt rice husk-sand series filter in term of D.O. content and anaerobic condition development, and limited the filter run of the former case. THANH and PESCOD (1976) reported that the burnt rice husk slow filter operated continuously at filtration rate of 0.1 m^3/m^2-h could last 4½ months, but the filter studied here was last 66 days with discontinuous operation. The high detention time of water in the filters was responsible for the prevailed of anaerobic condition and low D.O. content of the filter effluent. It can be said that the burnt rice husk-sand series filter was feasible to operate discontinuously while the coconut fiber-burnt rice husk series filter cannot, and the burnt rice husk was not suitable used as the roughing filter medium.

Performance of the Dual Media Filters (F_3 and F_4)

Two dual media filters consisting of 80 cm of burnt rice husk overlying 60 cm of sand (F_3), and 80 cm of coconut fiber overlying 60 cm of burnt rice husk (F_4) was supplied with raw water at filtration rate of 0.15 m^3/m^2-h discontinuously with the objective of looking into a wider range of alternatives for treatment of tropical surface water. The head loss limit was set at the 0.6 m which was the supernatant water head in the filters. As shown in Fig. 4.1c, the dual media filters have quite similar effluent turbidity variation curves. The turbidity of F_4 effluent was lower than that of F_3 effluent. Their turbidities were well below 5.0 JTU which was the WHO Drinking Water Standard from 25th day onward, denoting higher turbidity removal efficiency. The turbidity removal efficiency for F_3 was 91.2% and for F_4 was 92.0% showing that the latter have better turbidity removal than the former.

Head loss development in dual media filters bed is illustrated in Fig. 4.2b, the curve of F_3 was relatively smooth with very low build-up rate in the first 40 days of operation, and then increased rapidly with a rate of 1.4 cm/day until the head loss built-up to the limit (0.6 m) in the 73rd day. If the head loss limit increased to 1.2 m and linear extrapolation was applied then a discontinuous filter operation of 2½ months could be contemplated. The slow development of head loss across the filter F_3 bed can be explained by the burnt rice husk overlying the sand bed which removed the turbidity in the raw water. The remaining very small particles were allowed deeper into the polishing bed, forming a thin bio-layer. This resulted in slow development of the total head loss of the system. The head loss of filter F_4 was insignificant in the first 37 days of operation and then built up to 1 cm in the 38th day. Thus, the coconut fiber-burnt rice husk dual media filter performed better than burnt rice husk-sand dual media filter in terms of head loss development at filtration rate of 0.15 m^3/m^2-h and discontinuous operation.

The dual media filter F_4 was shut down in the 40th day doe to the bad odóur from the effluent. The odor was first detected in the 22nd day when the D.O. in the effluent was 0.3 mg/l and the influent D.0 content was 5.9 mg/l. The anaerobic condition prevailed till the 40th day which showed zero D.O. content in the effluent. The development of anaerobic condition could probably be due to the high detention time of water of 31.3 hours in the filter with a filtration rate of 0.15 m^3/m^2-h for a total water depth of 2.30 m and discontinuous filter operation. With this detention time, the activity of the bio-layer and the deposited organic matter was increased, resulting in depletion of dissolved oxygen in the water. However, no odor was detected from the F_3 effluent, although the average value of D.O. was 0.9 mg/l. It is important to point out that with the discontinuous operation of the slow filters (F_1, F_2, F_3 and F_4), their effluents have low dissolved oxygen content. With regard to this aspect, burnt rice husk-sand dual media filter was feasible to be operated discontinuously at a filtration rate of 0.15 m^3/m^2-h but not for the coconut fiber-burnt rice husk dual media filter.

Regarding the bacteriological performance of dual media filters, the total coliform removal efficiency for F_3 was 91.6%, for F_4 was 85.8%. For the faecal streptococci removal efficiency it was 89.1% and 87.4% for F_3 and F_4 respectively. The effluent of F_3 was free of faecal coliform after 28 days of operation. The results of the bacteriological performance of the filters are presented in Fig. 4.4, 4.5 and Table 4.2. The absence of faecal coliform in the effluent of burnt rice husk-sand dual media filter from 29th day onward, suggesting that the treated water from F_3 could be served to rural communities.

Phase II - Filters Operated 8 Hours at Normal Rate and at Very Low Rate During High Time (16 hours)

This phase of study was carried out within a month, due to the shortage of time so only the preliminary study of the filters turbidity removal and head loss development was made.

The raw water turbidity ranged from 17 JTU to 75 JTU having an overall mean of 36.6 JTU over the test period. No rain was recorded in this period.

The depth of media in the slow filters were unchanged and three slow filters were used, burnt rice husk F_1, sand F_2 and coconut fiber-burnt rice husk F_4 (dual media). The two roughing filters were coconut fiber (40 cm) filter and coconut fiber-burnt rice husk (20 cm-20 cm) having the same supernatant water head of 1.2 m. The filter operation was previously mentioned.

Fig. 4.6a, b and c are the curve of the turbidity of the raw water and the filters effluent. The turbidity ranges of the filters were: 3.3 JTU to 12.0 JTU for R_1, 2.4 JTU to 8.0 JTU for R_2, 0.1 JTU to 0.3 JTU for F_1 and F_2 and 0.2 JTU to 1.0 JTU for F_4. The final treated water of the slow filters was well below 1.0 JTU with average of 0.2 JTU for the series filters and 0.5 JTU for the dual media filter. The turbidity removal efficiencies were high, 99.0% for R_1-F_1, series filter, 99.3% for R_2-F_2 series filter and 98.6% for the F_4 dual media filter. All the treated water qualities in term of turbidity were accepted by the WHO drinking water standards.

The head loss development of the filters is recorded in Table B1 and B2 in Appendix B and presented in Fig. 4.7. Head loss built up in the coconut fiber-burnt rice husk dual media filter F_4 was insignificant throughout the test period of 15 days, it was same as the head loss of the filter F_4 studied in Phase I. The continuous or discontinuous operation of coconut fiber-burnt rice husk dual media filter have showed no different on the head loss build up, suggesting that the duration of filter run was independent on the operations. The initial head loss of the burnt rice husk polishing filter F_1 was 3 cm and no further head loss built up was recorded throughout the study. The sand filter F_2 after 15 days of operation, the head loss increased from 11.0 cm (initial) to the head loss limit (1.20 m). The short duration of the sand filter run can be explained by the inappropriate cleaning of the sand bed and the continuous operation of the filter. The head loss rate of the roughing filter R_1 was about 0.3 cm/day, indicating that the filter R_1 could run for a year if linear

