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A STUDY OF FILTRATION METHODS FOR PROVIDING INEXPENSIVE POTABLE WATER TO SMALL COMMUNITIES IN ASIA

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TO SMALL COMMUNITIES IN ASIA

Thesis by

Alberto S. Sevilla

For the Degree of Master of Engineering

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A STUDY OF FILTRATION METHODS
FOR PROVIDING INEXPENSIVE POTABLE WATER
TO SMALL COMMUNITIES IN ASIA

by

Alberto S. Sevilla

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

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ABSTRACT

An attempt was made on a laboratory scale to find a new method for treating surface water that would be technologically and economically applicable to small communities in Asia. The most promising solution found was the use of local materials in a series filtration system incorporating both a roughing or primary filter followed by a secondary or polishing filter of the slow sand filtration design. Since there were no basis for the design and filtration rates to be used for each media under study, the study was geared toward evaluating an optimum filtration rate andinfluent turbidity limit for the filter to function efficiently and for an extended period of time to minimize the frequency of cleaning. Materials that are ordinarily available in abundance in rural Asian villages were investigated as filter media and compared in terms of turbidity removal, length of filter run and head loss development. The following were the media investigated: pea gravel, burnt rice husk, raw rice husk, coconut husk fiber, charcoal and sand.

No one medium proved to be superior to all the others at this stage of comparison but the burnt rice husk and shredded coconut husk fiber proved to be more efficient than sand in terms of length of run and turbidity removal. Burnt rice husk appears to be a potential substitute for sand in slow-sand filters while coconut husk fiber could be substituted for coarse sand in the roughing filter.

A detailed economic comparison with conventional water treatment systems was not possible. However, a general comparison of the possible savings from the new system was made and it was found that financial and labor requirements and the level of training needed by the operator could be substantially reduced by using the series filtration treatment system.

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I INTRODUCTION

Rural Community Water Supply in Asia

Asia is the largest continent of the world comprising almost 55 per cent of the world's population exclusive of the Russian portion, ninety per cent of which are village-dwelling, agrarian people whose way of life is basically primitive. The lack of potable water system is one factor that hinders them from achieving the benefits of a modernized urban community.

Water is considered a key element in the growth of any community, rural or urban. As far as water supply development is concerned, an urban area may be further defined as a district densely enough settled to make it economically feasible to supply piped water to its inhabitants.

DIETERICH and HENDERSON (1963) made a study of urban water supply conditions and needs in seventy-five developing countries. The 1962 survey revealed that only 33 per cent of the urban population were supplied with piped water andabout 41 per cent of urban population and probably 70 per cent of total population had no access to piped water at all within reasonable distance. These people simply relied upon wells, rivers and other natural sources or private vendors who sell water at a considerably high price for their drinking water supplies. The remaining portion of the population obtained their water from public outlets. Table 1 summarizes the urban water supply situation in 1962 by region and Table 2 shows the urban water supply by country in Asia.

REGION	URBAN POPULATION SUPPLIED						URBAN POPULATION NOT SERVED	
	HOUSE CONNECTIONS		PUBLIC OUTLETS		TOTAL SERVED			
	NO.	%	NO.	%	NO.	%	NO.	%
NORTH AFRICA	10650	57	3700	20	14350	77	4190	23
AFRICA SOUTH OF SAHARA	2780	13	8060	38	10840	51	10150	49
AFRICA, SUB-TOTAL	13430	34	11760	30	25190	64	14340	36
CENTRAL AMERICAN AND CARIBBEAN	15690	55	8550	30	24240	85	4270	15
TROPICAL SOUTH AMERICA	30830	59	14000	27	44830	86	7150	14
TEMPERATE SOUTH AMERICA	14880	67	4930	22	19810	89	2440	11
LATIN AMERICA, SUB-TOTAL	61400	60	27480	27	88880	87	13860	13
SOUTH-WEST ASIA	10220	39	9475	36	19695	75	6575	25
SOUTH CENTRAL ASIA	13320	14	19350	20	32670	34	62570	66
SOUTH-EAST ASIA	5965	15	10635	26	16600	41	24190	59
EAST ASIA	3010	20	4720	30	7730	50	7720	50
ASIA, SUB-TOTAL	32515	18	44180	25	76695	43	101055	57
TOTAL	107345	33	83420	26	90765	59	129255	41

Table 1 - Urban Water Supply, 1972: Served and Unserved Population by Region

REGION AND COUNTRY	URBAN POPULATION SUPPLIED				TOTAL SERVED		URBAN POPULATION NOT SERVED	
	HOUSE CONNECTIONS		PUBLIC OUTLETS					
	NO.	%	NO.	%	NO.	%	NO.	%
SOUTH-WEST ASIA								
Iran	1010	15	2540	40	3550	55	3200	45
Iraq	1480	50	880	30	2360	80	600	20
Israel	1530	90	85	5	1615	95	85	5
Jordan	400	60	60	10	460	70	200	30
Saudi Arabia	420	20	1050	50	1470	70	630	30
Syria	840	60	420	30	1260	90	140	10
Turkey	3760	40	4230	45	7990	85	1410	15
Yemen	30	10	60	20	90	30	210	40
Lebanon	750	75	150	15	900	90	100	10
SOUTH CENTRAL ASIA								
Afghanistan	140	10	830	60	970	70	410	30
Ceylon	330	15	660	30	990	45	1200	55
India	9700	12	14600	18	24300	30	56700	70
Nepal	30	10	140	50	170	60	100	40
Pakistan	3120	30	3120	30	6240	60	4160	40
SOUTH-EAST ASIA								
Burma	240	10	380	15	640	25	1940	75
Cambodia	100	15	250	35	350	50	350	50
Federation of Malaya	520	20	1040	40	1560	60	1040	40
Indonesia	2580	15	3420	20	6000	35	11200	65
Laos	45	15	105	35	150	50	140	50
Philippines	1460	15	2890	30	4350	45	3500	55
Republic of Vietnam	670	15	1580	35	2250	50	2250	50
Thailand	330	20	970	30	1300	40	1980	60
EAST ASIA								
China	1730	25	1720	25	3450	50	3450	50
Republic of Korea	1280	15	3000	35	4280	50	4270	50
GRAND TOTAL	32515		44040		76695		101095	

Table 2 - Urban Water Supply, 1962: By Country in Asia

The greatest urban water need existed in Africa, south of Sahara, South Central Asia, Southeast Asia and East Asia. The worst conditions were found in Southeast and South Central Asia, where about two-thirds of urban population had no piped water at all. This was further complicated by the fact that by 1977, 207 million more urban dwellers in 75 countries or about 106 million people in Asia alone will be in need of water service (see Table 3).

From a comparison of conditions, it may be seen from the study given above that the urban water supply situation in 75 countries selected is least satisfactory in Asia and most satisfactory in Latin America (see Table 4). Present conditions indicate that the mass of population hardly gets any potable water at all. The greatest construction needs and deficiencies exist in India, Burma, Indonesia, Ceylon, Philippines and Thailand.

The above description of some of the worst conditions of water supply in Asia suggests only one thing - Asian rural communities are in need of a potable water system that is technically simple and economical. However, there exists a great diversity of conditions in individual countries and these differences should be studied in detail.

In this part of the world, rarely do the rural communities have qualified technicians to operate a conventional coagulation-sedimentation-rapid sand filter efficiently. Furthermore, lack of laboratory facilities and unreliability of chemical supplies pose a great operational problem which sometimes leads to plant breakdown. The use of slow-sand filters in Asia appears to be favourable because

REGION	1962	1977	% INCREASE	ANNUAL GEOMETRIC GROWTH RATE (1%)
NORTH AFRICA	18540	32260	74	3.8
AFRICA SOUTH OF SAHARA	20990	32100	53	2.9
AFRICA, SUB-TOTAL	39530	64360	63	3.3
CENTRAL AMERICA AND CARIBBEAN	28510	51950	82	4.1
TROPICAL SOUTH AMERICA	51980	95620	84	4.2
TEMPERATE SOUTH AMERICA	22250	31540	41	2.3
LATIN AMERICA, SUB-TOTAL	102740	179110	75	3.3
SOUTH WEST ASIA	26270	46990	77	3.9
SOUTH CENTRAL ASIA	95240	139440	46	2.6
SOUTH EAST ASIA	40790	70420	72	3.7
EAST ASIA	15450	26700	73	3.7
ASIA, SUB-TOTAL	177750	283550	59	3.1

Table 3 - Estimated Urban Populations in the 75. Selected Countries, 1962 and 1977 by region.

REGION	URBAN POPULATION SUPPLIED						URBAN POPULATION NOT SERVED	
	HOUSE CONNECTIONS		PUBLIC TOILETS		TOTAL SERVICE			
	NO.	%	NO.	%	NO.	%	NO.	%
NORTH AFRICA	57	10	20	4	77	7	23	3
AFRICA SOUTH OF SAHARA	13	2	38	10	51	6	49	8
AFRICA, SUB-TOTAL	34	12	30	14	64	13	36	11
CENTRAL AMERICA AND CARRIBEAN	55	15	30	10	85	13	15	3
TROPICAL SOUTH AMERICA	59	29	27	17	86	24	14	6
TEMPERATE SOUTH AMERICA	67	13	22	6	89	10	11	2
LATIN AMERICA, SUB-TOTAL	60	57	27	33	87	47	13	11
SOUTH-WEST ASIA	39	10	36	11	75	10	25	5
SOUTH CENTRAL ASIA	14	12	20	24	34	17	66	48
SOUTH EAST ASIA	19	3	30	5	49	4	51	6
ASIA, SUB-TOTAL	18	31	25	53	43	40	57	78
TOTAL	33	100	26	100	59	100	41	100

Table 4 - Urban Water Supply, 1962: Served and Unserved Population by Region, as a Percentage of Total Urban Population.

of availability of inexpensive land and labor, warm climatological conditions all year round, simplicity of construction and operation and availability of local materials reducing the need for foreign exchange.

Slow-Sand Filter and Series Filtration

Before the introduction of mechanical gravity filter in 1885 in USA, the slow-sand filter had been the accepted standard method of water purification. In cases where the raw water source sontained high amounts of turbidity and algae, pre-filters were used to take out most of the turbidity and algae before passing through a slow sand filter for polishing the water and taking out the remaining impurities. This double or series filtration was used until the principle of coagulation followed by rapid sand filtration gained popularity due to advantages of low capital expenditures, less labor requirement and capability of system to handle serve and sudden changes in quality especially colloidal turbidity. However, the rapid-gravity system has certain limitations especially for small communities in Asia. Most important of which are its high operating cost due to chemicals and lack of qualified technicians to operate it efficiently.

Past experiences especially in London water supply show that double filtration can increase the capacity of a slow-sand filter up to twice the capacity of single filtration. The primary or roughing filter handles much of the load and the secondary filter serves as a polishing or finishing filter. Pre-filters normally have coarser sand as the media and in many respects are similar to the American rapid sand filter. There are, however, different types of primary filters which have been found to increase the capacity of typical slow-sand filters. These will be discussed in detail in the subsequent section.

1) Pench-Chabal degrossiseurs
2) Slow-sand filters
3) Rapid-gravity filters
4) Microstraining

The advantages offerred by slow-sand filter especially in tropical countries have been detailed by HUISMAN~~N~~ (1970).

Cost of Construction Where land is not very expensive and hand labour is abundant, the actual cost of construction of slow sand filters is less than that of rapid filters. Moreover, in developing countries, where foreing exchange is of special importance, the use of local available material favours slow-sand filters.

Ease of Construction Because the dimension of slow-sand filters are much less critical, minimum skilled supervision is required and design is simpler with no special pipe-work, equipment or instruments required.

Cost of operation Cost of operation consists mostly of labour required to clean the filter bed and in rural areas where labour is readily available and inexpensive, this will be an advantage. Except for the motor fuel and maintenance of pumps and motors and chlorine, no other supplies are needed.

Ease of Operation Since ther are no complicated instruments and supervision required, operations requires far less training and skill for operators than for those in charge of rapid gravity filters.

Wash Water Requirements. A lesser amount of wash water is required; thus in cases where the quantity of available water is limited, slow-sand filtration is a further advantage over rapid gravity filters which require a large amount of wash water.

Slow-sand filtration is in itself a complete single stage water treatment and in small installations, the only treatment given aside from chlorination as a safety measure. Chemical coagulation with alum, pre-chlorination or introduction of algicides such as copper sulphate are not recommended before slow-sand filtration as it may upset the biological action in the filter.

If there is one factor that hinders the maintenance of slow-sand filter in good working condition, it is excessive turbidity (particularly inorganic turbidity) which causes rapid clogging of filter surface necessitating frequent cleaning. Series or double filtration can minimize this drawback.

Cleaning of slow-sand filters is usually done by hand in small installations, scraping the top inch or two where most of the turbidity is accumulated and replacing it if necessary.

In London, it was proven in some installations that double filtration was still less expensive than rapid gravity system, if properly maintained, due to the high operating and maintenance cost of the latter.

Purpose of the Research

The present needs of developing nations, not only in Asia, but in other parts of the world, include potable water, considered as one of the key factors to modernization. Little has been done during the past decades to cope with this ever increasing problem in rural communities. Very little development has occurred in rural areas such that the majority of Asia's rural population has not even heard or seen a clean water supply. Furthermore, present rural systems have not yet adapted present technological advances, or maybe, people are aware but have ignored the fact because they fear the cost and technological requirements associated withe new developments. They have overlooked the fact that there exists a great diversity among localities and countries and that what seems to be costly in other countries may be cheaper in other places. These are but some of the physiological reasons behind the slow progress occurring in developing nations, some are due to century-old customs and traditions that village folk still believe and practice.

One of the oldest processes of water treatment is slow-sand filtration. This method of treating water has been discarded by many in the West because it requires a large land area and where land is expensive, this is a costly method. Yet this limitation is not applicable in under-developed areas where there are greater limitations on available capital.

It was the primary purpose of this study to develop an inexpensive method of treating surface water technically and economically applicable to small communities in Asia. The primary phase of this study was to evaluate on a laboratory scale: (i) efficiency of series filtration incorporating the use of locally available materials that can be substituted for sand in the roughing filter and/or in the secondary filter;

(1) pea or rounded coarse gravel
(2) coconut husk fiber
(3) raw and burnt rice husk
(4) charcoal

(ii) develop design parameters for the different types of media or system,

(iii) determine optimum loading or filtration rates, and

(iv) calculate endurance of the system in terms of head loss, filtration rate and influent turbidity.

Roughing or primary filters were designed to handle most of the gross turbidity and a secondary filter designed as a standard slow rate filter was used for finishing or polishing. Finally, the series filtration system was evaluated versus a conventional rapid sand filtration and a straight slow sand filtration system from an economic point of view.

Scope of Research

Laboratory tests were conducted to determine the effect of filtration on turbidity only and effect on other chemical or bacteriological characteristics and impurities of water was not considered. In order to test the ability of various systems to treat waters with high turbidity loadings at various filtration rates, influent water was prepared by mixing kaolin clay with tap water to obtain a range of turbidity levels. This at the same time gave results as to the optimum filtration rate and design parameter for the media.

Two levels of turbidity were tested on primary filters, 100 - 300 JTU* and 1000-1500 JTU, each of which were run at two levels of filtration rates: 2.5 and 1.25 $m^3/m^2/h$. For the secondary filter, influent turbidity was maintained at approximately 50 JTU. Other factors that affect filtration efficiency which were not studied in detail included size and depth of media, height of water above the bed and variable turbidity loading.

The performance of the various media in the primary filter was evaluated and compared with a standard rapid sand filter in terms of turbidity removal, head loss and length of run. Method of cleaning was also observed as to its applicability and use in the vilages.

Finally, in order to determine whether the laboratory results obtained from the filter performance using synthetic waters of each media was realistic, a series of runs were conducted using Chao Phya surface water. Color removal was analyzed in this series of run but effects on other qualities except turbidity were not included. The final proposed system was then compared with a conventional rapid sand filter and a straight slow-sand filter treatment plant for a typical village size in terms ofanticipated:

1) Annual Cost

2) Operation and Maintenance Cost

---

* JTU stands for Jackson Candle Turbidity Unit
1 JTU = 1 ppm or mg/l of SiO_2

3) Capital Investment
4) Labor requirements, and
5) Level of training required for the operator

II LITERATURE REVIEW

Slow sand filtration has been the oldest method of treating surface water and yet in the past decades little has been done with regards to research. Literatures on slow-sand filter updated to modern technology is almost non-existent except for those reports and periodicals from the Metropolitan Water Board of London. Reports and research on series filtration is especially scanty on its applicability to small installations or rural villages.

Although slow-sand filtration and series filtration declined in popularity since conventional rapid sand filtation came into popularity, large cities are still using slow-sand filters, as example in London, England. Slow-sand filtration practice became obsolete in Northern countries where the filters were subject to freezing but this is one disadvantage which is not applicable in tropical countries. Another disadvantage is the sizeable areas of land required. Slow-sand filtration's applicability is more defined where raw water is not subject to sudden changes of physical quality, especially high turbidity and color. Its efficiency as a biological process cannot be denied. This is one outstanding characteristic of this type of filter and as long as it is not subjected to high inorganic turbidity, it will function well and better than a conventional filter.

Roughing or primary filtration has been accepted as a method of reducing the gross turbidity in the raw water before loading to the slow-sand filter. This method of series filtration has been in use for a century in London supplying the whole city with water from surface sources. One major advantage that this treatment process offers is its low operating cost compared with the conventional method. Although no really comprehensive cost analysis have been published in recent years, the Metropolitan Water Board of London reports the cost of operating its double sand filtration plants. HOUGHTON (1970) reported that the capital costs of double sand filtration for a 32 million gallons per day plant (MGD) to be £ 1.5×10^6 versus a capital cost of £ 1.1×10^6 for conventional treatment excluding land cost for the same plant size. Yet comparing the operting cost, the double sand filtration plant had a considerably lower cost of 0.56-0.74 pence/1000 Imperial gal (excluding maintenance) in 1963/64 while operating costs for conventional treatment cost was 2.93 pence/1000 gal. This relatively low cost cannot be said to be a great advantage in London since thehigh land cost and the prevailing interest rates might balance this difference in operating cost. Numerous data on this aspect of comparison are needed before a realistic comparison can be made or a more detailed economic analysis based on prevailing local conditions can be accomplished. However, according to the M.W.B.'s Chief Engineer's Department based on investigations made, "...... it seems certain that the chemical treatment method, even with the recovery of chemicals from sludge, would be more expensive than filtration or its modern equivalents even when capital costs of land and initial construction of the works are included."

Biological Filtration - Complete Water Treatment

The most important part of water quality improvement in a slow-sand filter is the biological activity on and in the sand bed. HUISMAN~~N~~ (1969) visited installations in five European countries and studied data in USA and other parts of the world and made a report on slow-sand filter particularly the biological activity and the design operation of small installations. The following excerpts are taken from Huisman~~n~~'s publication.

Biological filtration, under suitable circumstances, may not only be the cheapest but also the most efficient method of water treatment, simple to construct and operate. The actions that take place inside the filter namely: straining, sedimentation, adsorption, oxidation and bacterial all play important part and improve the physical, chemical, and bacteriological properties of water in just a single process. All these actions are not distinct from each other and some even take place simultaneously.

As water enters, the waiting time takes about 4 or 5 hours and during this time, the larger particles settle, some smaller particles coalesce and become easier to remove, algae under influence of light and presence of CO_2 and nutrients starts growing. Organic matter forms a slimy and gelatinous layer on the surface of the sand known as a "Schmutzdecke" or biological layer which traps much of the impurities as water pass. This layer usually consists of threadlike algae and numerous forms of life, like plankton and diatoms. It is in this layer that most of the biological activity takes place - living organism consume organic matter, dead algae and the like, pathogenic bacteria are destroyed by other micro-organisms and due to energy from light that penetrates, it remains alive and active.

As water continues to pass through the bed, the main treatment process takes place. The mechanical straining action takes place preventing larger particles than the pore size to pass and adsorption affects the removal of colloids, bacteria or viruses. Adsorption which is attributed partly to electrical forces, partly to chemical bonding, and partly to molecular activity is a complex phenomenon, not yet fully understood. According to DANIELS and ALBERTY (1966), adsorption occurs on the surface of a solid because of the attractive forces of the atoms or molecules in the surface of the solids. The extent of adsorption depends greatly on the specific nature of the solids and the molecules being adsorbed and is a function of pressure (or concentration) and temperature.

Between the grains are pores or open spaces, which amount to approximately 40 - 45 per cent of the total bed volume. The velocity of water along these pores is temporarily reduced and as a result, millions of minute sedimentation basins are formed in which the smallest particles settle on to the nearest grain of sand.

In brief, during the 4 hours or so that the water passes through the sand bed, various forces or action have acted upon every drop of water and the particles that are present. By the time the water has reached a depth of 40 cm, it is virtually free of all such matter and naturally, it is in the upper layers that the greatest quantities are deposited. Not only is the water free from particulate matters but also, the dissolved nutrients have been reduced by bacteria and micro-organisms in the active biological layer.

According to FAIR, et al (1968), the distinguishing features of slow-sand filters are their unvariant sand mixtures at all depths, the small effective size and large coefficient of non-uniformity of their grains, and the associated selective removal and accumulation of raw-water impurities at the surface of the bed within its top inch or two. General features and design parameters of a slow-sand filter are given in Table 5.

