2 5 5 . 1
7 5 S L

Asian Institute of Technology
Bangkok Thailand

ARY
national Reference Centre
ommunity Water Supply

thesis No. 882

SLOW FILTRATION FOR SURFACE WATER TREATMENT IN THE TROPICS

By

Md. Nizam Uddin

Asian Institute of Technology

Bangkok, Thailand

1975

255.1 -75SL

II · 25 · 11
255.1
75 SL

SLOW FILTRATION FOR SURFACE WATER TREATMENT IN THE TROPICS

by

Md. Nizam Uddin

For the Degree of Master of Engineering

Asian Institute of Technology

Bangkok, Thailand

1975

SLOW FILTRATION FOR SURFACE WATER TREATMENT IN THE TROPICS

by

Md. Nizam Uddin

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

Approved by: N C Thanh 19 March '76

Dr. Nguyen Cong Thanh
Assoc. Professor of Environmental Engineering

M. B. Pescod March '76

Prof. M.B. Pescod
Professor of Environmental Engineering

Accepted by: Milton E Bender Jr 26 March 1976

Dr. Milton E. Bender, Jr.
President

ACKNOWLEDGEMENTS

The author wishes to take this opportunity to express his heartiest thanks and deepest sense of gratitude to his adviser, Dr. Nguyen Cong Thanh, for his suggestions and continuous guidance throughout the course of this research, particularly during the preparation of the manuscript.

Heartfelt thanks are expressed to Professor Mainwaring B. Pescod for his invaluable comments and suggestions during the works, particularly regarding the design and construction of the Pilot Plant.

Thanks are also due to Mrs. Samorn Muttamara for her help and advice in laboratory works; to Dr. Maung Nay Htun, Dr. P.Y. Yang and Mr. B.N. Lohani for their encouragement; to Mr. N.C. Binh and Mr. Julian D. Centeno, Jr. for their help in plant operation and to all of my friends, specially Amin Zahangir, Paul and Khalid, who help me in manuscript preparation and inspired me towards its completion.

The author expressed his gratitude to his parents for their sacrifice and moral support.

Finally, the author wishes to acknowledge his indebtedness to his scholarship donor, Canadian Government for the sixteen month financial support and the World Health Organisation for the overall finance of the pilot plant study on which this thesis was made possible.

ABSTRACT

In poor and populated tropical Asian Countries, the need of supply of drinking water to an acceptable level of safety needs proper and quick consideration. To do that an economic but a reliable method of water treatment system needs to be investigated. The present study pertains to treatment of available surface sources of water to meet the increasing demand of millions of community dwellers in Asia. Three types of filter combinations were studied as follows:

(1) Series, coconut-fiber-burnt rick husk filter
(2) Series, coconut fiber - sand filter and
(3) Dual media filter, using coconut fiber and burnt rick husk as filter media.

The combination of filter media were selected from the point of view of economy, local availability and their practical applicability.

The study was carried out at three levels of turbidity in raw water. Filtration rates ranging from 0.10 m^3/m^2-hr to 0.6 m^3/m^2-hr were tried to find out an optimal filtration rate for each type of filter.

The findings of the investigation led to a filtration rate of 0.20 m^3/m^2-hr as optimal one for burnt rice husk filter of depth 80 cm at all the levels of turbidities. The optimal rate for slow sand filter of depth 80 cm was equal to or less than 0.2 m^3/m^2-hr, to give about one moth of filter run and that for dual media filter of coconut fiber; depth of 80 cm and burnt rick husk depth of 60 cm was found to be 0.20-0.25 m^3/m^2-hr to produce water with acceptable level of turbidity value around 5 JTU for water sources of all the levels under investigation.

Though removal efficiencies of coliform ranged from 75% in dual media filter to 98.9% in sand filter operating at low rates of 0.20 m^3/m^2-hr, but chlorimation is recommended to be practiced before drinking. However, required chlorine doses were found as minimal as 1.0 mg/l to 1.2 mg/l.

Finally, the potential use of locally available burnt rice husk which is considered as a solid waste, in place of expensive and scarce fine sand leads to the hope that, the increasing water demand in the tropical countries could be met in a near future; using the country's human resources.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

I INTRODUCTION

Problem

Water is abundant in this world but only a small portion of it is potable and suitable for human consumption. Most of the water from surface and underground sources are persistently getting polluted by natural and man-made activities of waste disposal.

These polluted waters are the carrier of pathogenic bacteria and thus when ingested, cause diseases and disorders among the consumers. Therefore, water from most of the natural sources demand treatment before use. Uptill now, research on water treatment system have been done mostly on rapid sand filtration and pressure filtration, both of which are costly and need specialized manpower and selective materials for effective operation. In tropical countries about 80% of the total population live in villages (Table 1.1) and small communities: the income level is low, skilled workmen are heardly available, high quality fine sand is scarce and power source - electricity is not always available.

Under these circumstances, the lack of safe water supply continues to remain a burning problem in the tropics, especially in Asian countries.

Table 1.1 - Program for Rural Water Supply in 90 Developing Countries, 1970-1980 (After WHO, 1972)

Type of Supply	1970		1980	
	Population, millions	%	Population, millions	%
Access to Safe Water	140	12	375	25
Without Access	1,026	88	1,081	75
Total Population	1,166	100	1,456	100

It is evident from the Table 1.1, that by the year 1980, 75% of the total population in developing countries will not get safe drinking water. By that time, the population might increase due to high birth rate in Asian countries. Thus the situation will aggravate more. To meet the scarcity of drinking water steps are to be taken to find out economical but stable process of treatment in the rural communities of Asian countries. The present research was carried out to find out a suitable, economic and low-cost method of treatment of surface water. In doing so, slow filtration process and its modifications were studied for optimal efficiencies of turbidity and coliform removal in filters, using locally available filter materials.

Purpose of the Research

The pilot units consisting of coconut fiber-burnt rice husk, coconut fiber - sand and dual media filters were studied. The purpose of the study was to determined:

1. The efficiency of series coconut fiber-burt rice husk, coconut fiber - sand and dual media filters in terms of turbidity and bacterial removal. This comparative study was done using Asian Institute of Technology pond surface water, assuming a typical source in the tropical Asian countries.

2. The suitable filter type producing effluents conferming to the local drinking water standards that may be accepted by the consumers in rural areas.

3. The optimum filtration rate in series coconut-fiber-burnt rice husk, coconut fiber - sand and dual coconut fiber-burnt rick husk filters in terms of water quality, filter run and ease in operation - at variable turbidity levels of raw water.

4. The potential of the above mentioned types of filters in terms of costs (constructional, operational and maintanance) and benefit.

5. (a) The effectiveness of chlorination for the effluents from the above mentioned filters in terms of the minimum dose of chlorine requirement to leave a free chlorine residual of 0.10 mg/l after a contact period of 30 minutes, which is the criteria for complete kill of pathogenic bacteria as set by World Health Organization (1971) and American Public Health Association.

(b) To find out the 'break point' chlorination level for the effluents from the mentioned filters at their optimal rates of filtration.

Scope of Research

The study was carried out in four phases:

1. Phase I studied raw water turbidity at average of 50 JTU.

2. Phase II studied raw water having average turbidity level of 100 JTU.

3. In phase III, raw water turbidity level was kept at 150 JTU.

4. Finally, in phase IV, chlorine dose was applied to determine the chlorination break point in case of filtered water and raw water.

In each of the first 3 phases, three runs were designed to study the performances of the filters at the following rates as given in Table 1.2.

Table 1.2 - Arrangements of Filtration Rates
(Modified Later On)

Filter Type \ Run		Run-1	Run-2	Run-3
1. Series Filter - Coconut fiber-burnt rick husk filters				
Filters	F1	0.20 m^3/m^2-hr	0.40 m^3/m^2-hr	0.60 m^3/m^2-hr
	F2	0.10 "	0.30 "	0.50 "
2. Series Filter - Coconut fiber - sand filters				
Filters	F3	0.20 m^3/m^2-hr	0.40 m^3/m^2-hr	0.60 m^3/m^2-hr
	F4	0.10 "	0.30 "	0.50 "
3. Dual Media - Coconut fiber-burnt rice husk filter				
Filters	F5	0.10 m^3/m^2-hr	0.30 m^3/m^2-hr	0.50 m^3/m^2-hr

Laboratory tests were performed to determine removal efficiencies of filters in terms of turbidity, coliform organism. pH and temperature of raw waste and filtered water along with recording of head loss in filters.

Constructional and operational problems were evaluated regarding pump failure, media preparation and washing etc. Optimum filtration rates of each type of filters were evaluated in terms of turbidity and coliform removal efficiency, head loss rates and operational problems.

Finally, tests were done to determine to chlorine demand of filtered water coming from filters at their optimum rates of operation, in terms of amount of available residual free chlorine after 30 mins. of contact time which is one of the chlorination time criteria as mentioned before.

II LITERATURE REVIEW

Filtration Theory and Mechanism

Filtration is a straining process in which suspended particles are removed from raw waster by media with pores sufficiently small to prevent passage of these suspended particles.

HUISMAN (1970) reported slow filtration as combination of four basic mechanisms:

1. Mechanical Straining - This action occurs at the surface of the media when water enters the pores but the suspended particles cannot pass through the interstices. This theory is supported by observations of SEGALL (1966).

2. Sedimentation Basins - The pore openings of the filter media act as individual sedimentation basins for the settlement of suspended particles. HAZEN (1904), observed this kind of sedimentation basins and explained the loss of velocity of those suspended particles when pass through the constriction of grains and falls in the pores. The loss of energy from the water molecules makes them to drop the sediment charges. This mechanism may be well applied in case of coconut-fiber and burnt rice husk. In coconut fibers the water looses its kinetic energy in moving centrifugally and thus the particle charges settle down (Fig. 2.1).

3. Adsorption - Adsorption of suspended particles occur on sand and other media surface which gets the particles adhered to it. STEEL (1965) accepted this adherence of particles as well as the loss of energy through centrifugal motion. He further indicated flocculation and settlement of suspended particles with bacteria. However, STEIN (1940) supported the 'chance contact' of particles with media surfaces as well as the convergent flowpath through the constrictions.

The adsorption mechanism is promoted by Van dar Waals force of attraction between colloidal suspended particles and media surface, when this force becomes more than the repelling force of zeta-potential. This chemical process of particle attachement is supported by O'MELIA and STUMM (1967). Considering mean particle size of the filter media equal to 0.50 mm, a nonscouring area of 1000 m^2/m^3 is mathematically available which is active for adsorption. In fine sand having mean diameter $\simeq$ 0.25 mm and porosity of 38%, a surface area of 1500 m^2/m^3 is available which is generally negatively charged for electro-chemical adsorption. However, the mechanisms of electro-chemical activity depends on the crystal structured clean quartz sand which has got negative charge. The composition of colloidal flocs of carbonates, iron and aluminium hydroxides, cations of iron, manganese and aluminium - all of which are impurities, and they have got positive charges. Therefore, these impurities get attracted by Van dar Waals force and thus adsorbed.

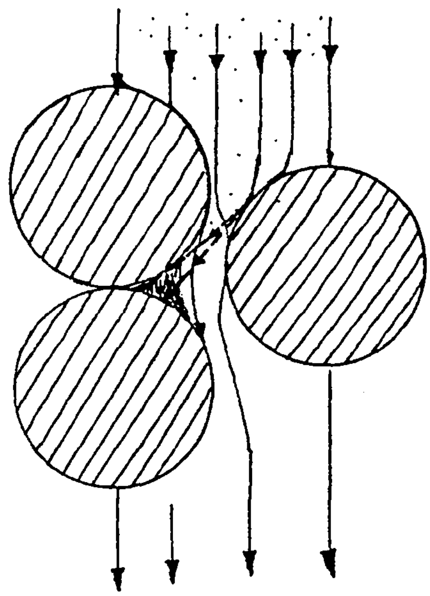
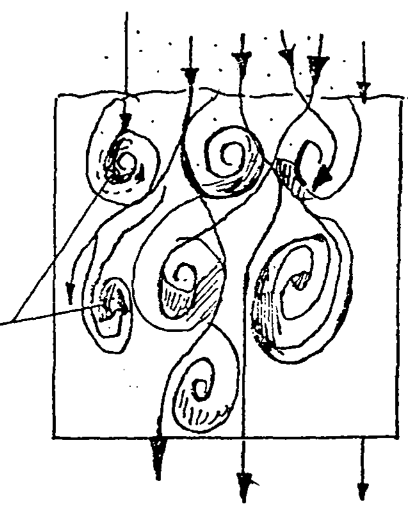


FIG. Showing how inertial and centrifugal forces cause particles to move out of flowline and deposit in spaces between the sand grains. (Courtesy WHO, (1970))



On the above principle of inertial and centrifugal action of forces, particles are settling in the cavities of coconut fibers.

FIG. 2.1 ACTION OF FORCES ON PARTICLE SETTLEMENT.

4. Electro-biological and Bio-chemical Properties - The organic colloids present in raw water as bacteria and others are mostly negatively charged. They are not attracted by sand grains untill and unless the positively charged inorganic colloids adsorbed in such an amount as to oversaturate the sand surface with positive charge. At this stage, the newly formed surface can attract the negatively charged microorganisms and other bio-mass by coulomb's law of electrochemical attraction. The time-lag between this supersaturation is called the ripening period of biological slow filters. HUISMAN (1972) further explained the biological action in glow filters that, the adsorbed bacteria use oncoming organic colloids for metabolism and degrade them in layers which are entraped into sedimentation basin pores. Below 30-40 cm, when bacterial action ceases, the chemical conversion of amino-acid to ammonia and NO_2 to NO_3 take place combining with oxygen present in the pore spaces. DANIELS and ALBERTY (1966) had the same opinion about the process of adsorption but they indicated the effects of pressure, concentration and temperature of the fluid containing the suspended particles. The later opinion is supported by O'MELIA and STUMM (1967) but added to this the influence of media size, rate of filtration and size of the suspended particles were also related. At low flowrates, the velocity of water and suspended particles entering into millions of sedimentation basins in the bed is assumed to be laminar and the settling velocity of perticles obey STOCKES' law:

$$\mu = \frac{1}{18} g/\nu \cdot \Delta\rho/\rho \cdot d_p^2 \qquad (2.1)$$

where μ = settling velocity
ν = kinematic viscosity of fluid and is a function of temperature
ρ = density of water,
$\rho+\Delta\rho$ = density of wet suspended matter (with water)
d_p = particle diameter,
g = acceleration due to gravity $\simeq$ 9.81 m/sec^2

In a sand bed, pore size is little over 20 μ_m (micrometer) in diameter but on the other hand colloids have diameter 1 μ_m or less and length of bacteria 15 μ_m or less; therefore, they cannot be screened out. But during their tortuous course of movement they come together and agglomerate to d_p. If $dp \geq 4\ \mu_m$, settling velocity becomes $\geq 0.2 \times 10^{-3}$ m/h - which is sufficient for total settlement of colloids and bacteria.

In the early studies of PERSALL and others (1946) the action of zooglea and schmutzdeck were mentioned. Zooglea, a tenacious bacterial envelop of jelly surrounding the individual sand grains is responsible for biological oxidation of organic colloid matters. Schmutzdeck or 'filter skin' is formed as the filter ripens with time increases the screening effect of filter bed but gradually fills up the constricted openings of filter material and clogs it, thus shortening the filter run. However, these mechanisms of suspended particle of diameter $d_m \geq 1\ \mu_m$ removal by sand particles may be applied for locally available coconut fibers and burnt rice husk. Coconut fiber has large surface area, pores space and tortuous intersticial path and burnt rice husk is a form of activated carbon (char) which posses electro-chemical and electrokinetic negative properties. Thus, both of the laws of electrostatic attraction and coulombs' law of electrostatic attraction might act behind the filtering mechanism of burnt rice husk and coconut fibers.

Advantages of Slow-Sand Filter over Rapid Sand Filter

The advantages of slow filtration comes from the process mechanism of straining, sedimentation, adsorption, chemical and biological oxidation through a single process. The following are the main points on which the advantages are counted:

Turbidity - Slow filter are able to remove turbidity 100-200 JTU for shorter run but acts very well with turbidity lower than 50 JTU.

Bacteria Removal - Under ideal conditions, it can remove 99.9-99.99% of coliform bacteria. Laboratory tests (HUISMAN, 1970) had shown that the slow sand filters can remove some forms of virus which may not be possible to remove by rapid sand filters.

Prefilter Use - Prefilters can be used in case of a slow filter if the turbidity load exceeds the limiting value of 50 JTU.

Cleaning Time and Frequency - Frequency of cleaning in slow sand filters is low due to their low rate and longer runs. Moreover, the colloids and suspended matters which are generally intercepted within top few centimeters of depth, can be cleaned by non-skilled labours by simple scraping.

Construction - Readily available unskilled labour of rural area can be employed in the construction of slow sand filters in place of highly skilled labours and personnels - which are required by delicate construction of a rapid sand filter. Moreover, the dimension of the plant and media grade are not so much critical for its performance. Use of local materials and locally trained workmen saves the cost of skilled supervisors and sophisticated equipments needed by the rapid sand filter construction.

Operation - Locally recruited and trained staff saves the cost of operation. Moreover, in slow filters, biological and physical process predominate over chemical uses, therefore, chemical cost is saved. Use of local labour force for cleaning the filters saves the cost of fuel or power needed by mechanical scraper and back washing equipments in a rapid sand filter.

Sludge Disposal - Lesser amount of sludge per volume of treated water is produced because, most of the organic and inorganic suspended colloids are metabolised by micro-organisms and algae. Thus, problems of sludge collection, storage, dewatering and disposal is minimized.

Chemical Use - As the bacterial removal efficiency in slow filters is higher (99.99%), chlorination is generally not practised for the effluent from slow filters.

In conclusion, in tropical developing countries, where 80% of the total population - live in rural communities, installation of complicated mechanical, electrical and electronic control devices of a rapid sand filter is impracticable. In these areas, simple, reliable, stable and safe means of slow filters will get support from the consumers.

Alternative Media for Slow Filtration

HEIPLE (1959) carried out a pilot-scale study using pea gravel in place of sand as filter media. The effective size of gravel used were ranging from 1.26 cm (0.5") to 0.63 cm (0.25") and depth 42 cm (16".0). At the rate of 0.3 m^3/m^2 -hr (0.01 gpm/ft^2) the efficiency was '50% turbidity removal' and '50% coliform removal'. He observed that the efficiency increases with the increase in depth. This finding, however, is the obeyance of the clarification theory which states in brief that - the more is the depth, the more is the chance of contact of smaller particles with larger one and thus both of them settle down together.

BAILEY (1939) studied filtration using anthrafilt media of diameter 0.40-0.45 mm, $u = P_{60}/P_{10} = 1.40$, depth = 28 cm (11"). The filter gave effluents "sufficiently free from organic matters, colour and turbidity". However, his studies left no specific data to come to any conclusion.

RIPPLE (1938) used anthrafilt coal and sand, the former being half as hard as the later and weighing half of sand. The anthracite having more void space gave higher filtration rate. But this type of anthracite coal is not readily available in tropical countries. Moreover, no specific data is available about the filtrate quality; and the price of the material is also high in comparison to the other filtering materials.

SEVILLA's (1971) comparative studies on the effluents from filters having media of coconut fiber, raw rice husk and burnt rice husk with conventional media of sand and pea gravel showed that the efficiency of purification and length of run in burnt rice husk and combination of coconut fiber and burnt rice husk were better. But his studies needed further clarification about the use of local medium in the field. JACKSIRINONT (1972) and LOW (1974) carried out laboratory and pilot scale studies on local filter medium. Media depth of 80 cm coconut fiber followed by 60 cm burnt rice husk gave 99% coliform and turbidity removal after ripening period. JACKSIRINONT (1972) found that coconut fiber depth = 100 cm and burnt rice husk depth = 80 cm gave 99.8% removal efficiency in a series filter after a few hours of operation whereas the same media when were used in dual media filter gave 96% removal efficiency for coliform after 40 hrs of operation. Burnt rice husk is free of cost in this region and coconut fiber is also cheap. These studies exposed a new era in slow filtration in Asia, where fine sand is scarce and costly. Therefore, comprehensive studies are to be undertaken to find out the optimum rate of filtration at different levels of turbidity.

Factors Affecting Filtrate Quality

The quality of the filtrate in terms of the removal of turbidity, bacterial content (MPN), pH, hardness, colour and temperature depends on the following:

(1) Influent water characteristics
(2) Characteristics of filter media
(3) Filter bed characteristics and condition
(4) Depth of filter bed
(5) Filtration rate and
(6) Ambient temperature.

Influent Water Characteristics - For better filterability of raw water without affecting adversely the treatment system, the U.S. National Technical Advisory Committee (1969) recommended standards of properties of raw water for slow and high rate filters interms of:

Colour - The source water should not contain more than 75 colour units (Pt Co. Std.). In present case the colour range was 10-20 JTU.

Turbidity - Turbidity should be readily removable by coagulation, sedimentation and filtration; must not be so high as to overload the filter. The upper limit for most exceptional cases $\ngtr$ 100 JTU and should not vary so frequently as to upset the plant operation schedule. In the present case, the source had turbidity range $\simeq$ 20 JTU and high values were experienced during rainy days. This concluded the usefulness of the water as a source.

Particle Size - According to HUISMAN and WOOD (1974) the straining effect of sandmedia is independent of flow rate, and sedimentation removes only a fraction of particles having diameter range 4-20 micro-meter (μm), therefore particles having size less than 4 μm cannot be filtered by usual sand media except through biological and electro-chemical action.

Coliform Content - The coliform content in the raw water should not exceed 5,000-10,000/100 ml of water. The present source had MPN range of 2,000-3,000/100 ml.

pH - The raw water source should not outway the range 6.0-8.5.

Total Dissolved Solids - the raw water should not contain dissolved solids (total) more than 2,000 mg/l except in localities where water is very scarce.

Alkalinity - Recommended alkalinity for source water should not exceed 500-1,000 mg/1 as $CaCO_3$.

Nitrate and Nitrite - Recommended nitrate and nitrite values should not exceed 10 mg/1 as NO_3-N or/and NO_2-N.

ROBERT (1964) suggested that if the turbidity of raw water is less than 25 JTU, steps of conventional filtration namely flocculation and sedimentation may be omitted.

HUISMAN (1970) mentioned that excess turbidity makes it difficult to treat water by slow filters. The suggested turbidity range for longer run as 10-50 JTU. However, tests have shown that a turbidity of 100-300 JTU may be removed by slow filters by providing a prefilter of roughing media to bring the turbidity of influent down to less than 50 JTU.

It is reported that coconut fiber can be used as a roughing media for slow filters when they are overloaded by turbidity more than 50 JTU. FRANKEL (1973) mentioned that the roughing media broke after second washing and the volume reduced to 35%. FAN (1974) reported that coconut fiber depth of 80 cm reduces to a depth of 60 cm after washing.

Filter Bed Characteristics

It is reported that (HUISMAN, 1970) the velocity of water through slow filters is low and it provides laminar flow obeying DARCY's law:

$$H = v_f/K \cdot h \tag{2.2}$$

where, v_f = filtration rate
h = depth of bed
K = coefficient of permeability, m/hr.

The emperical formula used to find out the value of K is

$$K = 150(0.72 + 0.028T) \cdot p^3/(1-p)^2 \cdot \phi^2 \cdot d_s^2 \tag{2.3}$$

where, T = temperature °C.
p = porosity
ϕ = sphericity (shape factor) of filter media
d_s = specific diameter of media

Thus the filtrate quality is affected by the variation of the parameters in the equations (2.2) and (2.3); which subsequently cause short-circuiting, bed cracking, mud ball formation, air binding and thus the filter runs are shortened.

Depth of filter bed - HUDSON (1958) concluded that if other factors such as rate and media characteristics remains the same, the greater depth of bed will produce better quality of effluent.

Mathematically,

$$n_q = f(d);\ Q,\ U,\ T \text{ are constant} \qquad (2.4\ a)$$

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

JACKSIRINONT (1972) and FRANKEL (1973) reported depth of coconut fiber = 80 cm to remove heavy colloid load. According to them, dual media filter of depth 80 cm coconut fiber and 20 cm burnt rice husk removed high turbility (100-30 JTU) and bacteria content. However, LOW (1973) recommended modification of these systems by changing depth of coconut fiber to 80 cm and burnt rice husk = 60 cm in polishing part.

However, according to DARCY's low $H = \nu_f/K \cdot h$; if depth h increases, bed resistance also increases and velocity of flow and rate of filtration decreases simultaneously.

Filtration Rate

Filtration rate depends on quality of influent water (HUDSON, 1957), pretreatment facilities, sand size, bed depth, hydraulic head of supernatant water and head loss in underdrainage systems.

$$\nu_f = \alpha\ (H_1 - H_2) \qquad (2.4\ b)$$

where, H_1 = inlet water head
H_2 = filtered water head
α = coefficient of permeability and

$$\alpha = f(d,\ \delta_m,\ R) \qquad (2.5)$$

where, d = depth of medium
δ_m = effective grain size of medium
R = under-drainage resistance

δ_m and 'd' decide the formation of compressible slime on surface of grains and incoiled pores of fiberous medium.

As α decreases, the fiberous pores decrease and vice-versa. Now, the resistance offered by the underdrainage

$$H_1 - \tfrac{1}{2}\,Kh \cdot \nu_f \cdot (a/2)^2 \qquad (2.6)$$

where,
K = coefficient of permeability

h = thickness of underdrainage
a = effective distance of drain

According to equations (2.3) to (2.5), it can be concluded that sand of 0.5 mm size is twice better in removing turbidity than that removed by sand of 0.7 mm size. But the run shortens to one quarter if the diameter is halved.

JACKSIRINONT (1972) carried out investigation with bed depth 15 cm, 30 cm, 60 cm and 90 cm and found that for the same filtration rate and run length, effluent quality deteriorated as the depth was increased. Moreover, the early experiments of BAYLIS (1937) showed that the filtration run varies as the 2.15 th power of effective size of material.

$$\text{i.e., Run} = K_{dm}^{2.15} \tag{2.7}$$

where, d_m = effective size of media
K = constant

From equations (2.2), to (2.6) it is found that filtration rate is almost inversely proportional to filter run.

From the above reviews of the action and interaction of different parameters on the removal efficiencies of slow filter it can be concluded that the filtration rate depends on so many factors each of which are also not independent. Therefore, a thorough investigation in this field is still warranted.

III EXPERIMENTAL INVESTIGATION

Water Source

Raw water source was a pond located nearby the regional experimental centre of the Asian Institute of Technology, Bangkok, Thailand. Analysis of this surface water denotes a low turbidity content. In order to bring the turbidity up to levels from 50 to 100 and 150 JTU water jet was used to create turbulence in the baffled portion of the pond (Fig. 3.1).

Water was pumped from the pond by a 10-h_p centrifugal pump through a screened intake to intercept clogging particles. Two by-pass lines were provided: one to regulate the amount of influent and the other to create turbulence in the baffled portion to increase turbidity to desired levels. Flows in each by-pass section were controlled by regulating valves.

The results of physical, chemical and bacterio-logical tests according to 'Standard Methods' (1971) are given in Table 3.1. Raw water characteristics of the source are compared with those of Chaophya River and Klong Prapa (Table 3.2) which are supplying raw water to SAMSEN Water Treatment Plant, Bangkok, Thailand - to provide an example of variable characteristics in tropical water source.

From Table 3.1 and Table 3.2 it is evident that the turbidity of the source did not vary much as was seen in the raw water of Chaophya River and Klong Phrapa. pH of the raw water from all the 3 sources were in 6.4 to 8.9 range with less variation. Temperatures of the sources showed in value well around 30°C indicating favourable ambient condition for high biological actions. Dissolved oxygen ranged from 6.6 to 7.1 mg/l in the present source and 2.4 to 5.0 in Chaophya River water. This indicated less pollutional load in the present source in the forms of organic matters.

Pilot Plant Set-up

The pilot-plant as shown in Fig. 3.2 was composed of:

- Reserve raw water tanks.
- Pumping Units
- Wooden structures.
- Filtration Units.

Reserve Raw Water Tank - Two galvanized iron sheet tank each having a volume of 2.0 m^3 (2.0D x 1.0W x 1.0L) - were used to receive raw water. First tank was provided with paddle mixer, driven by an 1.0 hp electric motor. The mixer was not used due to the fact that the jet turbulence at the intake was able to raise turbidity to desired levels. The second tank served as reserve source for supplying raw water to roughing filters and dual media fiter .