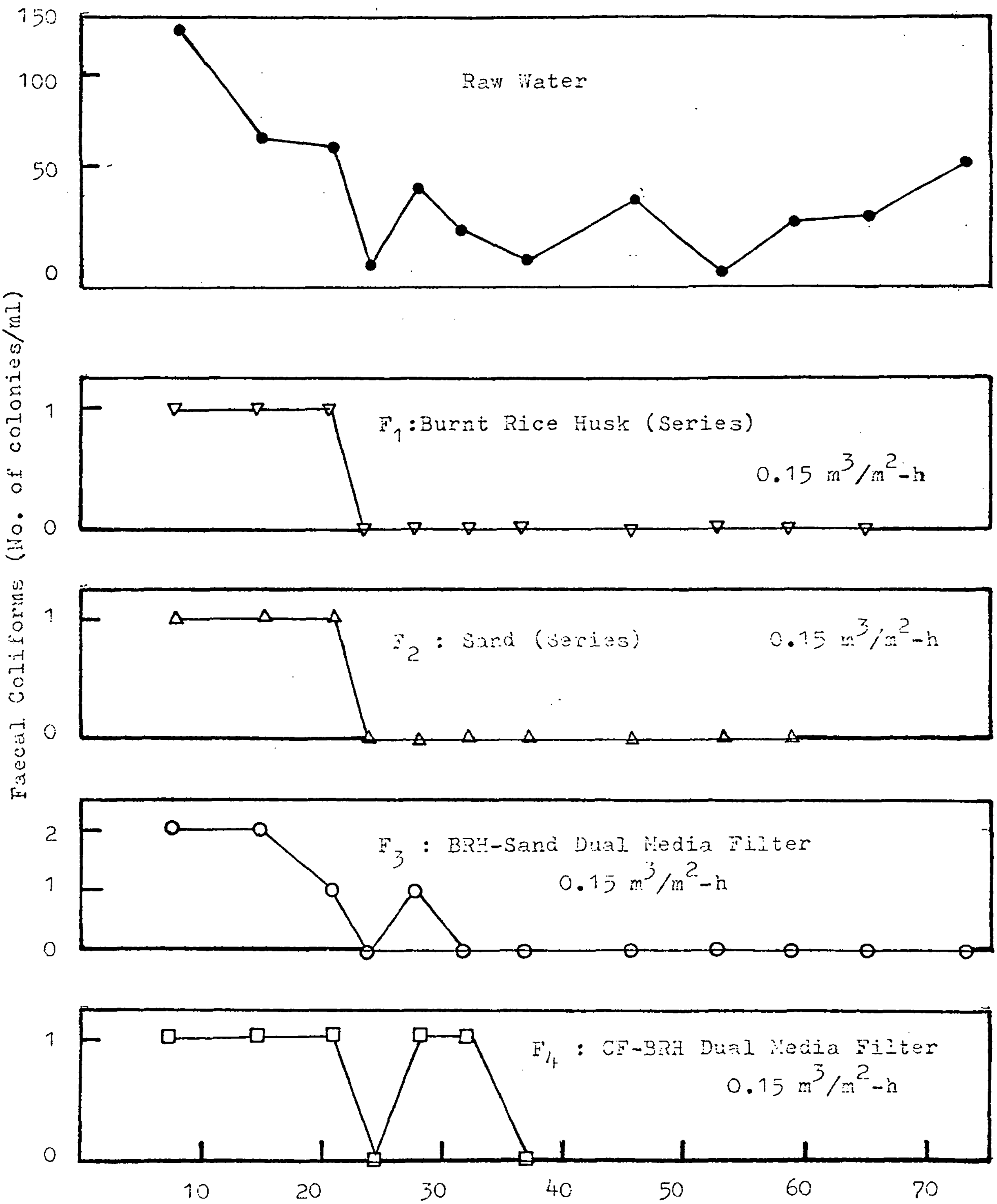


Fig. 4.5 - Results of Faecal Coliform Plate Count Tests

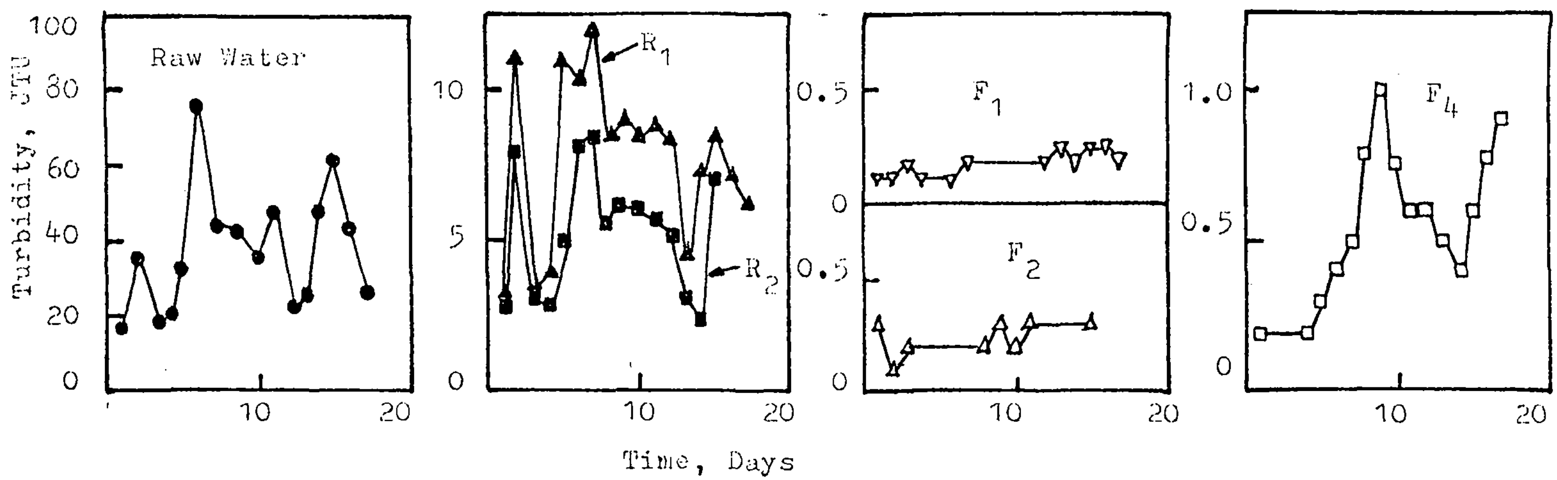


Fig. 4.6 - Turbidity of Raw Water and Different Filters (Phase II)