Table 5

General Features and Design Parameters of Slow-Sand Filters

		From FAIR, et al (1968)	From WAGNER, et al (1959)
1.	Rate of filtration	0.1 $m^3/m^2/hr$ (2-6 in/hr) as secondary filter: 0.2-0.3 $m^3/m^2/hr$.	2.8 $m^3/m^2/day$
2.	Size of Bed	large, 2000 m^2 or more	
3.	Depth of bed-sand and gravel	sand: 0.6 - 0.9 m gravel: 30 - 60 cm	sand: 1.0m gravel: 40cm
4.	Effective Sand size	0.3 mm	0.3 - 0.4 mm
5.	Uniformity Coefficient	1.7 - 2.0	2.0 - 2.5
6.	Gravel size	18 cm: 20 mm 7.5 cm: 8 mm 5.0 cm: 2-3 mm	20 cm: 75 mm-25 mm 10 cm: 25 mm-10 mm 10 cm: 10 mm- 5 mm
7.	Underdrains	(a) split-title laterals laid in coarse gravels discharging to tile or concrete main drain	(a) baked clay or concrete pipes, laid with open joint

		(b) no fines concrete floor	
8.	Head Loss		
	Initial	5 - 7.5 cm (.2 ft)	
	Final	60 - 90 cm (4 ft)	
9.	Length of run between cleaning	2 weeks - 3 months Avg - 2 months	
10.	Penetration of suspended matter	Surface layers	
11.	Method of cleaning	(a) Surface layer scraped by hand, washed and replaced (b) Mechanical surface washed	(a) Scrape top 5-8 cm. of sand off the top of the filter
12.	Costs - Initial		
	Capital	High	
	Operating	Low	
	Depreciation	Low	
13.	Bacterial removal efficiency	as high as 99.9%	
14.	Water Quality	Reduce tastes and odor, reasonable amounts of suspended and settleable matter	less than 50 ppm Average of 30 ppm

Slow-sand filters can handle as much as 100 - 200 mg/l of turbidities for a few days but best results are obtained when the average turbidity is 10 mg/l or less (as SiO_2). When working ideally, biological filters have been shown to reduce total bacterial counts by 99.9 to 99.99%, and E. coli by 99 to 99.9 per cent. Viruses have shown to reduce in lower flow rate than higher flow rate.

PEARSALL and others (1946) defined two important factors in biological filtration, schmutzdecks and zooglea. Schmutzdecke has been defined previously and zooglea is defined as a tenacious envelope of jelly, mainly bacterial, that surrounds the individual sand grains, it may extend up to 23 cm (9 in.) into the bed. It is this layer that is mainly responsible for the biological oxidation of organic matter, with consequent production of CO_2 and utilization of oxygen. Photosynthesis is valuable in providing oxygen necessary for chemical oxidation but excessive photosynthesis may lead to too much oxygen which may be retained within algae cell causing a mass of algae to float. Finally, it would be wholly advantageous if some control could be exercised over the amount and type of algae growth on the surface of the sand.

Experience in Double Filtration

HAZEN (1953) in his study of possible application of microstrainers to water treatment in Great Britain reported that the main obstacle in double filtration is the periodic dense growth of algae because raw water is first stored in open reservoirs where the presence of organic matter is ideal for algae growth. The treatment plant have been using double filtration where the first filter is similar in most respect to American rapid gravity filter with relatively coarse sand. The pre-filters remove most of algae and turbidity. It was found that filter rates in the plants with pre-filters are 2.5 times the rates without pre-filters. A summary of effects of pre-filters on secondary filter operation is given in Table 6.

Table 6

*Effect of Prefilters on Secondary Filter Operation**

PLANT	PREFILTERS			SLOW SAND FILTER			
NO.	NO.	ARES (SQ.FT.)	RATE (gpm/ft^2)	NO.	AREA (ACRES)	CAP. (MGD)	RATE (MGAD)
With Pre-filters							
1	32	43680	1.53	38	41.01	96	2.34
2	24	9984	3.00	12	9.00	45	4.80
3	18	7488	2.67	6	4.92	29	5.85
4	12	10800	2.31	9	9.04	36	3.98
Average							4.24
W/out Pre-filters							
1	9	2592		20	24.19	41	1.69
2				24	26.11	48	1.84
3				25	24.75	49	1.99
4				27	20.53	36	1.75
							1.82

*London Metropolitan Water Board

The micro-strainer reduced turbidity only slightly but turbidity was effectively reduced by the pre-filter. The greatest effect of micro-strainer was on algae removal which showed 98 per cent removal and on the amount of water filtered per acre of sand cleaned.

BROWN and OKUN (1965) made a study of European practice in water filtration and reported that double filtration isstill used over most of Western Europe when water is taken directly from surface source.

In the symposium on the trends in the treatment of water for public supply, HOUGHTON (1970) reported the biological merits of slow sand filtration and the associated primary treatment use to knock down some of the impurities before loading in the slow sand filter. He stated the fact that modern literature on this filter is scanty except for the periodical reports of the London Metropolitan Water Board. The references and experiences he gave in the report were also from the London Metropolitan Water Board especially on double sand filtration and the advantages and limitations of biological filtration. He noted that in North America the slow sand filter is now regarded as largely obsolete but still some find it favourable in Europe and the United Kingdom. The decline of this filter was due to the costly structures and the sizeable land it occupies. The bilogical process was highly unpredictable and with using euthrophic waters, output of a given works was difficult to forecast due to the sudden blockage by algae. For highly colored and turbid water, coagulation was essential so as not to overload the primary filters, while on the other extreme, microstraining may be sufficient.

Prefiltration has long been regarded as desirable in the slow sand filtration of euthrophic waters, in most cases, conventional rapid filters are used. The primary aim being to get the water into the best possible condition for secondary filtration. Simple prefiltration without coagulation is advisable if one wants to take advantage of the merits of slow sand filtration, while keeping costs low.

A great merit of slow sand filtration is thatlittle mechanical and no chemical skill is required in its operation. Although slow sand beds sometimes behave in an unpredictable and inexplicable way, they can be well managed by an intelligent and experienced foreman. Any bacterial breakthrough can be corrected by chlorination and consequently theonly chemical treatment applied and thus no problems of dosages of coagulants, weak floc, residual alum, etc. result. Another advantage cited was that, if a number of beds are operated in parallel, they are often at different stages of head loss and should there be any abnormality in one filtrate the chances are that others will not be affected. By dilution, therefore, the blend remains acceptable. Meanwhile the offending bed can be detected and isolated or stopped.

A slow sand filter can remove up to 90% of faecal coli present in the influent but there are cases of bacterial breakthrough and it is believed that there is a limit to the bacterial load a bed will deal with satisfactorily, yet, it is difficult to define because it is temperature and head loss dependent. Small viruses can be expected to be removed through low filtration velocities and slow sand schmutzdecke. The relative importance of adsorption and biochemical oxidation when a slow sand filter removes dissolved organic matter does not appear to have been firmly established but there is no doubt that ammonia can be oxidised and also that biochemical oxidation must proceed in the decomposition of the filter mat, once formed. There are questions that slow sand filters add taste and odor. This complaint might hold true when a stagnant slow sand filter is put back to use or a relatively low filtration rate is applied. This production of taste is normally related to the organic fouling of the lower sand layer and this can be avoided by proper bed management: frequent san reconditioning and deeper skimming. Since the top layer of the bed is the operative one, the lower strata simply acts as a support and becomes fouled with adsorbed organic matter of a humus-like nature. In Essex[1] it has been necessary to change and recondition the bed after 15-20 years and surely is a fairly costly maintenance item. In filtering euthrophic waters subject to algal growth, the relative efficiency of slow sand and coagulation methods in handling such water is evidently very pertinent. Actually, slow sand filter offers more merit in that the velocity is low and sand is so fine and in the author's opinion, algal penetration is something quite rare.

Although any comparison of methods always involve cost comparison, there is no really comprehensive cost analysis published in recent years. A convenient datum for coagulation plants is the one contained in the report of Burley and Mawer[2], of the Water Research Association, on desalination and gives details of operating and capital cost in 22 cases.

RIDLEY (1967), Senior Biologist of the Metropolitan Water Board reported experiences in London in using slow sand, double sand filtration and microstraining. Practical difficulties arose when the source contained excessive amounts of suspended matter, particularly when this material was of algal origin. This problem frequently occurred until the Metropolitan Water Board introduced its first rapid sand filter in 1923 as a means of increasing the works

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[1] Metropolitan Water Board. 42nd. Report (1965-66) on Result of Examination of London Waters. E. Windle Taylor.

[2] Burley, M.J. and Mawer, P.A. Water Research Ass. Technical Paper TP. 60.

out-put. The "primary" filtration doubled the normal volume of water per unit area of slow sand filter and with only monor modifications this system of double filtration is still accepted by many authorities. More recently, "filtration" by rotary micro-strainers has been developed as an alternative to sand, but the choice of method or media will always be determined by the type of water to be purified as well as by economic factors such as capital expenditure and running costs.

It is always difficult to obtain reliable comparisons, in order to avoid undue emphasis of abnormal situation, the operational statistics cover a period of five years. Comparative figures of operational data for 5 years are shown in Table 7. The Hanworth Road works is entirely slow sand filter; Kempton Parks has double sand filtration and in Ashford, micro-strainer followed by slow sand filtration is employed. Details of filter areas, sand characteristics and normal daily output are shown in Table 8, whilst in Table 9, general indications of unit costs are provided.

Table 7

Operational Data of Sample Filtration Works

Primary Filtration	Washwater used as %
Kempton Park rapid sand filters	1.15 - 1.62 of filtered water
Ashford Common Microstrainers	1.64 - 2.03 of filtered water

Cont'd.

Slow Sand Filtration	Rate of filtration gal/ft^2	Million gallons per Acre of bed cleaned
Hanwoth Road	0.9 - 1.2	28 - 63
Kempton Park	2.7 - 3.1	113 - 143
Ashford Common	2.7 - 2.8	89 - 140

The usual cause of ineffectiveness of either a rapid sand filter or microstrainer is the dominance of diatoms. Increases in the rate of cleaning rapid sand filters are locally acceptable if the filter run still exceeds 12 hours, if the filter requires cleaning every 8 hours the position is difficult, whilst a 6-hour period is intolerable for more than a few days. This same problem applies to microstrainers.

The term "primary filtration" is used in this paper as a colloquial expression describing first-stage clarification. There is, of course, no justification for including microstraining in the same category as rapid sand filtration except in the physical removal of particulate matter. The differences were defined by Van de Vloed[1], when he referred to porous membranes such as fibers of woven fabrics. The rapid filter functions as a biological complex, where many plants and animals are involved in assimilation, digestion, oxidation of ammoniacal nitrogen, adsorption etc., and these processes are not available in microstraining, so that this system is limited to the physical capability of particular grades of micromesh gauze.

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[1] Van de Vloed, A. Comparison between slow sand and rapid filters Report to International Water Supply Association, 3rd Congress London, 1955.

Table 8 - Works Data

<table>
<tr><th rowspan="3">Works</th><th colspan="5" rowspan="3">"Primary Filtration"</th><th colspan="5">Secondary (slow sand) Filtration</th><th rowspan="3">Normal Daily Output (m.g.)</th></tr>
<tr><th rowspan="2">Number of filters</th><th rowspan="2">Total Filtering area (acres)</th><th colspan="3">Sand*</th></tr>
<tr><th>Average depth (inches)</th><th>Average effective size (mm)</th><th>Uniformity coefficient</th></tr>
<tr><td>Hanworth Road (constructed 1871)</td><td colspan="5">None</td><td>6</td><td>4.98</td><td>24</td><td>0.312</td><td>1.19</td><td>5</td></tr>
<tr><td rowspan="4">Kempton Pard (rapid filters constructed 1927-1929; slow sand filters constructed 1906 and re-constructed 1936-38)</td><td colspan="5">By rapid gravity sand filters (Paterson); cleaned by compressed air and upward water scour#</td><td rowspan="4">12</td><td rowspan="4">9.0</td><td rowspan="4">24</td><td rowspan="4">0.285</td><td rowspan="4">1.54</td><td rowspan="4">30</td></tr>
<tr><td rowspan="2">Number of filters</td><td rowspan="2">Total filtering area (sq. ft.)</td><td colspan="3">Sand*</td></tr>
<tr><td>Average depth (inches)</td><td>Effective size (mm)</td><td>Uniformity coefficient</td></tr>
<tr><td>24</td><td>9984</td><td>27</td><td>0.8</td><td>1.6</td></tr>
<tr><td rowspan="3">Ashford Common (constructed 1960)</td><td colspan="5">By rotary microstrainers (Glenfield & Kennedy); backwash pressure and speed of rotation variable</td><td rowspan="3">32</td><td rowspan="3">24.0</td><td rowspan="3">24</td><td rowspan="3">0.30</td><td rowspan="3">2.16</td><td rowspan="3">65</td></tr>
<tr><td colspan="2">Number of Microstrainers</td><td>Dimensions of single microstrainer</td><td colspan="2">Micromesh</td></tr>
<tr><td colspan="2">24</td><td>Length 10 ft.
Kiameter 10 ft.</td><td colspan="2">76000 apertures per sq. in.</td></tr>
</table>

*For further information on sand grading, see Manual of British Water Engineering Practice.
#Stand overlies graded shingle, average depth 20 inches.

Table 9

Operational costs in £ per million gallons (4.55x10^{3}m^3) filtered

	Apr 1959 to Mar 1960	Apr 1960 to Mar 1961	Apr 1961 to Mar 1962	Apr 1962 to Mar 1963	Apr 1963 to Mar 1964
Hanworth Road works - Slow sand filtration	3.45	3.14	5.5	3.84	5.1
Kempton Park words -					
Slow sand filtration	0.88	1.11	1.02	0.95	1.0
Rapid sand filtration	1.67	1.58	1.51	1.83	2.1
Total	2.55	2.69	2.53	2.78	3.1
Ashford Common works					
Rotary microstraining	0.33	0.37	0.30	0.41	0.45
Slow sand filtration	0.78	0.85	0.89	0.88	1.45
Total	1.11	1.22	1.19	1.29	1.90
The above figures do not take into account the increased maintenance, replacement and repair charges which occur with ageing of a filtration plant. Unit costs also tend to be lower at very large works, and to illustrate this point, data from a "double sand" filtration works at Hampton are included.					
Hampton works -					
Rapid sand filtration	0.47	0.41	0.38	0.47	0.56
Slow sand filtration	1.03	1.06	1.14	1.26	1.66
Total	1.50	1.47	1.52	1.73	2.32

It has been universally proven that primary filtration, using coarse sand or microstrainers, reduces frequency of slow sand filter cleaning, but other methods and media should always be under consideration. Future trends show the possible use of anthracite in the rapid filters and recent experiments showed that turbidity of filtrate proved unsatisfactory when compared with double sand filtration but this offers a compromise between slow and rapid sand filter. It has been further found that low filtration rate can cause smell and odor problem, if the normal filtration rate of 5" per hour (2.7 mg/acre/day) is reduced to about 0.5" per hour (0.27 mg/acre/day).

A study by CPHERI through the effort of Prof. S.J. Arceivala reported that in India the weakest link lies in the operation of chemical dosing and coagulation units. The following colutions are now being inspected for use in rural area. Refer to Table 10 and Figure 1 for tentative design of double filtration.

Table 10

Tentative Basis of Design

Population	Supply	Roughing Filter $12\ m^3/m^2/hr$	Slow Sand Filter $0.3\ m^3/m^2/hr$	Upflow Type $9\ m^3/m^2/hr$
2000	100 l per cap per day for 8hr	1.45m x 1.45m	9.2m x 9.2m	1.7m x 1.7m
5000		2.3 m x 2.3 m	14.5m x 14.5m	2.6m x 2.6m

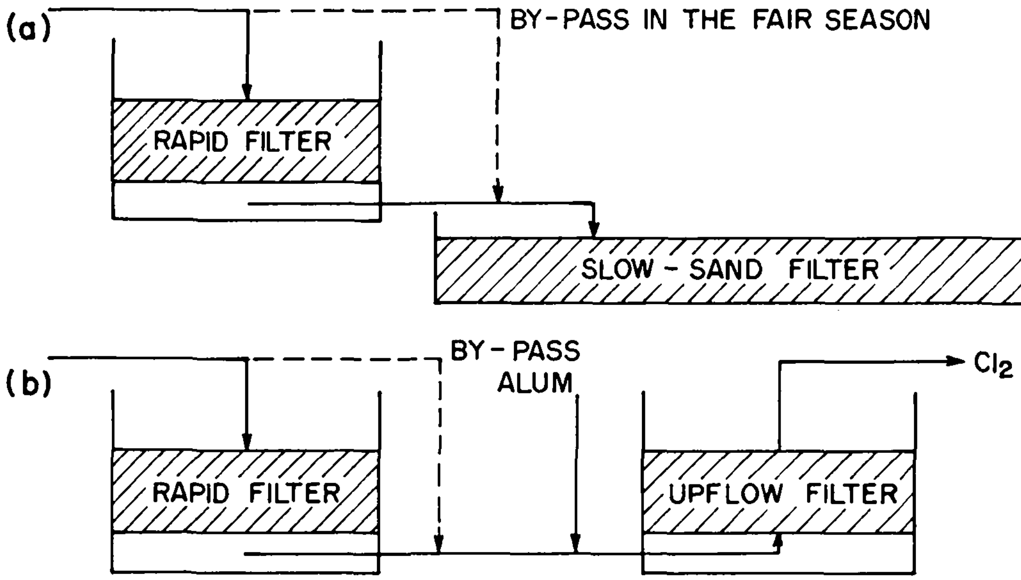

FIG. 1 TENTATIVE DESIGN OF FILTERS

Methods of Prefiltration

PESCOD (1968) and SKEAT, et al (1969) reported that one time or another at least four types of roughing "filters" have been used. The Peuch-Chabal filters are a series of beds ranging from gravel to sand arranged in steps. The beds are quite shallow and filtration rate progressively becomes slower as filter media becomes finer. The quality of water is good but the initial cost is considerably high and so is the head loss.

In certain cases, slow sand filters are operated in series, the first stage being loaded at a higher rate than usual. At Kagithane, Istanbul, for example, the primary filters operate at 15 $m^3/m^2/day$ and the secondary filters at 8 $m^3/m^2/day$.

In Western Europe and London, the rapid-gravity filter is often used as the roughing filter with no coagulation or sedimentation. Experiences in the use and performances have been discussed in the preceeding section.

BOUCHER (1961) reported that the development of micro-fabrics started right after the last war and the first square mesh employed was weaves of phosphor bronze, nickelplated with apertures in the range of 60 - 30 microns known to intercept microscopic planktons. Later, three standard sizes proved suitable: Mark II with 65 micron aperture, Mark I with 35 micron apertures and Mark 0 with 23 micron apertures, which are now known throughout the world.

The woven stainless steel Micro-fabrics are very fine, highly pourous material capable of arresting microscopic solids from water and of forming a thin mat or schmutzdecks from them which itself will arrest particles still smaller than the fabric apertures. It is thus impossible to employ a Micro-fabric as a fixed filter because blockage would be too rapid with increase in headloss and reduction of flow rating. The Micro-strainer therefore takes the form of a rapidly self-cleaning rotary drum filter, of which the filtering fabric is attached to the periphery. Water flows into the drum in one end and out radially through the fabric, the intercepted solids being retained on the inner surface. A row of external jet washer continuously backwashes the fabric, flushing the filtered solids into a waste hopper located inside the drum. The filtering head - the difference between the water level inside and outside the drum - is usually between 1.5" and 5 inches. The machines are available in a range of standard sizes which give a range of capacities based on filtration rates between 600 and 2,000 gallons per square foot per hour.

Operating conditions generally depend on raw water state. Washwater pressure varies from 5 to 25 lb. per square foot depending upon the state of water being filtered and the drum speed. In this case, Filtrability Index plays an important role because the pressure is proportional to the index value. Water consumption generally in the range of 1 per cent but if the raw water is bad and with high Filtrability Index, it may go up to 3 or even 5 per cent. In some cases, particularly with sewage effluents and river water contaminated with sewage, organic slimes are formed on the fabric by the aation of bacteria. These slimes cannot be controlled by backwashing and chemical conditioning at intervals has been necessary in certain cases. Sodium hypochlorite and forms of denatured acids have been successfully used.

It has been found out that the capital charges involved in micro-straining are low, often half compared to conventional treatment. Installations can be made 100 per cent automatic and require little supervision, only routine checks at intervals, inspection and attention to lubrication are necessary. Operating costs therefore, are extremely low: typical figure is 10 shillings, 6 pence per million Imperial gallons.

Experiences showed that impounded water can increase the filter runs of micro-straining up to three times and will alow normal filter ratings to be doubled. However, there exists some limitations as to its application. Water carrying very heavy loads of sand and silt, fibrous and other waste materials is not suitable to be treated firstly by a micro-strainer because of heavy blockage of the fabric. It is stressed that even the finest micro-strainer with apertures of a little more than 20 microns cannot be expected to remove colloidal turbidity without chemical coagulation. Its application however has been proven in many installations and can be used as, primary clarifier, final filtration of sewage effluents, and for clarifying industrial water. This type of primary filter is more suitable for large installations where land space is limited, qualified technicians are available and demand for water is high that high filtration rates are necessary.

HAMANN and McKINNEY (1968) reported the experiences with the use of upflow filtration in treating water. It is a process that seems to be a potential in satisfying present needs and is now waiting full development and application. Baker[1] reported that upflow filtration of water through sand was first documented in 1685 by an Italian physician named Porzio. It was actually a down-up process; filtering first downward and then upward, with a partition in the filtration vessel to separate the two process. In 1791, a British architect patented his upflow filter and the first to recognize the advantage of filtering through media in a coarse-to-find arrangement.

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[1] Baker, M. N. The Quest For Pure Water. AWWA, N. Y. (1949)

The first known municipal installation was in Greenock, Scotland where the slow sand filter can be operated either as an upflow or as a downflow filter, with cleaning to be accomplished by reversing the flow. There have been many installations using upflow filtration and later abandoned in the past century, many of which used multi-media filtration. Nearly all the upflow filters used had a common fault; they were cleaned by reversing the flow, passing the water downward through the media. This method was not effective, providing no scrubbing or agitation of the media and thus without expansion, suspended matter that had penetrated deep into the media was not completely removed.