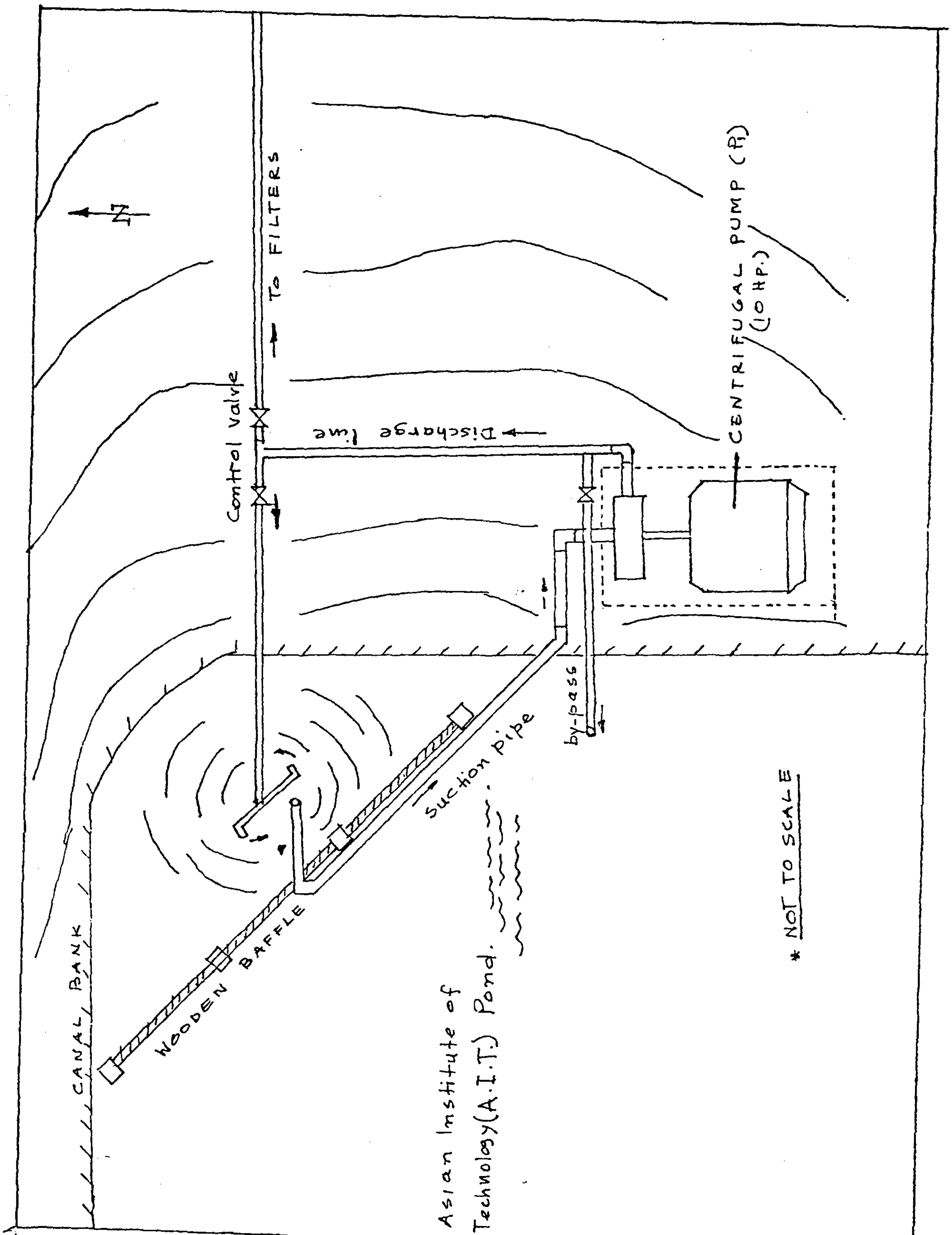


Fig. 3.1 - Plan View: Intake System and Baffled Pond

Table 3.1 - Characteristics of Raw Water (Source) from AIT Research Centre Klong (Pond)

Tests Done in the Year 1975	12 April	20 April	28 April	6 May	13 May	21 May
Physical Examination						
Colour, Units (Pt.Co.Stand)			10 - 20			
Temperature, ^oC	32	31	30	29	31	34
Turbidity, FTU	8	17	7	28	18	25
Chemical Examination						
Alkalinity, mg/l $CaCO_3$	108	118	126	102	120	120
pH	6.4	8	7.1	7.1	6.9	7.3
Chlorides, mg/l	35	21	16	16	16	16
COD_T, mg/l	38	42			27	
D.O., mg/l	6.6	6.9	6.9	7.0	7.1	6.6
Hardness (EDTA), mg/l as $CaCO_3$	143	150	139	135	135	115
Iron, mg/l	0.78	0.52	0.92		1.1	0.52
Manganese, mg/l	0.88	1.86	0.71	0.41	1.5	1
Bacteriological Examination						
Total Coliform MPN Index per 100 ml x 100	11	14	9	7	8	-

Table 3.2 - Chaophya River and Klong Prapa (Samsen Plant) Raw Water Quality (After MOUCHET, 1974)

Characteristics	Klong Prapa, Source - M.W.W.A., '74				Chaophya River
	Minimum	Maximum	Average	31.8. & 2.9. '74 Value	Date 3.9.'74.
Turbidity, JTU	5	250	90	75	150
Suspended Solids, ppm	8	411	72	86	170
pH	6.45	8.9	7.73	7.3	7.5
Temperature	26	32	-	29.5	-
Ammonia, ppm NH_4	0.0005	0.4	0.05	0.35	0.25
Iron, ppm, Fe	0.29	6.5	1.48	0.9	2.2
Dissolved Oxygen O_2, ppm	2.4	6.7	4.1	-	5.0
Colour	-	-	-	-	50 ppm Pt-Co.

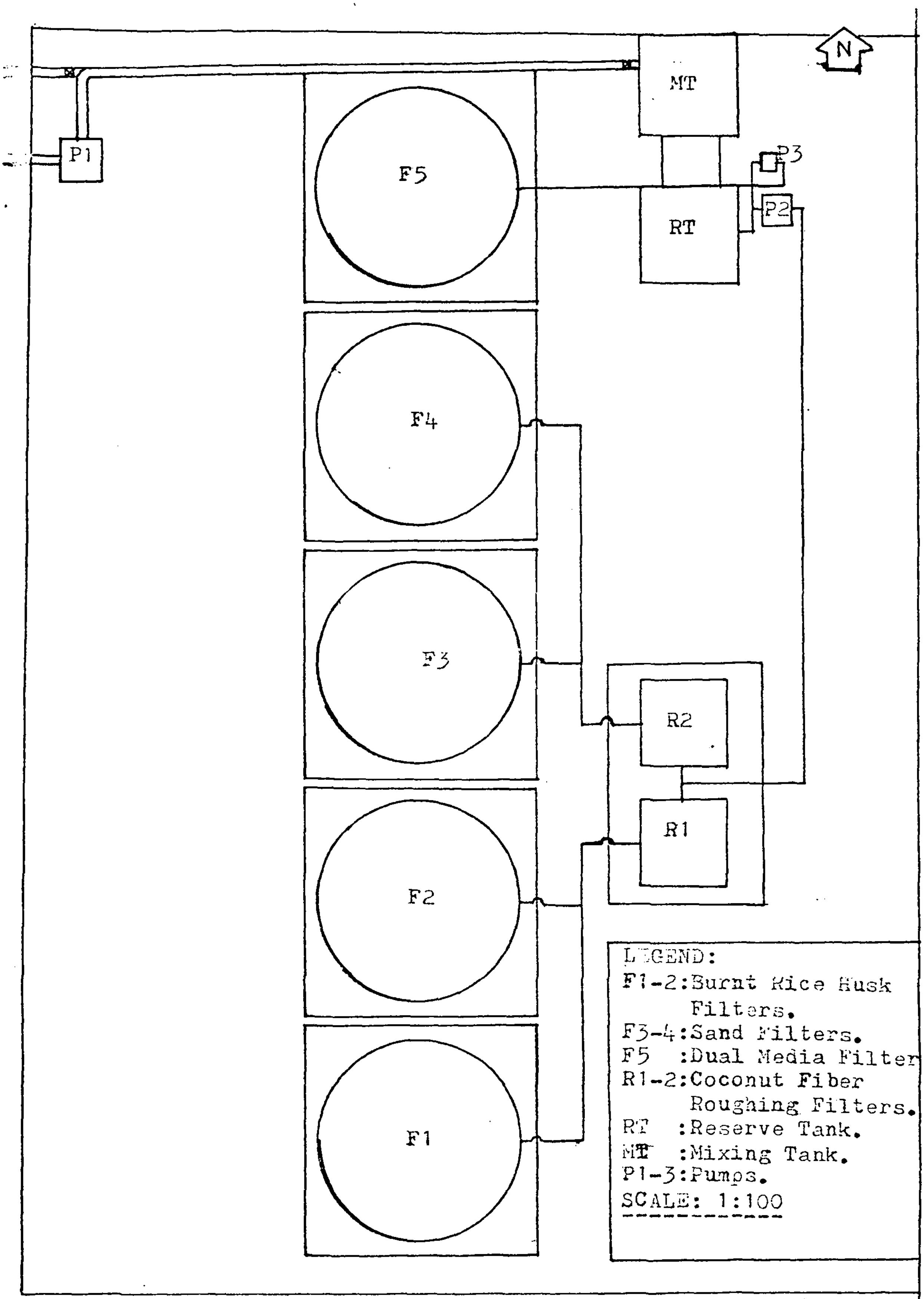


Fig. 3.2 - Plan View for Pilot Plant and Filter Set-Up

Overflow Pipes - 5.24 cm ∅ (2") PVC pipe was connected to the uppermost water level of filter columns as overflow pipe to maintain a water head of 1.20 m.

Pumping Units - One 2.0 KW. piston pump of capacity 6,000 l/hr was pumping water from the second tank to the roughing filters mounted on the wooden structures. Flow was controlled by a 5.24 cm ∅ by-pass pipe connected with drainage.

- One 1.0 KW. centrifugal pump of capacity 61/min was used to pump water to the dual media filter from the second tank.

Wooden Structure - A wooden structure as shown in Fig. 3.3(a) was designed to carry a maximum load of 10,000 kg, consisting of load of two (2.0 m x 1.0 m x 1.0 m - 0.31 cm thick) G.I. tanks full of water which were used as roughing filter columns, and contained 80 cm depth of coconut fiber and underdrainage crushed stone volume of (0.10 m x 1.0 m x 1.0 m) = 0.10 m^3.

Rotameters - Seven Elliot-2000 rotameters were used to control and measure flow of effluents from the two roughing, four polishing and one dual media filter.

Design of Filtration Units

Series filters systems consist of roughing and polishing filters were designed as follows:

Roughing Filters - 2 roughing filter boxes each having volumes of (2.0 x 1.0 x 1.0)m^3 were made of 0.31 cm thick galvanized iron sheet. Constructional dimensions and series filter set up are given in Fig. 3.3(b) and Fig. 3.4.

Slow Polishing Filters - Four polishing filter columns F_1, F_2, F_3, F_3 were made, each with 3 concrete pipes having diameter 1.54 m (5'0"∅), height 1.0 m and thickness of 10 cm. The bottom-most pipes were reinforced with steel wires and each were situated on a caste-in situ 1.75 m x 1.75 m x 0.15 m (depth) mass concrete floors. Dimensions and constructional details of the filters are shown in Fig. 3.4.

Dual Media Filter (F_5) - The design and set up was same as that of single polishing filter described above for polishing filters. Design and constructional details are shown in Fig. 3.5

Head Loss Measurement in Filters - Piezometers for head loss measurement were made of 0.63 cm ∅ internal diameter perspex tubing. These were inserted to the filter columns connecting each bottom level of filter media of coconut fiber, sand or burnt rice husk to upper level of the water surface as shown in Fig. 3.6 (typical piezometer connection).

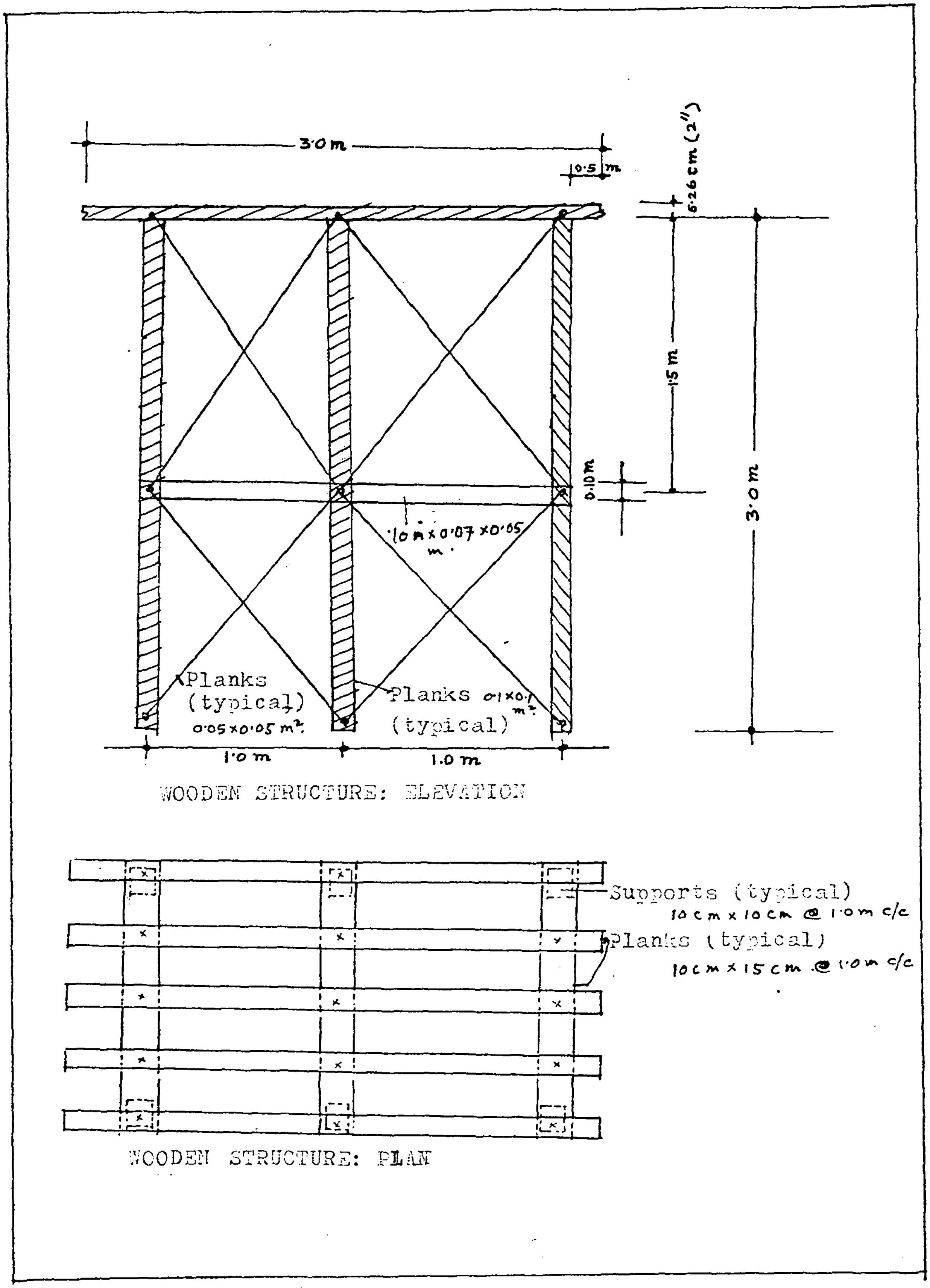


Fig. 3.3(a) Wooden Platform

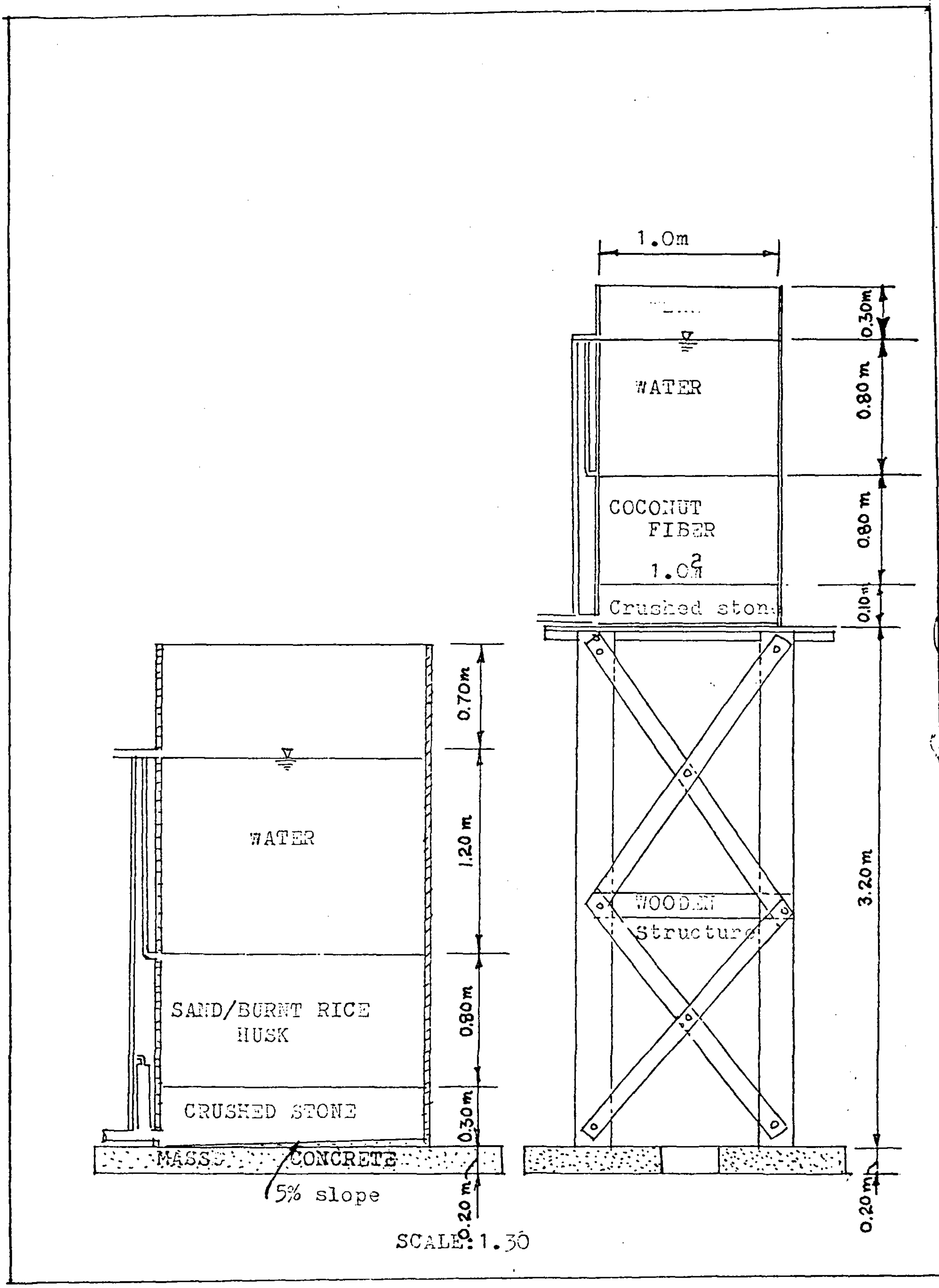


Fig. 3.3(b) Series Filters Set-Up

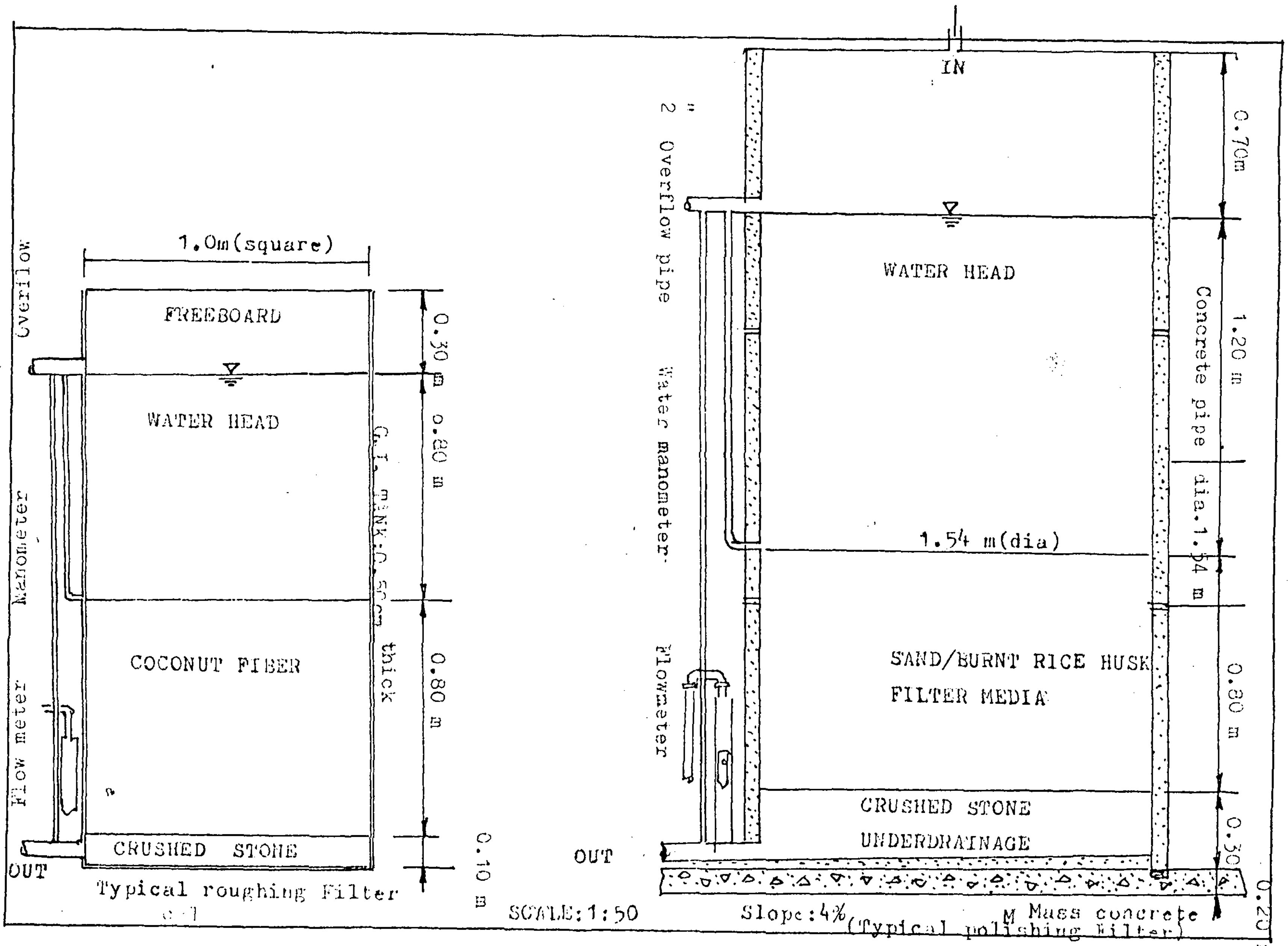


Fig. 3.4 - Typical Details of Series Filter

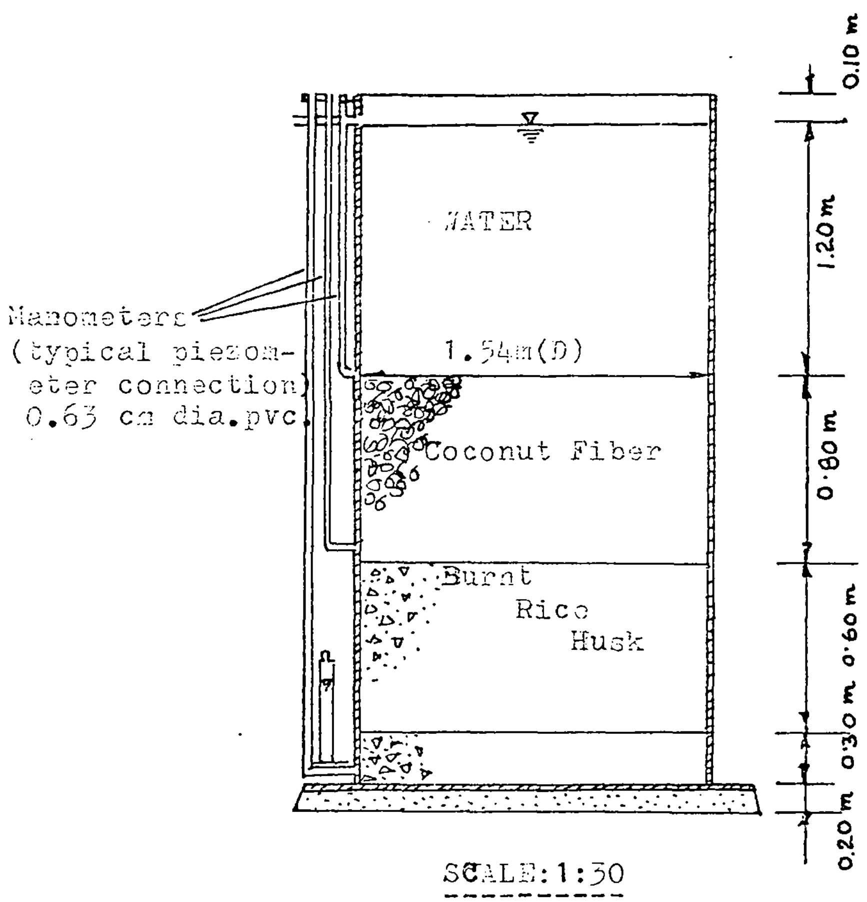
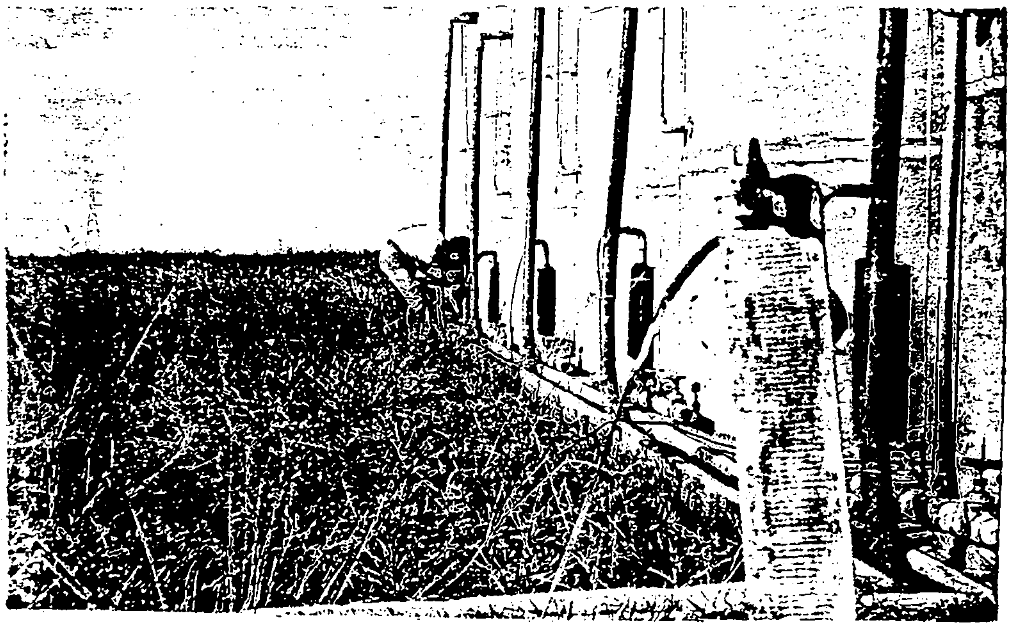


Fig. 3.5 Dual Media Filter, F_5



Sampling photo showing sampling from 1" PVC discharge pipes fitted with rotameters covered with black plastic sheets. PVC manometers are also seen which are connected with exhaust pipes. Overflow pipes are seen to be connected to the drainage channel made of precast concrete U-channel blocks. Oridinary valves are seen on discharge pipes which are used to control filtration rates.

Fig. 3.6 - Sampling Photo

5.6 cm ϕ (2") galvanised iron outlet pipes were connected to 2.54 cm ϕ PVC sampling pipes through Elliot-2000 type rotameters (Fig. 3.6).

Influent water was fed to filters through perforated PVC tubings as shown in Fig. 3.7; each having 15 openings of diameter 0.33 cm (1/8 in.). Influent water level was maintained by using 5.24 cm ϕ (2") PVC overflow pipes connecting the filters to drainage. The effluent flow was controlled and measured by rotameters manually at the interval of 4 hours.

Filter Media Depth - The depth of coconut fiber in roughing and dual media filter was 80 cm when uncompacted. The depth of burnt rice husk in polishing filters was 80 cm; whereas a depth of 60 cm was provided in dual media filter. The depth of sand in polishing filters was 80 cm. The arrangement is shown in Table 3.3.

Filter Media Characteristics - Filter media characteristics with depth combinations are given in Table 3.4.

Supernatant Water Depth - The following supernatant water depth were provided to avoid building up of negative head, to prevent air binding and to reduce disturbance on "filter skin" or biological layer by the falling influent water:

(1) A depth of 80 cm followed by a free board of 30 cm was provided in roughing filters.

(2) In polishing filters a depth of 1.20 m followed by a free board of 70 cm ware provided (Fig. 3.4)

(3) A depth of 1.20 m followed by a free board of 10 cm was provided in dual media filter (Fig. 3.5).

Underdrainage System - The underdrainage was provided with graded crushed stone to support filtering media and to provide free path to filtered water. The depth of underdrainage in roughing filter was 10 cm and that in polishing and dual media filters were 30 cm each. A 5% slope was provided on the floor of underdrainage. The combination of underdrainage material is shown in Fig. 3.7.

Experimental Design Parameters

Independent Variables - The following were the independent variables:

(1) Raw water quality (turbidity, coliform content (MPN), pH and temperature).

(2) Filtration rates e.g. flow rates from roughing, polishing and dual media filter.

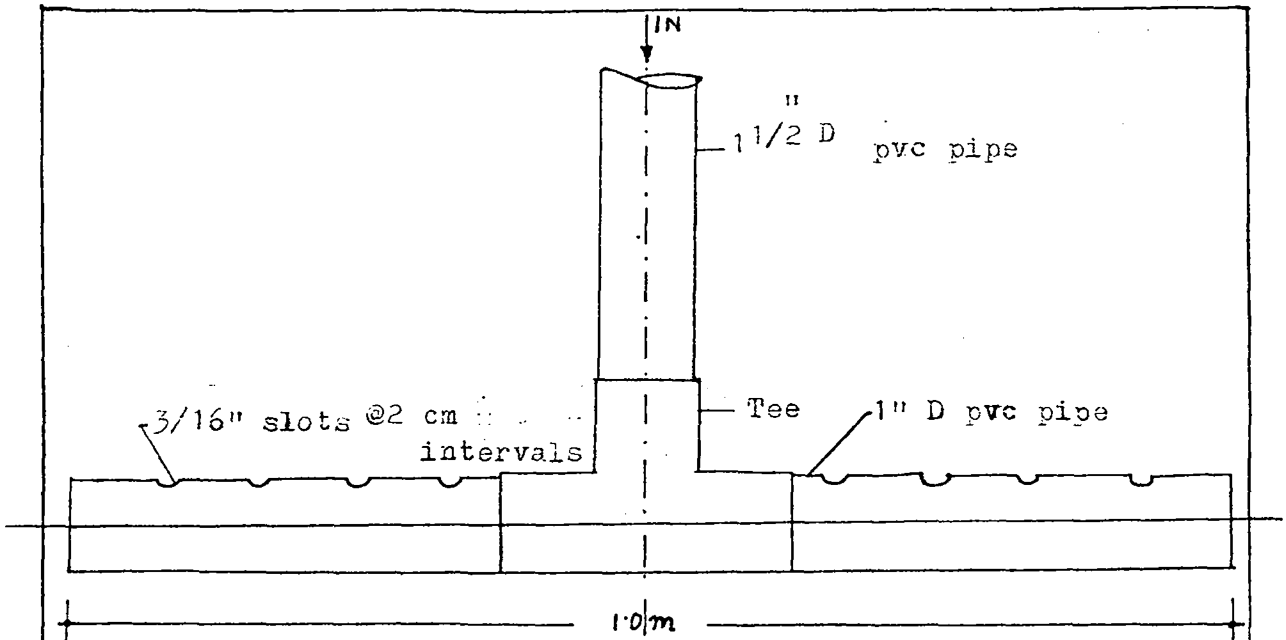
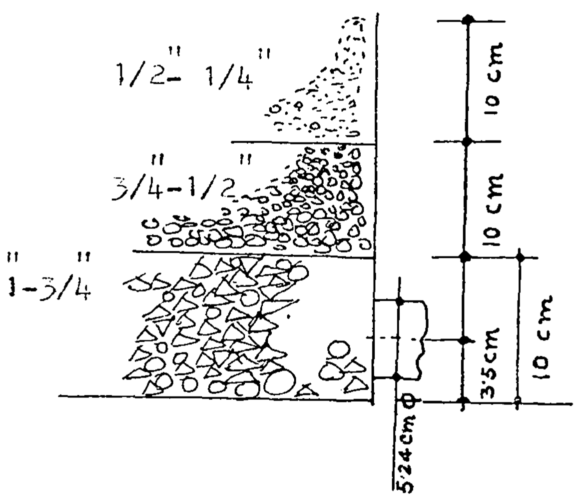
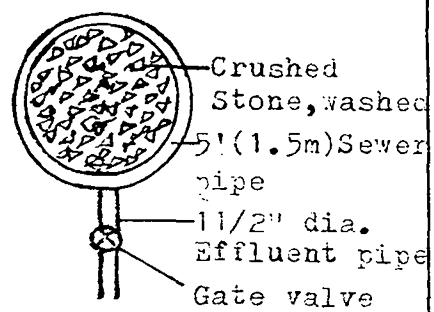


Fig., Showing Distributor Design





Underdrainage : Cross-Section   Underdrainage, PLAN

Fig. 3.7 - Distributor and Underdrainage Design

Table 3.3 - Combination of Filter Media

Media Characteristics \ Filter Type	Dual Media (F_5)	Series Filters: Roughing (R_1, R_2)	Series Filters: Polishing (F_1 to F_4)
Depth:			
Coconut fiber	80 cm.	80 cm.	
Burnt rice husk	60 cm.	-	80 cm. (F_1, F_2)
Sand	-	-	80 cm. (F_3, F_4)
Sand:			
d_{min}, mm. ($P_{.001}$)			0,22 mm.
d_{max}, mm. ($P_{99.99}$)			2.79 mm.
$d_{effective}$, mm. (P_{10})			0.90 mm.
Uniformity coefficient, P_{60}/P_{10}			2.30
Burnt Rice Husk (BRH):			
d_{min}, mm.	0.1 mm.		0.1 mm.
d_{max}, mm.	2.79 mm.		2.79 mm.
$d_{effective}$, mm.	0.80 mm.		0.80 mm.
Uniformity coefficient - $U = P_{60}/P_{10}$	6.1		6.1
Uncompacted specific gravity	2.25		2.25
Coconut Fiber Properties	mill shredded, soaked in water for 24 hr., washed carefully before placing manually.		