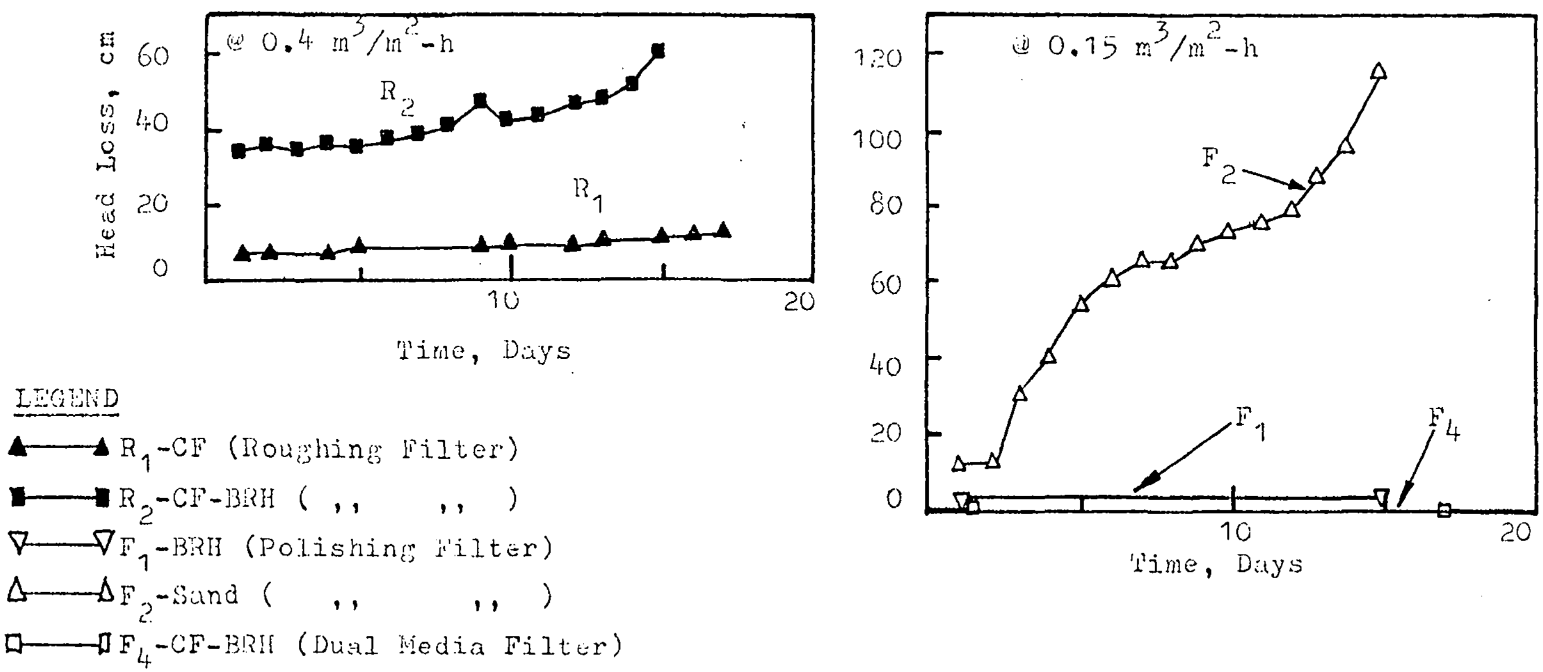


Fig. 4.7 - Head Loss Development in Different Filters (Phase II)

regression is applied. The roughing filter R_2 had high initial head loss of 35 cm same as the case in phase I. This high head loss showed that burnt rice husk again was not the appropriate roughing filter media in the series filtration system.

From the findings, it showed that the filter run of the sand filter was shortened by the inappropriate cleaning of the filter bed continuous operation of filter, while the run of the burnt rice husk filter F_1 and coconut fiber-burnt rice husk dual media filter were independent on the continuous operation of the filter. The conclusion was drawn from the short period of study, more study on the filters for bacteriological and chemical aspects with the mentioned continuous operation is required to investigate the ability and disability of the slow filtration system to treat tropical surface water.

V CONCLUSIONS

Phase I

(1) With the discontinuous operation at filtration rate of 0.4 m^3/m^2-h for the roughing filters, the performance of the coconut fiber-burnt rice husk (10-70 cm) dual media roughing filter was better than the cocobut fiber roughing filter in term of turbidity removal. The filter run of the former was 40 days while that of the latter was 50 days. The termination of the filter run of the dual media roughing filter was due to the clogging of the filter and the coconut fiber roughing filter was because of the development of anaerobic condition and odor in the filter bed and effluent. High detention time of water in the coconut fiber roughing filter which was 20.2 hours increased the dissolved oxygen depletion and developed the odor and anaerobic conditions. The coconut fibres were revealed to be a potential filtering medium to remove sufficient turbidity from raw water and produce an effluent acceptable for subsequent treatment by polishing filters with continuous operation but not with discontinuous operation. The short duration of the dual media roughing filter run indicated that the top 10 cm coconut fiber could not reduce the high head loss built-up by the burnt rice husk bed and limit the application of the burnt rice husk as a roughing filter medium. The coconut fiber roughing filter was tested only at a filtration rate of 0.4 m^3/m^2-h due to the deficiency higher filtration rate and lower supernatant. Water head is suggested for the discontinuous operation of the coconut fiber roughing filter.

(2) The filter run of the burnt rice husk polishing filter was 66 days, it was shut down because of the development of odor and anaerobic condition in the filter effluent and bed. The coconut fiber-burnt rice husk dual media faced the same problem and also shut down after 40 days of operation. The burnt rice husk-sand dual media filter was operated for 73 days and terminated the run due to the head loss limit of 0.60 was reached. The burnt rice husk-sand series filter could last for 40 days of discontinuous operation, the filter run was concluded by the head loss built up reached the limit (1.2 m). Only the latter two slow filtration system have no odor problem in their effluent and the creation of anaerobic condition in their filter beds. Therefore, it can be said that the discontinuous operation is not feasible for the filters using coconut fiber as the filtering medium. Although the burnt rice husk-sand series and dual media filters could operate discontinuously, the D.O. content in their effluent was quite low which was less than 3.0 mg/1.

(3) The turbidity removal efficiencies of the series filters and dual media filters were all over 90% and the effluents turbidity were within the WHO Drinking Water Standards indicating that discontinuous operation of the filters have no effect on the turbidity removal efficiencies. The merit of the performance in term of turbidity removal of the filters was in the following sequence: CF-BRH series > CF-BRH dual media > BRH-SAND series > BRH-SAND dual media.

(4) The bacteriological performances of the filters were not violated by the discontinuous operation. The series filters and dual media filters significantly improved the bacterial quality of the raw water and the efficient removal of faecal coliforms and faecal streptococci. After 20 days of discontinuous operation, the slow filtration system except coconut fiber-burnt rice husk dual media filter could completely remove coliform bacteria from raw water, indicating that the discontinuous operation was feasible to be applied on the slow filtration system. The rank of the performances of the filters was as the following: BRH-SAND series > CF-BRH series > BRH-SAND dual media > CF-BRH dual media.

(5) The depletion of dissolved oxygen of the water in the filter was increased due to the discontinuous operation which increased the detention time of the water in the filters. With the low D.O. content in water, the filter had a tendency of getting into anaerobic conditions and developing the odor. Thus the deficiency limit the application of the discontinuous operation.