The Russian version of upflow filter is known as "contact clarifier" and used for purifying water with turbidities of up 150 mg/l. This process combined coagulation and clarification by adding a chemical coagulant to the raw water before it passes into an upflow sand filter. Washing was done in the same direction but at a much higher rate. One of its main advantage over the conventional downflow filtration is the reduction in the physical size of the plant, reduction in amount of chemical coagulant, utilization of the full depth of the bed due to coarse to dine arrangement, and reduction in loss of head during filtration due to removal of substantial amount of suspended matter in the coarse portion of the medium. The original depth of the media tested varied from 7.5 to 8.5 ft. with a better effluent water quality than the conventional gravity system. Filtration rate was not to exceed 2.5 gpm/sq ft to prevent bed expansion and coagulant must be added immediately ahead of the filter for the formation of "micro-aggregates" of floc. As a result, lower coagulant dosage is needed balancing the cost of higher washwater requirement. Furthermore, there is savings in the initial cost which make it more attractive than conventional rapid gravity filter.

European practice had recognized the problem of fluidization of the bed during filtration and had come up with two possible solutions. The first design involved the effluent collection system near but below the top of the sand layer and eliminated the difficulty of washing by passing water downwards through the media from time to time. Another innovation was the use of grid system just below the top of the bed and consisting of parallel vertical plates. Generally, the spacing is 100 - 150 times the size of the fine sand so that it will not permit fluidization and at the same time not to make upflow backwashing difficult.

Laboratory studies were conducted to determine the relative merit of this process. Using laboratory scale models, three different depths were studied: 2, 4, and 6 ft., sand having an effective size of 0.55 mm. uniformity coefficient, 2.0 and porosity of 41 per cent. The filter performance was compared on the basis of turbidity removal and head loss rate at different filtration rate with and without grid system. Filter runs were short and ranged from 2 to a miximum of 7 hours. All runs were terminated either due to bed lifting or fluidization of finer sand and this occurred when the weight of the bed above a given level becomes equal to the head loss developed above that level. Results showed that increasing the bed depth produced better results and less problem of bed upset. Using the grid system increased the length of run and better solids removal capability, although, there is a need for compressed air for backwashing. This process offers more advantage over gravity sand filtration but works quite well only with the aid of a coagulant. Furthermore, it requires deeper bed or a grid system to prevent bed lifting or fluidization of finer sand.

Even with the use of multi-media filtration, there still exist some difficulty, rather defect in the performance due to the regrading of media from fine to coarse arrangement after backwashing. In this connection, filter gets clogged faster at the top and results in shorter filter runs. The idea of filtering water through a media of coarse to fine arrangement eliminated this problem. While this process was a perfect answer to the problem, another problem occurs as to how to prevent the bed from expanding in the upward direction as the pressure difference increases with the clogging of the bed.

BOBY and ALPE (19), cited the different merits of upflow filtration and advantages over downflow filtration. The first solution to the problem stated above was using a bi-flow system, whereby the water is passed downward and upward through the filter at the same time and the filtrate is collected in the center of bed. The downward flow helped in retaining the bed in position but the filtrate quality depended a lot on the performance of each part. Therefore effluent quality was undependable and the centre collection system was cumbersome and expensive. The use of grid system was therefore promising. The authors reported some experiences in the use of this upflow filtration and were convinced that this process is indeed more advantageous than downflow filtration. Not only does it give longer filter runs, it also saved chemical expenses in lesser coagulant dosages needed in "in-line" application and eliminated coagulation and sedimentation units. However, this type of filtration is still technically new in the world of purifying water and research is still being conducted to determine the optimum size of media and composition of filter beds for different applications. No design criteria can yet be depended upon for its application in more remote and under-developed places.

Alternative Media for Filtration

HEIPLE (1959) showed from a pilot plant study over a seven-month operating period that turbidity of normal surface waters may be substantially reduced by filtration without prior treatmemts through coarse-grained material such as pea gravel. Using a 16 in. bed of 0.5 - 0.25 in. gravel at an operating rate of 0.1 gpm/sq. ft. the average efficiency of turbidity removal was well in excess of 50 per cent and has reached 90 per cent on occasions.

Such filter has a capacity for effective long-term operation without appreciable head loss and without need for cleaning. In this study, the turbidity of the filtrate generally varied between

5 to 30 mg/l, and it was demonstrated that this kind of filtration will remove at least 50 per cent of the total bacteria present in normal waters. The efficiency of filtering method is greatest at low turbidity waters where particles size is preponderantly colloidal. It was found that the bed depth has an increasing effect on turbidity removal but no loss of head was detectable. Likewise, higher water depth gave higher removal efficiency which the author explained this to be due to the preliminary settling and agglomeration of particles before filtration.

AWWA[1] stated however, that fine sand may be shallower than course sand but the former produces greater head losses and clogs more quickly than the latter. It was therefore recommended that the size of sand should not be finer than will ordinarily give a good filtering efficiency and low head loss.

In order to improve the quality of water at Eastern Kodak Co., BAILEY (1939) made a study of using anthrafilt as a filtering medium in existing slow-sand filters. Four inches of sand were removed and replaced with thoroughly washed anthrafilt, having an effective size between 0.4 and 0.45 mm. and uniformity coefficient of 1.4. Each is twice the size of each grain of sand which made it in reality, a roughing filter on top of a regular filter.

It was found in a laboratory experiment that the sand and anthrafilt stayed in place with a definite line of demarkation but using a greater washing depth - there was considerable mixing of coal and sand at a depth of 11 inches. There was no loss of large

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[1] Water Quality & Treatment, 2nd edition, 1965.

particles of Anthrafilt in the wash water except for some very fine particles. The rate of filtration at the anthrafilt filter had no effect upon the turbidity of the effluent. The sand filter with incoming turbidity of 150 to 200 mg/l gave an effluent turbidity of 2 to 3 mg/l when pumping 160 mgd with a temperature of 40°C which was the same result taken from the Anthrafilt filter.

A test was conducted on a sample with 10 mg/l influent turbidity and change of chemical characteristics (See Table 11 and Table 12). The effluent of the anthrafilt filter was somewhat softer than the effluent of sand filter but the sand filter was more effective in removing organic matter as was indicated by the reduction of oxygen consumed values and albuminoid ammonia content in the anthrafilt filter. Sand showed more effectiveness in removal of organic matter as their time in service increased.

RIPPLE (1938) compared coal and sand as a filter medium and based his experimental work on Anthracite coal or Anthrafilt. Anthracite coal is approximately half as hard as sand and weigh half the weight of sand when dry of same volume. It was concluded that lighter material does not pack in filters as much as the heavier sand and also due to the difference in shape it has a larger per cent of voids than a sand bed of the same size grains. Anthrafilt filters can be designed with a less area for the same quantity of water due to the higher filtration rate that the bed handle.

Charcoal as defined by the McGraw-Hill Encyclopedia is a porous solid product containing 85 - 95 per cent carbon produced by heating carbonaceous materials such as cellulose, wood, peat and coals of bituminous or lower rank at 500 - 600°C in the absence of air.

Table 11

Comparison of Anthrafilt & Sand Filters Using a Raw Water With
10 ppm Turbidity
All Values in ppm except otherwise stated

Characteristics	Raw Water	Sand	Anthrafilt
Color	12	3	5
Turbidity	10	Trace	Trace
Odor			
Cold	1 Veg.	1 Veg.	1 Veg.
Hot	1	1	1
Iron	0.5	0.1	0.1
NH_3-N			
Free	0.038	0.002	0.002
Albuminoid	0.246	0.148	0.006
Nitrites	0.009	0.004	0.003
Nitrates	0.16	0.3	0.3
O_2 Consumed	2.90	2.4	2.2
Chlorides	13.80	14.0	13.4
Hardness (Total)	124.0	126.0	114.0
Alkalinity	95	95	95
PH	7.9	7.8	7.7
Bacteria per cc, 24 hrs at 3TC	600	2	2

Table 12

Comparison of Anthrafilt & Sand at Highest Turbidity
All values in ppm except otherwise stated

Characteristics	Raw Water	Sand	Anthrafilt
Color	10	2	5
Tuebidity	80	7	trace
Odor			
Cold	1 Aromatic	2 Aromatic	1 Veg.
Hot	"	"	1 Veg.
Iron	1.16	0.2	0.003
NH_3-N			
Free	0.030	0.002	0.004
Albuminoid	0.140	0.042	0.044
Nitrites	0.006	0.001	0.001
Nitrates	0.24	0.30	0.30
O_2 Consumed	3.3	2.3	2.4
Chlorides	13.4	14.2	11.0
Alkalinity	93.0	87.0	83.0
Harness, Total	120.0	114.0	122.0
pH	7.7	7.7	7.7

Chars or charcoal from cellulose or wood are soft and friable and used chiefly in decolorizing solution of sugar and foods stuff and for removing objectionable tastes and odor from water. Charcoals are rendered more pourous and are considered as an efficient material for sorption of air, carbon dioxide or steam by heating at 900°C for a brief period. However due to its physical characteristics, being soft and friable, reducing it to smaller sizes results in a lot of very fine dust-like particles, easily blown away and goes to waste. Normally, they are manufactured locally from branches and trunks of trees that the end product has varying sizes in chunks, mainly used fuel in villages.

There has never been any investigation published as to the filterability and/or physical characteristics of rice husk and coconut husk fiber. They have been considered as waste products but present needs proved that rice husk can be used as fuel, feed meal base for pigs and chickens and sometimes as insulators. Coconut husk fiber has been used as insulators, fuel, floor mats and cushion stuffing material. Rice husks when burned as fuel in remote villages gives a charred end product that looks like crushed or pulverized charcoal. The rice husks are friable but not as soft as charcoal and easily absorbs water so that it settles down. Coconut husk on the other hand when ground, gives fiberous material that resembles cloth fiber and wound together like cotton balls. No one has ever investigated its potential as a filter media and no background for this research can be referred to.

Factor Affecting Filtration

HUDSON (1958) made a study on filtration rates - its effect on filtrate quality and the factors that affect it. The ability of filter sand to remove turbidity is a function of size of the passage through the sand. The technical relationship governing the effectiveness of the sand in removing suspended matters states that this ability of the sand is related to the square of the particles size. For example, sand of 0.55 mm. diameter is twice as good in removing turbidity as sand of 0.7 mm. size. Although, finer sand produces a better quality of filtered water, it also produces short filter runs. If the effective size of the filter sand is halved, the filter run will be shortened to one-fourth of the former length. The porosity of sand is another factor which affects filter run. Angular media such as coal does a less adequate job of removing suspended matters than media of lower porosity.

It is possible to have more complete removal with a thicker bed and due to this coarser materials can be used resulting in longer filter runs. Although, bed depth has no effect on the length of runs. The author operated filters of thicknesses of 15.24 cm. (6 in.), 30.48 cm. (12 in), 60.96 cm. (24 in.), and 91.44 cm. (36 in.) and found the effect to be in water quality only. Furthermore, the higher the filtration rates, the shorter the filter runs.

One of the most critical factors in determining the quality of the filtered water is loss of head. So that the total flow will be maintained, water is forced to go faster through the remaining space. Velocity increases as loss of head increases and if velocity gets too high, sediment is transported clear through the bed. Filters that are connected to pumps which may produce variance in flow through the bed often cannot be expected to produce good water.

SEGALL and OKUN (1965) investigated the effect of filtration rate, influent quality on a plant scale. The principal question in their study was: 'What is the maximum filtration rate that will produce water of acceptable quality and how is this maximum rate affected by grain size and influent water quality?"

They based their work on a raw water supply taken from a 500-mg impoundment with quality shown in Table 13.

Table 13

Raw Water Quality Characteristics
January - February, 1965

	AVERAGE	RANGE
Turbidity	40	2 - 260 JTU
Hardness	16	12 - 20 mg/l as $CaCO_3$
Alkalinity	17	12 - 21 mg/l as $CaCO_3$
pH	7	6.4 - 7.8
Temperature		44° - 57°F

The treatment facility was a conventional filtration plant designed for 5 mgd. Consumption was only about 3 mgd but operated at 5 mgd, shut down periodically each day, generally at night. Sand used had an effective size of 0.57 mm. uniformity coefficient, 1.38 and porosity of 40 per cent. Turbidity was measured continuously along the bed. Influent and effluent turbidity were determined by using two Hach, low-range turbidimeters. The filters were operated at selected constant rates which were about 50, 100, 150, 200 and 400 per cent of the normal operating rate of 2 gpm per square foot.

Results showed that at 4 gpm/sq ft and less, effluent turbidity was not affected by flow rate and influent turbidity prior to occurrence of a breakthrough. After a breakthrough, the filtrate was affected by influent turbidity. Furthermore, effluent turbidity was significantly higher at higher flow rates than lower flow rates during the entire course of the filrun.

Anthracites media was also used for purpose of comparison. The characteristics were as follows: effective size, 0.76mm; uniformity coefficient, 1.78; porosity, 50 per cent. Runs were conducted under the same conditons and results showed that the filtrate quality was not affected by changes in influent turbidities less than 4 JTU and flow rate of 3 gpm/sq ft prior to breakthrough. At turbidities higher than 4 JTU, filtrate quality increased at all rates and during the entire course of the run. There also was a period of "breaking-in" after the filter was breakwashed and during this time, filtrate was affected by influent turbidity and flow rate. At higher flow rates and higher influent turbidity, filtrate quality was heavily affected.

The different results obtained from the two media showed that filtrate quality is dependent on grain size and porosity of the material rather than the materials themselves, although it is not well established. With relatively coarse and porous media, the breakthrough phenomenon occurred in a short period of time at low head loss through the filter. On the contrary, with less porous and finer media, head loss is in the vicinity of washing loss of 8 feet before a breakthrough occurred. The effects of filtration rate and influent turbidity on filtrate quality were also a function of media grain size and porosity. Higher filtration rates and increased influent turbidity had less of an effect on the sand filter than on the anthracite. These results indicated that there is a definite point reached in filter operation when filtrate turbidity increases rapidly with no apparent change in the quality of the influent water.

It was concluded that the conventional rate of 2 gpm/sq ft is not necessarily the correct rate. It largely depends on the size and porosity of the media. Current practice dictates that selection of media and flow rates are based on head loss, with little concern for the occurence of breakthrough, or poor post-washing performance, with the concomitant deterioration in effluent quality. The reason for this failure may be due to lack of sensitive devices to record the change in effluent turbidity. One important guide is that the maximum head loss, fixed by the hydraulics of the filter to prevent air-binding, should occur just before "breakthrough" occurs.

Inspite of the long use of conventional filtration, there still exist further question as to what filter media, filter depth and filter rate will produce water of adequate quality most economically.

CLEASBY and BAUMANN (1963) investigated the effects of high filtration rates on water quality in a model filter. Various types of influent water were used and turbidity was measured by a standard nephelometry technique. Effluent water was generally poor at the beginning of each run, but quickly improved to some minimum turbidity value with this minimum turbidity value being maintained throughout he filter run except at the higher rates of filtration rates on water quality in a model filter. Various types of influent water were used and turbidity was measured by a standard nephelometry technique. Effluent water was generally poor at the beginning of each run, but quickly improved to some minimum turbidity value with this minimum turbidity value being maintained throughout the filter run except at the higher rates of filtration. Results showed that the effect of filtration rate was a function of the type of influent water and that deposition of material within the pores of the filter resulted in a linear head loss development while the formation of a compressible surface cake on thesurface of the filter resulted in an exponential increase in head loss. They concluded that, at the optimum rate, surface mat formation is minimized and head loss development approaches linearity, however, effluent turbidity was not satisfacaory. Higher filtration rates prevents surface mat formation and increases filter utilization by deeper penetration and increased production butthe solids tend to pass through the filtering medium.

Laboratory Tests on Filtration

WADDINGTON (1961) stated that the other variables in filtration to be tested apart from flow should be different grades of different filter media. He posed several questions: can a shallow bed of finer material replace with equivalent filtrate quality a deeper bed of coarser material? Secondly, is a uniform bed of filter media within close limits more practical and economical than the same depth of bed composed of media graded between much wider limits? These are but a few variations that can be done on filtration tests.

ROEBECK and WOODWARD (1959) used six-2 in. diameter filter columns in order to help define the role of sand and other media in removing particulates. As long as the diameter is 50 times the size of media particle, wall effect is minimized. This same equipment handled any depth of media up to 91.44 cm. (36 in.) where 60.96 cm. (24 in.) was sand. The authors used a 20 ml. syringe and 3/4" (#23) needle to withdraw samples very slowly through a self-sealing rubber stopper. Flow was maintained at steady state either high or low rate by using expensive but precise gear pumps on the effluent end of the filter. Duplicate loading of parallel filters was accomplished by reducing the concentration of particles and the volume of reservoirs ahead of the columns.

Past experiences in laboratory test showed that primary rapid filtration was still acceptable as long as filter run exceeds 12 hours but intolerable at 6-hour runs. In slow-sand filtration, increase in filter surface and due to algae metabolisms.

Another experience showed that rate controllers can be used to maintain a constant flow through the filter, regardless of the head loss. Manual adjustment can lead to shear dislodgment of deposits in filter due to relatively small but sudden and significant changes in the interstitial velocities.

Water Supply Cost Comparisons

The cost of water supplies vary from country to country. Published reports on capital and operating costs are at most, guidelines for engineers who need available data for purposes of comparison between two or more alternatives of water treatment before final decisions are made. The water industry is greatly influenced by local factors and these play an important role in government planning.

MILIER, BURLEY and MAWER (1970) carried out a cost survey of conventional water supply schemes using data from seventy-five major water undertakings in the United Kingdom. Costs of water were obtained from scheme installed during the last ten years or for cases where detailed estimates were available for proposed schemes. Cost details on various cost components were included so that the relationship of these costs to design factors could be examined. Results were obtained for 20 surface schemes and four groundwater schemes.

Data showed that the total cost[1] of water at the service reservoir seldom exceeded 36 pence/1000 Imperial gallons and the majority was less than 24 pence/1000 gal.. Detailed cost of the twenty surface water schemes are given in Table 14 which include capital and total charges in pence/1000 gal. using the fixed charges given. In particular, impoundment reservoirs were often the most expensive components within treatment works and pipelines, treatment plant and other unspecified costs. These figures indicate that there would be a significant change in this proportion if river regulating reservoir systems move towards the improvement of raw water sources.

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[1] All cost used 6.5 per cent as the interest rate and ff. amortization period: Impounding reservoir, 60 yrs.; treatment plant and pumping stations, 25 years; pipelines, 35 years; service reservoir, 40 years; intakes and unspecified costs, 30 years.

Table 14

Investment in Surface Schemes

Component	Capital Investment		Capital Charges	
	Cost £'000's	%	Cost d/1000 gal.	%
River intakes	953	2.2	0.36	2.3
Impounding Reservoirs	18,411	42.8	6.07	39.3
Treatment plant	6,789	15.7	2.76	17.9
Pipelines	7,572	17.6	2.74	17.7
Pumping Stations	1,333	3.1	0.54	3.5
Service Reservoirs	1,623	3.8	0.57	3.7
Other Costs	6,380	14.8	2.41	15.6
Total	43,061	100.0	15.45	100.0

Total yield = 133 mgd

Treatment costs depended mainly on the quality of the feed and product water and on the size of the installation. Raw water as well as filtrate quality influenced the type and extent of the processes used and thus affected the capital investment. Likewise, raw water quality affected operating cost, particularly in the case of chemical treatment systems. Some idea of the chemical costs involved is shown in Table 15 which includes a number of the common chemicals used in water treatment.

Table 15

Cost of Chemicals

Chemical	Unit Cost Assumed	Dose Range mg/1	Cost d/1000 gal.
Aluminum Sulphate	£20/ton	20-60	0.43-1.29
Hydrated Lime	£7/ton	40-100	0.30-0.73
Soda Ash	£16.5/ton	60-100	1.06-1.77
Liquid caustic soda	£16.5/ton	60-100	1.06-2.83
Sulphuric acid	£18/ton	0.5-5	0.01-0.10
Chlorine	£49.5/ton	0.25-5	0.014-0.28
Sulphur Dioxide	£80/ton	0.2-1.0	0.018-0.09
Natural Polyelectrolyte	1s 9d/1b	0.1-3.0	0.021-0.63
Synthetic Polyelectrolyte	10s/1b	0.05-0.5	0.06-0.60
Powdered carbon	£80/ton	5-50	0.45-4.50

Two-stage treatment conventional rapid sand filtration plant was commonly used for treating waters with medium to high suspended solids and/or color levels where the load precluded the use of direct filtration. This was also used where surface or groundwater supplies were to be softened, or where high iron levels have to be reduced in groundwater supplies. Figure 2 shows the approximate cost estimates for different capacity made from plotting the cost survey data against given capacity.

Undoubtedly, changes in water resources will lead to some alternations in the cost of water treatment. The extent of treatment largely depend on raw water quality and the filtrate desired and thus heavily reflects on the cost of potable water. There is a continuing change in all aspects of the water industry and a closer inspection of treatment costs and an understanding of the various factors involved is necessary.