* Sieve analysis and distribution characteristics of burnt rice husk and sand are given in Fig. A3.1 and Fig. A3.2 in Appendix A.

Table 3.4 - Filter Media Characteristics

Reference	Media	Shape	Size	Specific Gravity	Charge	Remarks
TURNER (1944)	Anthrafilt	Sharp angular/ flat rounded	-	1.60	Negative	mineral inorganic, soluble in acid, alkali; Composed of carbon and stronger than sand.
TURNER (1944)	Sand	Rounded/ oval/ granular	-	2.65	Negative	Silica - SiO_2, insoluble in acid but sometimes soluble in alkali.
WILLIAMS and SOMPONG (1971)	Burnt rice husk	Cellular, crystalline silica	-	$\simeq$ 2.30 density 7.45-7.61 Kg/m3	Probably Negative	$SiO_2 \simeq 88.66\%$, $MgO = 3.53\%$ moisture = 8% W/W at $105^{\circ}C$. Has adsorptive power as activated charcoal

(3) Size and depth of filtering media.

(4) Chlorination doses.

Among the parameters, the raw water quality was uncontrollable, specially during rainy days.

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

(1) Removal efficiencies of turbidity and coliform bacteria (MPN) in all filters.

(2) Effluent quality (turbidity, MPN and pH).

(3) Head losses in filters.

(4) Run length of filters. The run length was concluded when at least one of the criteria was fulfilled:

(a) Development of 1.20 m head loss in one filter.
(b) Filtered water turbidity was more than 25 JTU, which is World Health Organisation prohitive drinking water standard.
(c) At least 10 days operation, when filteration rate was slow and run length seemed to be too long.

Schedule of Experiments

The experiments were carried out in 4 phases, three of which corresponding to three levels of raw water turbidities namely phase - I $\simeq$ 50 JTU, Phase II $\simeq$ 100 JTU and phase III $\simeq$ 150 JTU. In phase IV, the filtered water at optimal flow rates in filters and the raw water was chlorinated to find out chlorination break points. Summary of the schedule of works in phase, I, II and III are given in Table 3.5.

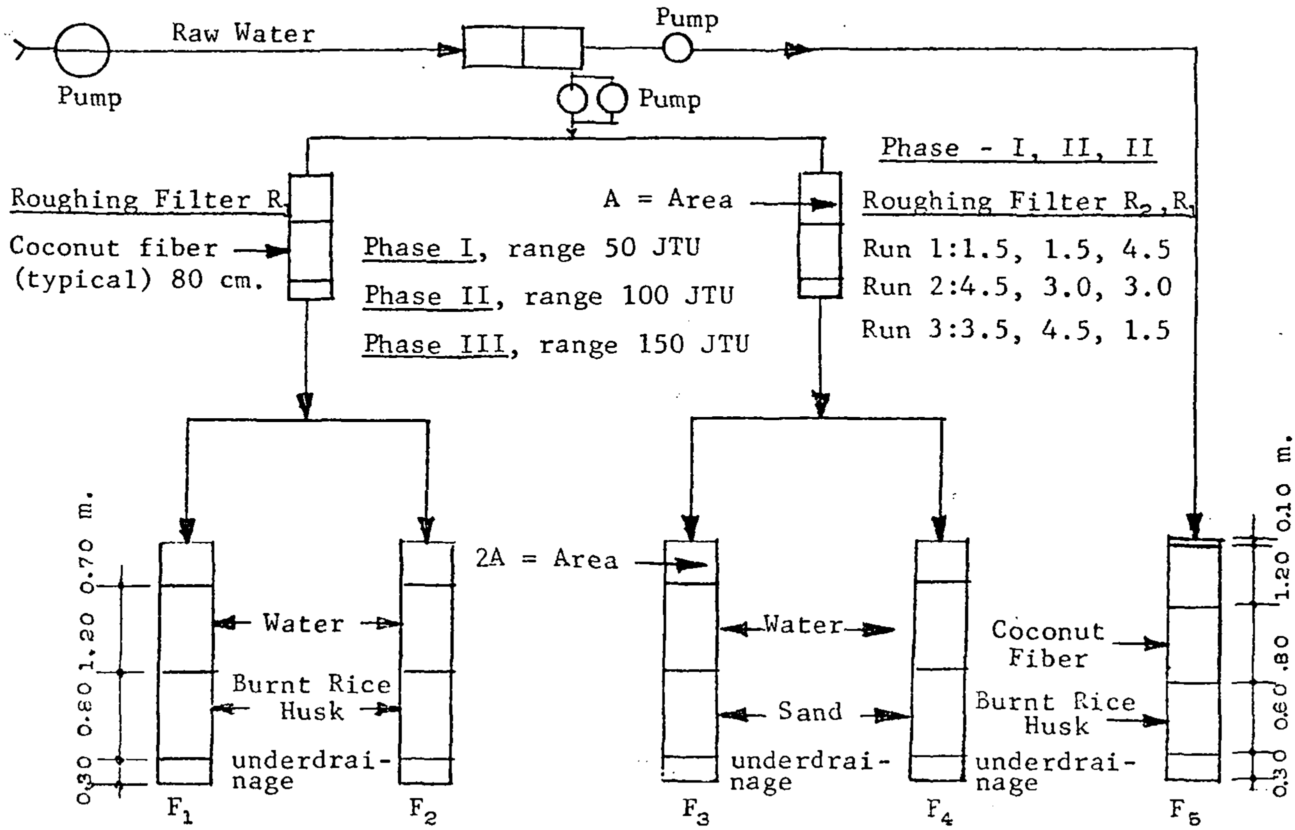
Materials and Equipment

Filter Media - (a) Locally available fine sand of effective size $E = 9.0 \times 10^{-2}$ cm. and uniformity coefficient $U = 2.3$ was used. Sieve analysis results are given in Fig. A3.1 in the Appendix A.

(b) Burnt rice husk of effective size $E = 8.3 \times 10^{-2}$cm. uniformity coefficient $U = 6.1$ was used. Sieve analysis results are shown in Fig. A3.1 in Appendix A.

(c) Shredded coconut fiber was collected from nearby shredding mill in Rangsit, Bangkok, Thailand, at a price of ฿ 70.00 per m^3. It was soaked for 24 hours in clear water before washing and putting into filter columns.

Table 3.5 - Summary of Operation Schedule



Phase - I

Run - 1:	0.20 m^3/m^2-hr	0.10 m^3/m^2-hr	0.20 m^3/m^2-hr	0.10 m^3/m^2-hr	0.10 m^3/m^2-hr
Run - 2:	0.60 "	0.40 "	0.60 "	0.40 "	0.50 "
Run - 3:	0.50 "	0.30 "	0.50 "	0.30 "	0.30 "

Phase - II

Run - 1:	0.20 m^3/m^2-hr	0.10 m^3/m^2-hr	0.20 m^3/m^2-hr	0.10 m^3/m^2-hr	0.10 m^3/m^2-hr
Run - 2:	0.40 "	0.30 "	0.40 "	0.30 "	0.30 "
Run - 3:	0.60 "	0.50 "	0.60 "	0.50 "	0.50 "

Phase - III

Filter -	F_1	F_2	F_3	F_4	F_5
Run - 1:	0.60 m^3/m^2-hr	0.50 m^3/m^2-hr	0.60 m^3/m^2-hr	0.50 m^3/m^2-hr	0.50 m^3/m^2-hr
Run - 2:	0.40 "	0.30 "	0.40 "	0.30 "	0.30 "
Run - 3:	0.20 "	0.10 "	0.20 "	0.10 "	0.10 "

<u>Control Operation</u> - In maintaining designed level of turbidity the by pass turbulence jet was operated at each 4 hours by opening the by-pass valve. Flow rates were adjusted 4 hourly to maintain designed filtration rates. The rotameters were cleaned after each run. To avoid algae growth inside the rotameter glass body, those were covered with black plastic sheets so that sunlight could not penetrate through the rotameter to give birth to algae.

<u>Cleaning and Overall Maintanance</u> - After each run the filters were cleaned. The roughing filters and roughing media in dual media filter was removed after each run manually. The material was washed in cleaned water in a tank. The media, after washing, was placed back into the colums immediately before it was dried. It was kept under clear water before the starting of each run. Some additional amount of soaked coconut fiber was added after each filter washing (not more than 10% V/V) to compensate wastage during cleaning.

The polishing burnt rice husk media was cleaned by scraping 2-3 cms each time. Same procedure of scraping was followed in case of polishing sand filter except that, the scraping depth was 1-2 cm.

At the time of cleaning, water level in the polishing filters was maintained in such a way that the filter bed did not go dry - allowing air-entrainment. When the media were put into the filters, water level was kept high up to overflow mark, so that the ashes present in burnt rice husk, dust in sand and coconut fiber float up and were removed with overflow water. On the other hand, the supernatant water from the filters were drained out by the help of 2.54 cm ϕ PVC siphons.

During each run interval the pumps and motors were cleaned and oiled.

IV PRESENTATION AND DISCUSSION OF RESULTS

The results of this pilot-scale study-report include the performance of series filters and dual media filter in removing turbidity and coliform content in raw surface waters. Head loss and filter runs were also recorded for the purpose of comparison. The temperature and pH variation in raw as well as in filtered water are also briefly reported. The studies were carried out in 3 phases at 3 levels of raw water turbidities. Phase wise discussions on the findings are supplemented by the data and results presented in the forms of tables and graphs.

Phase I - Experimental Study on the Performance of Series Coconut Fiber Burnt Rice Husk, Coconut Fiber-Sand and Dual Media Filters at 50 JTU Turbidity Level

The filter performances are reported and elaborated by means of following figures. Over the test period from June, 1975 to August 1975, the raw water turbidity ranged from 20 JTU to 180 JTU having an overall mean of 54.32 JTU. High turbidity occurred during rainy days due to drainage of silt and soil with surface runoff into the pond. pH of the raw water ranged from 6.9 to 8.3 during this phase. The variation of pH was insignificant over time. There was no variation of pH in the filtered water from that of the raw water.

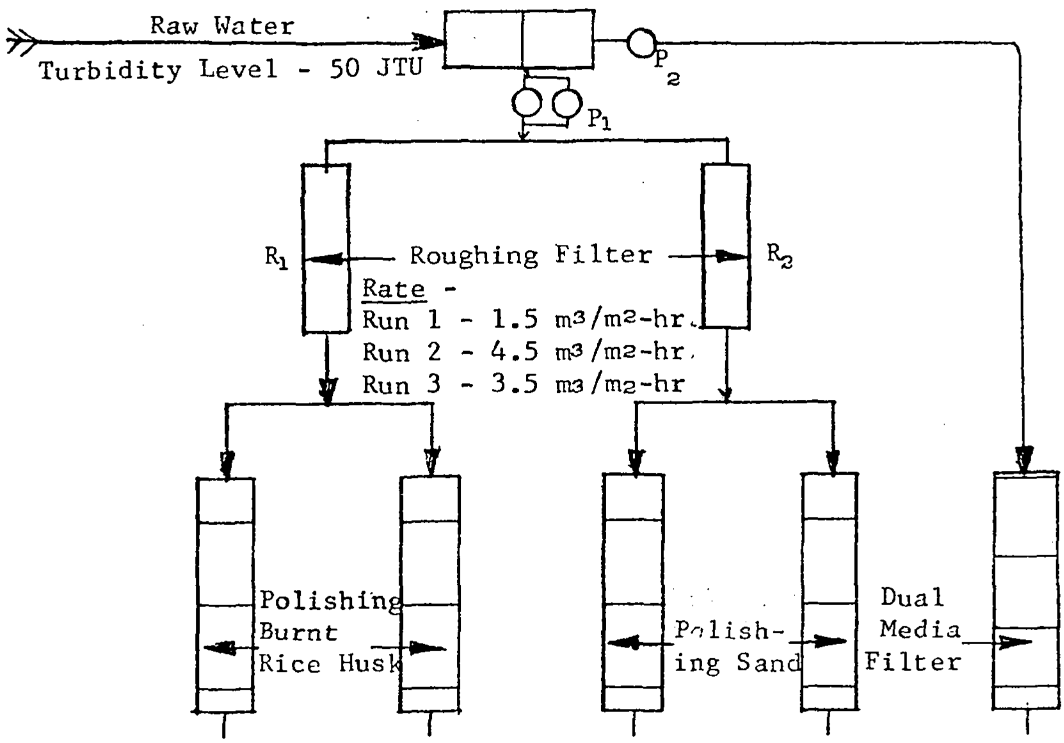
Temperature of the raw and filtered water was found in the range of 27 °C to 32.5 °C. Higher values were found to occur during mid-days.

Run 1 - Performance of Polishing Filter (F_{1-4}) and Dual Media Filter (F_5) at low flow rate of 0.1 and 0.2 m^3/m^2-hr on Raw Water Turbidity Level of 50 JTU

The filtration rate in roughing filters (R_{1-2}) was 1.5 m^3/m^2-hr as shown in Table 4.1. The turbidity of effluent from roughing filters ranged from 10 to 50 JTU. The value went over 50 JTU on 7th and 13th day of operation when there were heavy rainfall. High turbidity values in roughing filter effluent caused high turbidity in final effluent which ranged from 1.5 JTU to 10.0 JTU in burnt rice husk (F_1) and dual media filter (F_5) on 11th and 12th day. The run was terminated on 13th day of operation due to high turbidity in raw water (130 JTU and up) caused by rain. However, the constant value of turbidity in roughing filter effluent under a variable time-turbidity curve (Fig. 4.1) proved the shock load absorbing capacity of coconut fiber.

In the same Fig. 4.1, it can be seen that at filtration rate of 0.10 m^3/m^2-hr, the filtered water quality (turbidity) of sand filters (F_4) was better than those occurred in the effluent of burnt rick filter (F_2) and dual media filter (F_5). The arithmetic mean values of filtered water were 1.77 JTU for sand filter (F_4), 3.12 JTU for dual media filter (F_5) and 6.09 JTU for burnt rice husk filter (F_2).

Table 4.1 - Comparison Table - Phase-I



Filter Type	R_{1-2}	F_1	F_2	F_3	F_4	F_5
Filtration Rate, m^3/m^2-hr						
Run - 1	1.5	0.20	0.10	0.20	0.10	0.10
Run - 2	4.5	0.60	0.40	0.60	0.40	0.50
Run - 3	3.5	0.50	0.30	0.50	0.30	0.30
Filtered Water Turbidity (Mean) (J.T.U.)						
Run - 1	18	6.04	6.09	4.09	1.77	3.12
Run - 2	25	6.40	4.78	4.98	8.27	5.44
Run - 3	18.5	6.81	5.50	3.4	6.59	4.06
Head Loss Rate, (cm/day)						
Run - 1	-	2.17	0.36	1.88	2.23	0.38
Run - 2	-	7.05	2.0	30.0	30.0	3.0
Run - 3	-	4.88	1.20	5.86	14.6	2.54

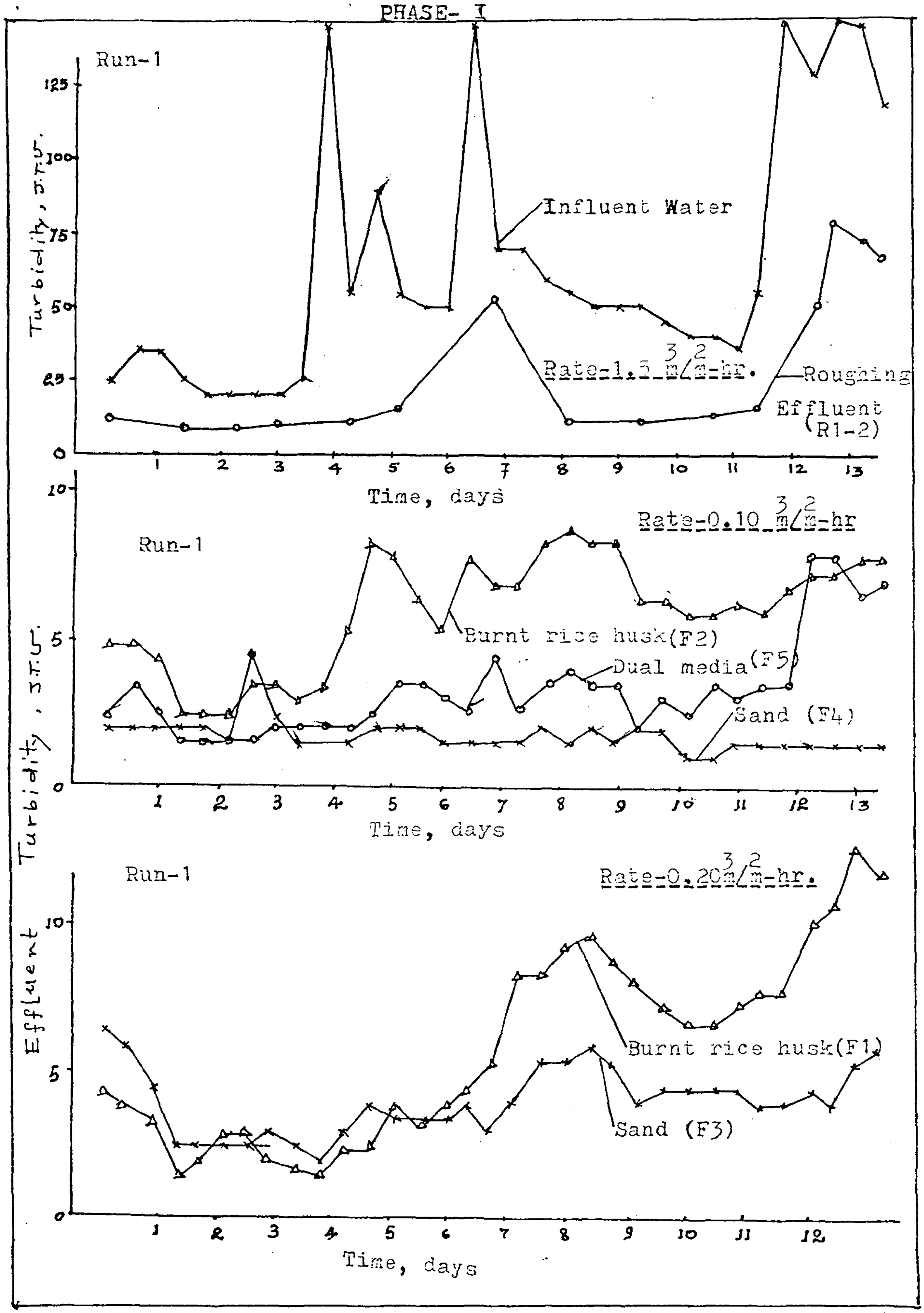


FIG.4.1 TIME-TURBIDITY CURVE

At the rate of 0.20 m^3/m^2-hr, the sand filter (F_3) also removed turbidity in a better way than the burnt rice husk filter (F_1). The sand filter (F_3) gave water having turbidity value 4.09 JTU which was competitive with the same type of sand filter (F_4) running at filtration rate of 0.10 m^3/m^2-hr, which gave effluent having turbidity mean value of 6.09 JTU both running at the same time. However, the turbidity of effluent from burnt rice husk filter (F_1) at the rate of 0.2 m^3/m^2-hr. was 6.04 JTU. which is very near to turbidity of effluent water from the filter (F_2) running at the rate of 0.10 m /m -hr. From these findings it may be concluded that at low filtration rates, sand filter is better than burnt rice husk filter in removing turbidity.

The filtered water from all the filters during this run was tested for coliform content. The sand filters (F_3 at 0.2 m^3/m^2-hr and F_4 at 0.10 m^3/m^2-hr) were found to contain 33 MPN/100 ml (F_3) and 23 MPN/100 ml (F_4), denoting a percentage removal of 98.62% and 99.04% respectively. In case of burnt rice husk filters F_1 (@ 0.2 m^3/m^2-hr) and F_2 (@ 0.1 m^3/m^2-hr), the residual coliform content value was 43 MPN/100 ml, amounting 98.20% removal efficiency (same of both). The MPN value in the filtered water from dual media filter - F_5 (@ 0.10 m^3/m^2-hr) was 122/100 ml; the 94.91% of removal efficiency showed lesser efficiency of coliform removal than those in sand and burnt rice husk polishing filters.

The head loss rates during this run ranged from 0.38 cm/day (F_5) to 2.23 cm/day (F_4), both running at the rate of 0.10 m^3/m^2-hr indicating a longer filter run in all the filters. The head loss rate values were found to be lower than the value (15 cm/day) observed by JACKSIRINONT (1972) for a dual media filter running at the rate of 0.25 m^3/m^2-hr. The reason might be the presence of less finer particles in the present raw water than that were present in raw water used by JACKSIRINONT. The comparative head loss-time curves (Fig. 4.2) support the conditions stated above.

Run 1 - Conclusions - At roughing filter rate 1.5 m^3/m^2-hr (R_{1-2}) and polishing filtration rates 0.1 m^3/m^2-hr (F_2, F_4) and 0.2 m^3/m^2-hr (F_1, F_3 and F_5):

(i) Roughing coconut fiber filters (R_{1-2}) were found to withstand variable turbidity load to produce effluent in the range 10 to 50 JTU.

(ii) Sand filters (F_3, F_4) were performing better than burnt rice husk and dual media filter and produced water having turbidity mean value around 5 JTU.

(iii) The head loss rates in all the filters were low indicating long filter run. However, the raw water turbidity went up to 150 JTU on 12-13th day and was no longer in the level of 50 JTU and therefore, the run was terminated.

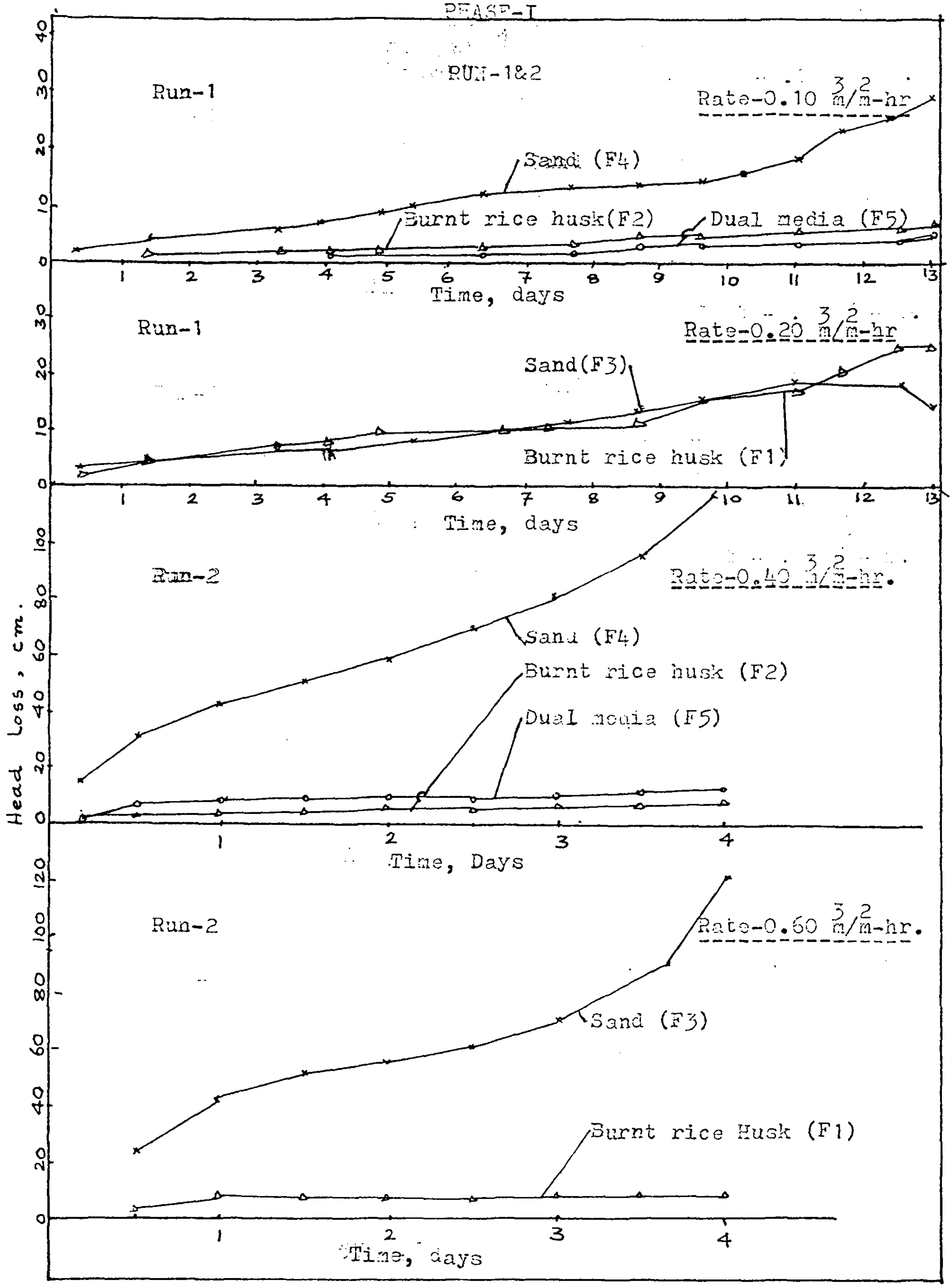


Fig. 4.2 - Time - Head Loss Curve

(iv) The coliform removal efficiency was higher in sand filters (F_3, F_4 leaving residual coliform of 33 MPN/100 ml). The residual coliform count in filtered water from burnt rice husk filters (F_1, F_2) was 43 MPN/100 ml and dual media filter was 122 MPN/100 ml.

The ripening period was allowed for only 3 days before the run had started. If the filters could be operated for more days, a better picture of coliform removal efficiency would have been found out. But the limitation of turbidity level (50 JTU) for this phase of work did not allow that. Moreover, the whole system was planned to run at rates of 0.10; 20, 0.30, 0.40, 0.5 and 0.6 m^3/m^2-hr over three levels of turbidity (50, 100, 150 JTU) in raw water. Therefore, run time could not be allowed for a sufficiently long period of time (1 month). The shortage of time allowed for the research limited the scope of work and a true picture of slow filter performance could not be achieved.

Run 2 - Performance of Filters at High Filtrttion Rates of 0.40 m^3/m^2-hr (F_2, F_4), 0.5 m^3/m^2-hr (F_5) and 0.60 m^3/m^2-hr (F_1, F_3) at Raw Water Turbidity Level of 50 JTU.

As shown in Table 4.1, the roughing filters (R_{1-2}) were operated at the rate of 4.5 m^3/m^2-hr. From Fig. 4.3, it is evident that the roughing filter effluent had turbidity values in a fair range of 20-27 JTU. The performance indicate potential of coconut fiber roughing filter at higher filtration rates. The run length was 4.3 days excluding 3 days of ripening period. The head loss development in sand filters (F_3,F_4) reached 1.20 m within 4 days of operation. In other filters head loss was low but the run was closed down to maintain similarity in operational condition in all filters. Fig. 4.3 shows very short filter run. The short filter run occurred in sand filters and at that time, the run was discontinued.

The mean values of filtered water turbidity were 6.40 (F_1 @ 0.6 m^3/m^2-hr) and 4.78 JTU (F_2 @ 0.4 m^3/m^2-hr) in burnt rice husk filters. The values in case of sand and dual media filters were 4.98 (F_3 @ 0.60 m^3/m^2-hr), 8.27 JTU (F_4 @ 0.40 m^3/m^2-hr) and 5.44 JTU (F_5 @ 0.50 m^3/m^2-hr). The filtered water turbidity never exceeded 10 JTU but always was around 5 JTU, conforming WHO drinking water standards. In addition to this, the Fig. 4.3 show that, the turbidity removal capacity of sand filter was better than burnt rice husk and dual media filter at the start of the run after a ripening period of 2 days. The removal capacity decreased with time at a faster rate in sand filters than that in the burnt rice husk and dual media filter. It is rather interesting to note that, the removal efficiency in burnt rice husk and dual media slowly increased as the run continued. This gives, however only an indication of requirement of longer ripening period in burnt rice husk filters.