(6) With respect to the filter bed cleaning, it is easier and takes less time in the case of series filter than in the case of dual media filter. This shows that dual media filtration system requires more man power in the cleaning of filter bed. On the other hand, more energy is required to pump raw water to a higher head in the case of series filtration system. From the technical aspects, the best slow filtration system in this experiment was the burnt rice husk-sand dual media filter.

Phase II

(1) The continuous operation of the slow filtration systems with very low filtration rate during the night time (16 hours) was feasible for the dual media filter. This operation of dual media filter was quite similar to the intermittent operation, the supernatent water head was reduced from 0.60 m to 0.12 m during the night time by the low flow rate of effluent then it was filled up to the 0.60 m mark and operated at normal filtration rates. In the case of series filters, the water head in the polishing filter was kept at constant by supplying the effluent of roughing filter to the polishing filter, it needed more control on the flow of water. Since all pump was cut off at night time, and no raw water was supplied to the roughing filter, thus the roughing filter was operated intermittently while the polishing filter was continuously.

(2) Burnt rice husk was not suitable used as the roughing filter medium in the series filtration system even overlying by a layer of coconut fiber.

(3) The continuous operation for the series filter have the difficulty in the measurement and control of such a low filtration rate of 0.06 m^3/m^2-h of the roughing filter effluent. It was easy to deal with the flow rate of the slow filters effluents. Therefore, it can be said that the continuous operation is feasible for the dual media filter.

VI RECOMMENDATIONS FOR FUTURE WORK

The results of this study have shown that burnt rice husk overlying sand dual media filter is feasible to operate discontinuously and produce safe drinking water with reasonable length of filter run. The odor and anaerobic condition prevailed in the slow filtration systems which using coconut fiber as the filtering media. Thus, in order to improve the operation of the dual media filter and solve the problems, the following points should be considered for any future study:

(1) To reduce the detention time of water in the coconut fiber roughing filter by using thinner layer of coconut fiber (<0.8 m) and lower supernatent water head (<0.8 m). It is also minimize the high pumping head and operating cost.

(2) To reduce the depth of the layer of burnt rice husk (<0.8 m) in the burnt rice husk-sand dual media filter which could give higher water head and consequently longer filter run. To find out the appropriate way of cleaning the bed thus reducing the cleaning time.

(3) A possible long term study on the slow filtration systems operate with normal rate for 8 hours and then very low rate for 16 hours. This is to reduce the detention time of the water in the filter. Investigation on the D.O. content in the effluents and bacteriological performances of the filters require a more detailed study.

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APPENDIX A

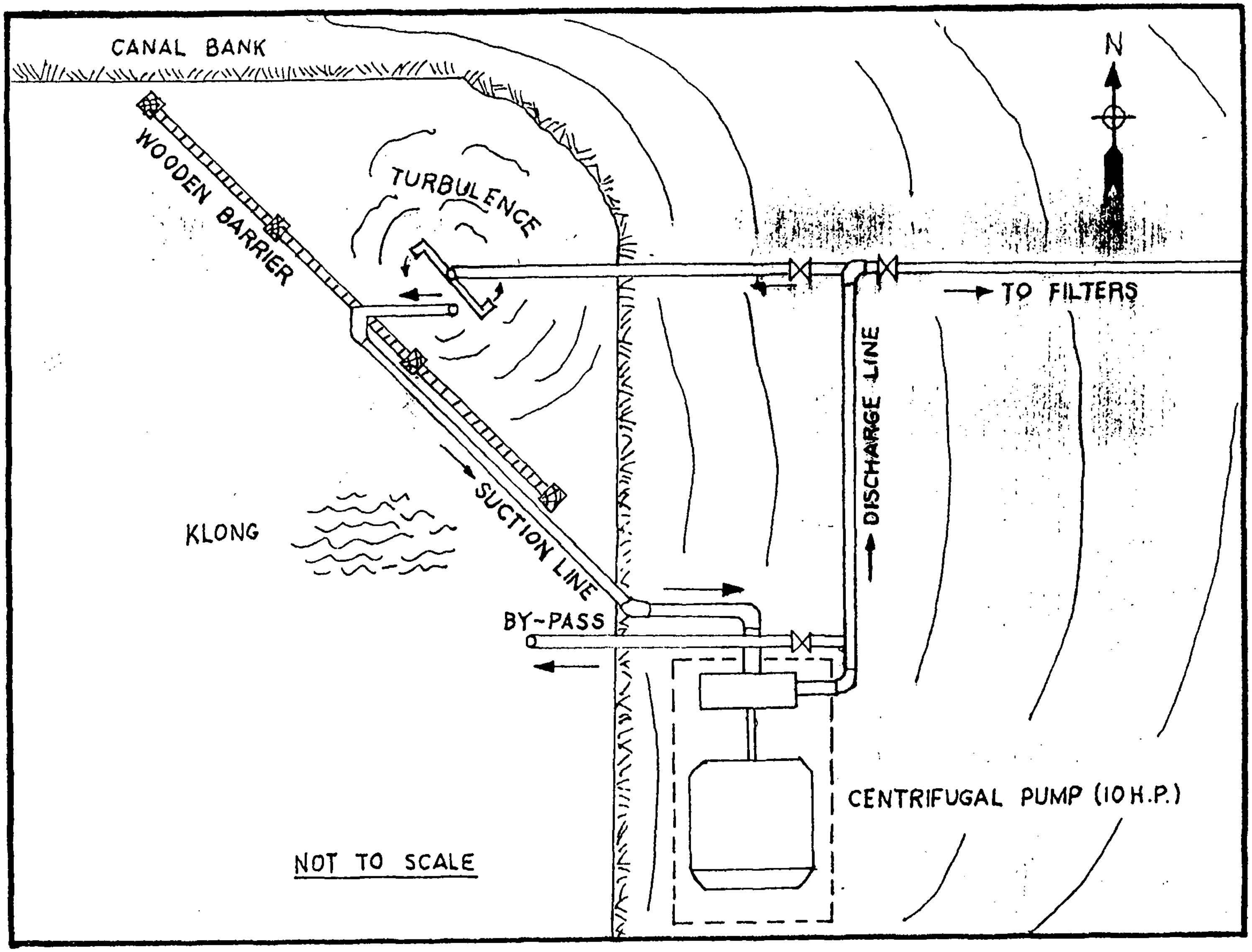
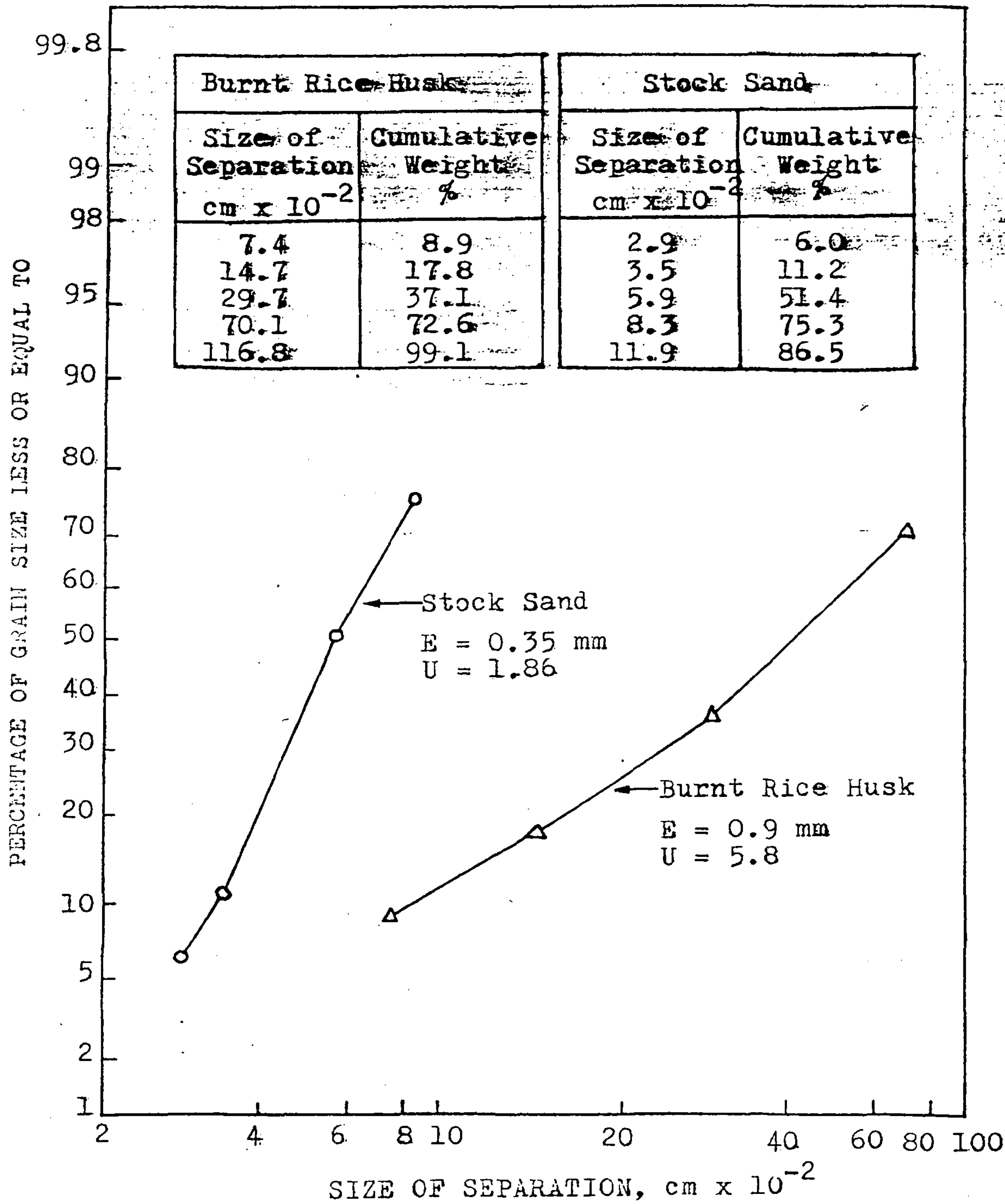