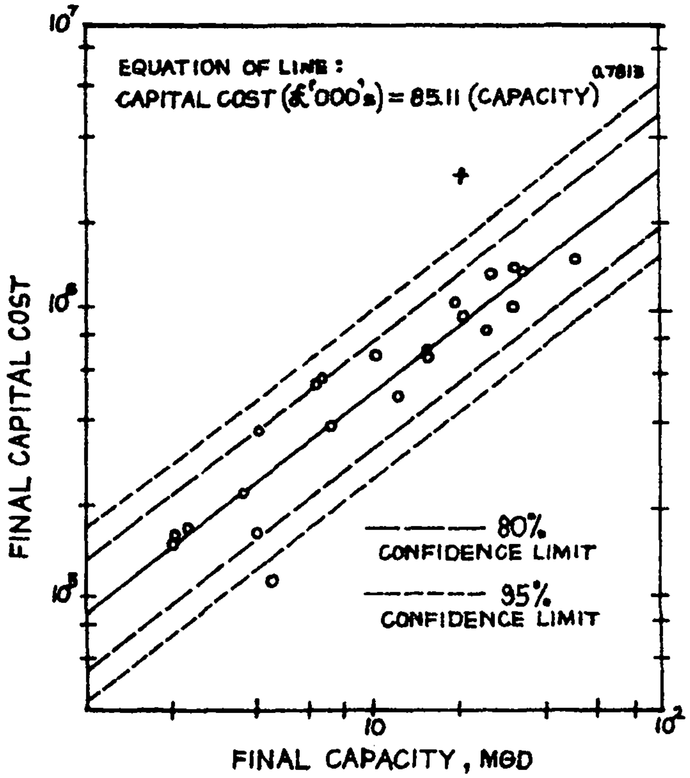


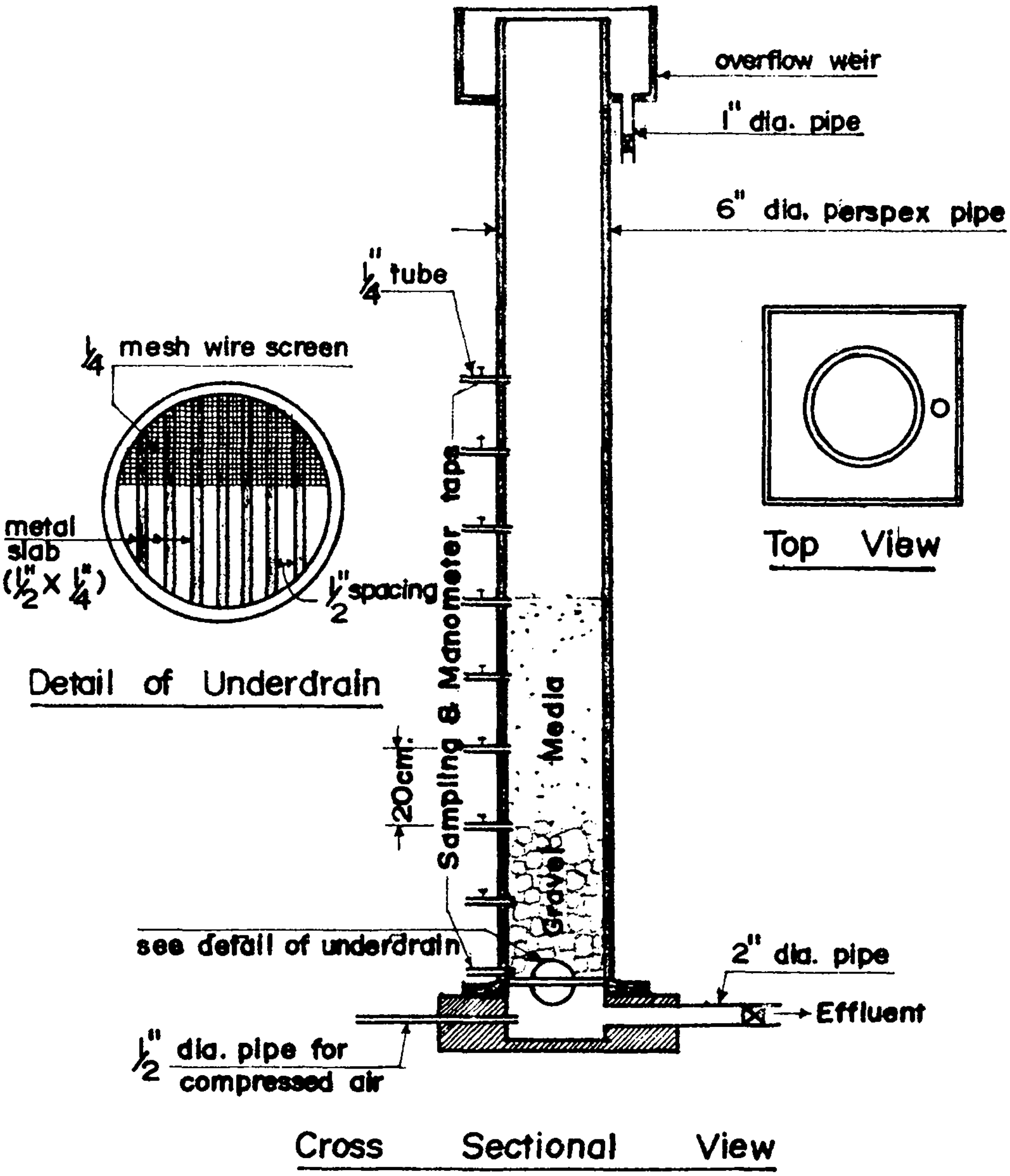
FIG. 2 FINAL CAPITAL COST VS. FINAL CAPACITY OF SEDIMENTATION & FILTRATION PLANT

III EXPERIMENTAL INVESTIGATION

Design of Experimental Filters

Preliminary tests were conducted on a 15.3 cm (6 in.) ID pipe, 2.5 meter in height of 0.9525 cm (3/8 in.) thick perspex. This single column was designed to be able to function as a slow, or rapid gravity filter and as an upflow filter. A constant-head tank was used to maintain a constant flow to the filter. An orifice of 1/4 in. opening in a 2-in. pipe was attached to the constant-head tank so that the flow to the filter could be measured. Sampling taps and manometer tubes of 0.6350 cm (1/4 in.) diameter plastic tubes were placed along the height of the column at an interval of 20 cm., starting from the bottom of the filter bed. A T-joint tube was used to connect the sampling taps and manometer tubes from one side of the column. Filter pipings were 2in. GI pipe with manual flow control valves. A 1/2 in. pipe was attached at the underdrain to supply compressed air to the bed during backwashing.

For the secondary filter runs, four (4) filters of the same area and dimensions were used and were made of 0.6350 cm (1/4 in.) thick PVC sheets. The surface area for all filters were the same as the column used in the preliminary test but the height was 2 meters since it were used for slow rate filtration only. The four (4) filters were connected to each other but functioned as individual filters. Figure 3 through 5 illustrates the detail and dimensions of the experimental filters used, whilst Figures 6 and 7 show the experimental set-up. Photographs of the experimental filters



Height of Column = 2.5 m.

Fig.— 3. Detail of Preliminary Filter

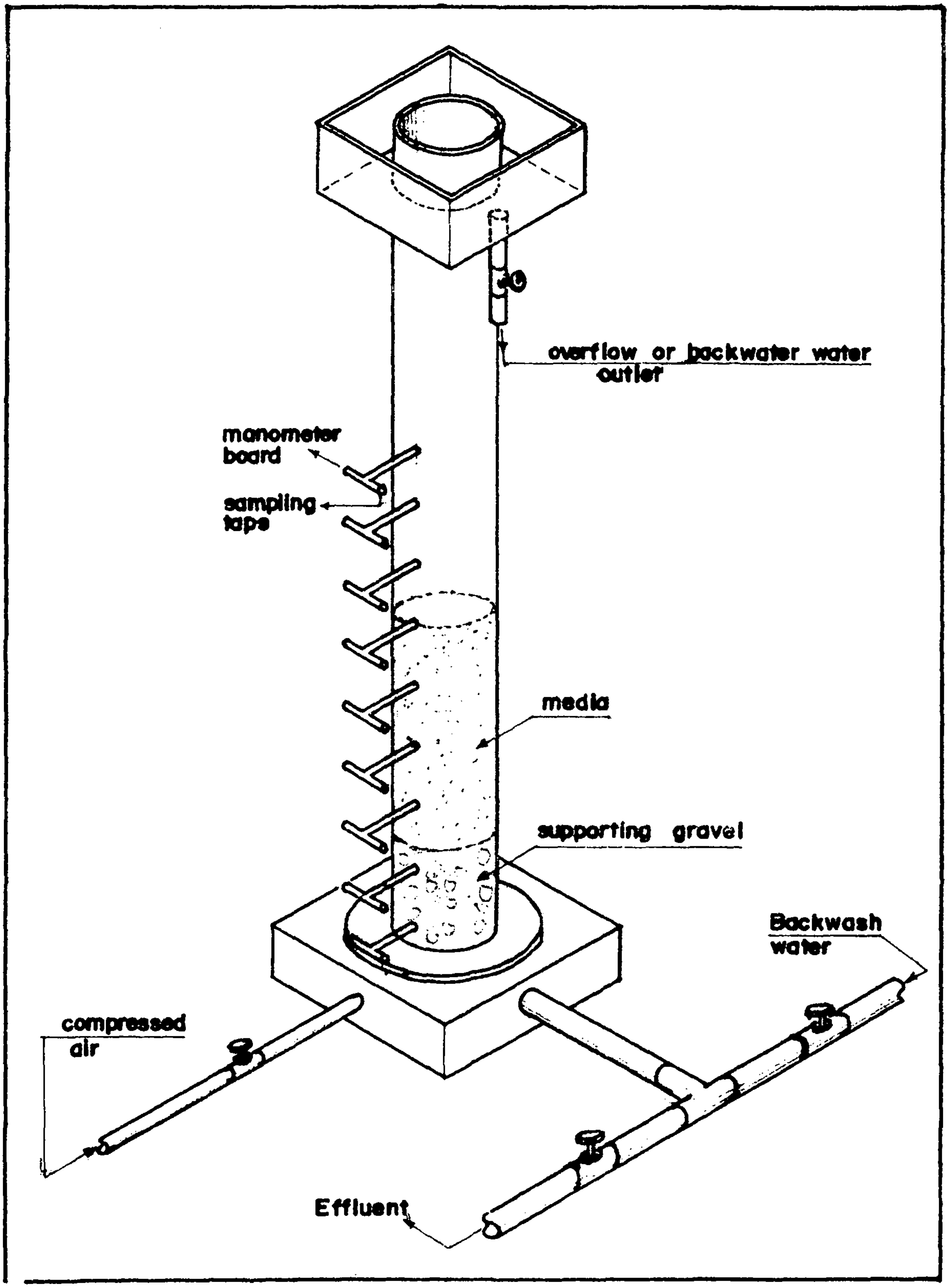


Fig.— 4 Isometric View of Preliminary Filter

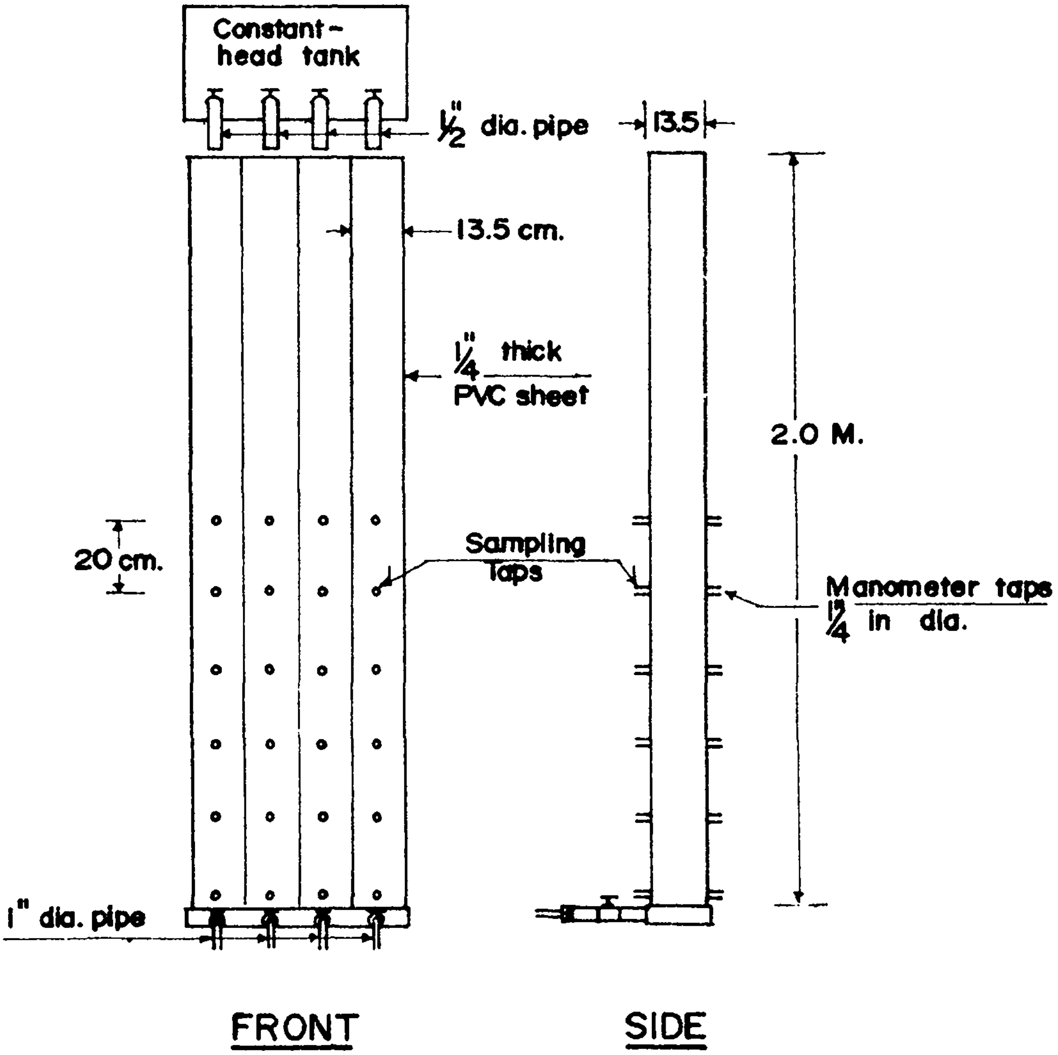


Fig.— 5 Detail of Secondary Filter Unit

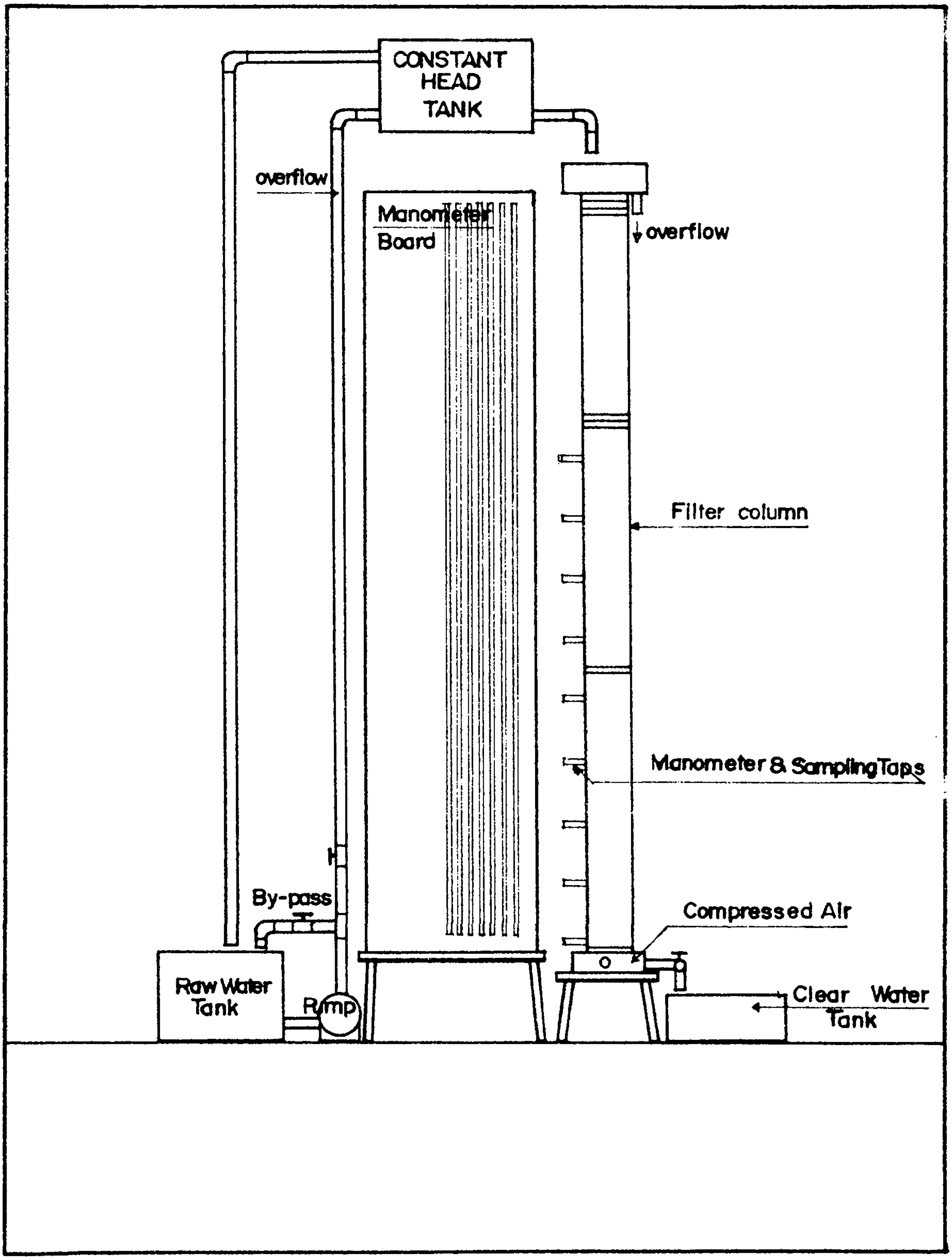


Fig.— 6 Experimental Set-up of Preliminary Filter Unit

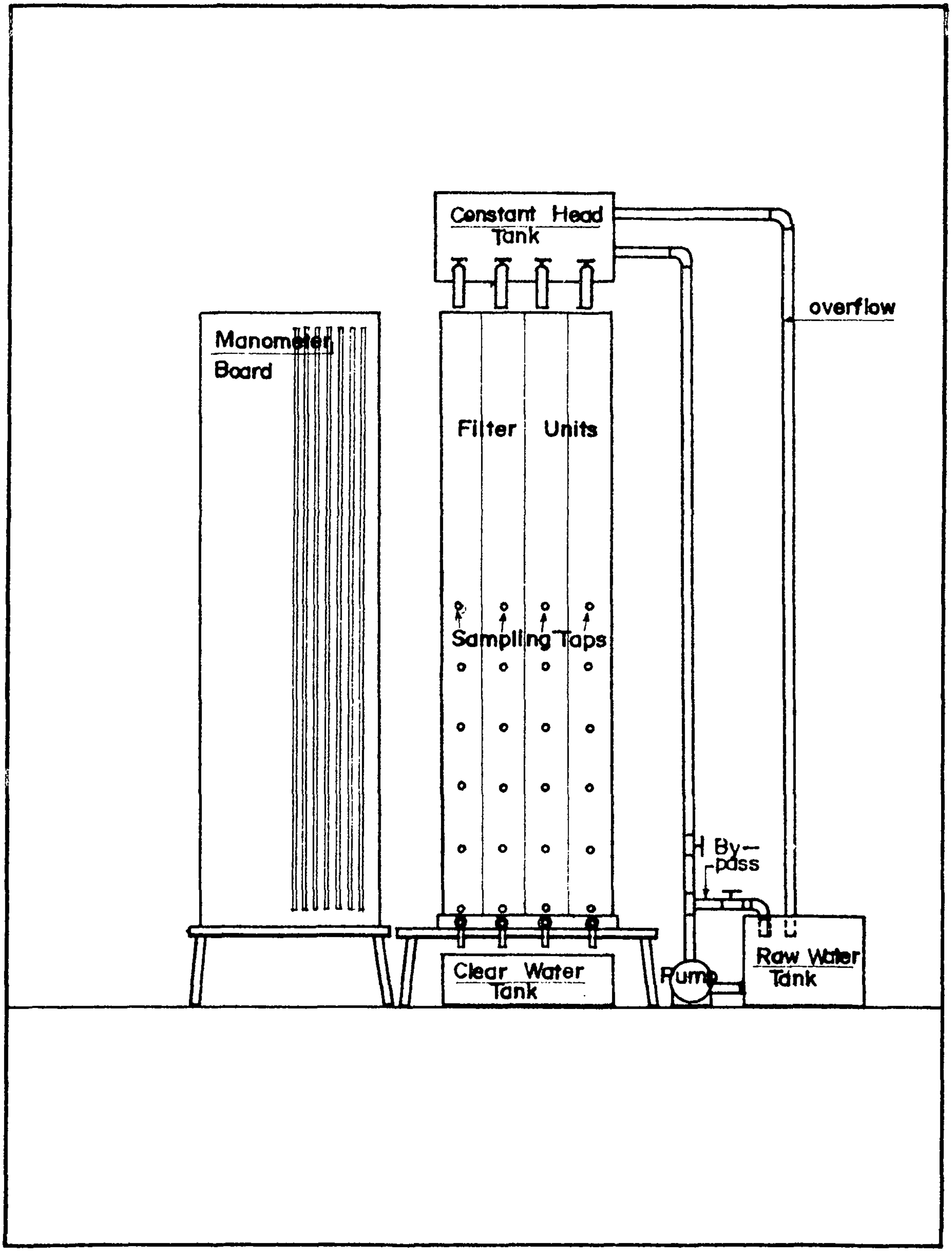


Fig.— 7 Experimental Set-up of Secondary Filter Units are shown in Fig. 8 through 10. One of the four filters was used as a slow sand filter, with the standard size of sand as the control media, in order to evaluate the performance of the other media under investigation. Influent waters in all the filters were fed from a single overhead tank with four (4) outlets going to each of the filters.