The coliform removal efficiency in burnt rice husk filters were 72.08% leaving residual of 670 MPN/100 ml whereas, removal efficiencies in sand and dual media filters were 94.08% and 86.04% respectively,

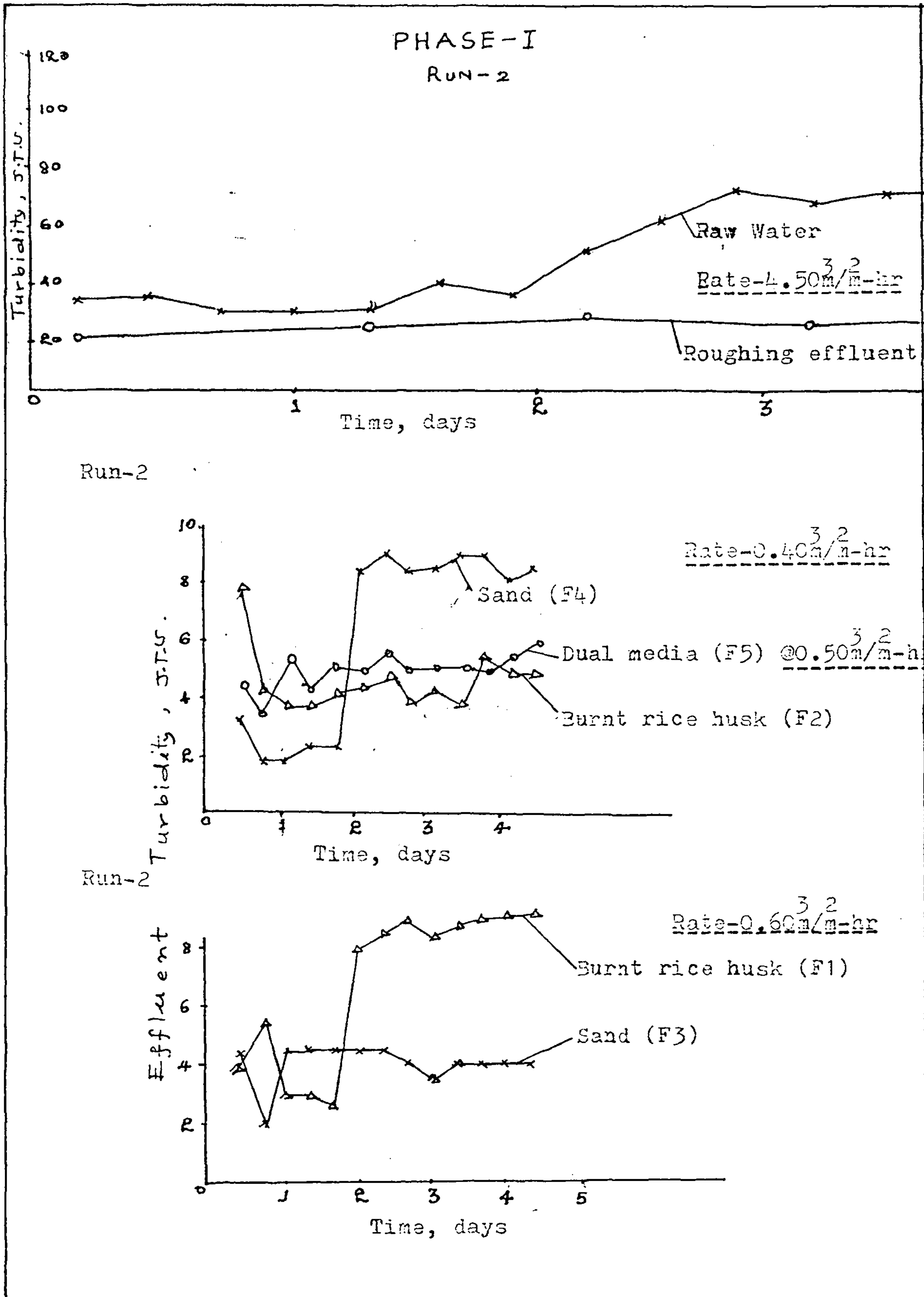


Fig. 4.3 - Time - Turbidity Curve

still leaving MPN residual not meeting the standard. The above findings infer that, even at high filtration rates coliform bacteria is better screened off by sand than by burnt rice husk.

The development of head loss (Fig. 4.2) and the rates of head loss as presented in Table 4.2, show that, at high filtration rates (0.4 and 0.6 m^3/m^2-hr), development of head loss in sand filter was very rapid (30 cm/day) - indicating a shorter filter run. On the other hand, head loss rates in burnt rice husk and dual media filter ranged from 2.0 (F_2 @ 0.40 m^3/m^2-hr) to 7.0 cm/day (F_1 @ 0.6 m^3/m^2-hr). This indicate longer filter run in burnt rice husk filters. It was observed that particle penetration was more than 5 cm in burnt rice husk bed (more than 3-4 cm in dual media filter) whereas, no contamination (mudding) of bed was found in sand beyond 2 cm of depth. This fact establishes more straining capacity of sand than that of burnt rice husk in case of ordinary compaction. From turbidity removal capacity, though it is evident that burnt rice husk also can strain out fine particles as sand can do, but it spreads over a greater depth and volume in burnt rice husk which ultimately necessitates changing of filter media rathern than scraping of sand. There were not much difference in filtered water turbidity in filters F_1 and F_2 running at different rates (F_1 @ 0.60 m^3/m^2-hr and F_2 @ 0.4 m^3/m^2-hr). But in sand filters (F_3 @ 0.60 m^3/m^2-hr and F_4 @ 0.4 m^3/m^2-hr) lower efficiency was observed in F_4, perhaps due to 'slight' short-circuiting. The term 'slight' is used here because if the short circuiting was a major one, it would then cause lesser head loss rate.

The run was short and a full 1.20 m head loss developed in sand filters in 4 days of operation (and 2 days ripening). But head loss in burnt rice husk and dual media filter were 35 cm (F_1), 28.5 cm (F_2) indicating more days during which the filters could be operated.

Run 2 - Conclusions:-

(i) At filteration rate of 4.5 m^3/m^2-hr the roughing filters (R_{1-2}) gave effluents having turbidity range 10 to 17 JTU without incurring significant head loss and thus indicated long filter run.

(ii) At high rates of .60 and 0.40 m^3/m^2-hr, (F_1, F_3 and F_2, F_4) and 0.5 m^3/m^2-hr (F_5), the turbidity removal efficiency was better (90%) in sand filters (F_3, F_4) but decreased over time; on the other hand the efficiency of removal increased with time in burnt rice husk and dual media filter.

(iii) Run length was short (4 days) in sand filters with high head loss rates (30 cm/day) but dual media filter head loss rate (3 cm/day) and burnt rice husk filter head loss rates (2-7.05 cm/day) were low indicating longer run length.

(iv) Particle penetration was found more in burnt rice husk (5-6 cm) than sand (1-2 cm) indicating necessity of changing burnt rice husk material rather than scraping off the sand.

Phase - I & II

Table 4.2 - Filter Head Loss Rates and Filter Run

Phase - I						Phase - II				
Run No.	Mean Influent Turbidity, JTU	Filter Type	Filtration Rate, m^3/m^2-hr	Length of Filter run, days	Head Loss Rate, cm/day	Run No.	Mean Influent Turbidity, JTU	Filtration Rate, m^3/m^2-hr	Length of Filter run, days	Head Loss Rate, cm/day
1	74.85	F_1	0.20	13 days	2.17	1	88.27	0.20	9.33 days	2.25
		F_2	0.10		0.36			0.10		0.38
		F_3	0.20		1.88			2.0		2.35
		F_4	0.10		2.23			1.0		2.25
		F_5	0.10		0.38			1.0		0.58
2	38.23	F_1	0.60	4 days	7.05	2	101.57	0.40	5.3 days	12.38
		F_2	0.40		2.0			0.30		3.37
		F_3	0.60		30.24			0.40		9.0
		F_4	0.40		30.24			0.30		11.25
		F_5	0.50		3.02			0.30		1.68
3	49.90	F_1	0.50	7.33 days	4.88	3	97.40	0.60	6.66 days	8.40
		F_2	0.30		1.20			0.50		2.77
		F_3	0.50		5.86			0.60		11.26
		F_4	0.30		14.6			0.50		10.0
		F_5	0.30		2.64			0.50		2.25

Lengend: F_1 and F_2 - Polishing burnt rice husk filters
F_3 and F_4 - Polishing sand filters
F_5 - Dual media (coconut fiber - burnt rice husk) fiter

(v) During the run, the filtered water turbidity from the filters was below 10 JTU but coliform removal efficiency was not high [72% (F_{1-2}) to 94% (F_{3-4})] but still higher efficiency was observed in sand filters (94%).

(vi) The run length was only 4.33 days due to 1.20 m head loss in sand filters. In maintaining similarity in operational condition, specially raw water turbidity, temperature and pH for all the filters, the nature of time-turbidity and time-head loss curves for other filters could not be known. After 4-5 days, the nature of the head loss-time curves could be more exponential in case of burnt rice husk and dual media filters (F_1, F_2, F_5). This implied weakness in the results - particularly in case of head loss rate in burnt rice husk filters, dual media filter and roughing filters. But on the other hand, the results give a competitive picture of their performance operated at the same time with same raw water turbidity for all the filters.

Run 3 - Performance of Filters at Medium Rates of Filtration of 0.30 m^3/m^2-hr(F_2, F_4, F_5) and 0.50 m^3/m^2-hr (F_1, F_3); at Raw Water Turbidity Level of 50 JTU

During this run, the roughing filter rate was 3.5 m^3/m^2-hr. The effluent turbidity ranged 12-18 JTU (Fig. 4.4). The flat nature of the time-turbidity curve shows consistent performance of roughing filters in withstanding fluctuating turbidity load in raw water. Head loss in roughing filters was insignificant. The run length was 7.33 days. The run was terminated due to 1.20 m head loss development in sand filter (F_4) operating at the rate of 0.30 m^3/m^2-hr. Head loss in other filters were low and run could be continued further but was not done so to maintain similarily in operational and environmental conditions in all the filters.

The turbidity of filtered water from burnt rice husk filters (F_1 @ 0.50 m^3/m^2-hr and F_2 @ 0.30 m^3/m^2-hr) were 6.81 JTU and 5.50 JTU, whereas those of sand filters (F_3 @ 0.50 m^3/m^2-hr and F_4 @ 0.30 m^3/m^2-hr) were 3.34 JTU, 6.59 JTU and 4.06 JTU respectively. From comparison Table 4.1, it can also be seen that the removal efficiency of turbidity in F_1 (86.35%) was lower than that of F_2 (88.97%) due to obvious reason of high rate of filtration in F_2. On the other hand the efficiency of sand filter F_4 was lower than that of F_3, though filtration rate in F_3 was higher. Itwas repetition of the case observed in run 2 as mentioned earlier. The efficiency of turbidity removal in dual media filter (F_5) was found to be more than sand (F_4) and burnt rice husk (F_2) filters.

The residual coliform content in filtered water from F_1 and F_2 was 270 MPN/100 ml. The value of filtered water from F_3 and F_4 (sand) were 132 MPN/100 Ml and 151 MPN/100 ml respectively, showing higher percentage removal (98.63%) in sand filter (F_4 @ 0.30 m^3/m^2-hr). The coliform removal efficiency in dual media filter F_5 was only 58.18%. From the point of view of WHO bacteriological standand, the filtered water

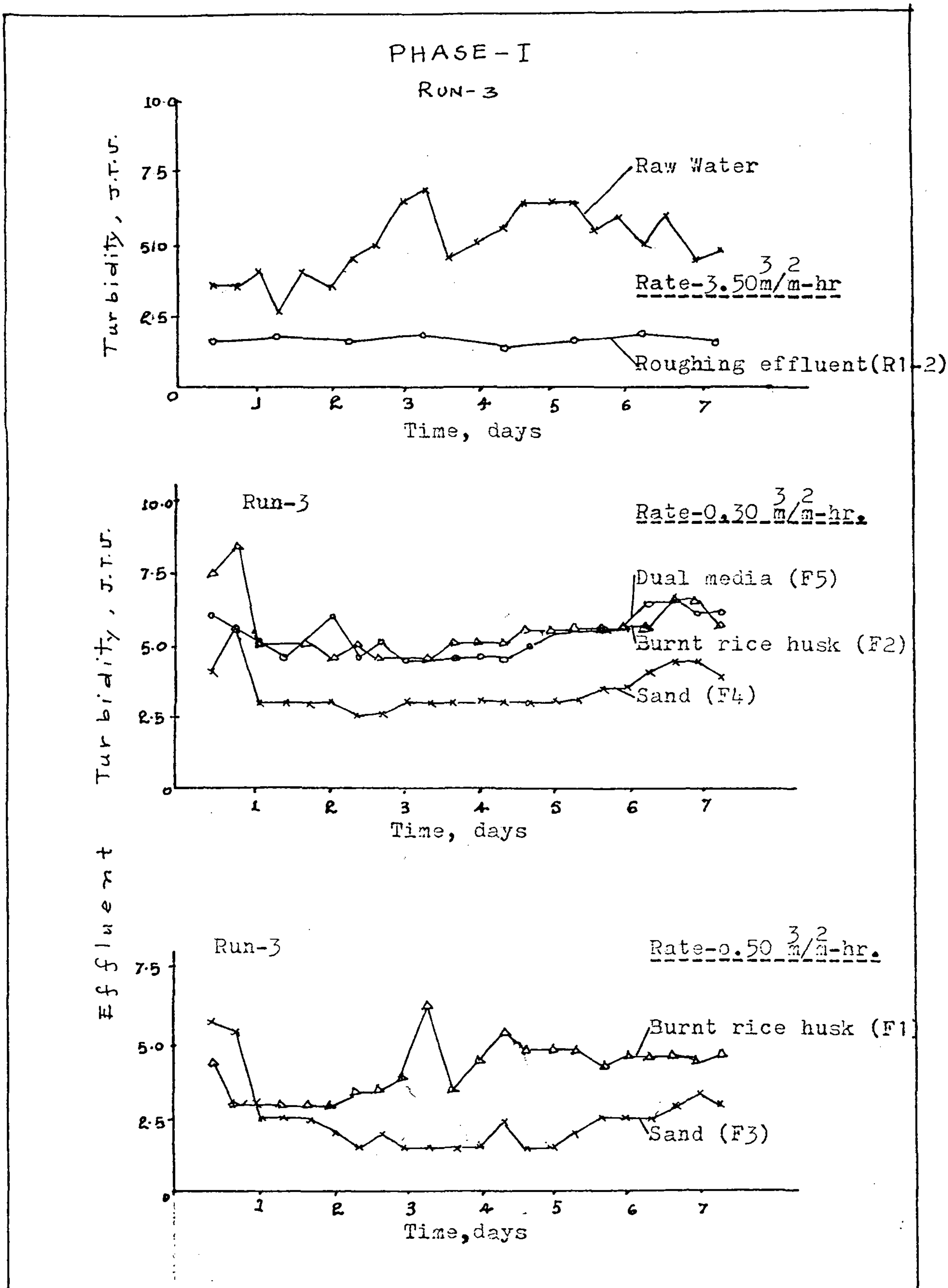


FIG.4.4 TIME-TURBIDITY CURVE

from all the filters were far from satisfactory for drinking. However, for the people living in rural communities - who usually drink untreated pond and river water, the effluent from sand filter may be considered safe enough.

Head loss rates in burnt rice husk filters (Fig. 4.5) (F_1 and F_2) were lower than those of in sand (F_3 and F_4) filters. Among the same rated filters F_2, F_4 and dual (F_5) media, highest head loss rate was observed in sand (F_4 @ 0.30 m^3/m^2-hr, head loss 14.6 cm/day) filter whereas lowest head loss rate was in filter F_2 (1.20 cm/day), having loss rate 2.5 cm/day in F_5. Later on anomaly like high head loss rate but lower turbidity removal efficiency in sand filter (F_4 @ 0.30 m^3/m^2-hr) was investigated. It was found that the upper part of the filter bed became hard due to sudden and unwanted drying of bed during electricity failure (during run 2). The summary of Phase I, containing statistical analysis of results of data are given in Appendix A4.1.

<u>Run 3 - Conclusions</u>: -

(i) At roughing filtration rate of 3.5 m^3/m^2-hr, effluent turbidity ranged from 12 to 18 JTU with less variation over time. The head loss rate was insignificant indicating long run length.

(ii)(a) Operating at the rate of 0.30 m^3/m^2-hr the burnt rice husk (F_2), sand (F_4) and dual media filter (F_5) gave effluent turbidity always around 5 JTU.

(b) At the rate of 0.50 m^3/m^2-hr, the burnt rice husk (F_1) and sand filter (F_3) gave effluent also below 5 JTU turbidity value, but in both the rates (a) and (b) the performance of sand filter (F_3, F_4) were found better than burnt rice husk filter. Dual media filter (F_5) at the rate 0.30 m^3/m^2-hr also gave high efficiency (89%).

(iii) Coliform removal was higher in sand filters (15-132 MPN/100 ml) and lowest in dual media filter (460 MPN/100 ml) and percentage removal was only 58%).

(iv) Head loss rate was highest in sand filter (5.86-14.6 cm/day) whereas low head loss rates occurred in dual media and burnt rice husk filters (1.22-4.6 cm/day) indicating longer filter run.

(v) Bed drying in sand filter (F_4) caused poor performance even at lower rates of filtration (.30 m^3/m^2-hr).

(vi) In maintaining turbidity levels in raw water similar in all filters, the burnt rice husk filter, dual media filter and one sand filter (F_3) were shut down after 6.33 days of operation when head loss of 1.20 m developed in sand filter F_4; this implies weakness in head loss rate and performance curves of time-turbidity and especially in coliform removal efficiency values of these filters. If the run was continued for these filters, the rate of head loss and removal

PHASE-I

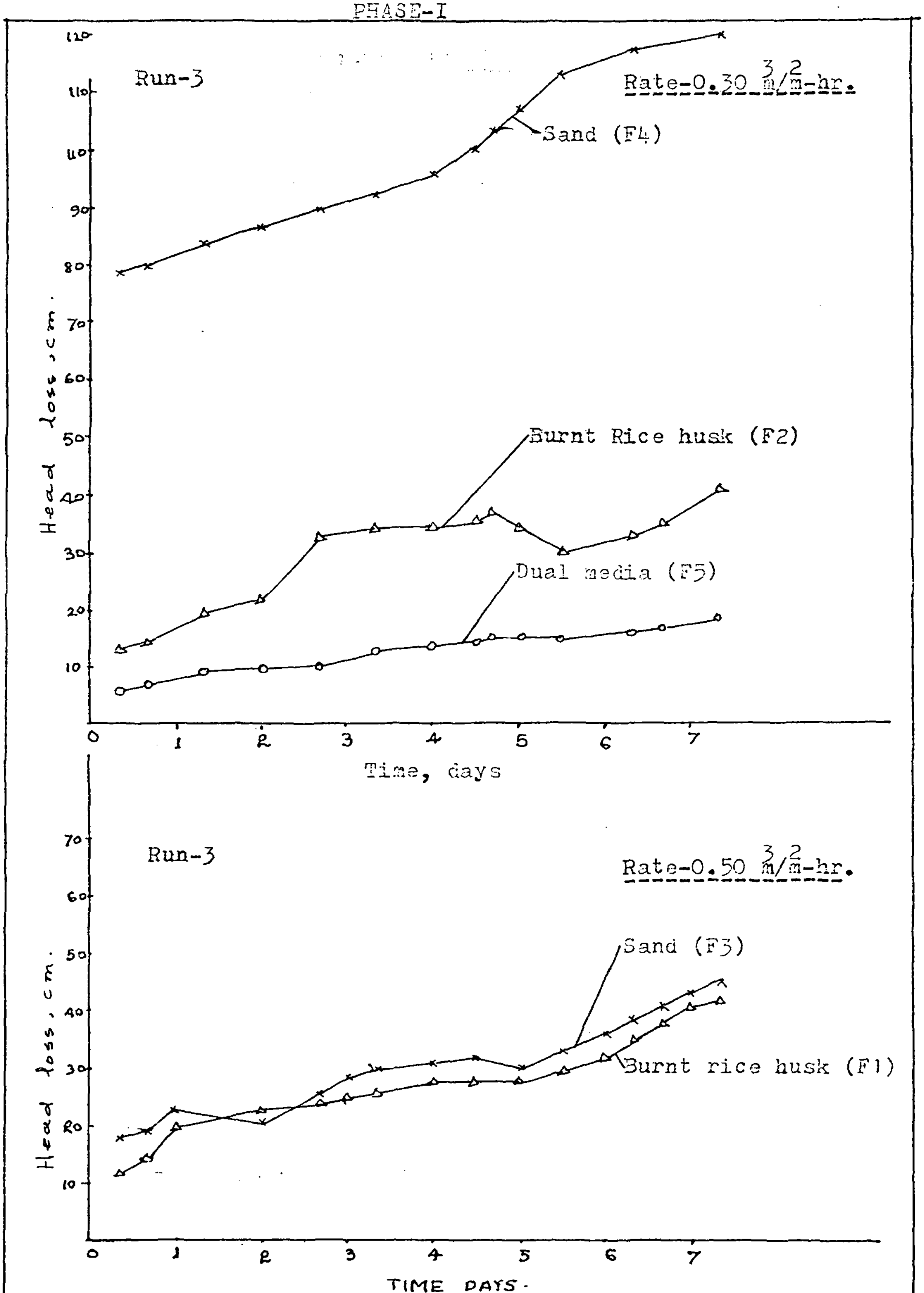


FIG.4.5 TIME-HEAD LOSS CURVE

efficiency of coliform and turbidity could have been different from those have found here. But the values obtained here under similar operating conditions for all filters give, however, a comparative picture of the performance for atleast first 6 days of operation.

Phase II - Experimental Study on the Performance of Series Coconut Fiber-Burnt Rice Husk, Coconut Fiber-Sand and Dual Media Filters at 100 JTU Turbidity Level

The raw water that was available in the source pond had usual turbidity range 20-40 JTU except during and immediately after heavy rainfall when turbidity increased to as high as 200 JTU. Therefore, to maintain a turbidity level 100 JTU, the water in the baffled portion of the pond was stirred and mixed with bottom clay with the help of by pass water jet directly taken from the intake pump P_1. The intensity of mixing was controlled by by-pass valve manually at the interval of 4 hours except in late night. During sunny and windy days it was difficult to maintain the level of turbidity as can be seen from the fluctuating influent water turbidity vs time curves. The pH of raw water as well as filtered water ranged 7.8-8.5 having overall mean and media values of 8.18 and 8.25. The mean standard deviation value was 0.08 (range 0.07-0.126) which indicate inappreciable change of pH due to mixing and filtration of the suspended particles, perhaps due to the neutral property of the bottom clay and soil.

During the three runs in this phase, the temperature of raw and filtered water ranged 27.5°C to 32.5°C; lower values occurred in the morning and at nights and high (30-32.5°C) values were observed in mid days. No appreciable change in temperature was observed in the filtered water from raw water.

Run 1 - Performance of Filters at Low Rates 0.1 m^3/m^2-hr (F_2, F_4 and F_5) and 0.2 m^3/m^2-hr (F_1 and F_3) at Turbidity Level of 100 JTU in Raw Water

The roughing filters (R_{1-2}) were operating at the rate of 1.5 m^3/m^2-hr. At this rate the effluent turbidity ranged 15-38 JTU (Fig. 4.6). The flat roughing filter effluent turbidity vs time curve indicate the shock load resisting capacity of coconut fibers. The run length was 9.33 days excluding 3 days ripening period and concluded due to shortage of time. At filtration rate of 0.10 m^3/m^2-hr, the dual media filter (F_5) performance was better than burnt rice husk (F_2) and sand (F_4) filters. The filtered water turbidity (mean) values were 6.85 (F_2), 9.68 (F_4) and 4.55 (F_5) (Table - 4.3). It was also observed that, at filtration rate 0.20 m^3/m^2-hr, the burnt rice husk filter (F_1, mean turbidity 7.06 JTU) gave better quality of filtered water (in terms of turbidity) than that given by sand filter (F_3, 13.46 JTU). From Table 4.3, it is also evident that at 100 JTU level of trubidity, the filtered water turbidity increased with the increasing filtration rate. However, the filtered water turbidity from all the filters operated at both the rates ranged from 1.7 to 16.0 JTU and may be acceptable to the villagers.

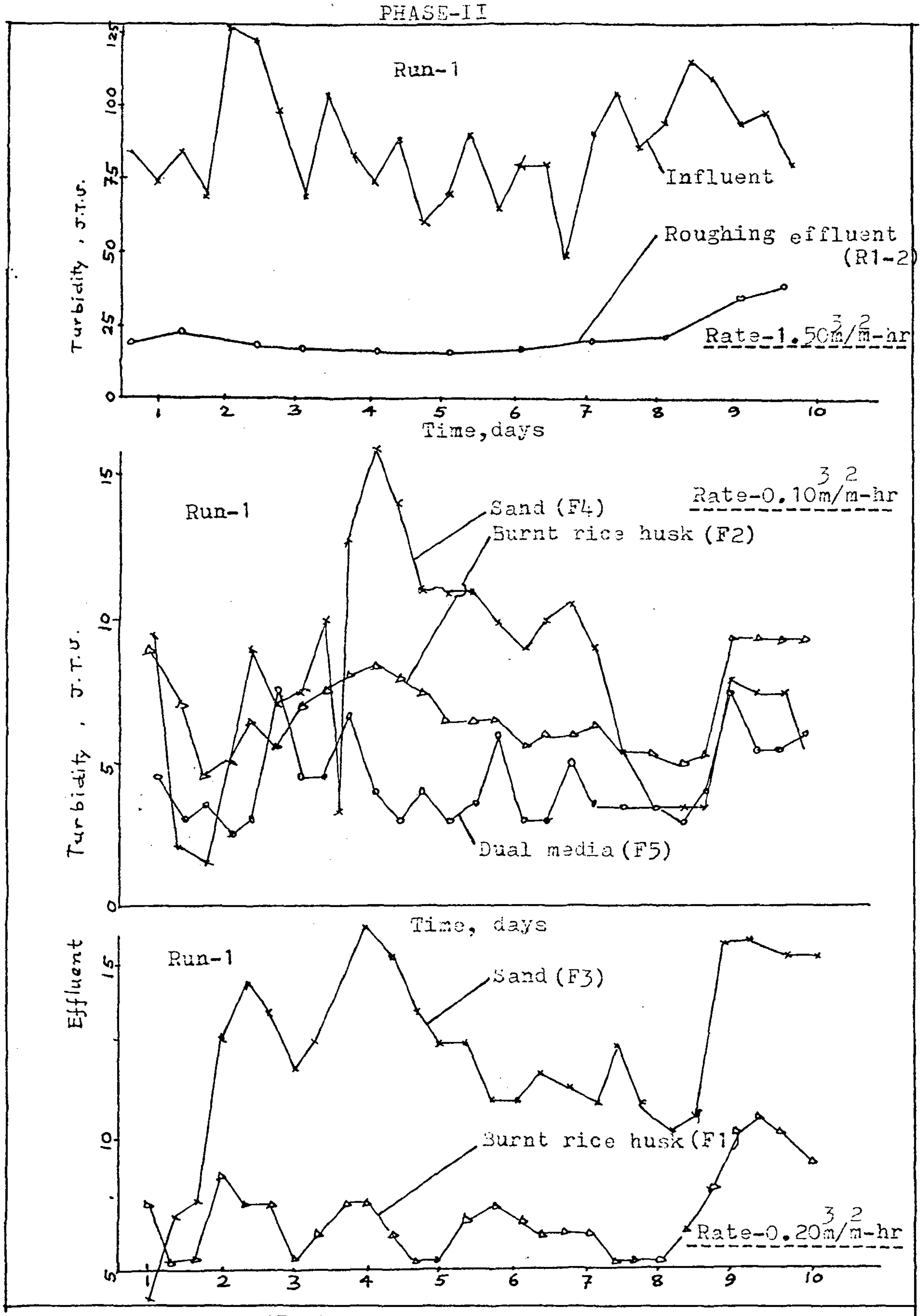
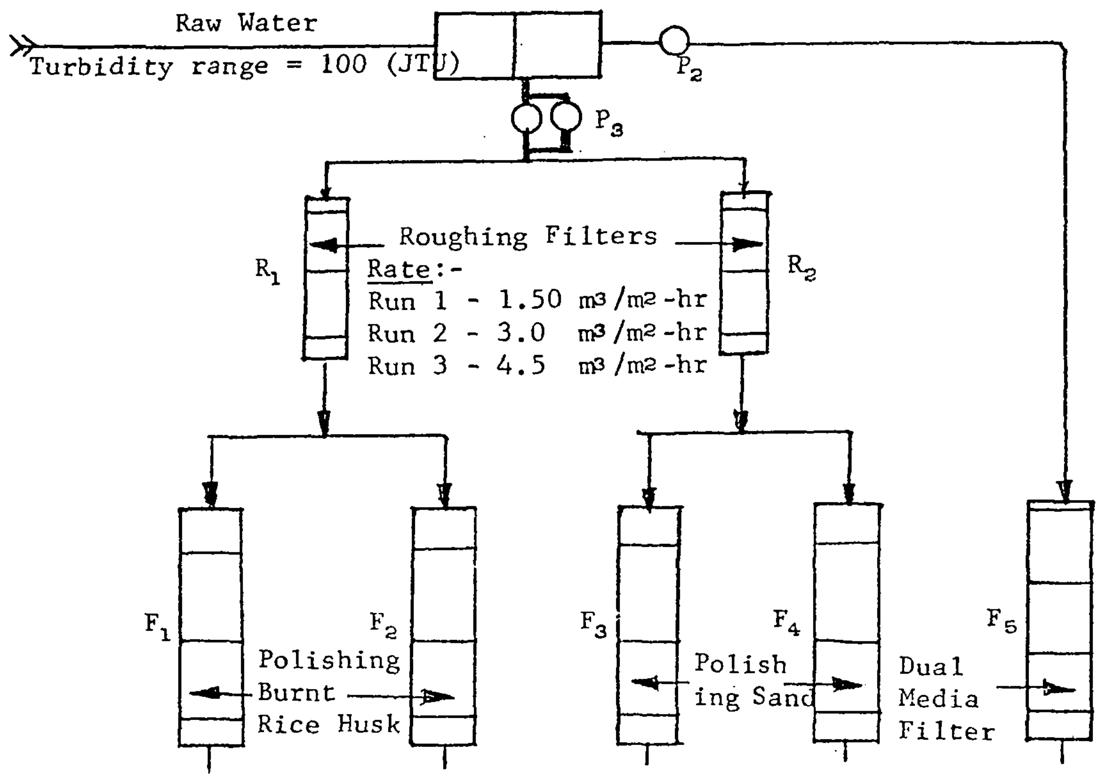


FIG.4.6 TIME-TURBIDITY CURVE

Table 4.3 - Comparison Table of - Phase II



Filter Type	F_1	F_2	F_3	F_4	F_5
Filtration Rate, m^3/m^2-hr					
Run - 1	0.20	0.10	0.20	0.10	0.10
Run - 2	0.40	0.30	0.40	0.30	0.30
Run - 3	0.60	0.50	0.60	0.50	0.50
Filtered Water Turbidity (Mean) (JTU)					
Run - 1	7.06	6.85	13.46	9.68	4.55
Run - 2	24.60	19.53	16.25	17.87	18.01
Run - 3	15.70	18.85	15.90	15.92	15.55
Head Loss Rate, (cm/day)					
Run - 1	2.25	0.38	2.32	2.25	0.58
Run - 2	12.38	3.37	9.0	11.25	1.68
Run - 3	8.40	2.77	11.26	10.0	2.25

The redidual coliform content in filtered water were found 43 MPN/100 ml for burnt rice husk (F_1 and F_2, efficiency of removal 98.20%) and 23 MPN/100 ml (F_4, @ 0.10 m^3/m^2-hr, % removal 99.04) and 33 MPN/100 ml (F_3 @ 0.20 m^3/m^2-hr, % removal 98.62) in sand filters. The residual coliform content in filtered water from dual media (F_5 @ 0.10 m^3/m^2-hr, % removal 94.91%) filter was 122 MPN/100 ml. The filtered water from sand filter (F_3 and F_4) may be considered safer for the village people. However, disinfection was necessary for the filtered water, before declaring it safe. Comparison of the above results show that, there was little effect of filtration rate in coliform removal efficiency in burnt rice husk filters and sand filters when operating at low flow rate.