Fig. A-1 Intake System



Burnt Rice Husk		Stock Sand	
Size of Separation cm x 10^{-2}	Cumulative Weight %	Size of Separation cm x 10^{-2}	Cumulative Weight %
7.4	8.9	2.9	6.0
14.7	17.8	3.5	11.2
29.7	37.1	5.9	51.4
70.1	72.6	8.3	75.3
116.8	99.1	11.9	86.5

Fig. A2 Sieve Analysis of Stock Sand and Burnt Rick Husk

Table A1 - Turbidity of Raw Water and Effluents (Phase I)

Run Duration, Days	Date	Raw Water JTU	Series Filtration System				Dual Media Filter	
			R_1 @ 0.4 m^3/m^2-h	F_1 @ 0.15 m^3/m^2-h	R_2 @ 0.4 m^3/m^2-h	F_2 @ 0.15 m^3/m^2-h	F_3 @ 0.15 m^3/m^2-h	F_4 @ 0.15 m^3/m^2-h
1	22-8-76	47.0	24.0	9.5	21.0	8.5	7.2	9.4
2	23-8-76	45.0	18.0	8.0	18.0	9.3	9.5	8.8
3	24-8-76	60.0	18.0	6.8	23.0	8.0	6.4	5.0
4	25-8-76	45.0	Charged R_1 medium and added CHF (10 cm) into R_2					
5	26-8-76	40.0	28.0	9.5	17.0	9.5	10.0	11.0
6	27-8-76	110.0	29.0	7.0	15.0	8.0	8.5	6.0
7	28-8-76	46.0	20.0	5.5	16.0	7.7	9.8	5.8
8	29-8-76	64.0	20.0	4.1	13.0	6.6	4.5	3.0
9	30-8-76	69.0	31.0	3.3	27.0	5.6	5.0	3.1
10	31-8-76	54.0	33.0	6.0	23.0	7.8	9.0	4.6
11	1-9-76	40.0	Pump failure					
12	2-9-76	30.0	20.0	5.4	17.0	7.4	7.3	3.8
13	3-9-76	30.0	18.0	5.4	15.0	6.3	8.4	4.3
14	4-9-76	32.0	10.0	2.5	8.0	3.2	4.0	2.1
15	5-9-76	140.0	40.0	3.0	25.0	4.3	3.1	3.2
16	6-9-76	130.0	54.0	9.0	29.0	11.0	12.0	5.8
17	7-9-76	80.0	40.0	5.0	25.0	7.0	6.0	2.6
18	8-9-76	50.0	28.0	10.0	17.0	8.0	11.0	4.4
19	9-9-76	60.0	18.0	4.9	14.0	3.8	8.3	5.0
20	10-9-76	59.0	18.0	3.0	8.0	1.4	5.5	2.5
21	11-9-76	50.0	17.0	4.1	10.0	1.6	6.0	4.5
22	12-9-76	45.0	17.0	5.0	11.0	4.0	4.6	16.0
23	13-9-76	80.0	40.0	8.0	23.0	7.3	15.0	4.6
24	14-9-76	60.0	20.0	4.3	14.0	2.0	9.0	6.1
25	15-9-76	65.0	22.0	3.8	19.0	4.1	7.4	6.2
26	16-9-76	42.0	18.0	5.1	10.0	3.2	4.9	3.8
27	17-9-76	15.0	12.0	2.4	4.0	0.7	2.0	2.7
28	18-9-76	15.0	8.0	2.5	4.8	2.2	3.5	3.3
29	19-9-76	12.0	7.0	2.7	4.9	3.6	4.3	1.2
30	20-9-76	27.0	6.0	2.3	3.8	3.2	4.0	1.1
31	21-9-76	20.0	5.5	1.5	3.4	3.5	4.4	1.8
32	22-9-76	24.0	4.9	1.3	2.3	3.2	2.4	1.4
33	23-9-76	34.0	5.8	1.3	2.7	3.4	2.7	0.8
34	24-9-76	22.0	4.0	1.2	2.1	2.8	3.4	0.6
35	25-9-76	15.0	3.8	0.7	1.7	2.2	2.2	0.4
36	26-9-76	12.0	0.7	0.2	0.6	0.2	0.6	0.2
37	27-9-76	13.0	4.8	0.5	1.4	1.9	1.7	0.3
38	28-9-76	11.0	2.3	0.6	1.0	2.2	1.1	0.2
39	29-9-76	75.0	18.0	0.5	6.2	1.3	1.2	2.8
40	30-9-76	66.0	6.0	2.1	2.9	0.3	0.7	0.6
41	1-10-76	40.0	7.8	1.6	End		2.1	Shut off
42	2-10-76	52.0	10.8	1.2	Cleaning of		1.7	-
43	3-10-76	46.0	10.0	1.3	F_2 sand bed.		1.4	-
44	4-10-76	40.0	8.1	1.0	Scrapped off 1 cm of sand		1.0	-
45	5-10-76	28.0	8.0	1.0	3.8	1.4	0.8	-