Raw water for both filters was mixed in a separate holding tank. A 1-cu.m. tank was used for the preliminary filter, whilst a smaller tank with dimensions 0.60 m x 0.32 m x 1.0 m, and volume of .192 m^3 was used for the secondary filter units. These tanks were also used as storage tanks for typical river water used in the final test runs. Influent water was pumped from the storage tanks to the overhead tanks by pilot plant-size centrifugal pumps. An air-water manometer conncected to the filter sides were used to measure the head loss through the bed as shown in Figure 11.

Design of Experiments

Since there were no basis for the design dealing with the media under investigation, preliminary test runs were conducted in three series. The first series of test runs were conducted to investigate the endurance (length of run) of the systems on the basis of turbidity removal, head loss rate and filtration rate, at high turbidity loadings and semi-rapid filtration rates. The second series of tests was used to compare the performance of the media at slow filtration rate and low turbidity loadings. The last series of test runs were used to investigate whether the performance of the media using water with synthetic turbidity was indeed realistic by running tests using Chao Phya river water.

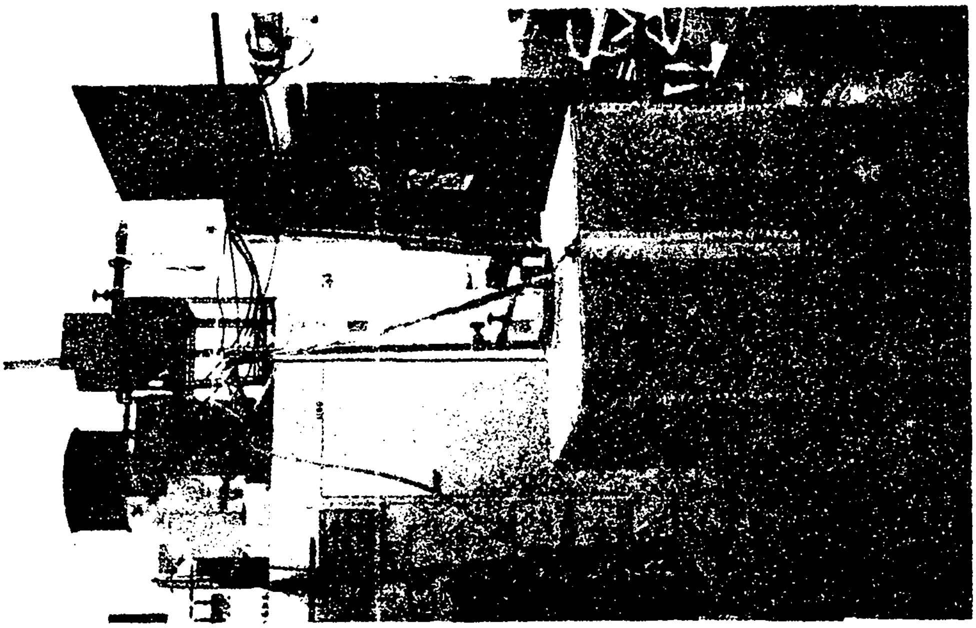


Fig. 8 - General Set-Up

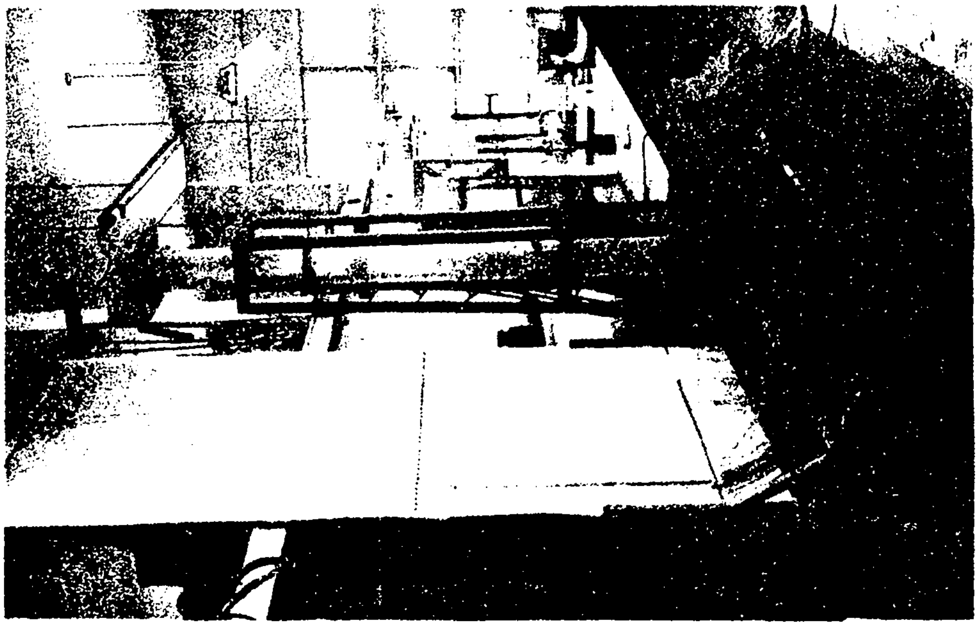


Fig. 9 - Preliminary Filter Set-Up

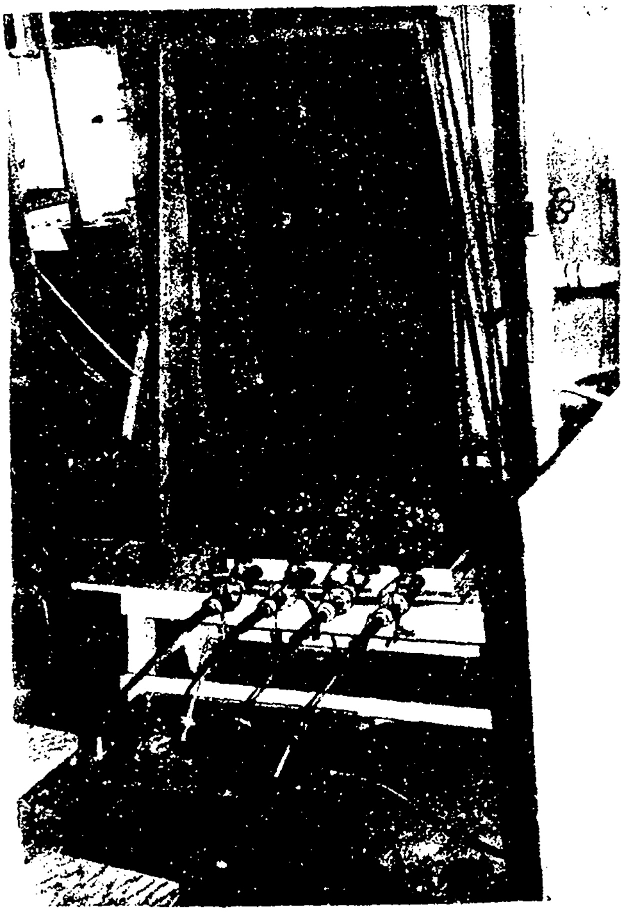


Fig. 10 - Secondary Filter Set-Up

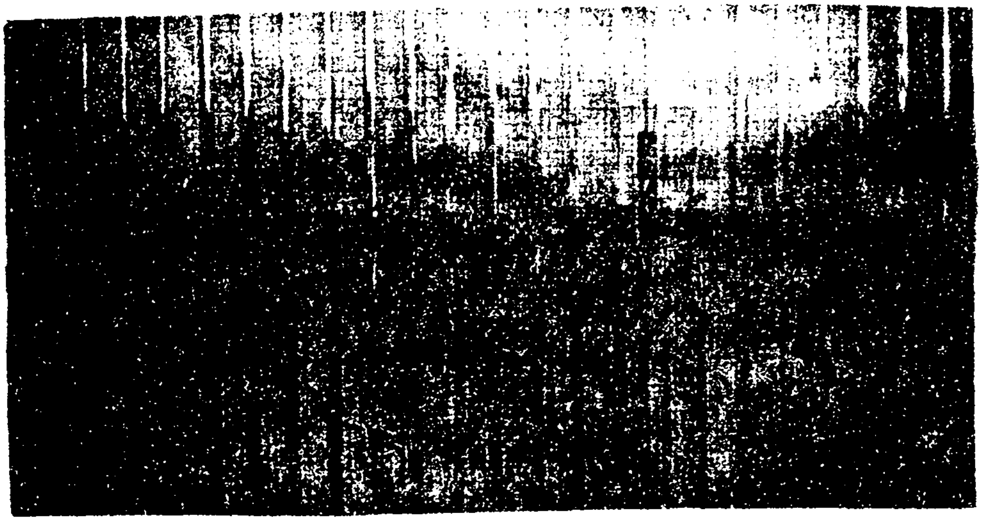


Fig. 11 - Manometer Board

Controlled conditions of the filter runs included constant turbidity level (range of value) and filtration rate throughout each run. No effect other than turbidity removal and rate of head loss were considered. A constant-water-level method of filtration control was used throughout the runs. This was done by setting the outflow rate at the desired level in the beginning of each run and trying to maintain the level of water constant by controlling the inflow rate.

The independent variables considered in the study were:

(1) loading or filtration rate

(2) influent turbidity

(3) effective size and type of media and the dependent variables were:

(1) head loss rate

(2) per cent turbidity removal (efficiency)

(3) length of run before breakthrough or build up of head loss.

The effect of different sizes of the same media and depth of bed were not considered in this study. Also, the effect of the water depths above the bed was ignored. Water depth was maintained at an average of 1.0 - 1.2 meters above the bed. Head loss or the hydraulic gradient through the bed of each media was analyzed by measuring the headloss through the bed as read by the air-water manometer tubes. Height or depth of the filter beds were all 70 cm. which was based on accepted design parameter of slow-sand filters. All media were supported by 30 cm. of graded-gravel as generally used in sand filters.

In selecting the sizes of the media to be used, the basis chosen was the natural state or size in which such material can be found in local conditions. This was to avoid complicated methods of preparation and to take advantage of non-complexity in using locally available media. Long term studies on the media (such as storage) and effect on other water quality parameters were not evaluated in this study.

For basis of comparison, a standard rapid-sand filter was used as a control factor in the first series of runs and a standard slow sand filter for the second series of runs. In terminating each run, the basis used was either a final head loss of 1.2 meters or a deterioration in effluent quality, usually termed as "breakthrough". Basis for the design of the experimental filters were the range of filtration rates and the capacity of raw water tank and in order to avoid possible head loss, a bigger diameter prpe was used than required.

The different systems were compared on the basis of turbidity removal, head loss rate, method of cleaning, washwater requirement, and the simplicity of preparing the media and operating the system. Results obtained from these filter runs were used to determine the design parameter of the final system and the endurance of the system.

Outline of Study

Run Series I In this preliminary test runs, two levels of filtration rates were studied: semi-rapid rates of 2.5 and 1.25 $m^3/m^2/hr$, although, 8 and .25 $m^3/m^2/hr$ were tested on pea gravel for confirmation test. The endurance of the media (length of runs) to high turbidity: 300 JTU and lower and 1000 JTU - higher. Difficulty in maintaining turbidity at a constant value throughout each run was encountered, so the level was maintained within a range of values desired. Table 16 gives the list of 14 runs conducted during this preliminary test, which included evaluation of the size of media investigated, filtration rate, and actual range of turbidity values applied to the system. In this series of runs, upflow filtration was also investigated using pea gravel, but for purposes of comparison only, thus no detail investigation was carried out.

Run Series II These series of runs were carried out to determine the performance of media at low turbidity loadings and slow filtration rate. Tests were carried out in the secondary filters designed for this purpose and were run simultaneously. The media that were investigated in the first series of runs and proved to perform well at rapid rate were used in these runs, namely: pea gravel, coconut husk fiber and burnt rice husk. A standard slow sand filter was used as the control factor for final comparison of performances. Turbidity levels used were 50 JTU average, since it was difficult to mix a constant influent turbidity of 50 JTU. Filtration rate was held at 0.25 $m^3/m^2/hr$, approximately twice the average slow sand filtration rate.

Two runs were conducted on each of the burnt rice husk and control sand filters. For the slow sand filters, two different sizes were investigated; (i) effective size, 0.31 mm; uniformity coefficient, 1.35. Table 17 summarizes the six (6) test runs conducted on the four media.

Table 16

Schedule of Test Runs in Run Series I

Run No.	Media*	Filtration Rate in $m^3/m^2/hr$	Influent Turbidity Range in JTU	Remarks
1	PG	2.5	100 - 300	Size: 3/8"-3/16"
2	PG	2.5	1000 & over	Uniform
3	PG	0.25	125 - 180	
4	PG	2.5	1500 - 3000	Upflow Filtration:
5	PG	8.0	2400 - 3500	Same size as above
6	PG	2.5	100 - 300	
7	BRH	2.5	150 - 300	Sizes not analyzed
8	BRH	1.25	100 - 300	
9	BRH	1.25	1000 - 1500	
10	RRH	1.25	1000 - 1500	Sizes not analyzed
11	RRH	2.5	1000 - 1500	
12	RRH	2.5	150 - 300	
13	CHF	2.5	1000 - 1500	Only fibers were used
14	CHF	1.25	1000 - 1500	
Control Sand		2.5	1000 - 1500	Eff. Size: 0.45 mm. Uniformity Coeff.:1.45

*The following stands for the symbols presented:

PG : Pea Gravel
BRH : Burnt Rice Husk
RRH : Raw Rich Husk
CHF : *Coconut Husk Fiber*

Table 17

Schedule of Test Runs in Run Series II

Run No.	Media	Filtration Rate in $m^3/m^2/hr$	Influent Turbidity Range in JTU	Remarks
1	Control	.25	40 - 85	Sand: Eff. Size: 0.31 mm. Uniformity Coeff.:1.25
2	Rice Husk	.25	40 - 85	
3	Control	.25	25 - 85	Sand: Eff. Size: 0.34 mm. Uniformity Coeff.:1.35
4	Rice Husk	.25	25 - 85	
5	Coconut Husk Fiber	.25	25 - 130	
6	Pea Gravel	.25	25 - 130	

Table 18

Schedule of Test Runs in Run Series III

Run No.	Media	Filtration Rate in $m^3/m^2/hr$	Influent Turbidity Range in JTU	Remarks
III-1	Rice	2.5	80 - 140	
III-2	Sand	0.25	80 - 140	Eff. Size: 0.34 mm. Uniformity Coeff.:1.35
III-3	Rice	0.25	80 - 140	
III-4	Coconut	0.25	80 - 140	
III-5	Pea Gravel	0.25	80 - 140	Size: 3/8"-3/16"

Run Series III For purposes of comparison whether the filter performances of the media using synthetic turbidity over and under estimated efficiency when using natural water, tests were conducted on some of the media at selected filtration rates using a typical surface river water. The river water was taken from Chao Phya River in Thailand and was delivered to Asian Institute of Technology where it was stored in tanks until needed. Analysis of sample is given in Table 19. Raw water turbidity was analyzed at different times during the length of each run for actual removal comparison during the runs. A summary of filter runs conducted on different media and filtration rates used is given in Table 18. Test runs were carried out for both slow and semi-rapid rates.

Table 19

Raw Water Analysis

Chao Phraya River - April 22, 1971

Constituent	Value
Turbidity	80 JTU ave.
Color (Apparent)	40 Hazen Units
pH	10.5 @ 25°C

Sampling Method

Influent and effluent turbidity were measured at different times during each run with out definite time interval, that is, random sampling as well as the effluent at different depths. For high turbidity, greater than 300 JTU, Jackson Candle Turbidimeter with a range from 25 to 5000 JTU was used. For lower than 300 JTU turbidity, Hach low-range turbidimeter was employed. Photographs of the turbidimeters used are shown in Figures 12 and 13.

Materials and Equipment Utilized

Sizes of media were analyzed in a sieve apparatus using Tyler Mesh. An air-water manometer was used to measure the head loss throughout the filter bed and piezometer for measuring the inflow rate to the filters. Two pilot plant size pumps were used to pump raw water from the holding or mixing tanks to the constant-head tank. In measuring the flow rate, a volumetric cylinder and a stopwatch were used. Ordinary valves were used at each filter to control the flow. Synthetic turbidity was made of commercial grade Kaolin clay and was mixed with tap water to obtain the desired level of turbidity.

Procedure and Analytical Method

Procedure for analyzing turbidity is given in detail in the Standard Methods for the Examination of Water and Wastewater and by the manufacturer of Hach Turbidimeter. Filter bed performance and particle penetration were observed and analyzed visually. Pictures were taken of each media to show the extent of bed penetration. Head loss were measured through the manometers attached at the filter surface and the level of water at any depth of the bed. All test runs were conducted only once on each media. No other techniques were employed since experimental runs were to determine which of the filter materials made attractive roughing filters prior to deciding on a filter configuration or flow system for longer-term study.

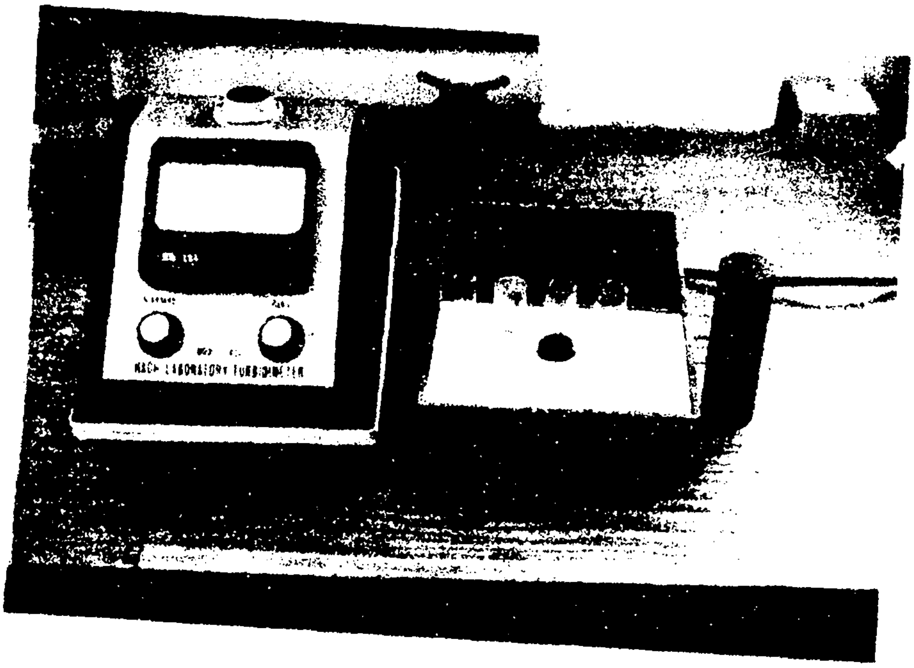


Fig. 12 - Hach Turbidimeter

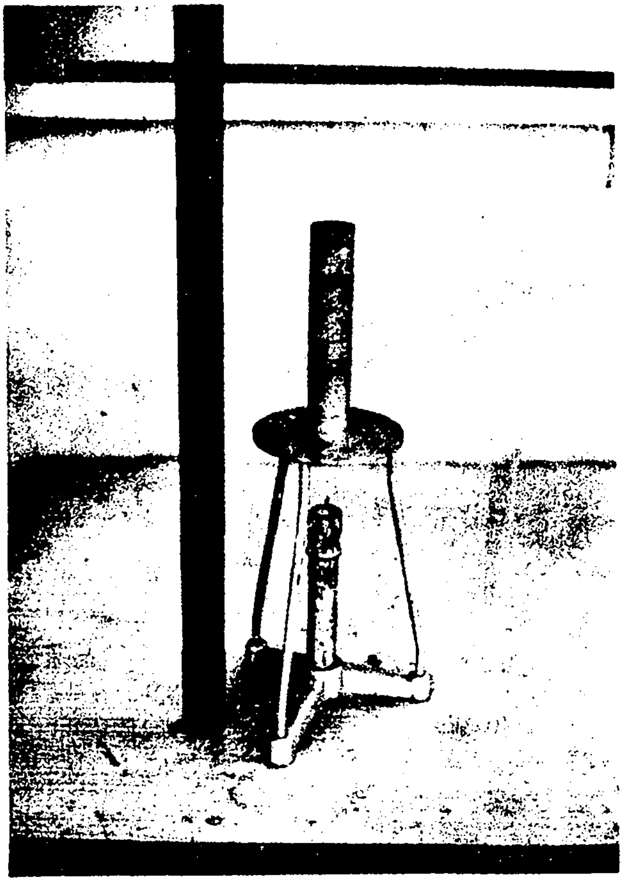


Fig. 13 - Jackson Candle Turbidimeter

IV PRESENTATION AND DISCUSSION OF RESULTS

All three series of runs were conducted at the Environmental Engineering Laboratory of the Asian Institute of Technology from January to May of 1971. Results from each series of runs are presented and compared in separate sections. A summary of results immediately follows each discussion. A final summary of conclusions from the three test series conducted are presented at the end of this section.

Selection and Preparation of Media

The sizes of media selected for the investigations made conformed to the original sizes found locally for raw and burnt rice husk and coconut husk. Coconut fiber was obtained from the coconut husk by grinding and shredding the husk then discarding the dust-like waste because it was very fine as a filter medium and would easily be blown away. Pea gravel was selected properly from a stock of gravel using a sieve apparatus to get a uniform size of 3/8 - 3/16". Charcoal was reduced in size since it can only be secured on the local market in different chunk-sizes. In the reduction of its size, two main difficulties were encountered: resultant sizes were found to have a non-uniformity coefficient of greater than 4.0 and the preparation was a tedious job with many of the fine particles being blown away resulting in considerable wasted material. Comparative sizes of media used are shown in Figures 14 and 15. Coconut husk was shown before and after grinding and shredding.