At filtration rates mentioned above, the head loss rates were found to be quite low (Fig. 4.7). The summary of head loss rate is given in Table 4.3 which shows lowest head loss rate in dual media filter (F_5, rate of head loss 0.58 cm/day) whereas, the highest rate occurred in sand (F_3, @ 0.20 m^3/m^2-hr, head loss rate 2.32 cm/day). These facts infer longer run length of filters at medium turbidity but lower filtration rates.

Run 1 - Conclusions:-

(i) At the filtration rate of 1.5 m^3/m^2-hr in roughing filters (R_{1-2}), the roughing filter turbidity ranged from 15-38 JTU with less fluctuation over time. The head loss rates at the raw water turbidity load of 100 JTU level were insignificant.

(ii) In all the polishing filter (F_{1-4}), the turbidity in filtered water increased with increasing filtration rate.

(iii) The filtered water turbidity from all the filters (F_{1-5}) were in the range of 1.7-16.0 JTU and considered to be acceptable to consumers.

(iv) Coliform content in sand filters (F_3, F_4) were 23 MPN/100 ml, all of which might not be faecal and the filtered water may be considered safer than that comming from other filters.

(v) There was no effect of filtration rate over coliform removal by the filters.

(vi) At 100 JTU turbidity level and .10 m^3/m^2-hr and 0.2 m^3/m^2-hr filtration rates, head loss rates in all the filters were low indicating long filter run of about 40 days.

(vii) The filters were operated for 9.33 days excluding 3 days ripening period; the head loss rates found during these time period may not be representative of the overall rate of head loss. Moreover, coliform removal efficiency could be higher if the system was run for longer period of time. But, considering limitation of time allowed

PHASE_II

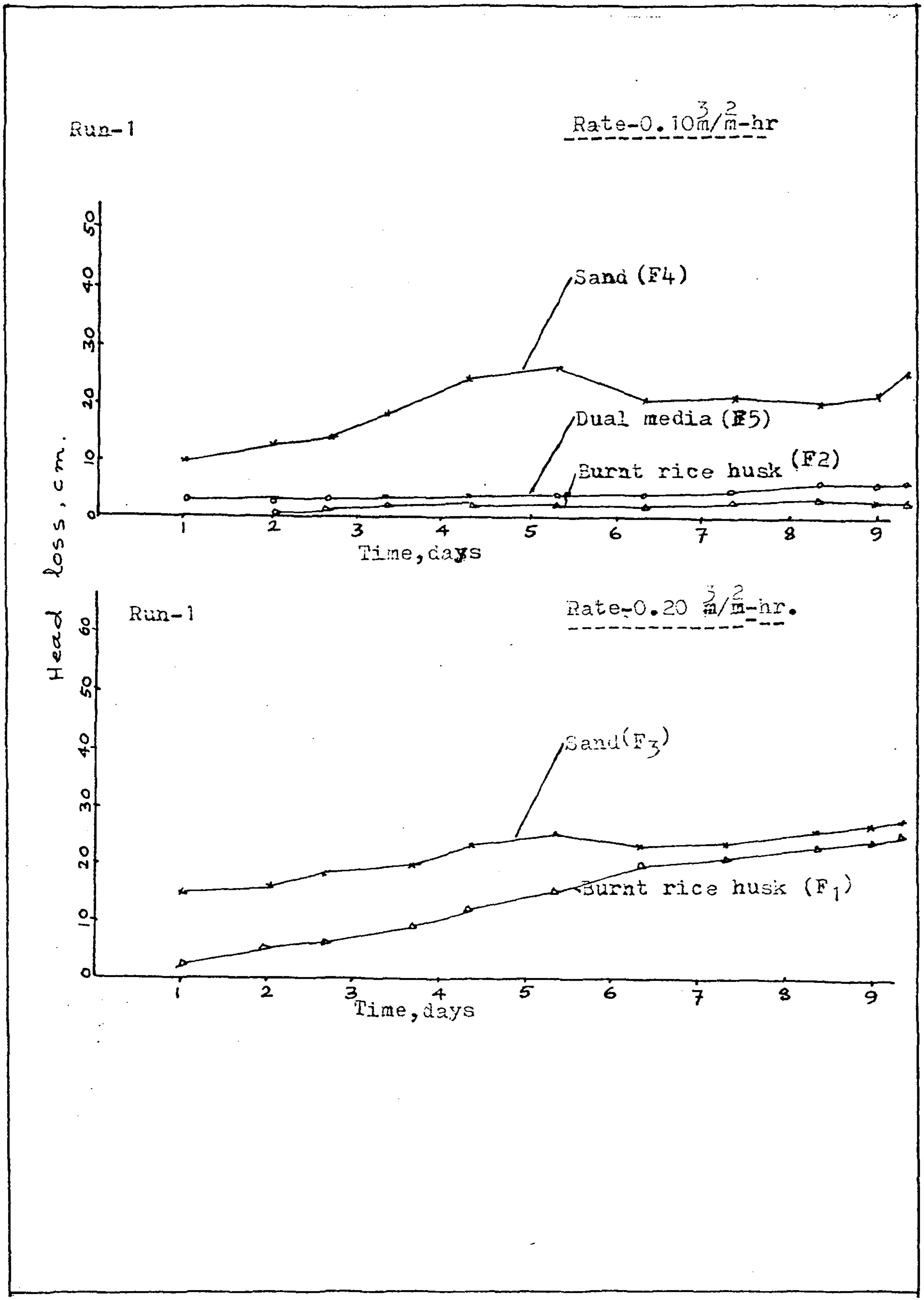


FIG.4.7 TIME_HEAD LOSS CURVE

for each run (15 days), the results found will serve the purpose of comparison of the performance of filters.

Run 2 - Performance of Filters at Filtration Rates of 0.3 m^3/m^2-hr (F_2, F_4, F_5) and 0.4 m^3/m^2-hr (F_1, F_3)

During this run roughing filters (R_{1-2}) were operated @ 3.0 m^3/m^2-hr. From the Fig. 4.8 it is seen that the effluent water from roughing filters had turbidity range 20 to 64 JTU. The turbidity values during 3 rd, 4th and 5th days went beyond 50 JTU. The data record shows that during those days it was heavily raining adding surface runoff water containing very fine particles which could not be retained by roughing filters. Head loss in roughing filters was insignificant. The run was concluded after 5.33 days of operation excluding 3 days of ripening prior the run started. The run was concluded because of the high value of turbidity in the influent and effluent water of polishing filters(F_{1-4} and F_5) as shown in Fig. 4.8.

During the run, the performance of burnt rice husk filters (F_1 @ 0.4 m^3/m^2-hr and F_2 @ 0.3 m^3/m^2-hr) and dual media filter (F_5 @ 0.3 m^3/m^2-hr) were better than that of sand filters, proving their more shock turbidity load withstanding capacity. The mean turbidity values of filtered water were 24.60 JTU (F_1), 19.53 (F_2), 16.25 (F_3), 17.87 (F_4) and 18.01 (F_5); performances were thus competitive. From Fig. 4.8, it is also evident that during first two days when there was no raining performance of sand (F_3, F_4) was better but during later 3 days the performance was very fluctuating with fluctuation in raw water turbidity due to raining. The turbidity vs time curves for burnt rice husk (F_1 and F_2) and dual media filter show poorer and steadily decreasing performance over the length of run. The filter performance curves in Fig. 4.8 also show the increase of removal efficiency as the filter ripened during 1-3 days up to the point where high shock load occurred in raw water.

From summary Table in Appendix A4.2, the residual coliform content in burnt rice husk filters (F_1 and F_2, % removal 98.20) was found 43 MPN/100 ml showing no variation in removal efficiency due to difference in filtration rates (F_1 @ 0.4 m^3/m^2-hr and F_2 @ 0.3 m^3/m^2-hr). The same case was also observed among sand filters (F_3 and F_4, removal efficiency 99.04%) where residual coliforms level was found 23 MPN/100 ml. From these findings it may be suggested that the filtered water may be safely supplied to rural people who are habituated in drinking untreated water. However, residual coliform content in filtered water from dual media filter (F_5, % removal 90%) was 240 MPN/100 ml, which was very high and recommended to be disinfected before public use.

At the rate of 0.4 m /m -hr, the burnt rice husk filter (F_1) had higher head loss rate than that sand filter (Fig. 4.9). But at lower rate (0.3 m^3/m^2-hr), the head loss rate in sand filter (F_4) was higher than those of burnt rice husk (F_2) and dual media filter (F_5).

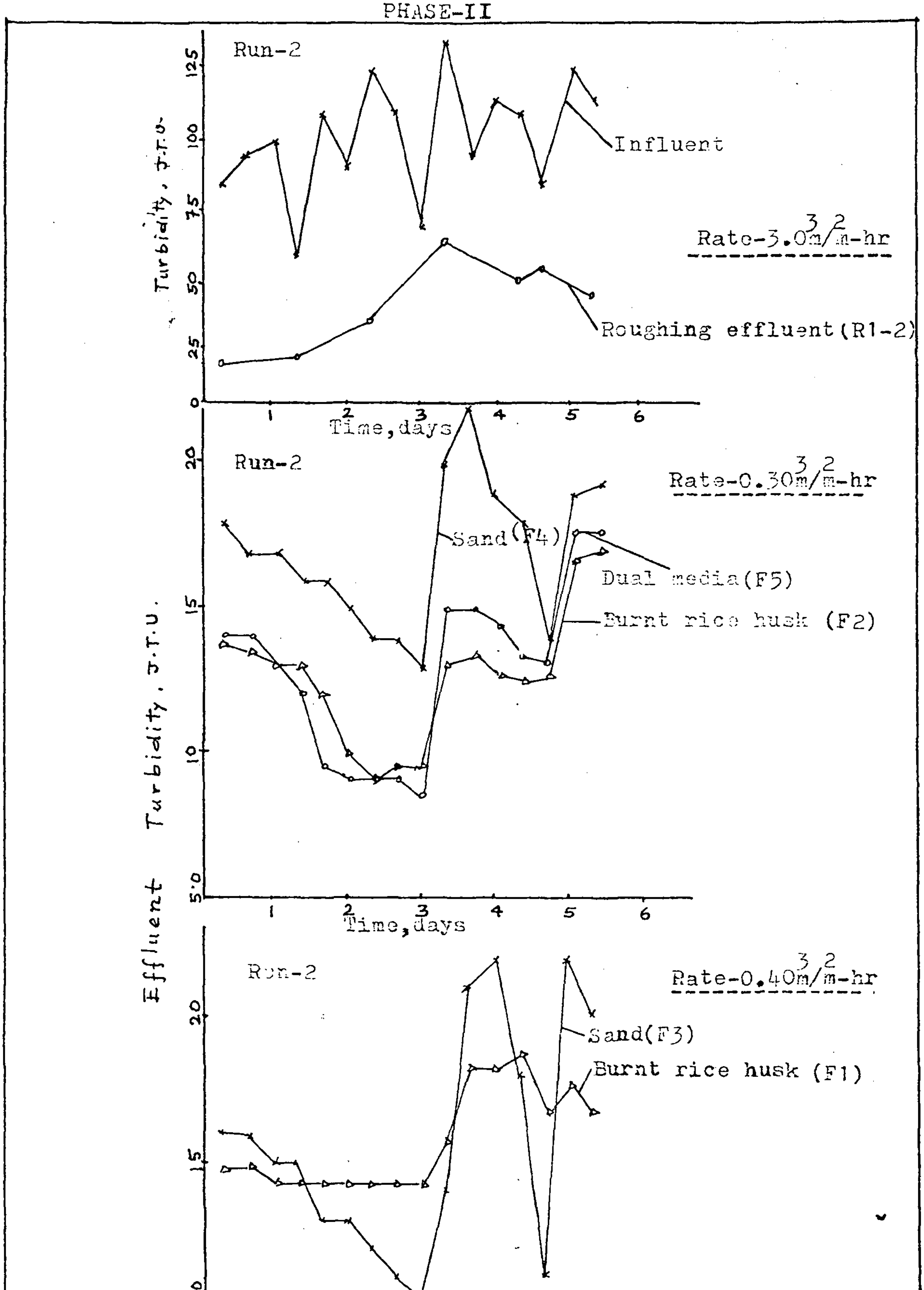


FIG.4.8 TIME-TURBIDITY CURVE

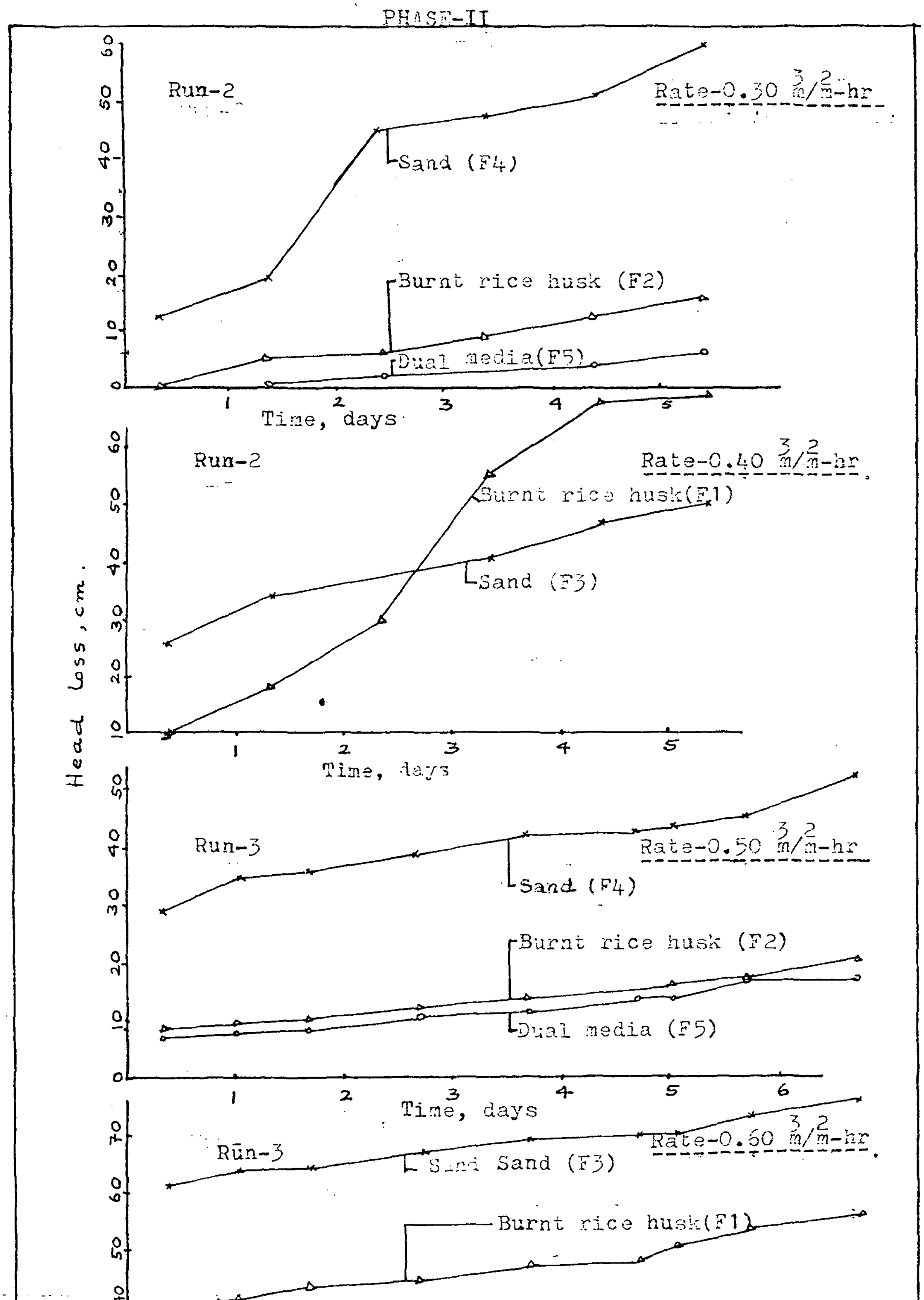


FIG-4.9 HEAD LOSS-TIME CURVE

Run 2 - Conclusion:-

(i) Roughing filters (R_{1-2}) at the rate of 3.0 m^3/m^2-hr and raw water turbidity level of 100 JTU gave effluent water having turbidity range 20-64 JTU. The higher values (> 50 JTU) occurred during 3-5th days of operation when there was raining.

(ii) The performance of sand filters (F_3, F_4) @ .30-0.40 m^3/m^2-hr, was very fluctuating during rainy days with fluctuation in raw water.

(iii) During first 3 days when these was no raining, the turbidity removal efficiency increased over run (80% to 95%) length.

(iv) Coliform removal efficiency in sand filters (F_3, F_4) were more (23 MPN/100 ml) than those in other filters.

(v) At rate of 0.4 m^3/m^2-hr, head loss rate in burnt rice husk filter was more than that in sand filter but at the rate of 0.3 m^3/m^2-hr, the head loss rate was lower in the former filter type and dual media filter (F_5) than that in sand filter (F_4).

(vi) During rainy days (after 4th day of run) high turbidity in raw water was caused by fine suspended particles which could not be removed by coconut fiber as well as sand and burnt rice husk. The influent and effluent turbidity of polishing filters were ranging as high as 65 JTU and 30 JTU respectively - thus giving indication of poor filter performance. Hence, the run was concluded for washing the filters.

Run 3 - Performance of Filters at the Rates of 0.5 m^3/m^2-hr (F_2, F_4 and F_5) and 0.60 m^3/m^2-hr (F_1, F_3) at Raw Water Turbidity Level of 100 JTU

During this run the roughing filter (R_{1-2}) rate was 4.5 m^3/m^2-hr. Fig. 4.10 shows a steady performance of roughing filters (R_1 and R_2), the effluent turbidity ranging 32-46, well below the limiting slow-filter-influent value of 50 JTU. But at this influent load, the performances in polishing burnt rice husk filter (F_1 @ 0.6 m^3/m^2-hr and F_2 @ 0.5 m^3/m^2-hr) and sand filters (F_3 @ 0.6 m^3/m^2-hr and F_4 @ 0.50 m^3/m^2-hr) were highly variable as may be seen in Fig. 4.10. The filtered water turbidity ranged 8-26 JTU in filters (F_2, F_4 and F_5) whereas, the range in filters (F_1 and F_3) was 10-37 JTU. At both the rates, sometimes the filtered water turbidity exceeded prohibitive limit 25 JTU - due to the presence of fine particles having diameter less than 5 micron which might have come with surface runoff during frequent light raining. The run continued for 9.33 days including 3 days of ripening period - when the effluent turbidity of burnt rice husk filter (F_1) and sand filter (F_4) went as high as 28 JTU. The other filters including (F_5, dual media) were shut down to maintain similarity in operation. However, the mean values of filtered water turbidity and their median and standard deviation (Table A4.2 in Appendix A) show that there was inappreciable variation in turbidity removal among all the filters. The Removal

PHASE-II

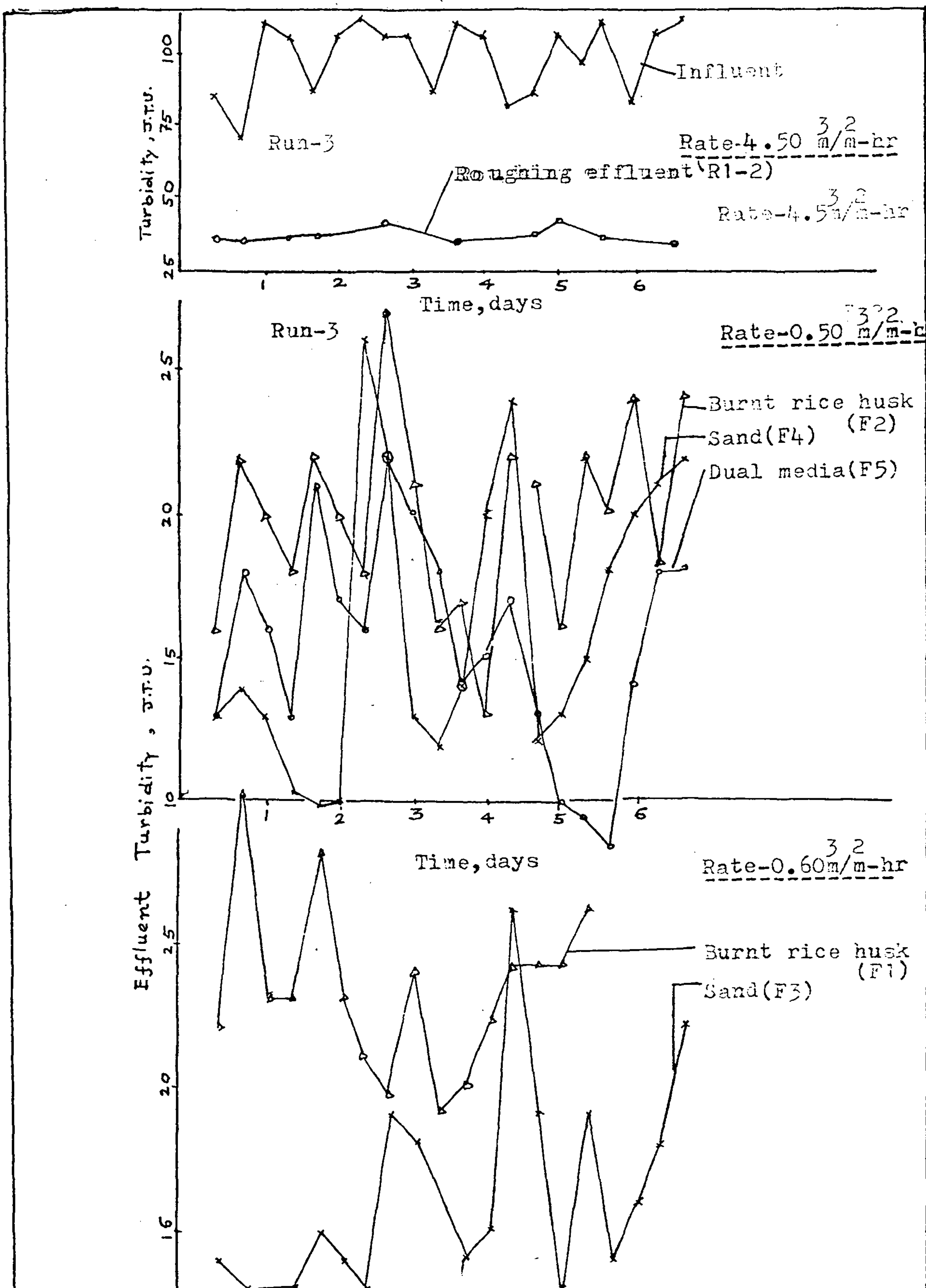


FIG.4.10 TIME-TURBIDITY CURVE

efficiencies were 83.88% (F_1 @ 0.6 m^3/m^2-hr), 79,62% (F_2 @ 0.5 m^3/m^2-hr), 83.67 (F_3 @ 0.6 m^3/m^2-hr), 83.65 (F_4 @ 0.5 m^3/m^2-hr) and 84.03% (F_5, dual media filter @ 0.5 m^3/m^2-hr). The mean values were 15.50 JTU for dual (F_5), 15.92 sand (F_4) and 12.56 burnt rice husk filter (F_2), operating at the rate of 0.5 m^3/m^2-hr. At the rate of 0.6 m^3/m^2-hr, the mean turbidity of filtered water were 15.7 JTU for sand (F_3) and 15.9 JUT for burnt rice husk filter (F_1).

The coliform removal efficiencies ranged from 66% - 84% with residual coliform 274 - 804 MPN/100 ml. The filtered water cannot be recommended for drinking without disinfection. Table A4.2 indicates, however, better efficiency of coliform removal in sand filter (residual 274 MPN/100 ml).

From Fig. 4.9 and Table 4.3, it is evident that head loss and head loss rates in sand filters (F_3 @ 0.60 m^3/m^2-hr, head loss rate 11.26 cm/day and F_4 @ 0.5 m^3/m^2-hr, head loss rate 10.0 cm/day) were highest, whereas the lowest rate occurred in dual media filter (F_5 @ 0.5 m^3/m^2-hr. head loss rate 2.25 cm/day). In burnt rice husk filters head loss rates were 8.40 cm/day (F_1) and 2.77 cm/day (F_2) indicating quite a long run. In summary, it can be concluded that quite a long run could be achieved in slow filters at 100 JTU turbidity level and filtration rates of 0.50 and 0.60 m^3/m^2-hr but the quality of filtered water (turbidity and MPN Content) will not meet drinking water standards without disinfection. A summary of results containing statistical analysis for turbidity, pH and coliform content of raw water and filtered water, head loss in filters and run length are presented in Table A4.2 in Appendix A.

In all the 3 runs during this phase turbidity and coliform content was measured after 2 days of ripening period. The coliform removal efficiency did not increase much from 66% (initial) over the run length in burnt rice husk and dual media filter though, a fair increase in efficiency was observed in sand filters (from 75% to 90%).

<u>Run 3 - Conclusion</u>:-

(i) Roughing filters (R_{1-2}) operating at the rate of 4.5 m^3/m^2-hr produced filtered water ranging 32 - 46 JTU from raw water level of 100 JTU with less fluctuation over run length. The head loss rate was low indicating a long run.

(ii) At filtration rate of 0.50 m^3/m^2-hr, the dual media (F_5), sand (F_4) and burnt rice husk filter (F_2) gave filtered water having overall mean of 12.56 JTU whereas, at the filtration rate of 0.60 m^3/m^2-hr, mean effluent turbidity from burnt rice husk filter (F_1) and sand filter (F_3) were 15.7 JTU and 15.9 JTU respectively. The fluctuation over time was very high and thus these rates may not be recommended for a reliable supply.

(iii) The coliform contents in filtered water from burnt rice husk filters (F_1, F_2) sand filters (F_3, F_4) and dual media filter ranged from 274-804 MPN/100 ml and the filtered water to be disinfected before supply. The coliform removal efficiency increased from 75% to 90% in sand filters but did not increase from 66% in other filters over the run length.

(iv) The head loss rates in burnt rice husk filters (F_1 and F_2 @ rate of 0.6 m^3/m^2-hr and 0.5 m^3/m^2-hr) and sand filters (F_3 and F_4 @ rate of 0.6 m^3/m^2-hr and 0.5 m^3/m^2-hr) ranged 2.77 - 8.4 cm/day and 10-11.66 cm/day respectively. The head loss in dual media filter (F_5 @ 0.5 m^3/m^2-hr) was only 2.55 cm/day indicating a long filter run.

(v) The run could be continued further for dual media and burnt rice husk filters and thus the head loss rate mentioned above are not truly representing the overall head loss rate. Moreover, the coliform removal efficiency would have been increased if those filters were run for more period of time. But in making a comparison of the performance of the filters at the same time with same raw water quality, the above mentioned filters were shut down. From these points of view, the comparative performance curves in Fig. 4.10 gave performance of filters during first week of operation, though not the performance of a true slow filter over a long period of time.

Phase III - Experimental Study on the Performance of Series and Dual Media Filters at 150 JTU Turbidity Level

During the runs 1, 2, 3 over a period of September - October - November 1975, the raw water turbidity was in the range of 95-250 JTU. The overall arithmetic mean value was ≃ 145 JTU. High variation in influent water occurred during heavy rainfall in late November (during run 2, value exceeded 250 JTU). On the other hand, difficulty was experienced in maintaining desired turbidity level (150 JTU) in sunny and windy days. The suspended particles which were introduced from bed clays as result of mixing effect of by-pass water jet, settle quickly as soon as the by-pass valve was closed. The by-pass valves could not be kept wide-open for all the times during higher rates of supply to filters (during .50-0.60 m^3/m^2-hr. filtration rates). pH of influent and effluent water ranged from 7.8 to 8.55 during the 3 runs. There was no appreciable change with pH upon filtration (Table A4.3, in Appendix A). Temperature charged from 27.5-28.5°C during morning and night time to 30°C-32.5°C during mid-days. There was no appreciable change in coliform content in raw water which ranged from 1100 to 2400 MPN/100 ml. The values were rather low in comparison to the values found in chaophya river water by JACKSIRINONT (1972). The high values 750,000 - 1,100,000 MPN/100 ml in chaophya river raw water were probably due to the presence of high pollutional load of organic matters.