Table A1 - Continued

Days	Date	Raw Water	R_1	F_1	R_2	F_2	F_3	F_4
46	6-10-76	20.0	6.0	1.1	3.0	1.0	1.0	-
47	7-10-76	32.0	8.5	1.0	5.6	1.7	0.8	-
48	8-10-76	30.0	7.8	0.8	4.9	2.5	1.2	-
49	9-10-76	31.0	6.0	0.9	5.2	2.0	1.4	-
50	10-10-76	25.0	6.4	1.3	7.9	7.7	2.1	-
51	11-10-76	15.0	5.3	0.4	4.7	1.8	1.6	-
52	12-10-76	14.0	6.0	0.3	4.0	1.0	1.8	-
53	13-10-76	40.0	6.9	0.5	5.0	0.5	1.5	-
54	14-10-76	15.0	5.4	0.5	3.6	0.5	1.8	-
55	15-10-76	16.0	6.3	0.7	7.4	0.9	2.0	-
56	16-10-76	44.0	9.5	0.8	8.2	2.0	2.5	-
57	17-10-76	35.0	9.9	0.8	9.8	2.5	1.7	-
58	18-10-76	34.0	9.6	2.3	5.4	2.3	4.7	-
59	19-10-76	18.0	7.8	2.4	2.8	1.5	4.2	-
60	20-10-76	57.0	12.0	1.4	4.8	2.4	2.2	-
61	21-10-76	21.0	6.7	2.2	2.2	1.4	3.4	-
62	22-10-76	140.0	28.0	0.7	4.8	1.5	1.1	-
63	23-10-76	55.0	7.0	0.8	End	Shut off	2.1	-
64	24-10-76	42.0	7.4	0.7	-	-	2.6	-
65	25-10-76	150.0	10.0	0.6	-	-	1.4	-
66	26-10-76	50.0	14.0	2.7	-	-	4.4	-
67	27-10-76	41.0	12.0	2.0	-	-	3.6	-
68	28-10-76	33.0	Shut	off	-	-	1.6	-
69	29-10-76	25.0	-	-	-	-	0.8	-
70	30-10-76	20.0	-	-	-	-	0.6	-
71	31-10-76	21.0	-	-	-	-	0.6	-
72	1-11-76	27.0	-	-	-	-	0.7	-
73	2-11-76	130.0	-	-	-	-	0.8	-
							End	

Legend:

R_2 = coconut fiber/burnt rice husk (10/70 cm) dual media roughing filter

R_1 = coconut fiber roughing filter

F_1 = burnt rice husk filter (series filter)

F_2 = sand filter (series)

F_3 = burnt rice husk-sand dual media filter

F_4 = coconut fiber-burnt rice husk dual media filter

Table A2 - Head Loss in Filters (cm) (Phase I)

Run Duration, Days	Date	R_1 @ 0.4 m^3/m^2-h	R_2 @ 0.4 m^3/m^2-h	F_1 @ 0.15 m^3/m^2-h	F_2 @ 0.15 m^3/m^2-h	F_3 @ 0.15 m^3/m^2-h	F_4 @ 0.15 m^3/m^2-h
1	22-8-76	-	7.9	4.0	2.5	6.0	-
2	23-8-76	-	28.0	4.0	3.0	6.0	-
3	24-8-76	-	63.0	4.0	3.0	8.0	-
5	26-8-76	-	21.0	4.0	3.0	8.0	-
6	27-8-76	-	22.0	4.0	4.0	8.5	-
7	28-8-76	-	24.0	4.0	6.0	8.5	-
8	29-8-76	-	27.0	4.0	6.0	9.0	-
9	30-8-76	-	31.0	4.0	9.5	9.0	-
10	31-8-76	-	22.0	4.0	13.0	9.0	-
12	2-9-76	-	16.0	5.0	21.0	9.0	-
13	3-9-76	-	14.0	5.0	23.0	9.0	-
14	4-9-76	-	21.0	6.0	27.0	9.0	-
15	5-9-76	-	22.0	6.0	30.0	12.0	-
16	6-9-76	-	30.0	6.0	31.0	12.0	-
17	7-9-76	-	24.0	6.0	35.0	11.0	-
18	8-9-76	-	23.0	6.0	43.0	11.0	-
19	9-9-76	-	25.0	7.0	45.0	10.0	-
20	10-9-76	-	31.0	5.0	47.0	10.0	-
21	11-9-76	-	25.0	7.0	50.0	10.0	-
22	12-9-76	-	52.0	8.0	60.0	10.0	-
23	13-9-76	1.0	55.0	8.0	60.0	11.0	-
24	14-9-76	1.0	53.0	8.0	55.0	11.0	-
25	15-9-76	1.0	55.0	9.0	60.0	11.0	-
26	16-9-76	1.0	62.0	9.0	65.0	10.0	-
27	17-9-76	1.0	53.0	9.0	57.0	11.0	-
28	18-9-76	1.0	60.0	10.0	59.0	11.0	-
29	19-9-76	1.0	63.0	10.0	62.0	14.0	-
30	20-9-76	2.0	56.0	10.0	51.0	13.0	-
31	21-9-76	2.0	57.0	8.0	49.0	13.0	-
32	22-9-76	2.0	56.0	8.0	50.0	12.0	-
33	23-9-76	2.0	60.0	9.0	66.0	11.0	-
34	24-9-76	2.0	55.0	9.0	68.0	11.0	-
35	25-9-76	2.0	50.0	9.0	73.0	11.0	-
36	26-9-76	2.0	57.0	9.0	77.0	11.0	-
37	27-9.76	4.0	56.0	9.0	86.0	11.0	1.0
38	28-9-76	4.0	53.0	9.0	89.0	11.0	2.0
39	29-9-76	4.0	50.0	10.0	99.0	11.0	2.0
40	30-9-76	4.0	48.0	10.0	120.0	11.0	2.0
41	1-10-76	4.0	44.0	11.0	End	12.0	Shut off
42	2-10-76	4.0	44.0	10.0	Bed	13.0	-
43	3-10-76	4.0	45.0	10.0	Cleaning	13.0	-
44	4-10-76	5.0	44.0	10.0	-	15.0	-
45	5-10-76	5.0	40.0	11.0	-	16.0	-
46	6-10-76	5.0	42.0	12.0	3.0	18.0	-
47	7-10-76	5.0	42.0	12.0	3.0	20.0	-
48	8-10-76	5.0	44.0	13.0	3.0	21.0	-