Fig. 14 - Comparative Sizes of Media

Fig. 15 - Comparison of Rice & Coconut Fiber

Sand used for the control filters were prepared by the standard method of selecting sand sizes with the corresponding percent distribution. Effective sizes and uniformity coefficients of the sand used were calculated from the percent distribution of sizes and sand were selected from a stock sand available from local construction supplies stores.

Run Series I: Exploratory Runs Using Various Media

The series of runs conducted on each media are discussed separately and results are presented in separate sections. A summary and comparison of runs in each series are given at the end of each section.

1. Pea Gravel Uniform size of 3/8"-3/16" pea gravel was used as the media in six (6) test runs. Figure 16 to 20 show the results obtained from downflow filtration at filtration rate of 2.5 and 0.25 $m^3/m^2/hr$ and influent turbidity levels of about 100 JTU and 1000 JTU. Figure 21 to 23 illustrates the performances of the media at upflow filtration rates of 8.0, and 2.5 $m^3/m^2/hr$ and influent turbidity of greater than 100 JTU and 1000 JTU.

Downflow filtration - In Run 1, the filtration rate was 2.5 $m^3/m^2/hr$ and influent turbidity was in the range of 100 - 350 JTU. The removal efficiency fluctuated significantly throughout the length of run and varied from 31 to 60 per cent, averaging 46 per cent. Turbidity removal at 40 cm below the top of bed shows a comparatively similar trend with that at 80 cm below the top, which was equal to the total depth of the bed. It is apparent that a 40 cm depth was not sufficient to insure high turbidity removals. The run was terminated due to a "breakthrough" of turbidity after 72 hours at which the efficiency went down to 23 per cent as can be seen in Fig. 16. The deterioration in effluent quality is termed as a "breakthrough" and attributed to the decrease in the removal capacity of the filter.

Fluctuation of efficiency was presumably due to the fluctuation of filtration rate which was difficult to maintain constant as the water level above the bed changed also. There was no constant-water-level controller used in these runs and control was done manually by adjusting the inflow valve to the filter from time to time. Incremental change of filtration rate consequently lead to sudden dislodgement of turbidity and thus, particles that had been filtered out and settled were carried deeper into the bed as the filtration rate went higher. Furthermore, there were times when the pores between the media were filled with deposition causing head loss to build up rapidly. Due to the relatively larger spaces between the grains, particles were carried deeper into the bed to equalize the flow. As a result, particles penetrated throughout the depth of bed and even extended into the supporting gravel. Figure 17 and 18 show the extent of particle penetration in the bed. The grain size and porosity of the media were attributable to the negligible head loss in the bed throughout the run. The head loss in the media is dependent upon these characteristics of media and thus with larger porespace, clogging of the bed seldom occurred at high filtration rates.

Run 2 was the same as Run I, only the influent turbidity was

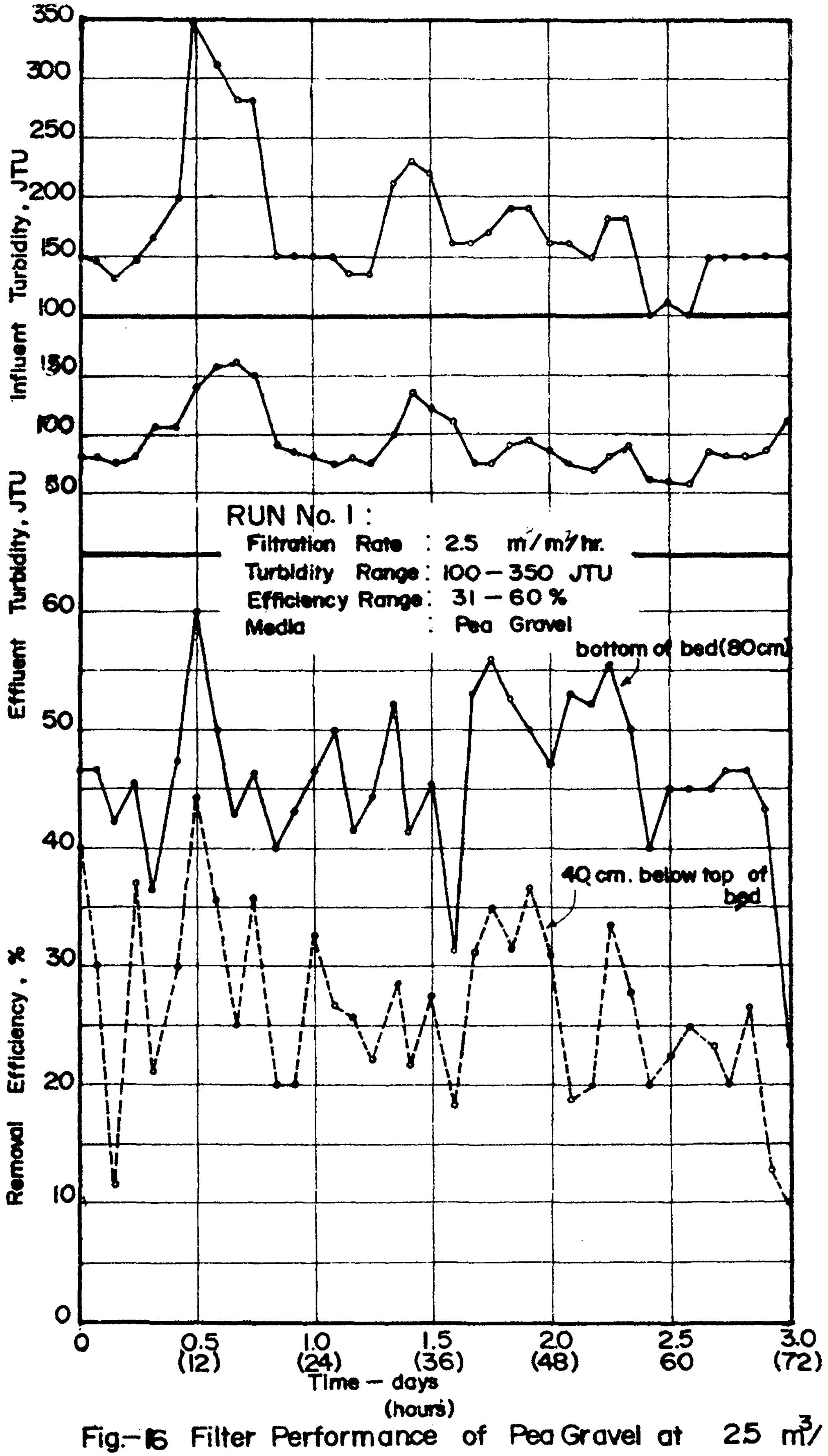


Fig.-16 Filter Performance of Pea Gravel at 2.5 m³/m²/hr.

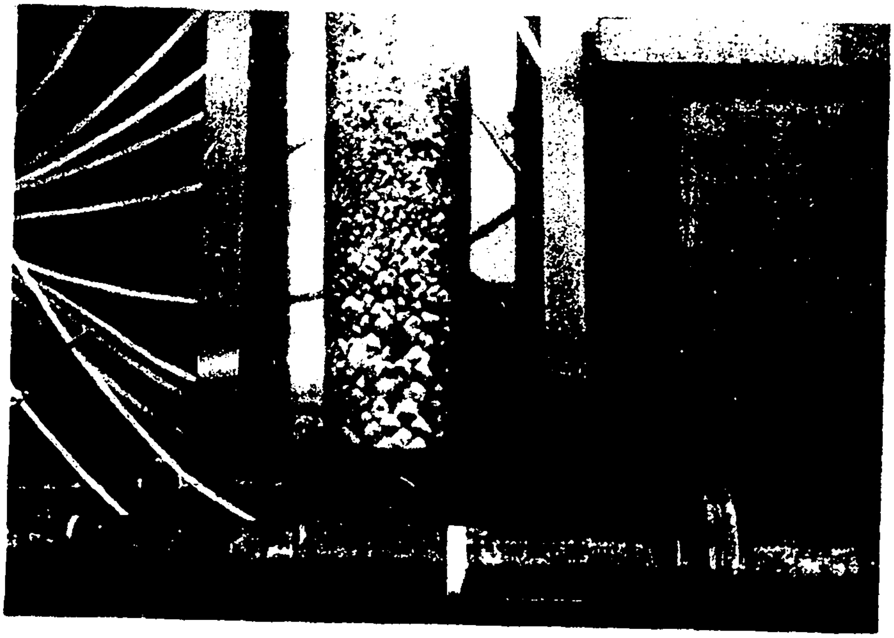


Fig. 17 Extent of Particle Penetration

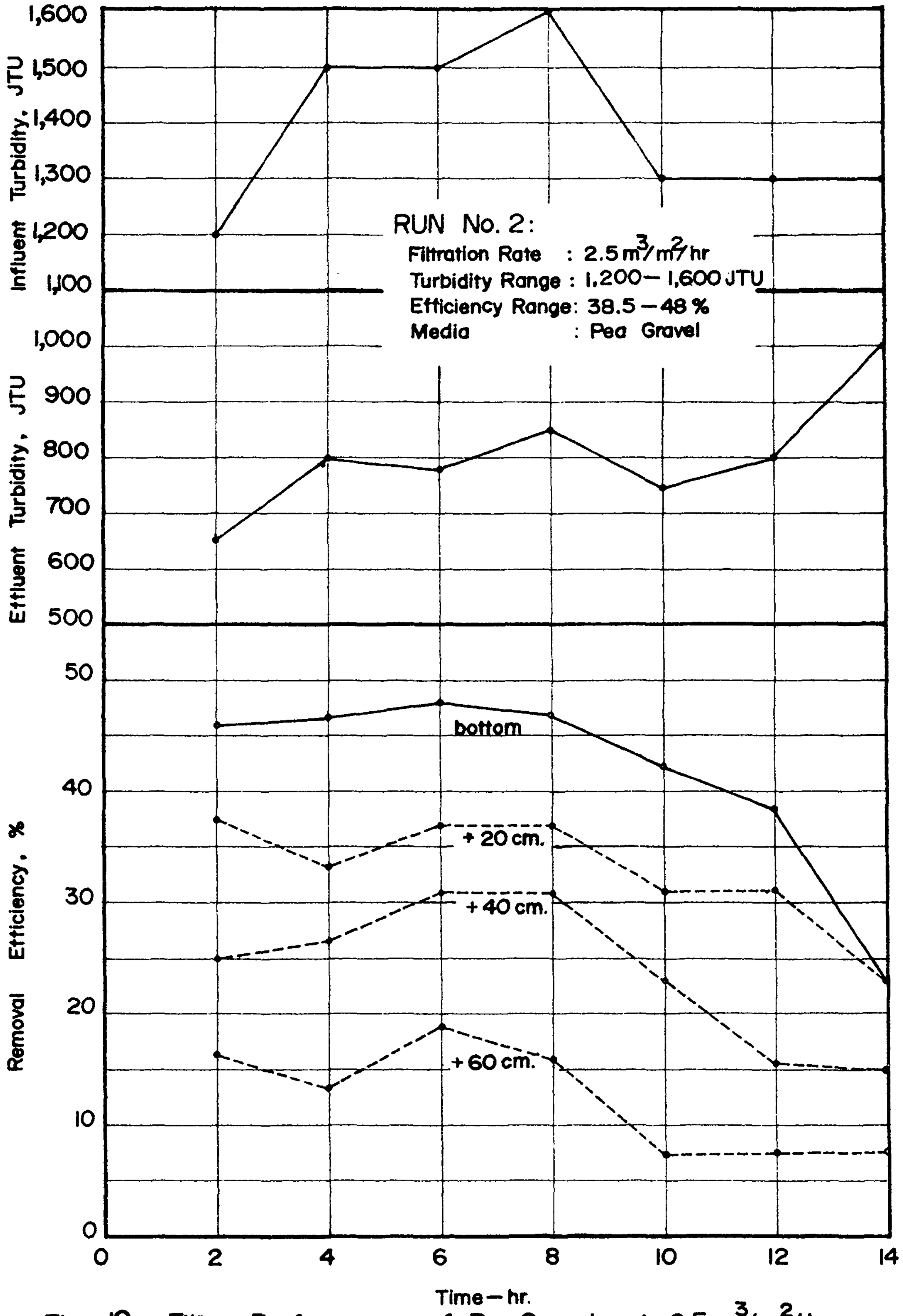
Fig. 18 - Bed Penetration in Pea Gravel

in the range of 1200 - 1600 JTU. Likewise, the run was terminated due to a filter breakthrough after 14 hours, when the efficiency went down to 23 per cent. In Figure 19, removal efficiency shows a smooth trend with a "break-in" period in the first four hours, increasing to 48 per cent and started to go down indicating deterioration in effluent quality. The decrease in effluent turbidity is referred to as the "break-in" period in the beginning of the filter run and is attributed to the increase in the removal capacity of the filter caused by the initial deposition of particles within the pores. Efficiency at different depths of bed shows relative ability of the media to arrest particles at different depths and can be seen that most of the particles are filtered out at lower than 40 cm below the top of bed. Average efficiency of this run was about 46 per cent regardless of the level of incoming turbidity. Penetration of particles was also throughout the bed as in Run I.

The smooth trend of removal efficiency indicated that no sudden dislodgement of turbidity or incremental change in flow rate occurred during the run and that the media has a limited capacity to hold the deposited particles within its pores with no subsequent head loss in the bed.

The coarse-grain media was also run at 0.25 $m^3/m^2/hr$ with an influent turbidity level of 125 - 180 JTU for twenty eight (28) hours with no breakthrough occurring as well as negligible head loss.

Removal efficiency was in the range of 92.3 - 95.4 per cent and it can be seen from Figure 20 that most of the turbidity was removed in the top 40 cm of the bed unlike in Runs 1 and 2 where turbidity was removed at lower than 40 cm. Performance at this rate was



Fig—19 Filter Performance of Pea Gravel at 2.5 $m^3/m^2/hr$.

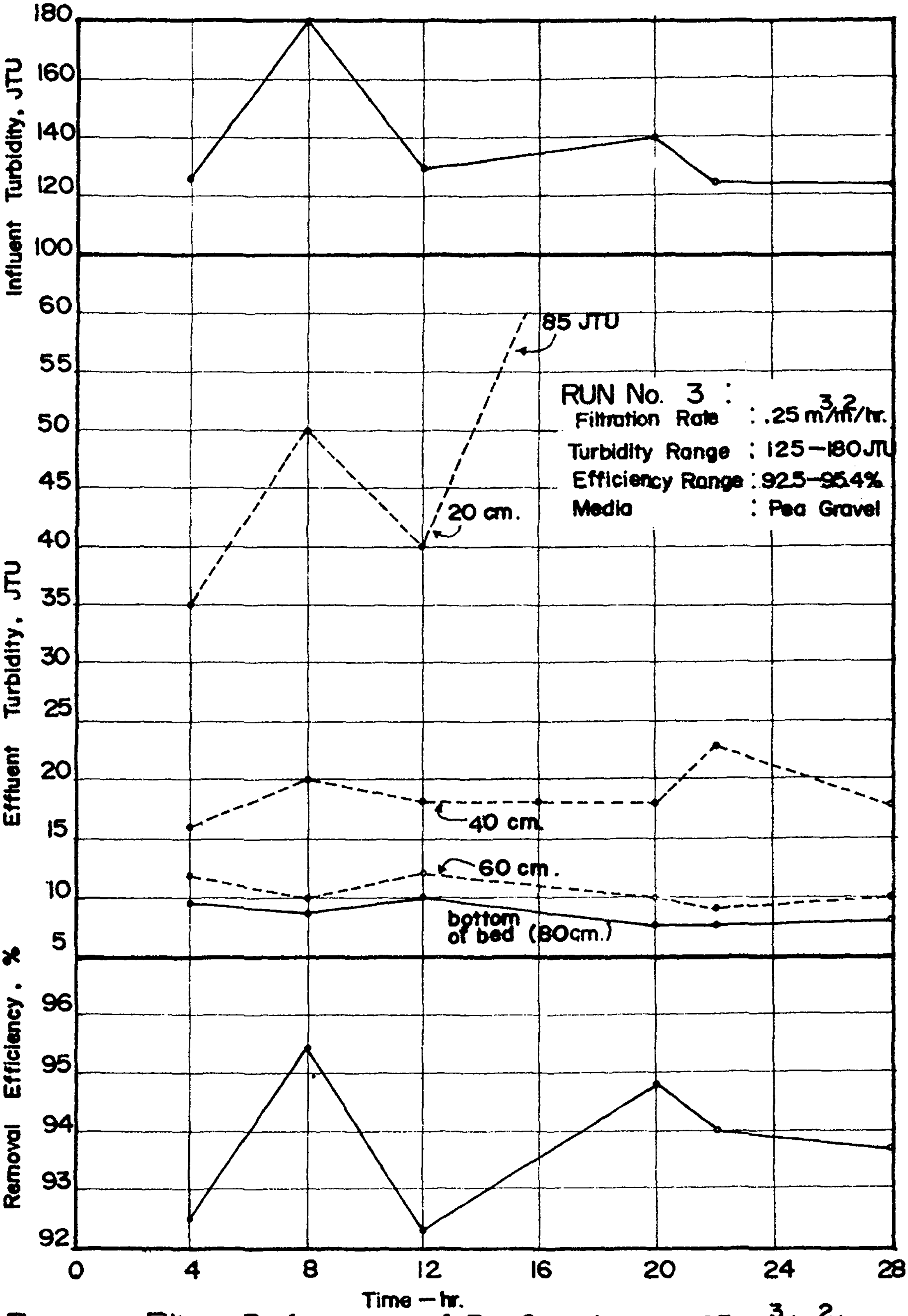


Fig.—20 Filter Performance of Pea Gravel at .25 m³/m²/hr.

significantly better than the two previous runs. The run was terminated with the intention to conduct a longer-time study in Run Series II.

At this lower flow rate, particles were given a greater chance to coalesce, forming bigger particles which settled more easily. Thus, the particles formed a surface mat on top of the bed and aided the filtering capacity of the media by decreasing the pore size. Bed penetration was primarily in the top 20 cm of the bed, although, noticeable penetration could be seen in thelower portion which was due to the finer particles that have passed through the top portion.

Upflow filtration - With this filtration process, breakthrough phenomenon were observed for all runs and was the reason for the termination of run with no subsequent head loss. Figure 21 show the performance of the media at 2.5 $m^3/m^2/hr$ and influent turbidity level of 1500 - 3000 JTU. The run was terminated after twenty hours with a decrease in efficiency from about 63 per cent (with a range of 45.5 - 66.6 per cent) to 23 per cent.

It was observed visually that the particles that penetrated up through the bed either remained in suspension or settled down on top of the bed. Presumably, those particles that settled had a greater settling velocity than the upward velocity of the water. Particles that remained in suspension increased in concentration as the run progressed. Breakthrough occurred when the suspended particles were carried up by theoutgoing water. This increases in turbidity, however, did not occur at the top of the bed until its filtering efficiency had deteriorated. No expansion of the bed or sedimentation at the inlet bottom occurred with this type of filtration.

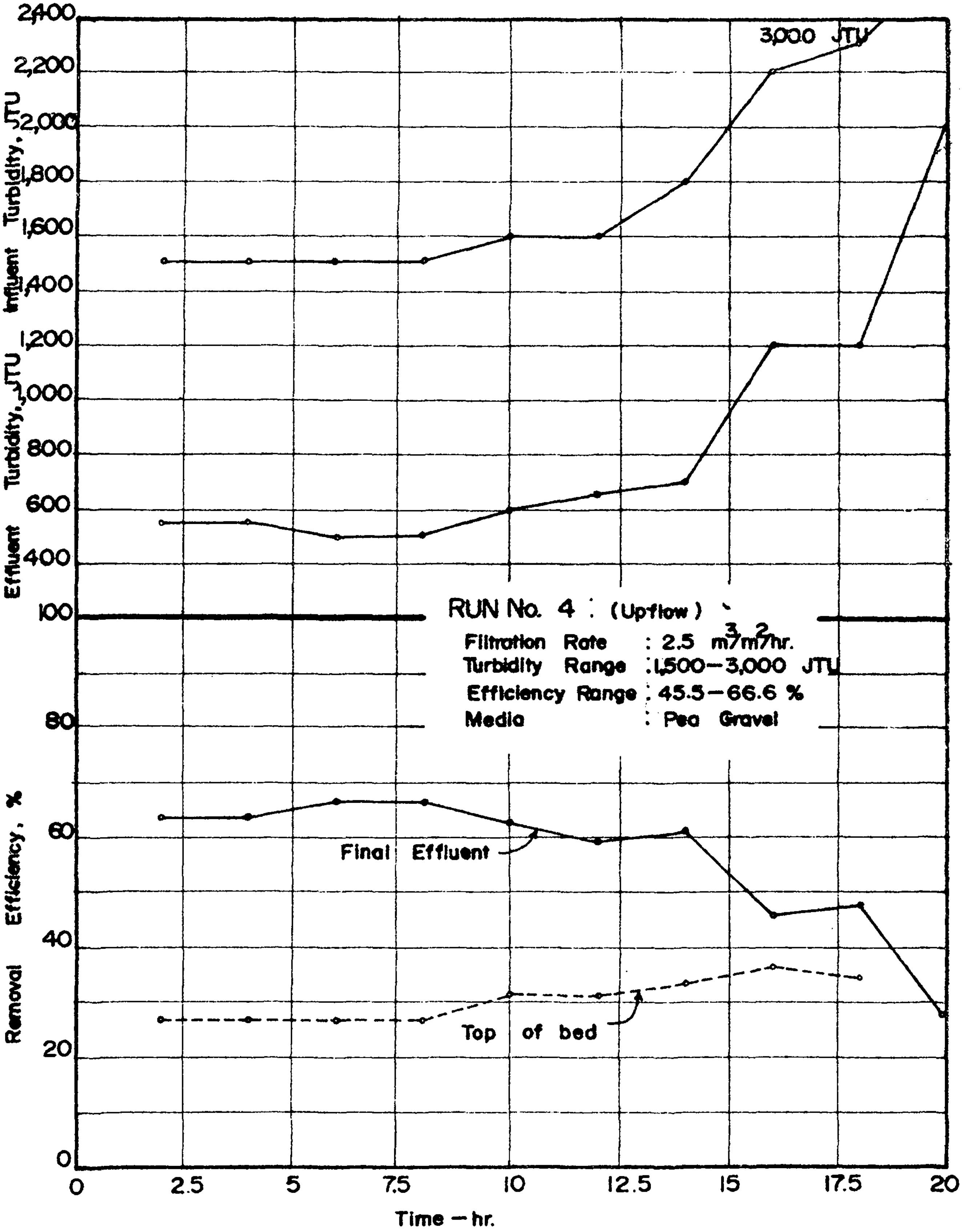


Fig.— 21 Filter Performance of Pea Gravel at Upflow Filtration

A run was also conducted on this media at high filtration rate, three times the normal rapid rate. Figure 22 shows the fast deterioration in efflunet quality, occurring after 5 hours only. With a relatively high filtration rate, approximately 8 $m^3/m^2/hr$, no head loss occurred through the run. Efficiency was down to 33 per cent and further decreased to 23 per cent, whilst at the top of the bed the efficiency was between 12.5 and 14.5 per cent. This point clarified the fact that at higher filtration rates and higher turbidity loadings, shorter filter runs resulted.