Run 1 - Performance of Filters at the Rates of 0.5 m^3/m^2-hr (F_2, F_4 and F_5) and 0.60 m /m -hr (F_1 and F_3) at Raw Water Turbidity Level of 150 JTU

Filtration rates in the roughing filters (R_{1-2}) was 4.50 m^3/m^2-hr. From Fig. 4.11, it is observed that, the filtered water turbidity of the roughing filter did not exceed 50 JTU limit and were in the

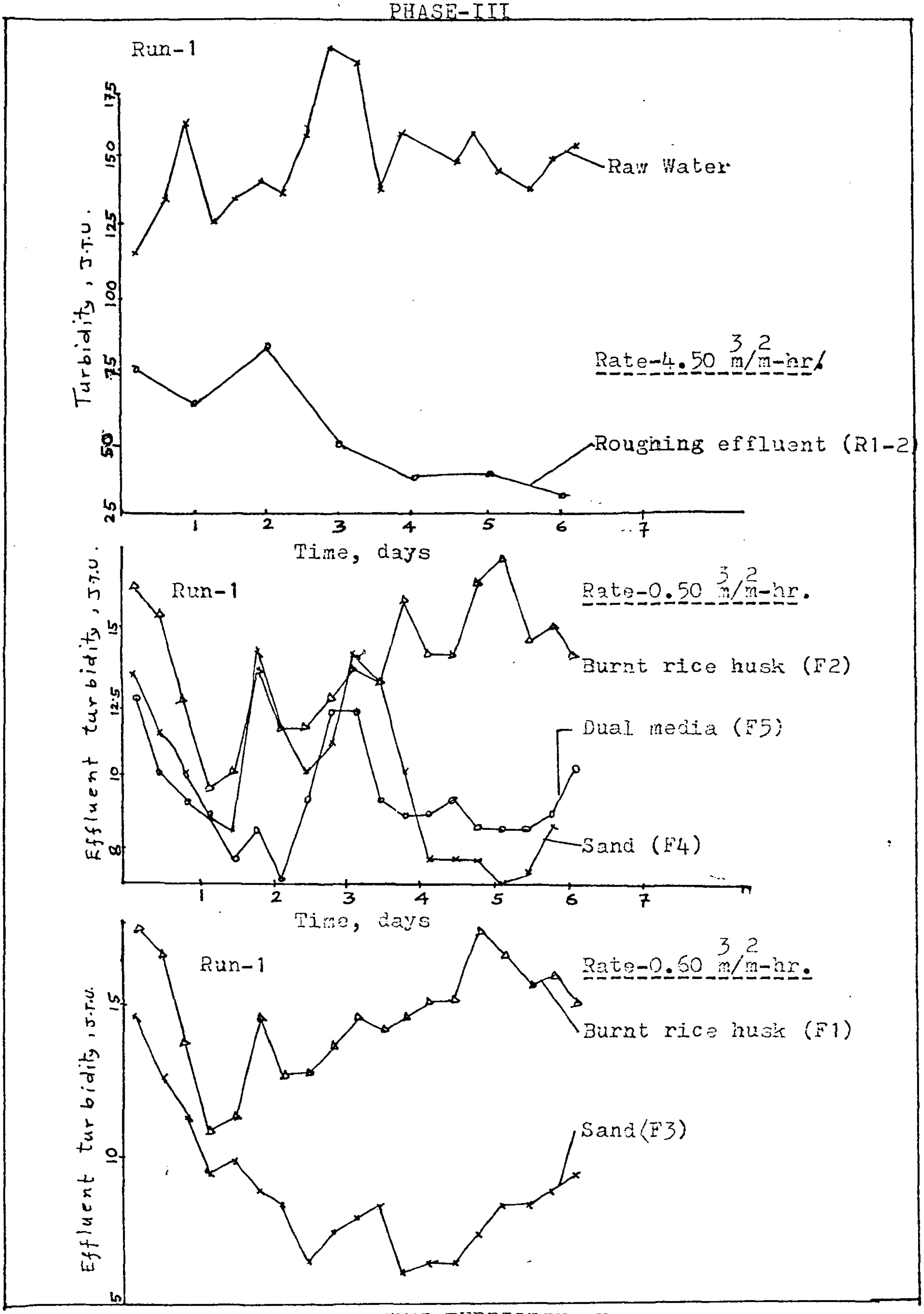


FIG.4.11 TIME-TURBIDITY CURVE

range of 27-48 JTU. The head losses in roughing filter were insignificant. From these facts it may be concluded that coconut fiber roughing filters were able to accept high turbidity load (150 JTU or more) to give filtered water turbidity load acceptable to slow polishing filters. This fact is supported by the laboratory scale experimental results of FARUQUZZAMAN (1975). The run was concluded after 6.33 days of operation due to full 120 m head loss developed in sand filters (F_3, F_4).

The filtered water mean turbidity levels were 20.94 JTU (F_1 @ 0.60 m^3/m^2-hr), 15.65 JTU (F_2 @ 0.50 m^3/m^2-hr) in burnt rice husk filters. In sand filters the effluent turbidity values were 8.90 JTU (F_3 @ 0.60 m^3/m^2-hr) and 11.54 JTU (F_4 @ 0.50 m^3/m^2-hr) whereas, the filtered water turbidity of dual media filter (F_5 @ 0.5 m^3/m^2-hr) was 10.50 JTU. Fig. 4.12 shows that at filtration rate 0.50 m^3/m^2-hr, the filter performance was not steady. But the turbidity removal efficiency in sand filter (F_4, 92.40%) and dual media filter (F_5, 93.0% removal) were more than that of burnt rice husk filter (F_2, 89.30%). Fig. 4.12 shows better performance of sand filter (F_3, 93.90% removal) than its counterpart burnt rice husk filter (F_1, 85.68% removal) both at filtration rate of 0.60 m^3/m^2-hr. From Table 4.4, it is seen that the filter F_2 (@ 0.5 m^3/m^2-hr) had better performance than filter F_1 (@ 0.60 m^3/m^2-hr) but the sand filter F_3 (@ rate 0.60 m^3/m^2-hr) performed better than F_4 (@ rate 0.50 m^3/m^2-hr) though filteration rate in F_4 was lower. However, the variation of performance was not high and might be caused due to unexpected drying of filter and subsequent mudball formation during electrical failure in phase - I.

The coliform removal efficiency (Table A4.3 in Appendix A) in burnt rice husk filters was 93.14% (residual 120 MPN/100 ml) whereas, that in sand filters (F_3 and F_4) was 90.40% (residual 167 MPN/100 ml). The efficiency of removal in dual media filter (F_5) was 83.42% leaving a residual of 290 MPN/100 ml. No change in removal efficiency was observed due to variation in filtration rate. But increase of removal efficiency was observed as the run continued. Removal efficiency after 48 hours ripening was 76-80% which increased to 93% after 6 days operation due to the obvious phenomenon of 'filter ripening'. As the coliform content in the filtered water from all filters ranged from 120 to 290 MPN/100 ml, the water should be disinfected before drinking.

The head loss rates in sand filters were highest (F_3 and F_4, head loss rate = 18.72 cm/day) (Table 4.5). The values for burnt rice husk filters were 12.24 cm/day (F_1 @ 0.60 m^3/m^2-hr) and 11.76 cm/day (F_2 @ 0.50 m^3/m^2-hr) - whereas, the rate of head loss in dual media filter (F_5 @ 0.5 m^3/m^2-hr) was lowest value of 5.04 cm/day. From Fig. 4.12, it is observed that head loss in sand filter reached 1.20 m after 3.33 days of operation whereas, the burnt rice husk filters and dual media filter could be run for more period of time.

Run 1 - Conclusions:-

(i) At high filtration rate of 4.5 m^3/m^2-hr and high turbidity level (150 JTU) in influent water, the turbidity of effluent ranged from 27-48 JTU with less fluctuation.

PHASE-III

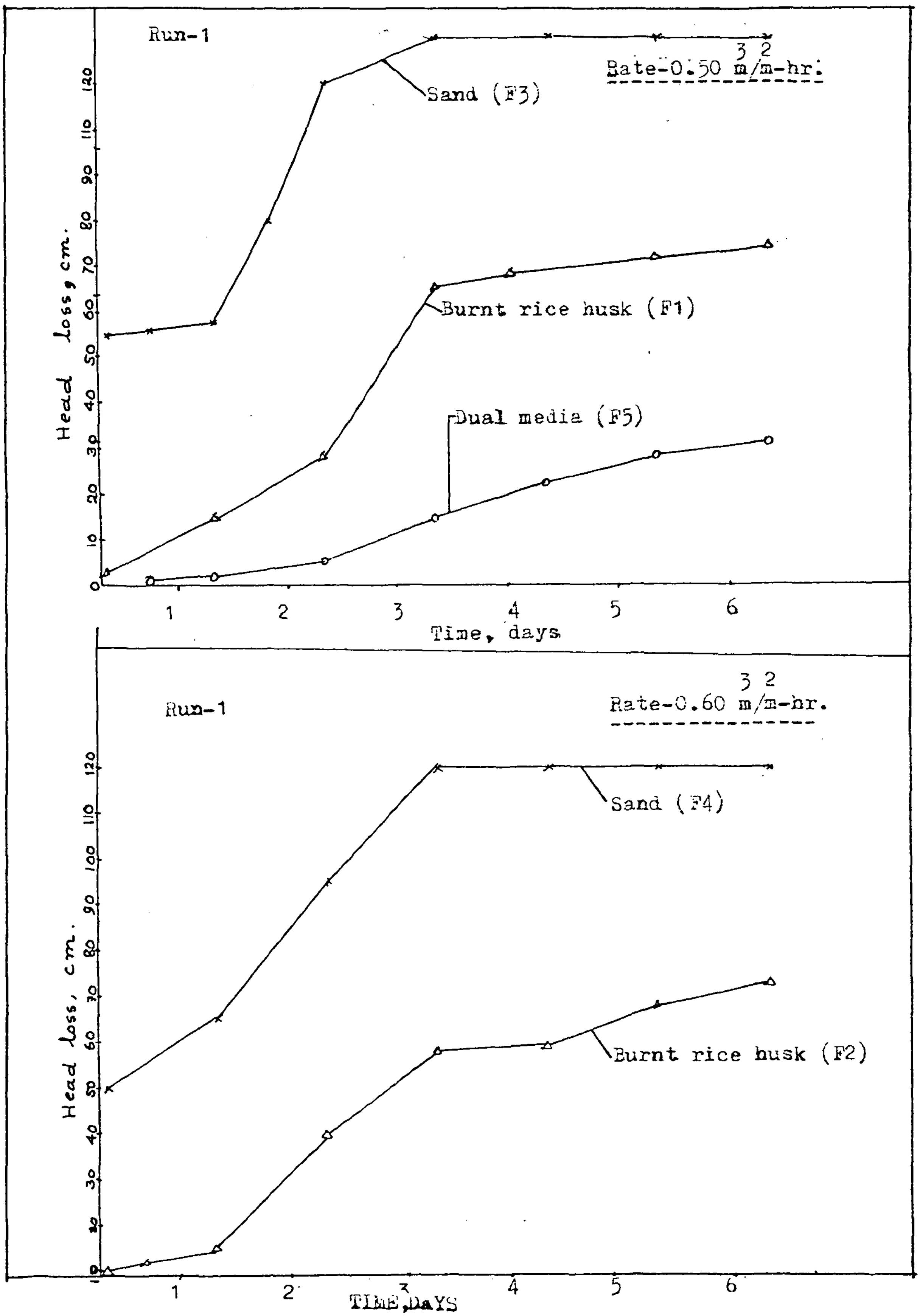
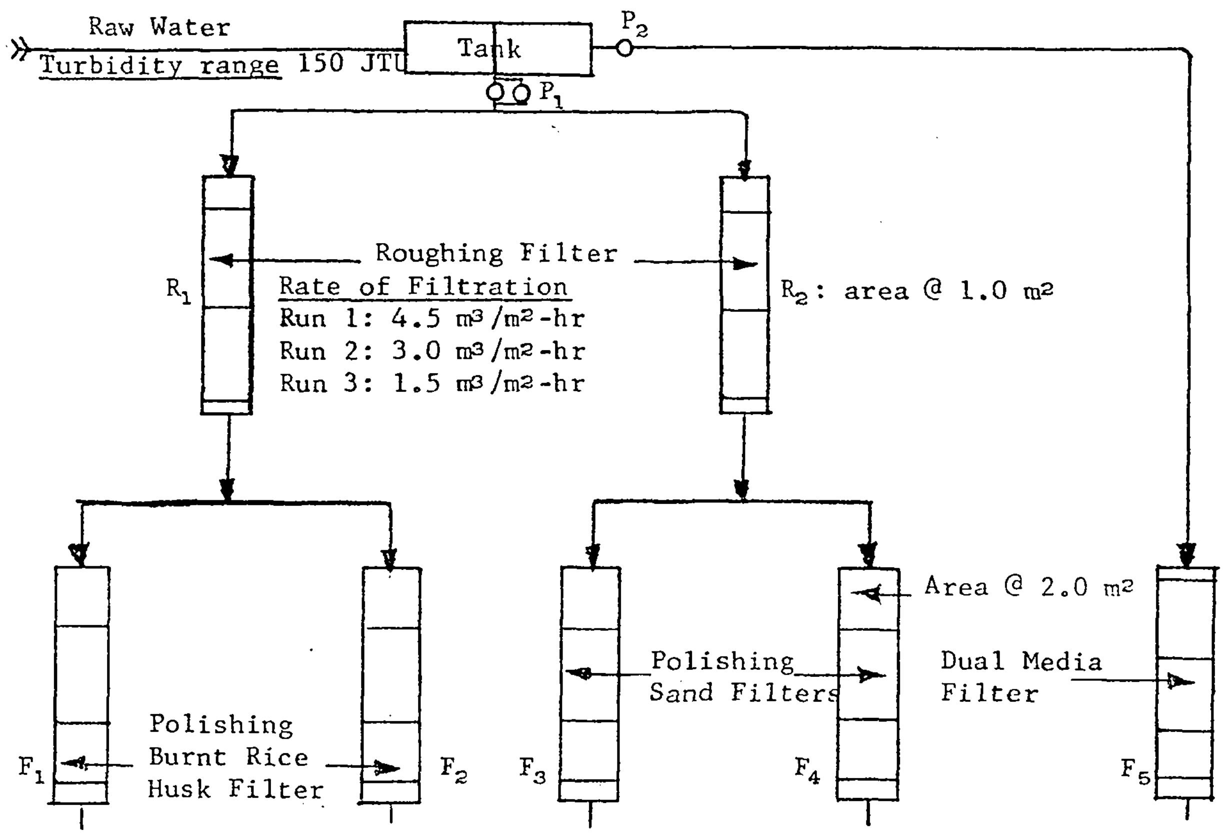


FIG. 4.12 TIME HEADLOSS CURVE

Table 4.4 - Comparison Table of - Phase III



Filter Type	F_1	F_2	F_3	F_4	F_5
Filtration Rate, m^3/m^2-hr					
Run - 1	0.60	0.50	0.60	0.50	0.50
Run - 2	0.40	0.30	0.40	0.30	0.30
Run - 3	0.20	0.10	0.20	0.10	0.10
Filtered Water Turbidity (JTU) (mean values)					
Run - 1	20.94	15.65	8.90	11.54	10.50
Run - 2	10.64	9.38	7.71	7.35	7.48
Run - 3	10.32	6.27	6.69	6.19	5.49
Head Loss Rate, (cm/day)					
Run - 1	12.24	11.76	18.72	18.72	5.04
Run - 2	14.88	10.08	16.32	16.32	1.68
Run - 3	5.04	3.12	4.08	1.44	1.68

Table 4.5 - Filter Head Loss Rate and Run Length in Phase III

Run No.	Length of Run, Day	Filter Type	Filtration Rate, m^3/m^2-hr	Influent Water Mean Turbidity, J.T.U.	Head Loss Rate cm/day
1	6.33 days	F_1	0.60	146.30	12.24
		F_2	0.50		11.76
		F_3	0.60		18.72
		F_4	0.50		18.72
		F_5	0.50		5.04
2	7.33 days	F_1	0.40	150.77	14.88
		F_2	0.30		10.08
		F_3	0.40		16.32
		F_4	0.30		16.32
		F_5	0.30		1.68
3	9.33 days	F_1	0.20	135.46	5.04
		F_2	0.10		3.12
		F_3	0.20		4.08
		F_4	0.10		1.44
		F_5	0.10		1.68

Legend:

F_1 and F_2 - Polishing burnt rice husk filter depth = 80 m

F_3 and F_4 - Polishing sand filters depth = 0.80 m

F_5 - Dual Media Filter (coconut fiber 0.80 m burnt rice husk) 0.60 m

(ii) At high filtration rates of 0.5-0.6 m^3/m^2-hr for the sand and dual media filter (rate 0.5 m^3/m^2-hr), the turbidity in effluent had mean value around 10 JTU whereas that in burnt rice husk filter was ranging 12.5-14 JTU.

(iii) At high filtration rates of 0.5-0.6 m^3/m^2-hr and at 150 JTU level turbidity load, the length of run was only 3.33 days in sand filter and thus may not be practicable.

(iv) The coliform removal efficiency was poorest in dual media filter (83%) leaving a residual of 290 MPN/100 ml. The residual coliform count in sand and burnt rice husk filter effluent ranged 120-167 MPN/100 ml. The filtered water should be disinfected before drinking.

(v) The head loss in sand and burnt rice husk filters were 18.72 cm/day and 11.76-12.23 cm/day respectively giving short filter run. The head loss in dual media filter was rating 5.04 cm/day indicating 25 day long run.

(vi) The head loss rate for dual media filter (F_5) and burnt rice husk filters (F_1, F_2) as mentioned above are truly not the overall head loss rate for the run, due to its termination before full head loss development. Moreover, the coliform removal efficiency of these filters would have been increased if the filters were run till their full head loss development of 1.20 m. Hence, the performance curves in Fig. 4.11 and 4.12 are only representing the performance of the types of filters on the same raw water source for a part of their run length.

Run 2 - <u>Performance of Filters at the Rates of 0.3 m^3/m^2-hr (F_2, F_4, F_5) and 0.4 m /m^2-hr (F_1, F_3) at Raw Water Turbidity Level of 150 JTU</u>

During this run the filtration rate in the roughing filters (R_{1-2}) was 3.0 m^3/m^2-hr. The effluent turbidity ranged 26-39 JTU. The head loss in roughing filters were insignificant indicating a long filter run. The run was concluded after 7.33 days of operation due to a full 1.20 head loss in sand filters (F_3, F_4)

The filtered water turbidity vs time curves in Fig. 4.13, show highly variable performance of filters in removing turbidity. The sand filter (F_4 @ 0.30 m^3/m^2-hr) was seen to gain efficiency over time.

The fact indicated requirement of longer ripening period in sand filters. The nature of performance curve is quite similar in case of sand filter F_3 (@ 0.4 m^3/m^2-hr) as can be seen in Fig. 4.14. On the other hand the performance of burnt rice husk filters (F_1 @ 0.4 m^3/m^2-hr, and F_2 @ 0.3 m^3/m^2-hr) and dual media filter (F_5 @ 0.30 m^3/m^2-hr), show fluctuating decrease in efficiency over the run-length of 7.33 days. The mean values of filtered water turbidity for the rate of 0.30 m^3/m^2-hr were found to be 9.38 JTU (F_2), 7.35 JTU (F_4) and 7.48 JTU (F_5). The values for the rate 0.40 m^3/m^2-hr were 10.64 JTU (F_1) and 7.71 JTU (F_3) respectively. From these

PHASE-III

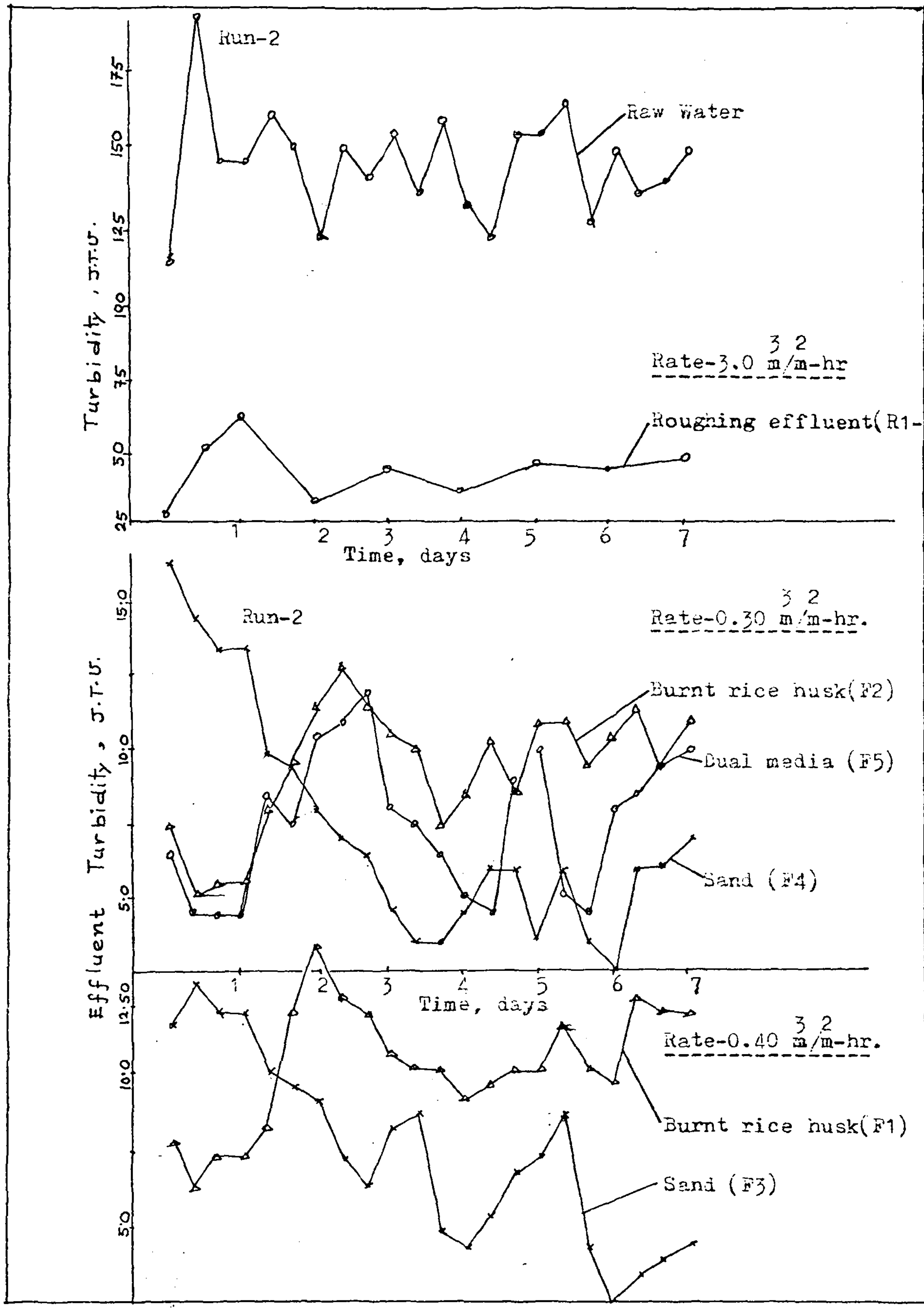


FIG.4.13 TIME - TURBIDITY CURVE

PHASE-III

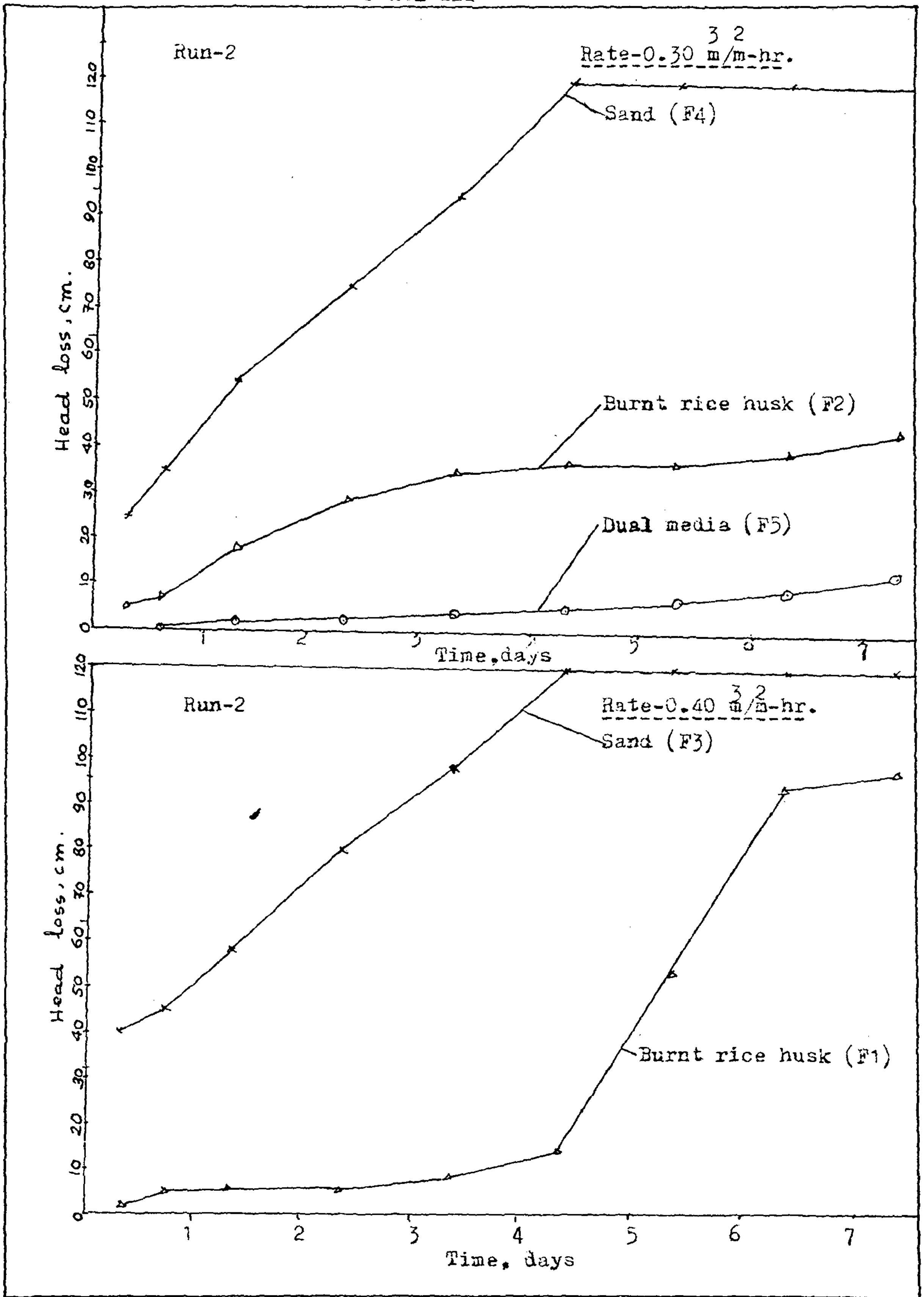


FIG.4.14 TIME-HEADLOSS CURVE

results it may be concluded that at the rates of 0.30-0.40 m^3/m^2-hr., Slow filters of sand and burnt rice husk can produce water having turbidity level well below prohibitive standard value of 25 JTU.

The coliform removal efficiency of burnt rice husk filters F_1 and F_2 was 88.50% and the residual coliform level was 275 MPN/100 ml; the removal efficiency for sand filters (F_3 and F_4) was 90.60% (residual 225 MPN/100 ml). In dual media filter the removal efficiency was 88.5% (residual 275 MPN/100 ml). In this case also, the variation of filtration rates (F_3 @ 0.4 m^3/m^2-hr and F_4 @ 0.3 m^3/m^2-hr) did not affect the coliform removal efficiency. But the sand filters were proven to remove bacteria in a better way than burnt rice husk and dual media filters.

The head loss development in sand filters (F_3 and F_4) were very rapid and full 1.20 m of head loss developed after 4 days of operation (Fig. 4.14). At the rate of 0.4 m^3/m^2-hr, rapid development of head loss was seen to occur in burnt rice husk filter F_1, after 4 days of operation. The summary of head loss rates are given in Table 4.4. The maximum head loss rate in sand filters (F_3 and F_4) was 16.32 cm/day whereas high values of head loss rates occurred in burnt rice husk filter F_1 (@ 0.40 m^3/m^2-hr, head loss rate 14.88 cm/day) and F_2 @ 0.30 m^3/m^2-hr, head loss rate 10.08 cm/day). Lowest head loss rate of 1.68 cm/day occurred in dual media filter, indicating long filter run. Thus at high raw water turbidity values, development of head loss were observed to be higher in sand and burnt rice husk filter than that of dual media filter, even at higher slow filtration rates of 0.4 m^3/m^2-hr. A very significant low head loss rate (10.08 cm/day) occurred in filter F_2 at the filtration rate of 0.3 m^3/m^2-hr - signifying longer filter run.

<u>Run 2 - Conclusions</u>:-

(i) At the rate of 3.0 m^3/m^2-hr the roughing filters gave effluent having turbidity range 26-39 JTU from raw water of 90-250 JTU turbidity range for an insignificant head loss rate.

(ii) At filtration rate of 0.3 m^3/m^2-hr, the effluent water from all the types of filter had turbidity value around 7.5 JTU whereas, at the rate of 0.4 m^3/m^2-hr the effluent from sand and burnt rice husk filter had turbidity value around 8.5 JTU. At this rate, the performance of sand filter was found better than burnt rice husk.

(iii) Head loss in sand filter was high giving a short (4 days) run. Head loss in dual media and burnt rice husk filter at the rate of 6.3 m^3/m^2-hr was low indicating long filter run.

(iv) The run was concluded before full head loss of 1.20 m in dual media (F_5) and burnt rice husk filters (F_1, F_2). Hence, the head loss rate and coliform removal efficiencies for those filters are not overall values over the full length of run. The Fig. 4.13 and 4.14 represent the performance of these filters over a part of their run length. These deficiencies in results could not be avoided due to short period of time allowed for each run to carry out this first phase of investigation. Detailed investigation over a long period of time should be carried out before final formulation of the design parameters of these filters.

Run 3 - Performance of Filters at filtration rates of 0.10 m^3/m^2-hr (F_2, F_4, F_5) and 0.20 m^3/m^2-hr (F_1, F_3) at Turbidity Level of 150 JTU in Raw Water

During the run the filtration rate in roughing filters (R_{1-2}) was 1.5 m^3/m^2-hr. Roughing filter effluent turbidity ranged from 17 to 37 JTU. The fluctuating nature of the time-turbidity curve in Fig. 4.15 was seen to be caused by the fluctuation of raw water turbidity values, over rainy and sunny and windy days.

The roughing filter effluent turbidity was below 50 JTU even when the raw water turbidity was as high as 180 JTU and over on the 5th day of operation.

The head loss rate was insignificant in roughing filters which indicated long filter run.

The length of the run was 9.33 days execluding 3 days of ripening period. The run was discontinued due to shortage of time. The low head loss rates in the filters give only an indication of long filter run at high level (150 JTU) of raw water turbidity. The performance curves in Fig. 4.15 and 4.16 and the coliform removal efficiencies of the filters are only valid for the part of the run length. The coliform removal efficiencies in the filters could have been increased if they were run for longer period of time till their full 1.20 m head loss development.

At the rate of 0.10 m^3/m^2-hr, filters F_2 (burnt rice husk), F_4 (sand) and F_5 (dual media) were seen to perform increasingly well (Fig. 4.15) till 6 day of operation. During heavy rainfall on 7th and 8th day, the performance of sand filter was worst. Quality of filtered water deterioriated on 8-9th day after the rain was over - probably due to the fact that the filter bed became saturated with accumulation of fine particles during rainy days, whereas the same sized particles had passed out through sand bed, keeping the bed normal for operation during subsequent 8th and 9th days. From this fact it can be postulated that burnt rice husk filter operating at lower rate can adsorb at least a portion of finer particles (smaller than 5 micron size) up to a certain capacity, which ' cannot be filtered out by slow sand filter' as has been postulated by HUISMAN (1972). The dual media filter (F_5) was seen to perform steadily over the length of run.