Table A2 - Continued

Days	Date	R_1	R_2	F_1	F_2	F_3	F_4
49	9-10-76	3.0	42.0	13.0	3.0	23.0	-
50	10-10-76	3.0	48.0	13.0	3.0	23.0	-
51	11-10-76	5.0	53.0	11.0	3.0	20.0	-
52	12-10-76	4.0	68.0	10.0	3.0	20.0	-
53	13-10-76	5.0	75.0	11.0	3.0	22.0	-
54	14-10-76	5.0	End	10.0	3.0	20.0	-
55	15-10-76	5.0	4.0	11.0	3.0	23.0	-
56	16-10-76	5.0	10.0	10.0	3.0	25.0	-
57	17-10-76	5.0	10.0	13.0	3.0	26.0	-
58	18-10-76	5.0	10.0	14.0	3.0	29.0	-
59	19-10-76	5.0	20.0	15.0	3.0	30.0	-
60	20-10-76	5.0	27.0	10.0	3.0	27.0	-
61	21-10-76	3.0	50.0	15.0	4.0	30.0	-
62	22-10-76	3.0	70.0	15.0	4.0	32.0	-
63	23-10-76	3.0	End	15.0	Shut off	35.0	-
64	24-10-76	8.0	-	15.0	-	35.0	-
65	25-10-76	8.0	-	10.0	-	38.0	-
66	26-10-76	8.0	-	12.0	-	40.0	-
67	27-10-76	8.0	-	12.0	-	39.0	-
68	28-10-76	Shut off	-	Shut off	-	39.0	-
69	29-10-76	-	-	-	-	40.0	-
70	30-10-76	-	-	-	-	45.0	-
71	31-10-76	-	-	-	-	50.0	-
72	1-11-76	-	-	-	-	54.0	-
73	2-11-76	-	-	-	-	56.0	-
						End	

Legend:

R_2 = coconut fiber-burnt rice husk (10/70 cm) dual media roughing filter

R_1 = coconut fiber roughing filter

F_1 = burnt rice husk filter (series)

F_2 = sand filter (series)

F_3 = burnt rice husk-sand dual media filter

F_4 = coconut fiber-burnt rice husk dual media filter

Table A3 - Results of MPN Tests for Total Coliform (Phase I)

Run Duration, Days	Date	Raw Water	Series Filtration				Dual Media Filtration	
			R_1 - F_1		R_2 - F_2		F_3	F_4
			@ 0.4 m^3/m^2-h	@ 0.15 m^3/m^2-h	@ 0.4 m^3/m^2-h	@ 0.15 m^3/m^2-h	@ 0.15 m^3/m^2-h	@ 0.15 m^3/m^2-h
2	23- 8-76	2400	240	150	460	150	240	150
5	26- 8-76	2400	210	150	93	93	150	210
9	30- 8-76	2400	460	43	120	75	460	460
12	2- 9-76	1100	150	75	75	75	120	93
16	6- 9-76	2400	150	150	210	75	120	150
19	9- 9-76	1100	210	21	150	9	93	120
23	13- 9-76	2400	150	43	150	7	150	240
30	20- 9-76	1100	150	7	93	<3	150	210
35	25- 9-76	1100	460	<3	93	<3	93	210
40	30- 9-76	460	93	4	43	<3	75	150
					End	End		Shut off
45	6-10-76	2400	150	4	-	-	23	-
51	12-10-76	2400	460	23	460	<3	23	-
60	21-10-76	1100	460	23	210	<3	23	-
64	25-10-76	2400	240	4	-	-	9	-

Legend:

R_1 = coconut fiber roughing filter

R_2 = coconut fiber-burnt rice husk (10/70 cm) roughing filter

F_1 = burnt rice husk filter (series)

F_2 = sand filter (series)

F_3 = burnt rice husk-sand dual media filter

F_4 = coconut fiber-burnt rice husk dual media filter

Table A4 - Results of Faecal Streptococcus MPN Tests (Phase I)

Run Duration, Days	Date	Raw Water	$R_1 - F_1$		$R_2 - F_2$		F_3	F_4
			@ 0.4 m^3/m^2-h	@ 0.15 m^3/m^2-h	@ 0.4 m^3/m^2-h	@ 0.15 m^3/m^2-h	@ 0.15 m^3/m^2-h	@ 0.15 m^3/m^2-h
6	27- 8-76	240	93	75	150	43	43	93
10	31- 8-76	460	210	20	150	23	75	23
13	3- 9-76	43	21	11	11	3	11	11
18	8- 9-76	93	43	15	15	7	11	15
22	12- 9-76	93	21	4	7	<3	15	7
25	15- 9-76	150	23	3	7	<3	7	7
31	21- 9-76	93	15	3	4	<3	4	4
36	26- 9-76	460	150	4	11	<3	11	11
39	29- 9-76	120	93	4	75	<3	11	11
44	5-10-76	75	23	4	End	End	7	Shut off
52	13-10-76	240	93	9	4	<3	11	-
58	19-10-76	240	28	7	93	<3	11	-
66	27-10-76	120	15	3	-	-	4	-
70	31-10-76	75	-	-	-	-	4	-

Legend:

R_1 = coconut fiber roughing filter

R_2 = coconut fiber-burnt rice husk (10/70 cm) roughing filter

F_1 = burnt rice husk filter (series)

F_2 = sand filter (series)

F_3 = burnt rice husk-sand dual media filter

F_4 = coconut fiber-burnt rice husk dual media filter

Table A5 - Results of Faecal Coliform Plate Count Tests (Colonies/ml)