Figure 23 shows the performance of the media during filtration at same rate as Run 4 but at a different influent turbidity range, i.e., 140 - 250 JTU. It was seen that the trend of removal efficiency for the final effluent and at the top of the bed was similar to that in Run 4 up to the 20th hour. Beyond this, filtering efficiency of the filter bed appeared to be constant in the range of 40 - 50 per cent, whilst that of the final effluent had a deteriorating trend. The run lasted only for 64 hours due to breakthrough with no head loss occurring. Thismedia would not give any head loss prior to a deterioration in effluent quality.

Summary of results on the performance of pea gravel - It is apparent in all the runs conducted on this media that the reason for the termination of the run was the breadthrough of turbidity after an efficient removal of gross turbidity. It is believed that there is a limit as to the turbidity load the filter media can deposit within its pores and once this limit is exceeded,

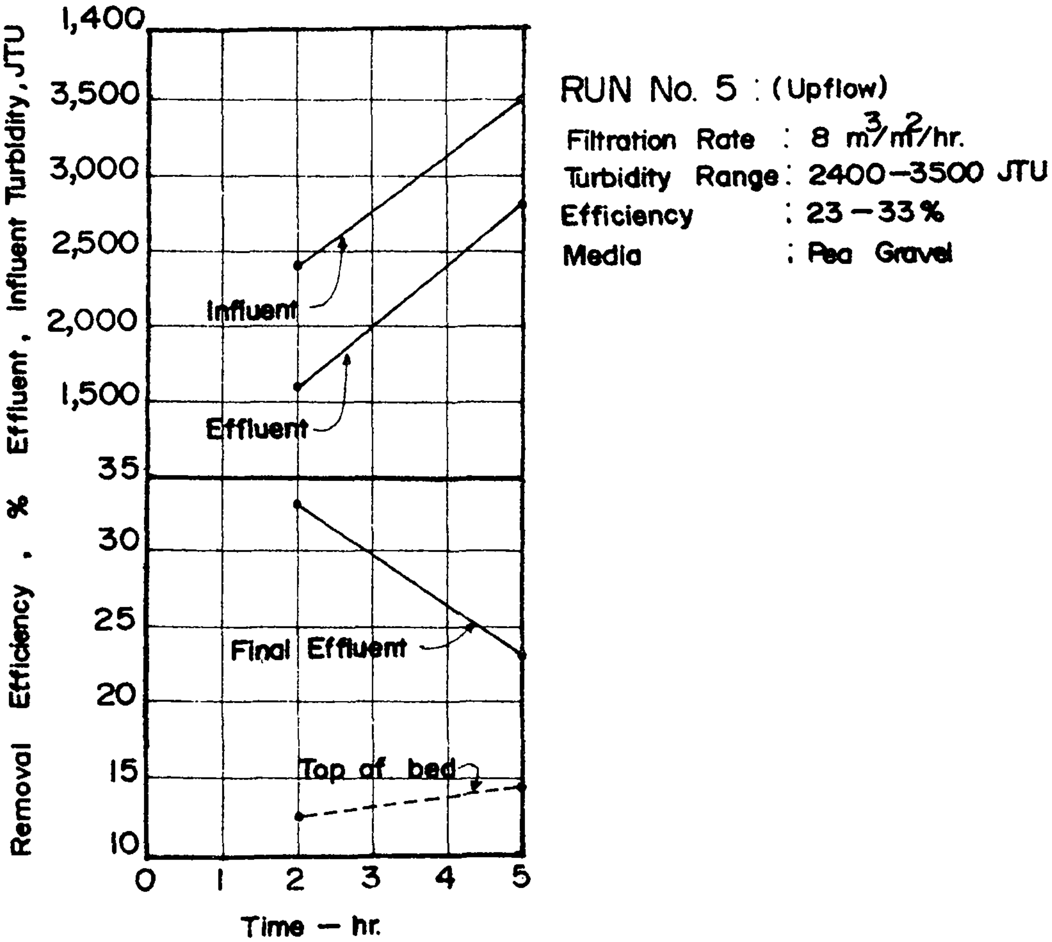


Fig.— 22 Filter Performance of Pea Gravel at 8 $m^3/m^2/hr.$

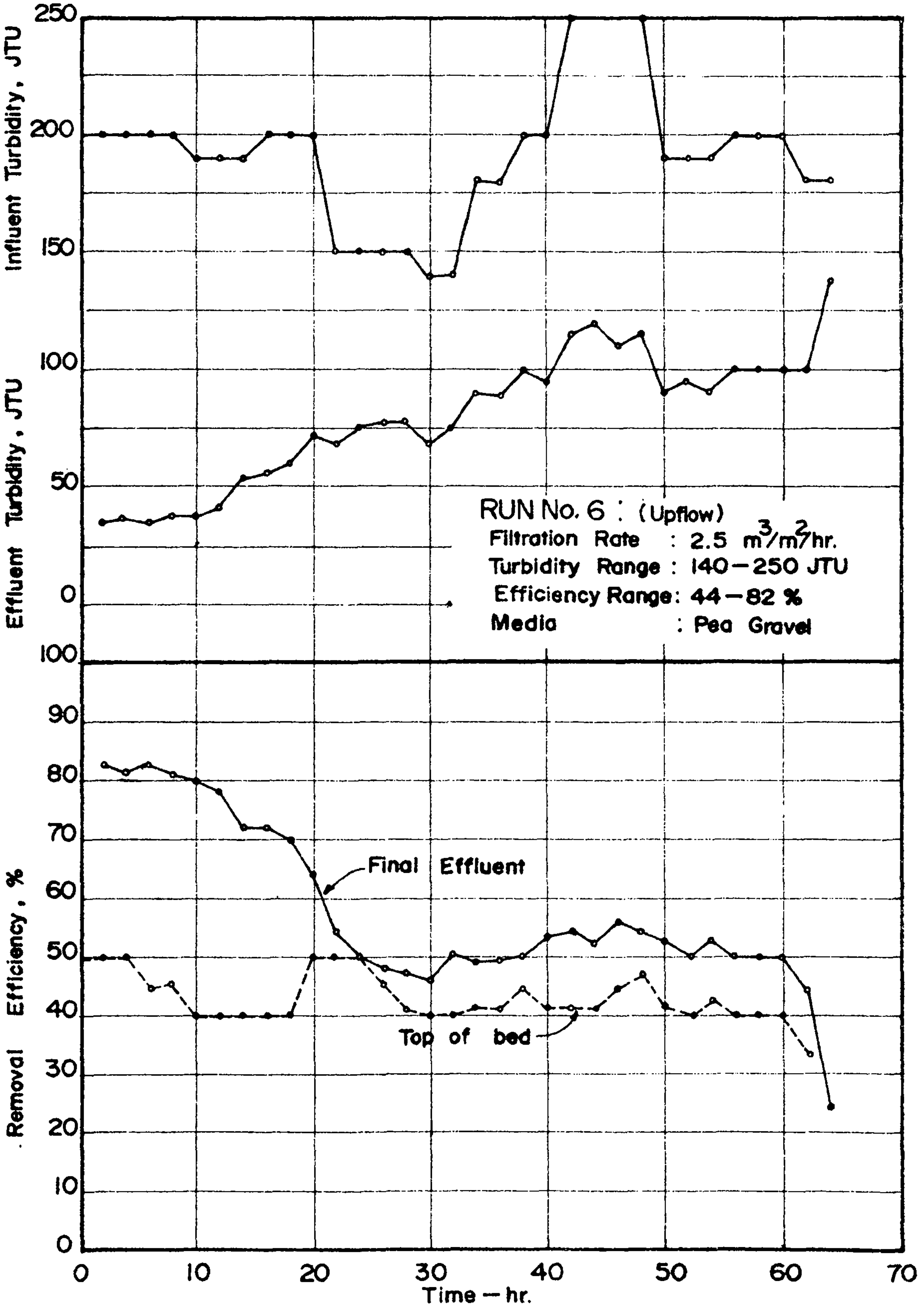


Fig.— 23 Filter Performance of Pea Gravel at Upflow Filtration breakthrough will occur. This limit is constant, however, the time before this limit is exceeded is dependent upon the influent turbidity level, kind of turbidity and filtration rate and likewise, the length of run is dependent on this limit.

As pointed out by SEGALL and OKUN (1965), one guide in selecting a media or operating conditions for a specific media is to permit maximum head loss before "breakthrough" occurs and this is fixed by the hydraulic gradient of the bed. In this investigation, it appears that his guide is inapplicable because the hydraulic gradient of the bed will only be significant at extremely high filtration rates in which case practically no removal of turbidity will be accomplished.

Results from test runs conducted using the downflow process show that removal of gross turbidity is more efficient at low filtration rate than higher rate of 2.5 $m^3/m^2/hr$. Upflow filtration give higher removal efficiency than downflow filtration for the same filtration rates and level of turbidity. Average turbidity was approximately 60 per cent for both levels of turbidity which tallied with the results obtained from downflow filtration that average efficiency was the same for both levels of turbidity. This indicates that removal efficiency is independent of influent turbidity before occurrence of breakthrough but dependent on filtration rate. There was no significant head loss in the filter bed in all the runs prior to the deterioration of filtrate quality. Filtration rates higher than 2.5 $m^3/m^2/hr$ definitely will not give an efficient removal.

It is apparent in Figure 24 that the removal efficiency of

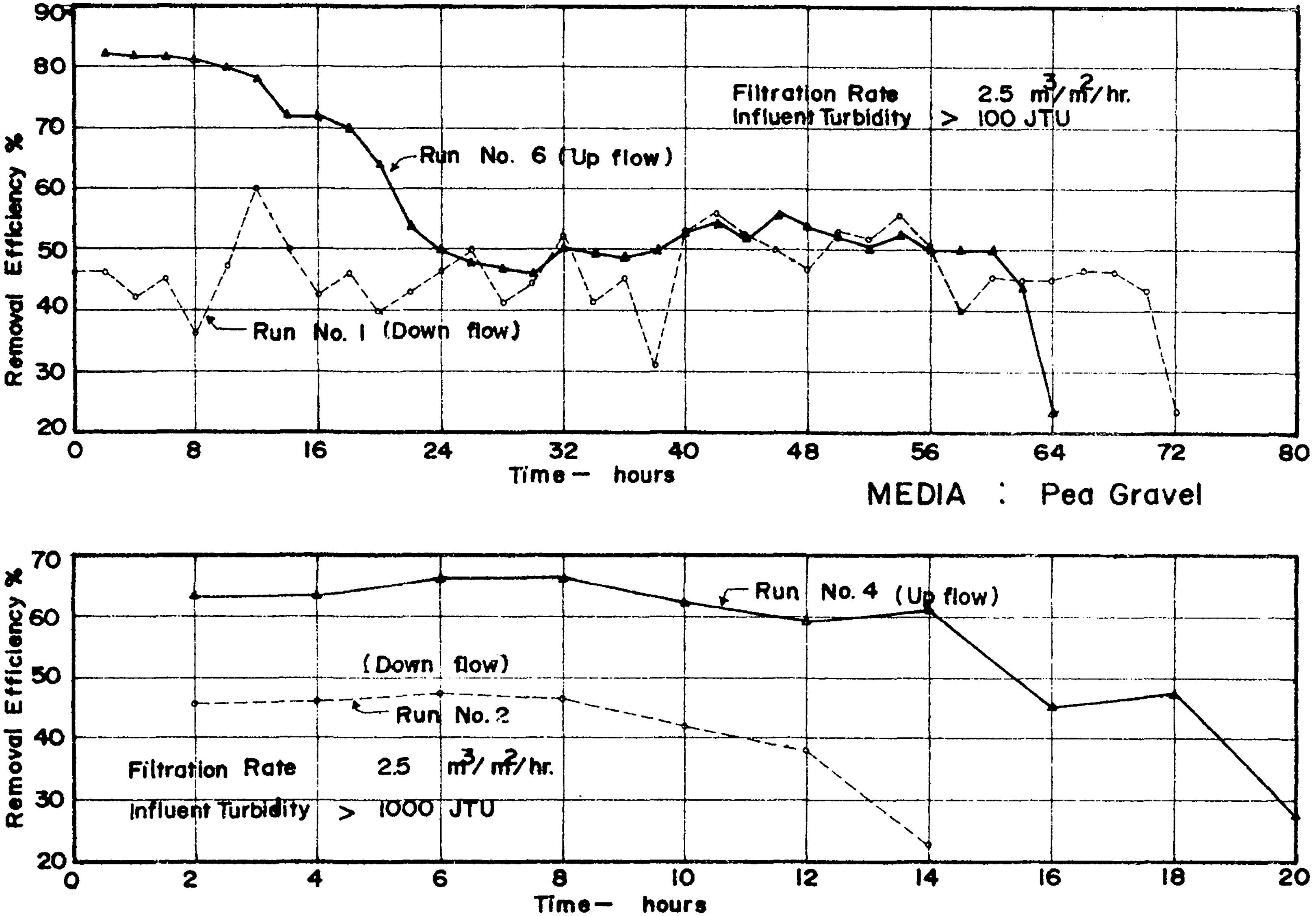


Fig.—24 Comparison of Removal Efficiency using Downflow and Upflow Filtration upflow filtration was better than downflow process at influent turbidities greater than 1000 JTU but relatively similar for the turbidity level of about 100 JTU. Performances of the four runs do not give a reliable conclusion or justification for selection since the length of run differs for each comparison. This may be due to the difference in influent turbidity range since the tests were conducted individually. So far, the relative merit of each process cannot be established from this investigation. The only relative merit of downflow filtration that is worth mentioning is the simplicity of operation involved compared to upflow filtration.

2. Burnt Rice Husk Three test runs were conducted on this media: Two with filtration rate, 1.25 $m^3/m^2/hr$ at two levels of turbidity and one for 2.5 $m^3/m^2/hr$ filtration rate and influent turbidity of greater than 100 JTU. Figures 25 to 29 illustrate the results obtained from the test runs.

The first test run conducted on this media was at a filtration rate of 2.5 $m^3/m^2/hr$ and influent turbidity level of 140 - 300 JTU. The significant build-up of head loss after 16 hours is apparent in Figures 25, the termination of run due to head loss of 1.2 meters. The increase in head loss did not result with corresponding increase in effluent turbidity. Effluent turbidity was only affected by influent turbidity at the beginning of the run after which, it remained fairly constant at 0.10 JTU, despite the changes in influent turbidity. Bed penetration was up to 20 cm. from top of bed with the heaviest concentration on the top 10 cm and a surface mat on top of bed. Hydraulic gradient through

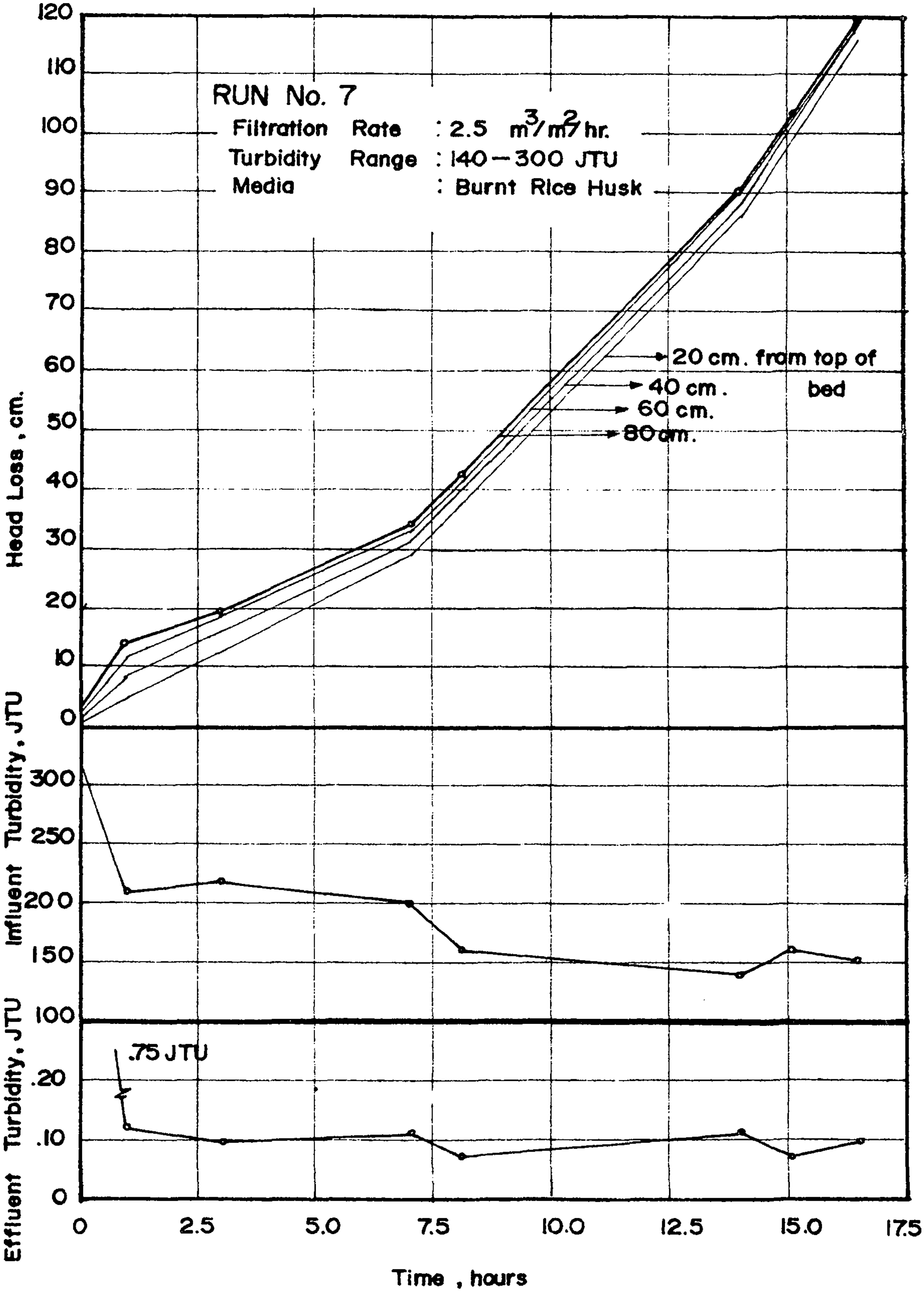


Fig.— 25 Filter Performance of Burnt Rice Husk at 2.5 $m^3/m^2/hr$.