At the rate of 0.2 m^3/m^2-hr, the sand filter (F_3) was seen to perform in a better way than burnt rice husk filter (F_1) as shown in Fig. 4.15. The filtered water turbidities (mean values) during the run were found to be 10.32 JTU (F_1 @ 0.2 m^3/m^2-hr), 6.27 JTU (F_2 @ 0.1 m^3/m^2-hr), 6.69 (F_3 @ 0.2 m^3/m^2-hr), 6.19 (F_4 @ 0.1 m^3/m^2-hr) and 5.49 JTU.

PHASE-III

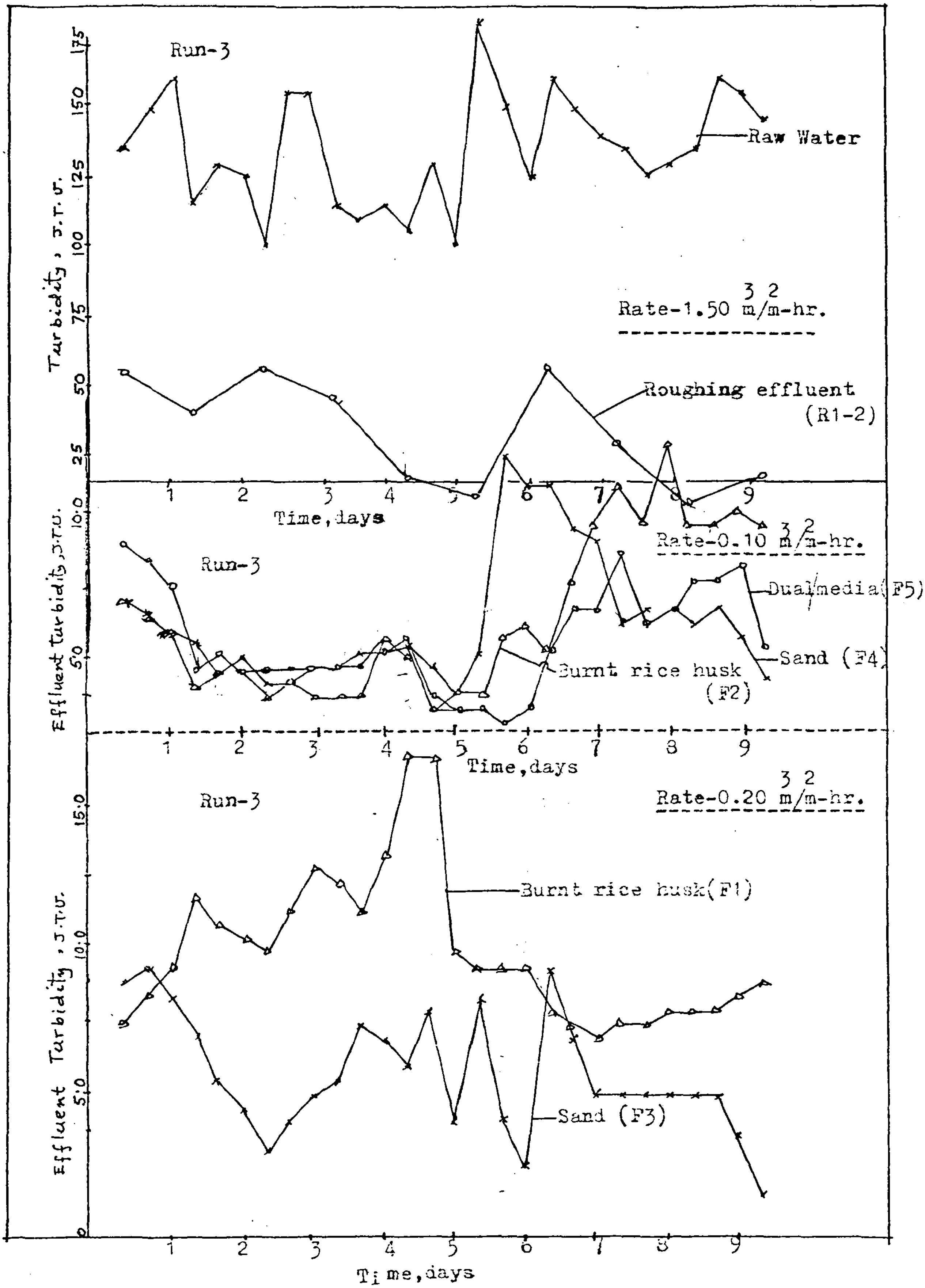


FIG. 4.15 TIME - TURBIDITY CURVE

(F_5 @ 0.1 m^3/m^2-hr) as tabulated in Table 4.14. The values are well around WHO drinking water standard 5 JTU and may be suggested as safe for the people living in rural communities in terms of turbidity. From the table it is also observed that increase in filtration rate increases filtered water turbidity as seen in filtered water from F_1 and F_2, F_3 and F_4. Moreover, it is also observed that at low rates sand filters and dual media filters removed turbidity in a better way than burnt rice husk filters (F_1 and F_2).

The coliform removal efficiency in burnt rice husk filters were 89.56% (F_1, residual coliform level 160 MPN/100 ml) and 91.60% (F_2, residual coliform level 120 MPN/100 ml). The removal efficiencies in sand filters were 90.10% (F_3 @ 0.20 m^3/m^2-hr) leaving a residual of 151 MPN/100 ml and 91.60% (F_4 @ 0.10 m^3/m^2-hr) leaving a residual of 128 MPN/100 ml - whereas, the removal efficiency in dual media filter (F_5 @ 1.0 m^3/m^2-hr) was only 87.50% (residual coliform level was 191 MPN/100 ml). Here also, filtration rate had played insignificant role in coliform removal efficiency. But sand filters were observed to remove bacteria in a better way than burnt rice husk filters. The head loss vs time curves in Fig. 4.16 show very low head loss rate over the run - signifying longer filter run at lower rates, even at high level of influent water turbidities (150 JTU). However, relatively higher head loss rates (5.04 cm/day in F_1 @ 0.20 m^3/m^2-hr and 4.08 cm/day in F_3 @ 0.2 m^3/m^2-hr) were observed to occur in filters operating at higher rates.

A summary of statistical analysis of influent and filtered water turbidities, pH, coliform content along with run length and head losses are presented in Table A4.3 in Appendix A.

Run 3 - Conclusions:-

(i) At lower filtration rates of 0.10 m^3/m^2-hr and 0.20 m^3/m^2-hr, the burnt rice husk (F_1, F_2), sand (F_3, F_4) and dual media filters (F_5) were producing water having acceptable level of turbidity (10 JTU). But coliform content in filtered water ranged 128-191 MPN/100 ml which needs disinfection before drinking.

(ii) At the stated rates of filtration the run lengths were found optimistically high (> 1 month) in all the types of filters.

(iii) Chlorination should be practised for filtered water from burnt rice husk, sand and dual media filters before supplying to the consumers, even when the filters are operating at the rates of 0.1-0.2 m^3/m^2-hr.

(iv) The performance of the filters in terms of turbidity and coliform organism removal and head loss rates found during this run are incomplete. A complete picture could be achieved if the run were continued till full head loss development of 1.20 m in all the filters. It could not be done due to shortage of time and thus has to be investigated in depth in the future. From the present results, a comparative

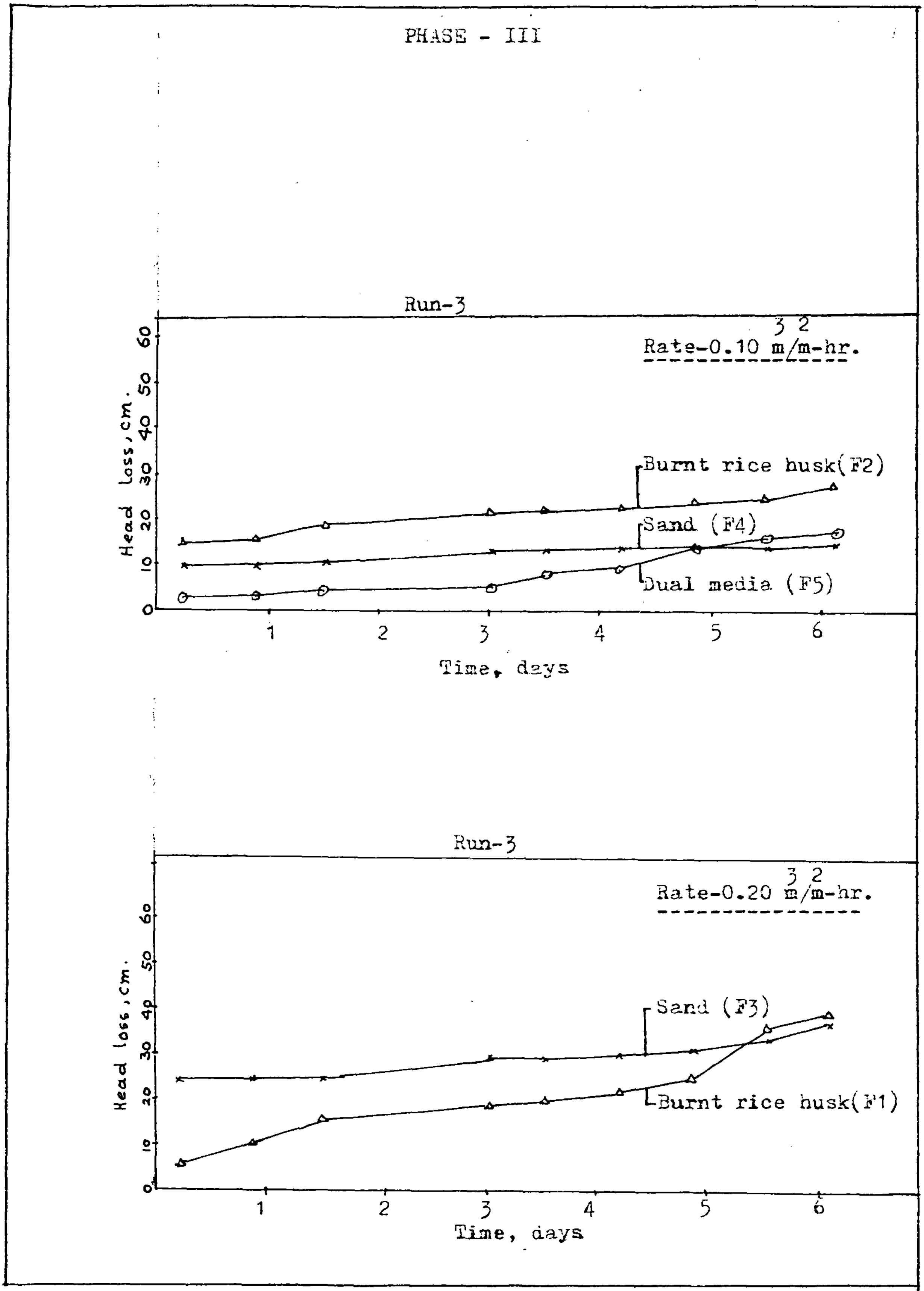


FIG.4.16 TIME-HEADLOSS CURVE

picture of filter performance is obtained to out line the filtration rates at which the filters concerned were found to work under optimal condition. However, a longer filter run would show increase in coliform removal efficiency due to more ripening and formation of schmutzdeck but it would give higher head loss rates. Hence it is recommended that, for final decision on filter design parameters (rates of filtration, head loss rate, run length and removal efficiencies of turbidity and coliform) the filters are to be run for a period of not less than 1 month during the subsequent phases of investigation.

Rate Optimisation of Filters

It was evident from the preceeding discussions that the filter performances in terms of turbidity removal efficiency and head loss rates e.g. virtually the length of filter run was seen to have certain degree of dependancy on the filtration rates. It had also been found that the degree of interrelation between filtration rates and turbidity removal efficiency and head loss rate were not the same in different raw water turbidity levels. Plotting turbidity removal efficiency (%) and head loss rates (cm/day) against filtration rates (m^3/m^2-hr) (in x-axis), the graphs in Fig. 4.17 are obtained. The graphs show three notable phenomenon:

(1) Turbidity removal efficiency decreases as the filtration rate increases in all the filters.

(2) The head loss rates increased rapidly with the increase in filtration rates, particularly in sand filters.

(3) The decrease in turbidity removal efficiency and increase in head loss rate with increase in filtration rates are not same for all the filters in case of the 3 lèvels (3 phases) of turbidity in raw water due to difference in media characteristics which affected filtration.

The economy in potable water production directly depends on optimal filtration rate. The word 'optimal' is closely related to quality (here turbidity) and amount of water produced in unit time as well as on the duration of filter performance (run length). High head loss rate cuts the filter run short involving money expenditure for washing and filter regenerating. Therefore, a filtration rate has to be choosen in such a way that, at that rate the amount of water will be maximum with best tolerable turbidity (quality) in filtered water and also the head loss rate should be low enough to give a practical filter run. Keeping the above guidelines in mind, a phase wise investigation was made to find out optimum filtration rates for different (burnt rice husk polishing filter, sand filter and dual media filter) filters at the 3 levels (50 JTU in Phase I, 100 JTU in Phase II and 150 JTU in Phase III) of raw water turbidity:

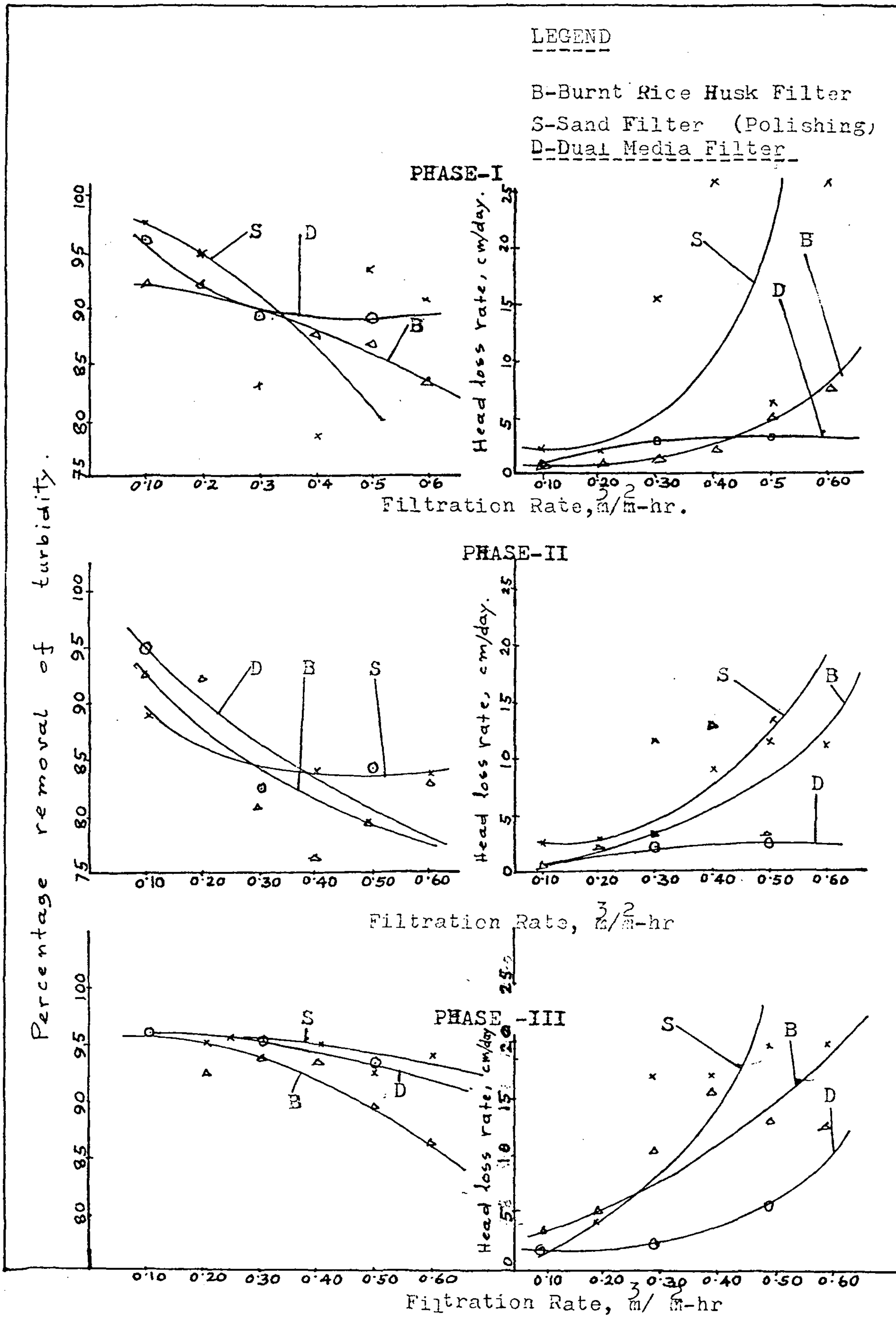


FIG.4.17 FILTRATION RATE OPTIMISATION CURVE

(a) Phase I - Optimisation of Filtration Rate at Raw Water Turbidity Level of 50 JTU

From Fig. 4.17, it is found that the head loss rate in burnt rice husk filters were low enough over 0.10-0.60 m^3/m^2-hr filtration rates, but beyond the rate of filtration 0.20 m^3/m^2-hr, the turbidity removal efficiency drops down to 90% which amounts filtered water turbidity around 6-7 JTU. An 89% of turbidity removal efficiency amounts residual turbidity $\simeq$ 8 JTU (Table A4.1 in Appendix A) and filtration rate $\simeq$ 0.30 m^3/m^2-hr or less may be choosen as optimal.

In case of sand filter (Fig. 4.17) the points for (S) curve were widely scattered. For 90% turbidity removal efficiency, the filtration rate was 0.30 m^3/m^2-hr. For this filtration rate the head loss rate amounts about 4.8 cm/day - which could give about 1 month of filter run. Therefore, the rate 0.20-0.25 m^3/m^2-hr, may realistically choosen as the optimal one.

The dual media filter was found to have 90% efficiency (filtered water turbidity 5 JTU) at the rate of 0.30 m^3/m^2-hr. At this rate of filtration the head loss rate was only 2.5 cm/day. This filtration rate (0.30 m^3/m^2-hr) might be taken as optimum for dual media filter also.

Considering lower head loss rates up to filtration rates of .30 m^3/m^2-hr, the optimal rates of filtration for 3 types of filters operating on raw water having low level of turbidity may be summarised as:-

(1) For burnt rice husk filter - 0.20-0.25 m^3/m^2-hr
(2) For sand filter - 0.20-0.25 m^3/m^2-hr
(3) For dual media filter - 0.30 m^3/m^2-hr

(b) Phase II - Rate Optimisation in Burnt Rice Husk, Sand and Dual Media Filter at Turbidity Level 100 JTU

In case of burnt rice husk filter the filtration rate 0.25 m^3/m^2-hr corresponded to the turbidity removal efficiency 87.5% - which leaves residual turbidity (100 x .125) = 12.5 JTU, a value recommendable for rural people. For this filtration rate head loss rate was 2.5 cm/day - which was low enough to give a long filter run. Therefore, this filtration rate might be recommended as optimal.

For sand filters (Fig. 4.17), filtration rate of 0.20 m^3/m^2-hr shows 86% removal. At the level of turbidity of 100 JTU, the removal efficiency leaves a residual turbidity of 14 JTU. At this rate the head loss rate is found to be 2.5 cm/day. The filtration rate 0.20 m^3/m^2-hr might be suggested as optimal.

For the removal efficiency 85-90%, the filtration rates for dual media filter ranged from 0.20 m^3/m^2-hr to 0.37 m^3/m^2-hr. The head loss rates were found to be insignificant at these filtration rates. Conservatively a rate of 0.25 m^3/m^2-hr might be choosen as optimal for dual media filter.

(c) Phase III - Rate Optimisation in Burnt Rice Husk, Sand and Dual Media Filters at Raw Water Turbidity Level of 150 JTU.

In case of burnt rice husk filter, the turbidity removal efficiency was seen 95% at filtration rate of 0.20 m^3/m^2-hr (Fig. 4.17) considering the raw water trubidity level not below 100 JTU, the residual turbidity in filtered water amounts (5 x 1.5) = 7.5 JTU. It would be unwise to choose a filtration rate more than 0120 m^3/m^2-hr due to expected fluctuation in raw water which might cause filtered water turbidity to exceed 25 JTU. At this filtration rate the head loss rate was found $\simeq$ 5 cm/day - indicating a practical filter run of about 1 month. The filtration rate of 0.20 m^3/m^2-hr, therefore, can be choosen as optimal. A value lower than this would reduce amount of water production per unit time, on the other hand, increased rate would reduce filter run as well as would deteriorate water quality.

Sand filter was seen to have removal efficiency of 95.5% at filtration rate of 0.25 m^3/m^2-hr. The head loss rate at this filtration rate was found to be 5.2 cm/day. Beyond the rate of 0.25 m^3/m^2-hr the head loss rate curve jumps up rather exponentially (Fig. 4.17). Therefore, the rate of filtration 0.20 m^3/m^2-hr might be optimal for sand filter. Though the flat nature of the curve (S) in Fig. 4.18 indicated high turbidity removal efficiency and production of more water in unit time but the exponential nature of (S) curve for head loss showed a short filter run. From these points of view, conservative value of filtration rate of 0.20 m^3/m^2-hr might be well adopted.

The turbidity removal efficiency in dual media filter was seen fairly high (> 95%) up to filtration rate of 0.40 m^3/m^2-hr. At this rate of filtration, the head loss rate was also not high (only 3.5 cm/day). But it was seen that, at high filtration rates, the quality of filtered water in dual media filter was poorest in terms of residual coliform content (value observed as high as 475 MPN/100 ml). This fact warrants conservative selection of filtration rate. Considering these factors, the optimal filtration rate might be choosen as 0.20 m^3/m^2-hr.

Optimisation of Filtration Rates - Summary and Discussions

The summary of the optimal filtration rates for burnt rice husk filter, sand filter and dual media filter are presented below for raw water tubridity levels of 50, 100 and 150 JTU.

(a) For Phase I - Raw water turbidity level of 50 JTU

(1) Burnt rice husk filter = 0.20 - 0.25 m^3/m^2-hr
(2) Sand filter = 0.20 - 0.25 " " "
(3) Dual media filter = 0.30 " " "

(b) For Phase II - Raw water turbidity level of 100 JTU

(1) Burnt rice husk filter = 0.25 m^3/m^2-hr
(2) Sand filter = 0.20 " " "
(3) Dual media filter = 0.20 - 0.37 m^3/m^2-hr

(c) For Phase III - Raw water turbidity level of 150 JTU

(1) Burnt rice husk filter = 0.20 m^3/m^2-hr
(2) Sand filter = 0.20 " " "
(3) Dual media filter = 0.20 " " "

Discussions - The optimal rates recommended here were valid for the filters and the raw water under investigation. These findings are believed to provide guidelines in choosing filtration rates in slow filters built/ to be built for the treatment of surface waters which are generally found to occur in various turbidity levels. Realising the varying nature of raw surface water in different tropical Asian countries, it is suggested that pilot-scale study to be performed before adopting any filtration rate as the optimal one for the filters concerned.

Moreover, the percentage removal of turbidity was calculated for various filtration rates ranging from 0.10 m^3/m^2-hr to 0.60 m^3/m^2-hr for all the filter types on the basis of a few days (4 to 15) of operation. But for slow filters efficiencies of turbidity and coliform removal are not adequately representative one unless and until the filters are run for a long period (1-2 month) of time so that, the biological layers are fully developed for adsorption and interception of suspended particles.

Again, the head loss rates in burnt rice husk and dual media filters were low and the run was not continued till full head loss development of 1.20 m due to shortage of time. In sand filters also, the head loss was low when the filtration rate was in the lower range of 0.1-0.30 m^3/m^2-hr. Therefore, the calculated head loss rates for the particular filtration rate are results of a fraction of run length and may not be representative of the mean head loss rate over the run. Due to these reasons, the optimal filtration rates were choosen rather conservatively taking these inadequacies of the tests compensated by factor of safety in design.

(d) Phase IV - Investigation on the Break Point Chlorine Dose for Filtered Water of Different Filters, operated at Optimum Filtration Rates at Normal Level of Raw Water Turbidity

The optimum filtration rates in filters were choosen conservatively 0.20 m^3/m^2-hr and 0.25 m^3/m^2-hr from the previously suggested optimal rate ranges 0.20-0.35 m^3/m^2-hr to avoid rapid fluctuations in filtered water turbidity as were experienced during the last 3 phases of operation. A ripening period of 10 days was allowed before collection of filtered water sample. Analysis of raw and filtered water was made for turbidity, coliform content, pH, temperature. Head loss rates were also measured. The characteristic of raw and filtered water as found before and during chlorination tests are presented in Table 4.6. Discussion on breakpoint chlorination tests results are supplemented by breakpoint chlorination curves (Fig. 4.18) and data (Table 4.7) presented herewith.

(1) Breakpoint of Raw Water - Raw water having mean turbidity value 39 JTU and coliform content 1100 MPN/100 ml (pH $\approx$ 7.5) was chlorinated. Plotting applied chlorine dose (mg/l) in x-axis and free and combined residual chlorine (mg/l) along y-axis the breakpoint chlorination curve (1) (Fig. 4.18) was obtained. From the curves it is evident that the breakpoint occurred at a chlorine dose of 2.5 ppm where a free chlorine residual of 0.2 ppm was left. At that point, the amount of combined chlorine residual was found to be 0.3 ppm to kill the pathogenic bacteria which might be present. However, 48 hr fermentation test confirmed absence of coliform organisms.

(2) Breakpoint for Filtered Water from Burnt Rice Husk Filter (F_1) operated at Filtration Rate of 0.2 m^3/m^2-hr - The filtered water turbidity was 4.3 JTU. Residual coliform content was found to be 93 MPN/100 ml at filter head loss rate of 1.5 cm/day. From curve (2) (Fig. 4.18), the breakpoint could be seen to occur at chlorine dose of 1.5-1.75 ppm. The dose 1.5 ppm, free chlorine residual was found 0.10 ppm which also sometimes taken as sufficient criteria fo complete kill of microorganisms present. However, conservatively the chlorine dose of 1.75 ppm (leaving free chlorine 0.2 ppm and combined chlorine residual 0.25 ppm) might be suggested as breakpoint chlorine dose.

(3) Chlorination Breakpoint for Filtered Water from Burnt Rice Husk Filter (F_2 @ 0.25 m^3/m^2-hr) - The filtered water turbidity was 3.4 JTU, residual coliform 93 MPN/100 ml at the filter head loss rate 1.5 cm/day. From curves (3) (Fig. 4.18), the breakpoint was seen to occur at 1.5 ppm of chlorine dose. The free and combined chlorine residual at that point was 0.2 ppm and 0.3ppm respectively.

(4) Chlorination Breakpoint for Filtered Water from Sand Filter (F_3 @ 0.20 m^3/m^2-hr) - The filtered water was found to have mean turbidity 1.5 JTU, coliform content 43 MPN/100 ml during the time of chlorination. The breakpoints were found to occur (curve (4), Fig. 4.18) at chlorine doses 1.5 ppm (free chlorine 0.1 ppm) and at 1.8 ppm (free chlorine 0.2 ppm). As the coliform content and turbidity were found low enough, the chlorine dose of 1.5 ppm might be considered sufficient to ensure complete kill of microorganisms.

(5) Chlorination Breakpoint for Filtered Water from Sand Filter (F_4 @ 0.25 m^3/m^2-hr) - Filtered water turbidity was 2.2 JTU; coliform

Table 4.6 - Raw Water and Filtered Water Characteristics During Break-point Chlorination Test - Date Nov. 29, '75 and Nov. 30, '75

Filter Type \ Parameters		Filtration Rate, m^3/m^2-hr	Turbidity, JTU	Coliform Content MPN/100 ml	Head Loss Rate, cm/day
Series Polishing-Burnt Rice Husk Filter	F_1	0.20	4.3	93	1.5
	F_2	0.25	3.4	93	1.5
Series Polishing Sand Filter	F_3	0.20	1.5	43	2.5
	F_4	0.25	2.2	43	2.5
Dual Media Filter	F_5	0.25	4.4	93	0.5
Influent			39.0	1100	

pH = 7.5; Temperature (mean) = 30.5°C

* Chlorine dose found for break points were applied in the raw and filtered water and tests were done for coliform content. A-48 hr fermentation (incubation) time showed absence of any gas e.g. coliform organisms in all the 6 types of water samples.