Run Duration, Days	Date	Raw Water	$R_1 - F_1$		$R_2 - F_2$		F_3	F_4
			@ 0.4 m^3/m^2-h	@ 0.15 m^3/m^2-h	@ 0.4 m^3/m^2-h	@ 0.15 m^3/m^2-h	@ 0.15 m^3/m^2-h	@ 0.15 m^3/m^2-h
8	29- 8-76	136	16	1	3	1	2	1
15	5- 9-76	65	5	1	20	1	2	1
21	11- 9-76	60	10	1	15	1	1	1
24	14- 9-76	8	0	0	0	0	0	0
28	18- 9-76	40	2	0	3	0	1	1
32	22- 9-76	24	1	0	1	0	0	1
37	27- 9-76	10	0	0	0	0	0	0
46	7-10-76	36	1	0	-	-	0	-
53	14-10-76	6	0	0	0	0	0	-
59	20-10-76	26	2	0	0	0	0	-
65	26-10-76	30	0	0	-	-	0	-
73	2-10-76	52	-	-	-	-	0	-

Legend:

R_1 = coconut fiber roughing filter

R_2 = coconut fiber-burnt rice husk (10/70 cm) roughing filter

F_1 = burnt rice husk filter (series)

F_2 = sand filter (series)

F_3 = burnt rice husk-sand dual media filter

F_4 = coconut fiber-burnt rice husk filter

Table A6 - Summary of Results of Statistical Analysis (Phase I)

Filter	Turbidity, JTU			Total Coliform MPN/100 ml			Faecal Streptococcus MPN/100 ml		
	Mean		Removal %	Mean		Removal %	Mean		Removal %
	Influent	Effluent		Influent	Effluent		Influent	Effluent	
Roughing Filter									
R_1 @ 0.4 m^3/m^2-h	45.9	14.3	68.8	1797	256	85.6	187	64	65.8
R_2 @ 0.4 m^3/m^2-h	41.5	8.7	79.0	1697	178	89.5	203	48	76.4
Polishing Filter									
F_1 @ 0.15 m^3/m^2-h	14.3	2.9	79.7	256	50	80.5	64	12	81.3
F_2 @ 0.15 m^3/m^2-h	8.7	3.1	64.4	178	40	77.5	48	7.0	85.4
Series Filter									
R_1 - F_1	45.9	2.9	93.7	1797	50	97.2	187	12	93.6
R_2 - F_2	41.5	3.1	92.5	1697	40	97.6	203	7.0	96.6
Dual Media Filter									
F_3 @ 0.15 m^3/m^2-h	45.6	4.0	91.2	1797	123	93.2	187	16	91.4
F_4 @ 0.15 m^3/m^2-h	48.7	3.9	92.0	1686	199	88.2	195	20	89.7

Legend:

R_1 = coconut fiber roughing filter
R_2 = coconut fiber-burnt rice husk (10/70 cm) roughing filter
F_1 = burnt rice husk filter (series)
F_2 = sand filter (series)
F_3 = burnt rice hisk-sand dual media filter
F_4 = coconut fiber-burnt rice husk dual media filter

APPENDIX B

Table B1 - Turbidity of Raw Water and Effluents (Phase II)

Run Duration, Days	Date	Raw Water JTU	R_1 @ 0.4 m^3/m^2-h	R_2 @ 0.4 m^3/m^2-h	F_1 @ 0.15 m^3/m^2-h	F_2 @ 0.15 m^3/m^2-h	F_4 @ 0.15 m^3/m^2-h
1	14-11-76	17.0	3.3	2.7	0.1	0.3	0.2
2	15-11-76	35.0	11.0	8.0	0.1	0.1	0.2
3	16-11-76	18.0	3.5	3.2	0.2	0.2	0.2
4	17-11-76	20.0	4.0	3.0	0.1	0.2	0.2
5	18-11-76	32.0	11.0	5.0	0.1	0.2	0.3
6	19-11-76	75.0	10.0	8.2	0.1	0.2	0.4
7	20-11-76	42.0	12.0	8.3	0.2	0.2	0.5
8	21-11-76	43.0	8.0	5.5	0.2	0.2	0.8
9	22-11-76	40.0	9.0	6.2	0.2	0.3	1.0
10	23-11-76	35.0	8.1	6.0	0.2	0.2	0.7
11	24-11-76	46.0	8.5	5.5	0.2	0.3	0.6
12	25-11-76	22.0	7.8	5.0	0.2	0.3	0.6
13	26-11-76	24.0	4.5	3.2	0.3	0.3	0.5
14	27-11-76	47.0	7.2	2.4	0.2	0.3	0.4
15	28-11-76	60.0	8.4	7.0	0.3	0.3	0.6
16	29-11-76	42.0	7.0	shut off	0.3	End	0.8
17	30-11-76	25.0	6.2	-	0.2	-	0.9

Legend:

R_1 = coconut fiber (40 cm) roughing filter.

R_2 = coconut fiber-burnt rice husk (20/20 cm) roughing filter.

F_1 = burnt rice husk filter (series).

F_2 = sand filter.

F_4 = coconut fiber-burnt rice husk dual media filter.

Table B2 - Head Loss in Filters (cm) (Phase II)

Run Duration, Days	Date	R_1 @ 0.4 m^3/m^2-h	R_2 @ 0.4 m^3/m^2-h	F_1 @ 0.15 m^3/m^2-h	F_2 @ 0.15 m^3/m^2-h	F_4 @ 0.15 m^3/m^2-h
1	14-11-76	6.0	34.0	3.0	12.0	-
2	15-11-76	6.0	35.0	3.0	12.0	-
3	16-11-76	6.0	34.0	3.0	30.0	-
4	17-11-76	6.0	35.0	3.0	40.0	-
5	18-11-76	7.0	35.0	3.0	54.0	-
6	19-11-76	7.0	36.0	3.0	60.0	-
7	29-11-76	7.0	37.0	3.0	65.0	-
8	21-11-76	7.0	40.0	3.0	65.0	-
9	22-11-76	7.0	45.0	3.0	70.0	-
10	23-11-76	8.0	40.0	3.0	73.0	-
11	24-11-76	8.0	42.0	3.0	75.0	-
12	25-11-76	8.0	45.0	3.0	80.0	-
13	26-11-76	9.0	49.0	3.0	89.0	-
14	27-11-76	9.0	50.0	3.0	96.0	-
15	28-11-76	9.0	56.0	3.0	115.0	-
16	29-11-76	10.0	-	3.0	End	-
17	30-11-76	10.0	-	3.0	-	-

Legend:

R_1 = coconut fiber (40 cm) roughing filter.

R_2 = coconut fiber-burnt rice husk (20/20 cm) roughing filter.

F_1 = burnt rice husk filter (series).

F_2 = sand filter (series)

F_4 = coconut fiber - burnt rice husk dual media filter.