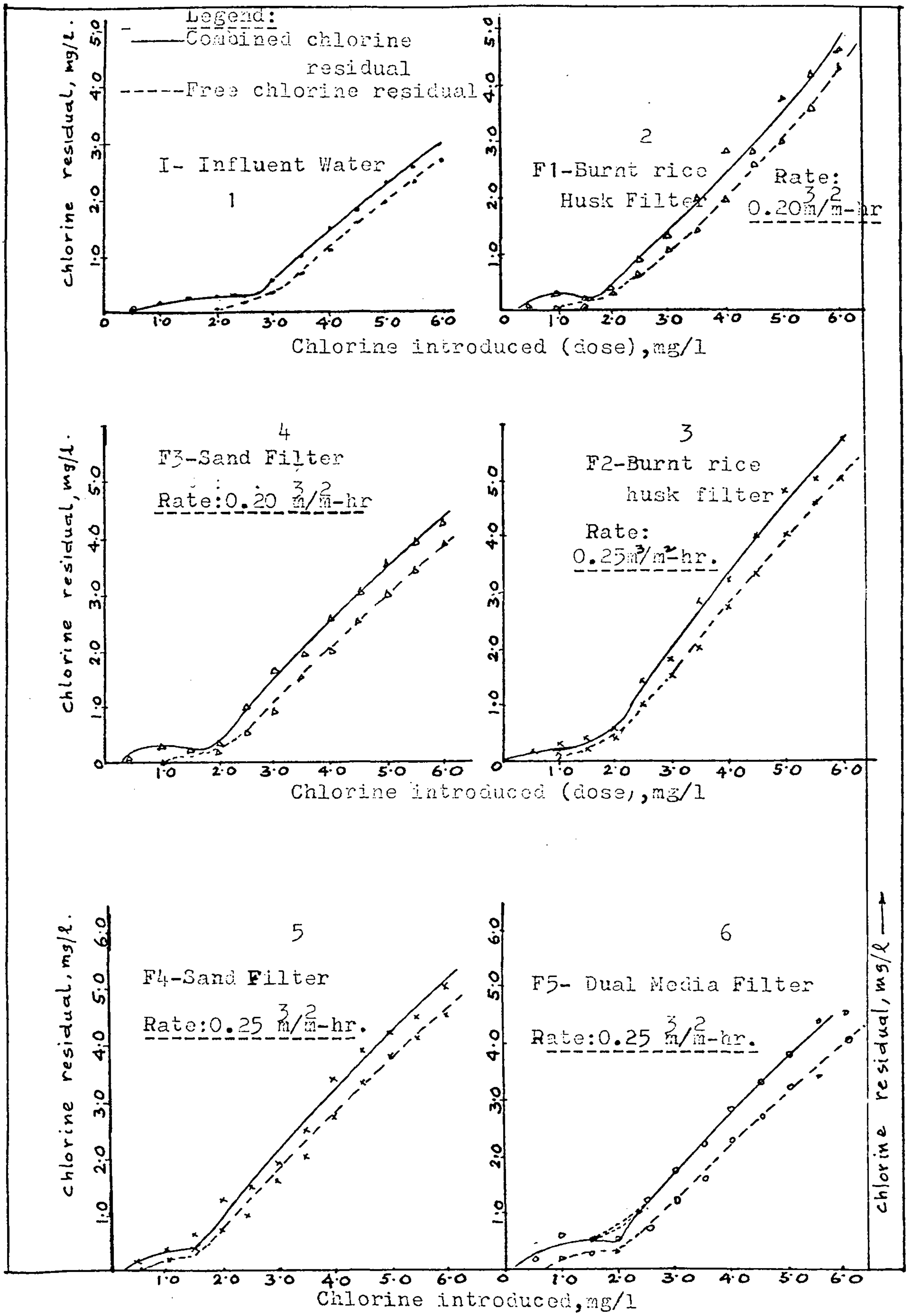


FIG.4.18 BREAKPOINT CHLORINATION CURVES

Table 4.7 - Study of Chlorination Breakpoint for Raw and Filtered Water (DPD Method)
Date, November 29-30, 1975

Filter Type / Chlorine dose/ppm	Influent Water		Polishing F_1		Polishing F_2		Polishing (Sand) F_3		Polishing (Sand) F_4		Dual Media F_5	
	Free Chlorine, ppm (mg/l)	Total Residue ppm	Free cl - ppm	Total Residue ppm	Free ppm	Total Combined ppm(mg/l)	Free ppm	Total Combined ppm(mg/l)	Free cl - ppm	Total Residue ppm(mg/l)	Free Chlorine ppm(mg/l)	Total Residue ppm(mg/l)
0.5	0	0.05	0.	0.10	0	0.1..	0.	0.20	0.05	0.20	0	0.15
1.0	0	0.15	0.05	0.25	0.05	0.30	0.10	0.30	0.15	0.40	0.15	0.50
1.5	0	0.25	0.1	0.20	0.2	0.40	0.15	0.25	0.25	0.40	0.30	0.40
2.0	0.10	0.30	0.25	0.35	0.4	0.55	0.2	0.4	0.7	1.20	0.3	0.45
2.5	0.20	0.30	0.5	1.0	1.0	1.4	0.5	1.0	1.0	1.5	0.7	1.12
3.0	0.40	0.60	0.9	1.65	1.5	1.8	0.8	1.6	1.6	1.8	1.2	1.7
3.5	0.7	1.0	1.5	2.0	2.0	2.8	1.5	1.9	2.0	2.5	1.6	2.2
4.0	1.1	1.5	2.0	2.6	2.7	3.2	2.0	2.5	2.7	3.4	2.2	2.7
4.5	1.6	1.8	2.5	3.0	3.3	4.0	2.5	3.0	3.3	3.4	2.2	2.7
5.0	1.95	2.30	3.0	3.55	4.0	4.7	3.0	3.5	3.8	4.2	3.20	3.7
5.5	2.30	2.60	3.4	4.0	4.5	5.0	3.4	3.9	4.1	4.4	3.4	4.4
6.0	2.65	3.0	3.8	4.4	5.0	5.4	3.8	4.3	4.5	4.9	4.0	4.5

pH = 6.5; Phosphate buffer was used.

cotent was 43 MPN/100 ml during chlorination. The breakpoint chlorine dose was found to be 1.0 ppm (curve (5), Fig. 4.18) leaving free and combined residual chlorine amounting 0.2 ppm and 0.35 ppm. As the turbidity and coliform content in filtered water were low enough, this 1.0 ppm chlorine dose might be enough to ensure total kill of pathogens.

(6) Chlorination Breakpoint for Filtered Water from Dual Media (F_5 @ 0.25 m^3/m^2-hr) Filter - The filtered water was found to have 93 MPN/100 ml respectively, during the chlorination experiments. From curve (6) (Fig. 4.18), the breakpoint was found to be 1.0-1.3 ppm. The mid value 1.2 ppm also could be considered to leave a free residual 0.2 ppm. In this case, the combined chlorine residual was found to be high enough amounting 0.4 ppm which ensured complete kill of pathogens, if any were present...

General Discussions

Filter Media Washing and Reuse - The coconut fiber media used in roughing filters and dual media filter was taken out after each run. It was cleaned with water manually. It was observed that the media property did not change much even after 8th cleaning, in terms of turbidity removal capacity. But if the media was dried before placing into filter columns, it became brittle and broken down into pieces. Again, turbidity removal efficiency of the filter was found to increase over the run length (2-3 days) and it was found more than that was just after putting new media into the filters. Moreover, the efficiency of removal increased at a faster rate when the used and wet media was utilised along with new media. This might be reasoned as the presence of previously occuring seed biological layer in the wet and used media. But however, the volume of the media reduced drastically to about 60% after each use, therefore it is suggested to use new stock after each run along with some of the old media.

Polishing Media - Burnt rice husk and sand was scraped off after each run keeping the water level in such a level that the scraping could be done conveniently. It was observed that the filter performance became poorer at the beginning of the run if the scraping was done on a dry bed. The reason may be death of biological layer when the bed got dried. However, this process of bed cleaning overcame the difficulty experienced by FARUQUZZAMAN (1975) while cleaning the bed under submersed condition.

It was also observed that bed penetration of particles were less in sand and dual media-burnt rice husk. The reasons were as follows:

(1) Some retarding action were experienced by the suspended particles in dual media coconut fibers; (2) the biological layer in-between the two media layers of dual media filter was thicker due to less disturbance by falling water; (3) the particles were readily retained by fine sand than the coarse burnt rice husk. Further observations showed that, the solid waste of scraped off sand and burnt rice husk became rather

a filling material after about 24 hours of exposure to sun and aeration. This fact postulates the sensitivity of biomass helping in slow filtration to sun's UV rays in the absence of water.

Miscelleneous - Difficulties were experienced in placing media in roughing and polishing filters. In roughing filters a freeboard of 30 cm was kept (HUISMAN, 1972). The author thinks it better to reduce it to 10 cm., thus to save material cost and to decrease carrying hight. Moreover, this will help in aeration and sunray penetration/interception to influent water which will kill pathogenic organisms as has been practiced and experienced in open reservoirs used as sedimentation basins for large water supply projects. The expected problem of algal bloom in filter columns were insignificant. In this respect, the height of series filters can also be reduced more by using 10 cm free board in polishing filters in place of present freeboard of 70 cm (!). Conservative selection of supernatent water height in polishing filters (less than 1.20 m) will save about one third of the cost of construction of polishing filter columns. But in case of dual media filter, the present height of the column was found minimal for its operation.

V CONCLUSIONS

The investigation on the treatment of surface water in the tropics by series and dual media filters led to the following conclusion:

(1) It was possible to treat tropical surface water by slow series and dual media filters using locally available filter media.

(2) At low turbidity levels (50 JTU) in raw water the filtered water from all the filters had turbidity well around 5 JTU, conforming to the World Health Organisation drinking water standard even at high filtration rates of 0.50-.60 m^3/m^2-hr.

(3) Coconut fiber roughing filters were found to have high turbidity removal capacity even at high level of raw water turbidity (150 JTU) and at high rates of filtration (4.5 m^3/m^2-hr). Conservative value of 3.0 m^3/m^2-hr is suggested as optimal for all levels.

(4) Head loss in roughing filters were insignificant which indicated long filter run. They were found resistant to shock loads. The percentage efficiency increased with increasing turbidity load but did not decrease significantly as filtration rates increased. The effluent water always found to have turbidity less than limiting value of 50 JTU.

(5) Burnt rice husk and dual media filters were found to have better turbidity removal efficiency and lesser head loss rates at higher rates of filtration in all levels of turbidity in raw water (50, 100, 150 JTU).

(6) Burnt rice husk and dual media filter were more shock load (turbidity) resistant than sand filters.

(7) In general, the head loss rate was minimum in dual media filter and maximum in sand filter.

(8) The coliform removal efficiency was maximum in sand filters throughout the study. The minimum efficiency occurred in dual media filter.

(9) The optimal filtration rates were found as:

(a) <u>At low turbidity level (50 JTU)</u>

(i) Burnt rice husk filter	- 0.20-0.25	m^3/m^2-hr
(ii) Sand filters	- 0.20-0.25	m^3/m^2-hr
(iii) Dual media filter	- 0.30	m^3/m^2-hr

all being considered in terms of percentage removal efficiency of turbidity and rate of head loss development (in case of dual media conservative values were taken due to high coliform content in filtered water).

(b) <u>At medium turbidity level (100 JTU)</u>:

(i) Burnt rice husk filter - 0.20 m^3/m^2-hr
(ii) Sand filters - 0.20 m^3/m^2-hr
(iii) Dual media filter - 0.25 m^3/m^2-hr

If the filtered water was disinfected, optimal rates in dual media filter and burnt rice husk filter could be realististically increased.

(c) <u>At high turbidity level (150 JTU)</u>:

(i) Burnt rice husk filter - 0.20 m^3/m^2-hr
(ii) Sand filters - 0.20 m^3/m^2-hr
(iii) Dual media filter - 0.20 m^3/m^2-hr

These optimal rates were valid for surface water under investigation and might be taken as only guidelines in filter design. To avoid risk of residual coliform content, the optimal rate is suggested as .10 m^3/m^2-hr.

(10a) From operation, cleaning and constructual point of view, dual media filter was found to be less expensive due to requirement of low pumping head, less labour in cleaning and lower cost of construction of a single unit.

(b) From the above point of view, burnt rice husk and sand filters incur same cost except in the case of media and cleaning cost, where burnt rice husk was economical. Again, considering amount of filtered water produced per unit time/run, the burnt rice husk filter was found economical. From the point of view of disinfection, both were competing each other due to requirement of very close value of chlorine does for the breakpoints (1.20-1.50 mg/l).

(11a) The roughing media did not loose filtering property after cleaning 8 times, except the reduction of about 40% of volume.

(b) When roughing media got dried, it was found to break easily, gave bad odour (anaerobic formation) and lost filtering properties.

(c) A significant amount of water and labour force were required in cleaning roughing filter media.

(12) Breakpoint chlorine doses were found:

(a) Raw water - 2.5 ppm (mg/l)
(b) Burnt rice husk filtered water - 1.5 ppm
(c) Sand filter filtered water - 1.0-1.5 ppm
(d) Dual media filter effluent - 1.20-1.5 ppm

(13) No algal activity was observed during the study and cover on the filter columns were found not necessary. After removal of cover, the dissolved oxygen content of filtered water increased probably due to natural surface aeration.

VI RECOMMENDATIONS FOR FURTHER WORK

From the research findings it is evident that tropical surface water can be treated at a lower cost using local filtering media to meet the need of millions of poor people in tropical countries. The cost of chlorination, if done; was also found to be nominal. From the point of view of more cost savings, further research are to be done. Following are the recommendations for future research:

Research are to be carried out to find out the possibility of:

(1) Use of freely available burnt rice husk as roughing filter media;- discarding the media after each run.

(2) Use of infiltration gallery as roughing prefilter thus to avoid construction cost of building overhead structures, filter columns and installation and operation cost of high head pumps.

(3) Use of prefilter media in earthen self-sedimentation basins, as roughing filter thus to avoid pumping, overhead structure building and more labour requirement costs in cleaning.

(4) Use of lower ($<$ 1.20 m) supernatent water head in roughing filter thus to minimise high pumping head and cost. Possibility of lower supernatent water head is also suggested to be tried in polishing filters thus to save significant construction cost of concrete pipe. If only 15 cm height is reduced the use of a concrete pipe of 1.0 m height (70 cm unused) could be avoided.

(5) The filters are to be operated at the optimal filtration rates as suggested, for a longer time until and unless a full 1.20 m head loss develop in all the filters. The long term filter operation results will give better picture of bacterial removal-efficiency and final head loss-development - pattern for the types of filters used here. Design of filtration rates can be based on the present data and the future data may be used as reference and check.

REFERENCES

ARMSTRONG, J. (1931), Filter Sand, J. Amer. Wat. Wks. Ass. Vol. 23, p. 1292.

AMER. WAT. WKS. ASS. (1950), Water Quality Management, Amer. Wat. Wks. Ass. Inc.,p. 225-288

AZIZ, M.A. (1968), Water Supply Engineering, Mullik Bros. p. 261-263.

BAILIS, J.R. (1937), Experiences in Filtration, J. Amer. Wat. Wks. Ass. Vol. 29, p. 1010-1048.

BAILY, A.C. (1937), Use of Anthrafilt as Roughing Filter, J. Amer. Wat. Wks. Ass., Vol. 29, p. 1909-1915.

BATTALONS, E.D. (1970), Algae Harvesting, AIT Thesis No. 321.

BINH, N.C. (1975), Operation of Tube Settler and Anthrafilt Sand Filter, AIT Thesis No. 834, Bangkok, Thailand.

CLEASBY, J.L. and BAUMANN (1954), Selection of Sand Filtration Rates, J. Amer. Wat. Wks. Ass., Vol. 54, p. 579-602.

CLEASBY, J.L. and SEJKORA, D.G., Effect of Media Intermixing on Dual Media Filtration, ASCE, Aug. 1975.

COMMITTEE OF THE SANITARY ENGG. DIVISION, (1936), Filtering Materials for Water and Sewage Works, Proc. ASCE, Vol. 62, p. 1543.

FAN, S.T. (1974), Operational Experience of Two-Stage Water Filters in Thailand, AIT Master's Thesis No. 634, Bangkok, Thailand.

FRANKEL, R.J. (1974), Evaluation of Pilot Water Treatment Using Inexpensive Local Materials as Filter Media for Supply Drinking Water to Rural Communities, p. 36-42

HANIF, M. and PESCOD, M.B. (1972), Water Quality Criteria for Tropical Developing Countries, AIT Research Report, AIT, Bangkok, Thailand, p. 6-10.

HANEY, B.J. and STEPHEN, S.S. (1975), Upflow Filter for Potable Water Production, ASCE, Env. Div. J.

HARRIS, R.R. (1970), A Summary of Guidlines for Water Supply in Developing Countries, J. Amer. Wat. Wks. Ass. Vol. 62, No. 9, p. 561-62.

HAZEN, ALLEN (1904), On Sedimentation, Trans. ASCE, p. 53-63.

HEIPLE, L.R. (1959), Effectiveness of Coarse Grained Media for Filtration, J. Amer. Wat. Wks. Ass. Vol. 51, No. 6, p. 749-760.

HOLLOWAY, A.B. and McJUNKIN, F.B. (1959), The Global Community Water Supply Program, War on Hunger, Vol. III, No. 2.

HUDSON, H.E. (1958), Factors Affecting Filtration Rates, J. Amer. Wat. Wks. Ass., Vol. 50, No. 2, p. 271-77.

HUISMAN, L. and WOOD, W.E. (1974), Slow Sand Filtration, World Health Organisation, Geneva, p. 15-78.

JACKSIRINONT, N. (1972), Development of a Series Filtration Water Treatment Method for Small Communities in Asia, AIT Master's Thesis No. 509.

LOW, B.P. (1973), Operational Testing of a Two-Stage Water Treatment Filter, AIT Thesis No. 591.

MOUCHET, P. (1974), Water Study for the Bang Khen Project, Report by Italthai Industrial Co., Ltd., Bangkok.

OKUN, FAIR and GEYER (1970), Water Supply, p. 133-206.

OKUN, D.A. and PESCOD, M.B. (1971), Water Supply and Wastewater Disposal, p. 106-136.

PESCOD, M.B. and KAROT, T. (1973), Anthracite Sand Filtration Studies in Bangkok, AIT-CDM Report, AIT, Bangkok Thailand.

SEGALL, B.A. and OKUN, D.A. (1966), Effect of Filtration Rate on Filtrate Quality, J. Amer. Wat. Wks. Ass., Vol. 58, No. 3, p. 368.

STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER. (1971), APHA, AWWA, WPCF, Washington.

STEEL (1966), Water Supply, p. 36-256.

SEVILLA, A.S. (1971), A Study of Filtration, AIT Master's Thesis No. 442, Bangkok, Thailand.

THANH, N.C. (1974), Low Cost Water System, TAB Magazine, Bangkok, Thailand.

WORLD HEALTH ORGANISATION (1971), International Standards for Drinking Water, 3rd Edition, Geneva.

APPENDIX A

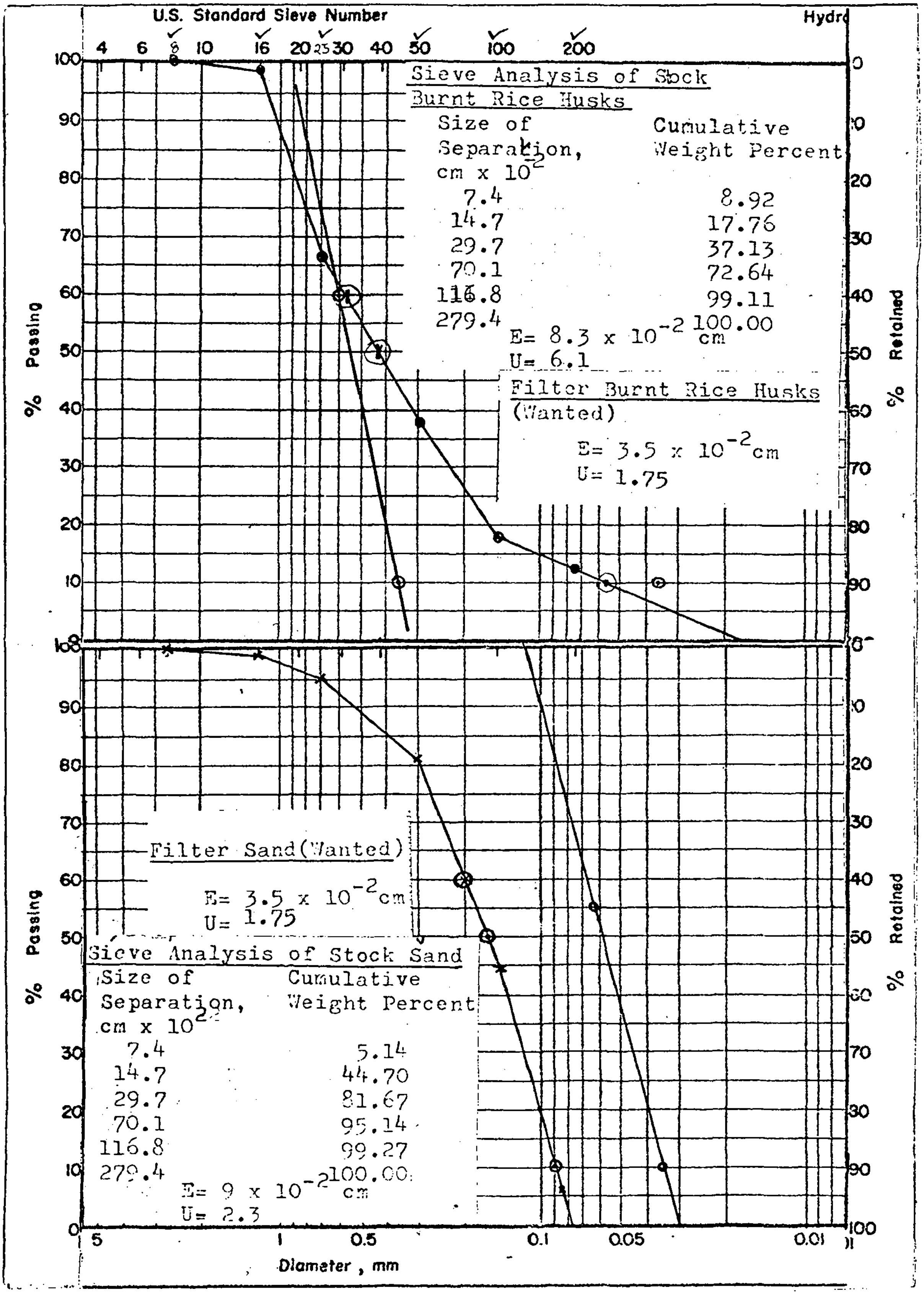


Fig. A3.1 - Sieve Analysis Results of Stock Burnt Rice Husk and Stock Sand

Phase - I

Table A4.1 - Summary of Results of Statistical Analysis

Filter Type	Filtration Rate, m^3/m^2-hr	Turbidity, JTU Influent Mean	Turbidity, JTU Influent Median	Turbidity, JTU Influent Std. Deviation	Turbidity, JTU Effluent Mean	Turbidity, JTU Effluent Median	Turbidity, JTU Effluent Std. Deviation	Turbidity, JTU % Removal	Coliform Content N/100 ml Influent	Coliform Content N/100 ml Effluent	Coliform Content N/100 ml % Removal	Head Loss, cm.	Run Length, Days	pH Influent, Mean	pH Effluent, Mean	Remarks
Seires Filter:	0.10	74.85	49.90	69.33	6.09	6.30	1.99	91.86	2,400	128	94.66	5.5	13.0	7.68	8.08	F_2 1st run
Roughing (R_1):	0.20	74.85	49.90	69.33	6.04	5.70	3.30	91.93	2,400	862	64.08	14.0	13.0	7.68	8.0	F_1
Coconut Fiber = 80 cm	0.40	38.23	30.00	16.05	4.78	4.5	0.99	87.49	1,100	240	78.18	28.5	4.0	7.6	8.06	F_2 2nd run
Polishing (F_{1-2}):	0.60	38.23	30.00	16.05	6.40	5.2	1.0	83.25	1,100	240	78.18	35.0	4.0	7.6	8.07	F_1
Burnt Rice Husk	0.30	49.90	50.00	11.47	5.50	5.2	0.98	88.97	2,400	670	72.08	8.0	7.33	8.17	8.08	F_2 3rd run
= 80 cm.	0.50	49.90	50.00	11.47	6.81	6.77	1.23	86.35	2,400	670	72.08	8.0	7.33	8.17	8.04	F_1
Series Filter:	0.10	74.85	49.90	69.33	1.77	1.6	0.56	97.63	2,400	70	99.88	29.0	13.0	7.68	7.97	F_4 1st run
Roughin (R_2):	0.20	74.85	49.90	69.33	4.09	4.1	1.21	94.53	2,400	74	96.91	24.5	13.0	7.68	8.08	F_3
Coconut Fiber = 80 cm	0.40	38.23	30.00	16.05	8.27	8.4	2.99	78.36	1,100	15	98.63	120	4.0	7.6	8.12	F_4 2nd run
Polishing (F_{3-4}):	0.60	38.23	30.00	16.05	6.59	8.3	2.67	82.76	1,100	240	78.18	120	4.0	7.6	7.8	F_3
Sand = 80 cm.	0.30	49.90	50.00	11.47	3.34	3.0	0.69	93.30	2,400	132	94.50	42	7.33	8.17	8.10	F_4 3rd run
	0.50	49.90	50.00	11.47	4.98	4.8	1.24	90.02	2,400	142	94.08	105	7.33	8.17	8.12	F_3
Dual Media Filter (F_5):	0.10	74.85	49.00	69.33	3.12	3.20	1.66	95.83	2,400	1,320	49.8	5	13.0	7.68	8.06	F_5, 1st run
Coconut Fiber = 80 cm	0.30	38.23	30.00	16.05	4.06	4.2	0.62	89.01	1,100	460	58.18	12	4.0	7.6	7.8	F_5, 2nd run
Burnt Rice Husk = 60 cm	0.50	49.90	50.0	11.47	5.44	5.35	0.987	89.01	2,400	335	86.04	19	7.33	8.17	8.03	F_5, 3rd run

Phase - II

Table A4.2 - Summary of Results of Statistical Analysis

Filter Type	Filtration Rate, m^3/m^2-hr	Turbidity, JTU							Coliform Content N/100 ml			Head Loss, cm.	Run Length Days	pH		Remarks
		Influent			Effluent			% Removal	Influent	Effluent	% Removal			Influent, Mean	Effluent, Mean	
		Mean	Median	Std. Deviation	Mean	Median	Std. Deviation									
Series Filter:	F_2 @ 0.10	87.27	85.0	18.14	6.35	6.35	1.54	92.23	2,400	43	98.20	3.5	9.33	8.41	8.24	F_2 } 1st run
Roughing R_1	F_1 @ 0.20	87.27	85.0	18.14	7.06	6.90	1.42	92.0	2,400	43	98.20	21.0	9.33	8.41	8.24	F_1
Coconut Fiber = 80 cm	F_2 @ 0.30	101.63	106.0	19.89	19.53	13.25	11.02	80.78	2,400	43	98.20	18.0	5.33	8.32	8.26	F_2 } 2nd run
Polishing Filter F_{1-2}	F_1 @ 0.40	101.63	106.0	19.89	24.60	13.0	16.72	76.25	2,400	43	98.20	66.0	5.33	8.32	8.21	F_1
Burnt Rice Husk	F_2 @ 0.50	97.40	105.0	12.56	19.85	20.0	3.29	79.62	2,400	804	66.50	18.50	6.66	8.38	8.40	F_2 } 3rd run
= 80 cm	F_1 @ 0.60	97.40	105.0	12.56	15.70	14.0	4.54	83.88	2,400	804	66.50	56.0	6.66	8.38	8.37	F_1
Series Filter:	F_4 @ 0.10	87.27	85.0	18.14	9.68	9.7	4.89	89.03	2,400	23	99.04	21.0	9.33	8.41	8.27	F_4 } 1st run
Roughing R	F_3 @ 0.20	87.27	85.0	18.14	13.46	13.46	4.47	84.75	2,400	33	98.62	23.0	9.33	8.41	8.28	F_3
Coconut Fiber = 80 cm	F_4 @ 0.30	101.63	106.0	19.89	17.87	17.0	4.04	82.41	2,400	23	99.04	60.0	5.33	8.32	8.27	F_4 } 2nd run
Polishing Filter F_{3-4}	F_3 @ 0.40	101.63	106.0	19.89	16.25	15.0	5.44	84.0	2,400	23	99.04	48.0	5.33	8.32	8.31	F_3
Burnt Rice Husk	F_4 @ 0.50	97.40	105.0	12.56	15.92	14.0	4.71	83.65	2,400	377	84.29	66.0	6.66	8.38	8.41	F_4 } 3rd run
= 80 cm	F_3 @ 0.60	97.40	105.0	12.56	15.90	14.50	3.67	83.67	2,400	274	88.58	75.0	6.66	8.38	8.42	F_3
Dual Media Filter -																
F_5	F_5 @ 0.10	88.27	85.0	18.14	4.55	4.0	1.84	94.84	2,400	122	94.91	5.5	9.33	8.14	8.17	F_5, 1st run
Coconut Fiber = 80 cm	F_5 @ 0.30	101.63	106.0	19.89	18.01	13.5	10.63	82.27	2,400	240	90.0	9.0	5.33	8.32	8.02	F_5, 2nd run
Burnt Rice Husk	F_5 @ 0.50	97.40	105.0	12.56	15.50	16.0	3.61	84.03	2,400	804	66.50	15.0	6.66	8.38	8.36	F_5, 3rd run
= 60 cm																

Phase - III

Table A4.3 - Summary of Results of Statistical Analysis

Filter Type	Filtration Rate, m^3/m^2-hr	Turbidity, JTU							Coliform Content N/100 ml			Head Loss, cm	Run Length Days	pH		Remarks
		Influent			Effluent			% Removal								
		Mean	Median	Std. Deviation	Mean	Median	Std. Deviation		Influent	Effluent	% Removal			Influent, Mean	Effluent, Mean	
Series Filter:	0.60	146.30	144	16.62	20.94	21.0	4.51	85.68	1,750	120	93.14	73	6.33	8.42	8.32	F_1 1st
Roughing (R_1)	0.50	146.30	144	16.62	15.65	15.50	2.91	89.30	1,750	120	93.14	75	6.33	8.42	8.36	F_2 run
Coconut Fiber = 80 cm	0.40	150.77	151.5	18.82	10.64	10.50	2.10	93.3	2,400	275	88.5	98	7.33	8.37	8.31	F_1 2nd
Polishing (F_{1-2}):	0.30	150.7	151.5	18.82	9.38	9.7	2.11	93.7	2,400	275	88.5	44	7.33	8.37	8.26	F_2 run
Burnt Rice Husk	0.20	135.5	136.0	20.24	10.32	9.55	3.27	92.4	1,534	160	89.6	49	9.33	7.99	7.99	F_1 3rd
= 80 cm	0.10	135.5	136.0	20.24	6.27	5.5	2.74	95.37	1,534	128	91.60	28	9.33	7.99	8.03	F_2 run
Series Filter:	0.60	146.3	144	16.62	8.90	8.50	2.22	93.90	1,750	167	90.40	120	6.33	8.42	8.34	F_3 1st
Roughing (R_2)	0.50	146.3	144	16.62	11.54	11.50	3.42	92.40	1,750	167	90.40	120	6.33	8.42	8.31	F_4 run
Coconut Fiber = 80 cm	0.40	150.77	151.5	18.82	7.71	7.75	3.12	94.88	2,400	225	90.60	120	7.33	8.37	8.33	F_3 2nd
Polishing (F_{3-4})	0.30	150.77	151.5	18.82	7.35	6.20	3.84	95.12	2,400	225	90.60	120	7.33	8.37	8.36	F_4 run
Sand = 80 cm	0.20	135.46	136.0	20.24	6.69	7.15	2.06	95.06	1,534	151	90.10	37.5	9.33	7.99	8.05	F_3 3rd
	0.10	135.40	136.0	20.24	6.19	5.7	2.24	95.43	1,534	128	91.60	15.0	9.33	7.99	8.02	F_4 run
Dual Media Filter																
(F_5):	0.50	146.30	144	16.62	10.50	10.0	1.61	93.0	1,750	290	83.42	31.5	6.33	8.42	8.31	F_5, 1st run
Coconut Fiber = 80 cm	0.30	150.77	151.5	18.82	7.48	7.75	2.37	95.03	2,400	275	88.50	12.8	7.33	8.37	8.30	F_5, 2nd run
Burnt Rice Husk	0.10	135.46	136.0	20.40	5.49	5.0	1.8	95.6	1,534	191	87.50	17	9.33	7.99	8.04	F_5, 3rd run
= 60 cm																