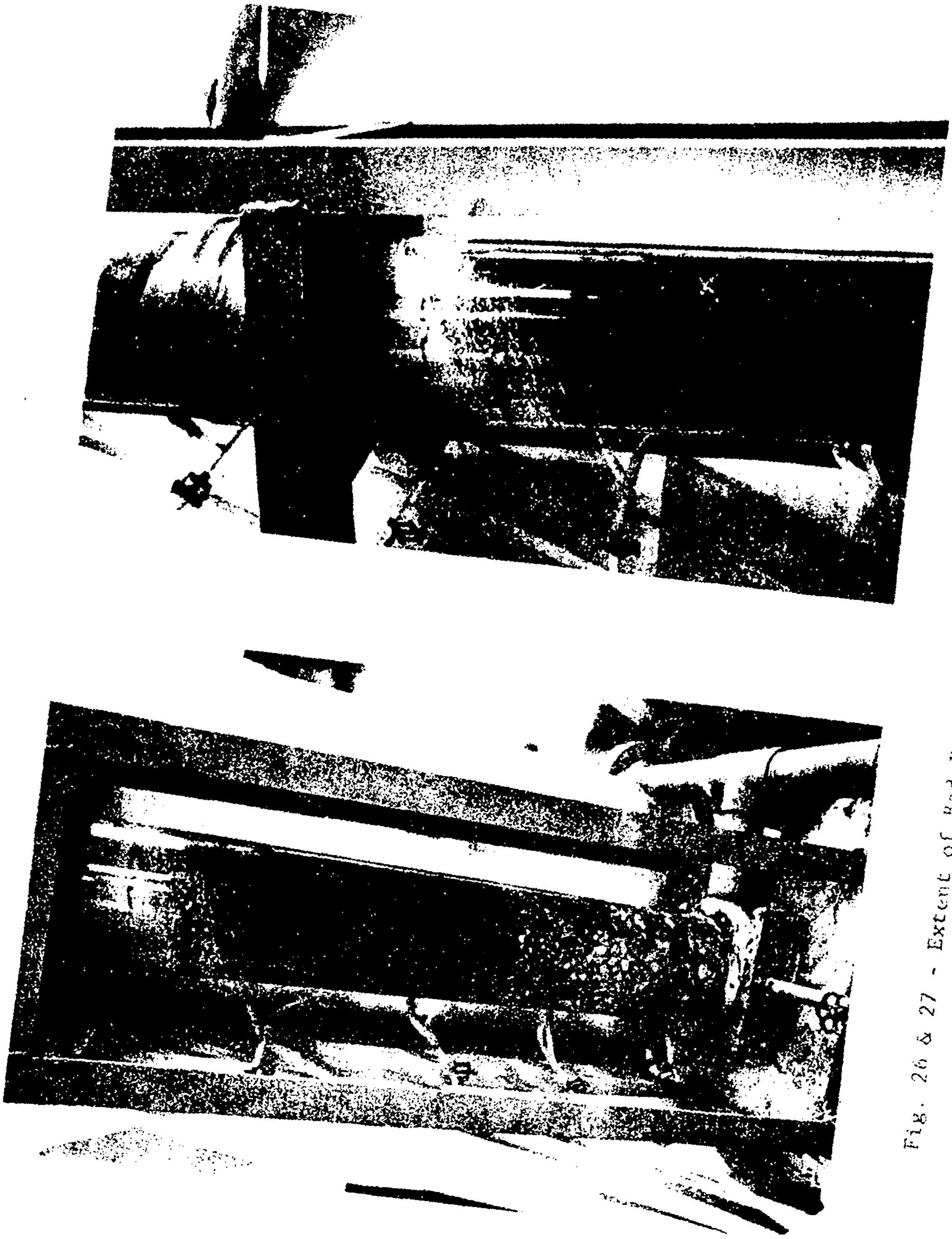


Fig. 26 & 27 - Extent of Bed Penetration in Burnt Rice Husk the bed appears to be constant throughout the run but with an exponential shape.

The main difficulty encountered was the bed expansion after the introduction of water. It was therefore necessary to put a fine mesh wire of 1 mm opening on top of the bed to prevent the bed from expanding and fine media from floating. The screen was observed to have aided in filtering but the extent to which it helped was not investigated. However, after initial deposition and absorption of water by the media, the filter bed remained in place and was noticed to have compacted by 2-3 cm from the original depth.

Removal efficiency was well over 99.9 per cent throughout the run. Despite the changes in influent turbidity, effluent turbidity appears to be independent of this change at this filtration rate with no deterioration in removal capacity before the occurrence of 1.2 m head loss. The length of run was relatively short which is attributable to both high filtration rate and influent turbidity.

Visual observations showed that particles were not just filtered out by the mechanical straining action but was helped by adsorption. This phenomenon was observed visually with some of the particles adhering to the grains and some to other particles. DANIELS and ALBERTY (1966) explained that this is due to the attractive forces of atoms and molecules in the surface of the solids, dependent on the specific nature of the solids and molecules being adsorbed and a function of concentration and temperature. This was further verified by HUISMANN (1970) as one of the important actions that occurs in slow sand filtration which affects removal of colloids, bacteria and viruses. It is however, a complex phenomenon, not yet fully understood.

Results from Run 7 indicates that higher influent turbidity at the same filtration rate would result in shorter filter runs. No further attemp was made to investigate effects of higher filtration rates using high turbidity levels. The fluctuation in head loss rate is apparent in Fig. 28 at 1.25 $m^3/m^2/hr$ filtration rate and influent turbidity level of 60 - 190 JTU. However, the trend appears to be the same or in Run 7 with an exponential head loss through the length of run. *The fluctuation of head loss may be due to short circuiting* of the particles on the side of the column as can be seen in Figures 26 and 27. Penetration has extended to 40 cm of the filter depth but only on one side. Another reason for the fluctuation was probably the change in filtration rate trhough the length of run. Apparently the sudden change in filtration rate affected the head loss since it was highly dependent on flow rate. The run was terminated due to a head loss of 1.2 meters after almost seven days with no significant increase in effluent turbidity.

It appears that the effluent turbidity is not affected by influent turbidity because increase in influent turbidity did not result in corresponding increase in effluent turbidity. Effluent turbidity was well below 0.10 JTU throughout the run except during the break-in period of the clean bed. The dip in the curve at the 50th hour was not affected by the influent turbidity as can be seen in Figure 28. Removal efficiency was over 99.9 per cent and in

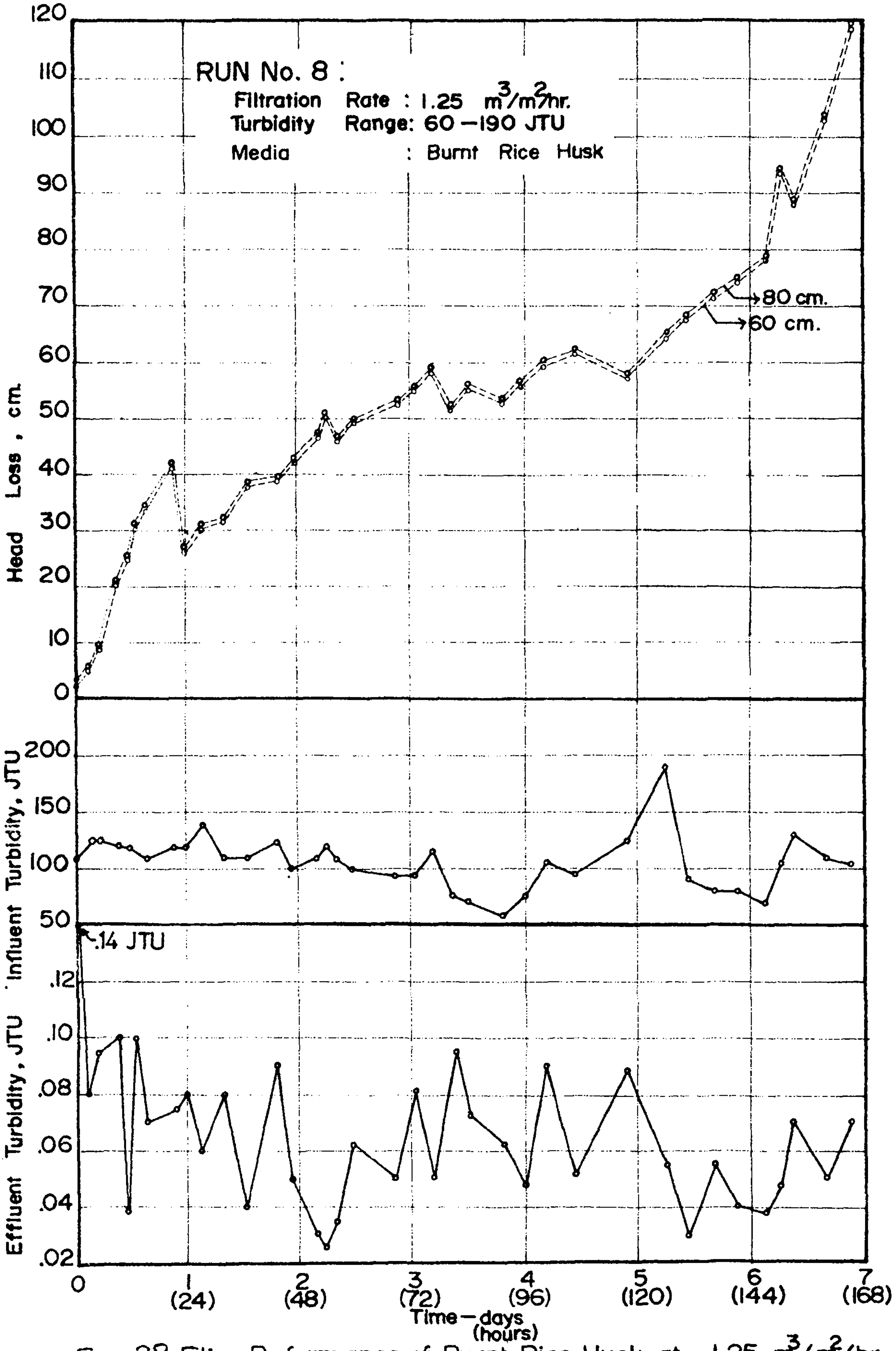


Fig.– 28 Filter Performance of Burnt Rice Husk at 1.25 m³/m²/hr.

some occasions were almost 100 per cent. Real bed penetration was on the top 5-10 cm only with a surface cake of about 1.5 cm on top of the filter bed. Inspite of the short circuiting of particles, no significant effect appeared in the effluent turbidity even when the head loss was 1.2 meters.

At influent turbidity levels of 900 - 1300 JTU and the same filtration rate, effluent turbidity se ms to be higher than at influent turbidity level of 60-190 JTU. However, removal efficiency was well over 99.9 per cent throughout the run. It is apparent in Figure 29 that break-in period occurred up to the 25th hour followed by a drop in effluent turbidity. At this point, effluent turbidity appeared to be similar to the previous run but the filter run had to be terminated due to a head loss of 1.2 meters. The smooth trend of head loss curve indicated that no fluctuation in filtration rate and/or short circuiting of particles occurred. Filter run was relatively longer than Run 9 inspite of the high influent turbidity level. It is believed that the rate of filtration has more effect on the length of run of this media than the level of influent turbidity.

Summary of results on performances of burnt rice husk - Filtration rate of 1.25 $m^3/m^2/hr$ appears to be more attractive than 2.5 $m^3/m^2/hr$ for any level of influent turbidity in terms of head loss rate and length of run. Effluent turbidity does not seem to be significantly affected by the range of filtration rate studied and the influent turbidity levels. There were no occurrences of particle breakthrough in all the runs inspite of short circuiting in one

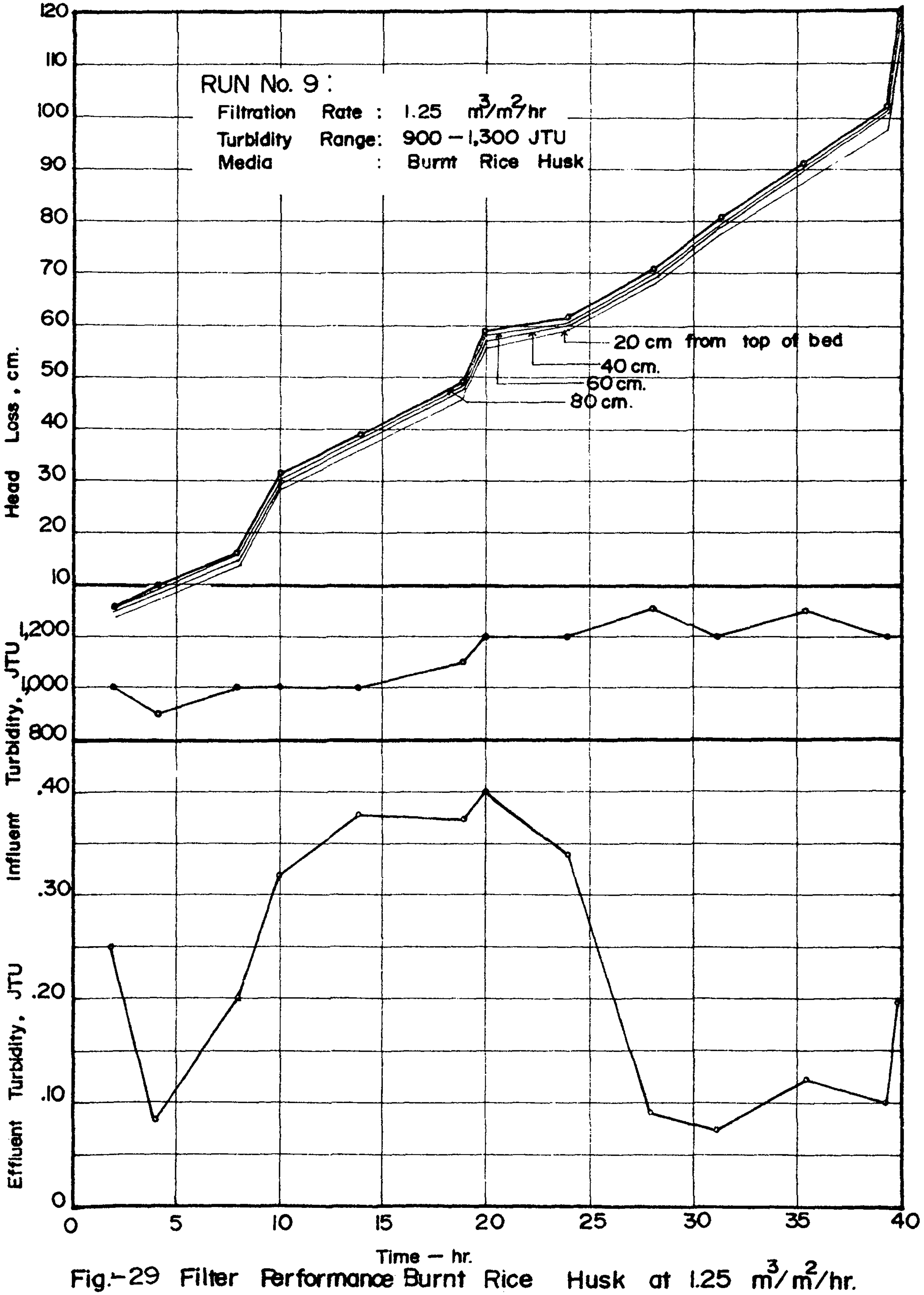


Fig.-29 Filter Performance Burnt Rice Husk at 1.25 m^3/m^2/hr.

of the runs. Termination of runs was mainly because of final head loss of 1.2 meters with no corresponding increase in effluent turbidity.

Penetration in the bed were dependent on filtration rate, the higher the filtration rate, the deeper the particle penetration. Likewise, the thickness of the surface mat on top of the bed was inversely proportional to the filtration rate. The hydraulic gradient of the bed appears to be linear but the head loss throughout the run appears to be exponential. This media could not be cleaned by washing and would have to be removed from the filter and wasted after each run. Table 20 summarized the results and the amount of water filtered until a head loss of 1.2 meters was obtained.

Table 20

Summary of Results of Burnt Rice Husk

Run No.	Filtration rate ($m^3/m^2/hr$)	Influent Turbidity Range in JTU	Removal Efficiency in Per Cent	Amount of Water Filtered
7	2.5	140 - 320	99.9	20.6 $m^3/m^2$of bed
8	1.25	60 - 190	99.99	208.0 $m^3/m^2$of bed
9	1.25	900 - 1300	99.99	50.0 $m^3/m^2$of bed

3. <u>Raw Rice Husk</u> Test runs were conducted using raw rice husk as shown in Figures 30 to 32. Filtration rates studied were: 2.5 $m^3/m^2/hr$ at influent turbidity levels of 1000 - 2000 JTU and

60 - 500 JTU and 1.25 $m^3/m^2/hr$ at level of 800 - 1600 JTU. Difficulty in preventing thebed from floating was encountered and to prevent it from floating, a wire mesh screen was placed on top of the bed. The media gave highly colored water, about 140 Hazen Units in the first hour of run but reduced to zero after six (6) hours of operation. It was observed that the color comes from the media itself and if soaked overnight or used for a longer time, color would not appear. Furthermore, if the media was soaked in water for a long time, 6-8 hours, it would not float when placed in use.

The increase in head loss with corresponding increase in effluent turbidity is apparent in Figure 30. It appears that head loss started to build up only after the bed was completely saturated with colloidal material and effluent quality had started to deteriorate. Head loss was only 32 cm after 74 hours and termination of the run was due to breakthrough. Filtrate quality was not affected by influent turbidity after break-in and before breakthrough. Removal efficiency was well above 95 per cent before breakthrough started at the 52nd hour and continued to decrease up to 87 per cent after which the run was stopped. At this filtration rate, it appears that the particles were deposited first in the upper layer and penetrated deeper only after breakthrough started, resulting in the usage of the whole bed depth. This effect can further be seen in the change of the hydraulic gradient in the bed, where the differences of head loss between different points in the filter bed increased. The significant feature of this media is the bowl-like appearance of each grain where the particles settle. This characteristic seems to be more efficient than

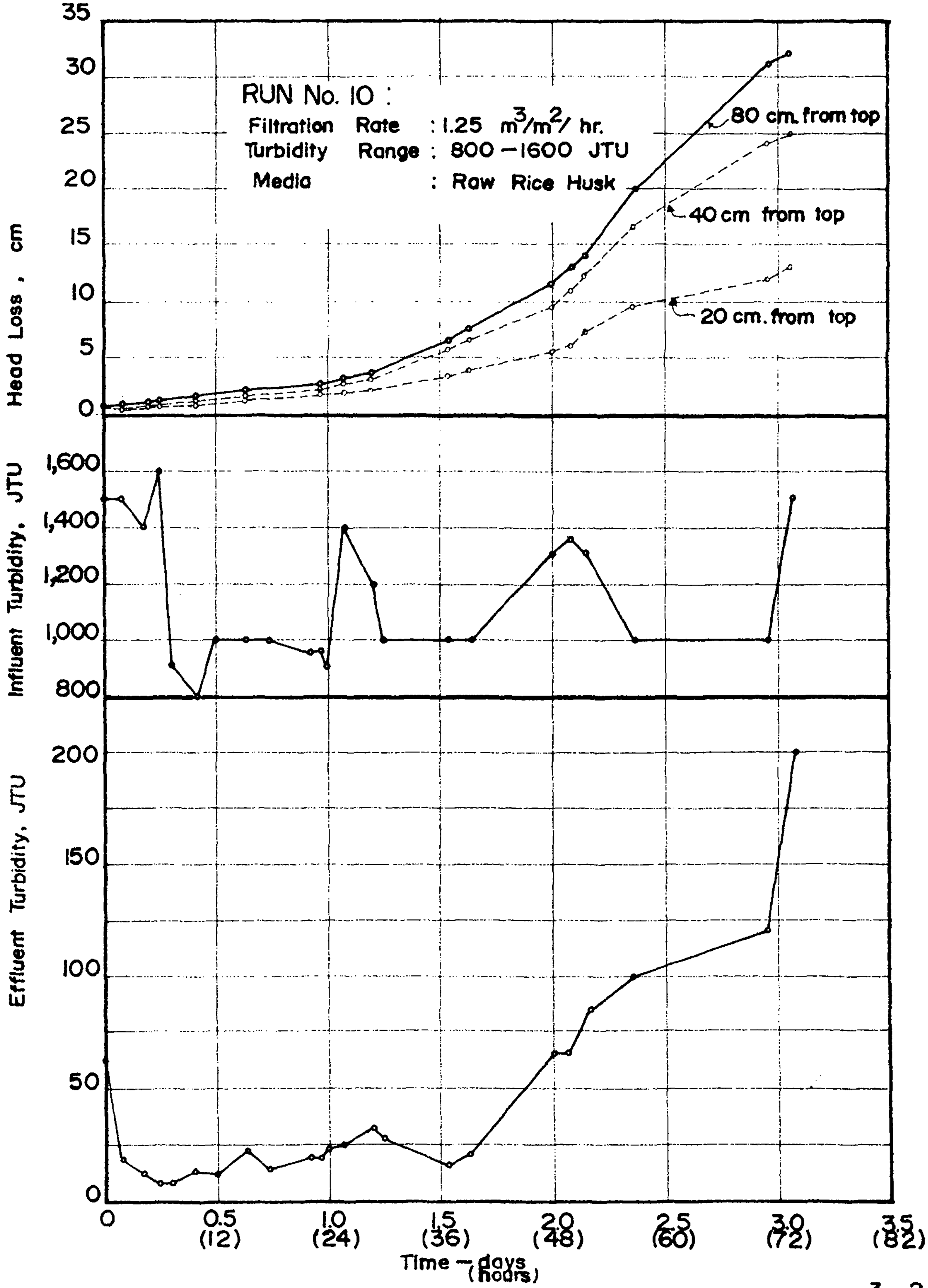


Fig.– 30 Filter Performance of Raw Rice Husk at 1.25 m³/m²/hr.

simple filtration, but the drawback is in cleaning the filter which makes it difficult to remove the particles caught between the grains. The media would need to be wasted after each run.

It is apparent in Figure 31 that at higher filtration rates clogging of pores in the media was less and that lower head loss in the bed occurred. Particles were carried faster down the bed hence effluent turbidity was of poorer quality and for relatively porous media, breakthrough occurred faster too. There seemed to be no efficient removal period since right after the break-in period, breakthrough started. Filtrate quality was not affected by the influent turbidity even after breakthrough, which could be due to the filtration rate of 2.5 $m^3/m^2/hr$, twice that in Run 10. Removal efficiency was over 95 per cent up to the 10th hour and continued to decrease to 80 per cent until the run was terminated after 16 hours.

After this run, the media was taken out and cleaned by hand before put into use for the next run. Run 12 was similar to Run 11 only the turbidity level was 20 - 500 JTU. Noticeable fluctuations in effluent turbidity corresponding to changes in influent turbidity occurred in this run. Removal efficiency was comparatively lower than the other two runs which was only over 80 per cent before breakthrough occurred at the 80th hour. However, the run was continued until the removal capacity of the media had really deteriorated to about 60 per cent. Influent turbidity seems to have affected the effluent quality even after breakthrough. This actually is in conflict with the results in Run 11 but this could be due to the faster

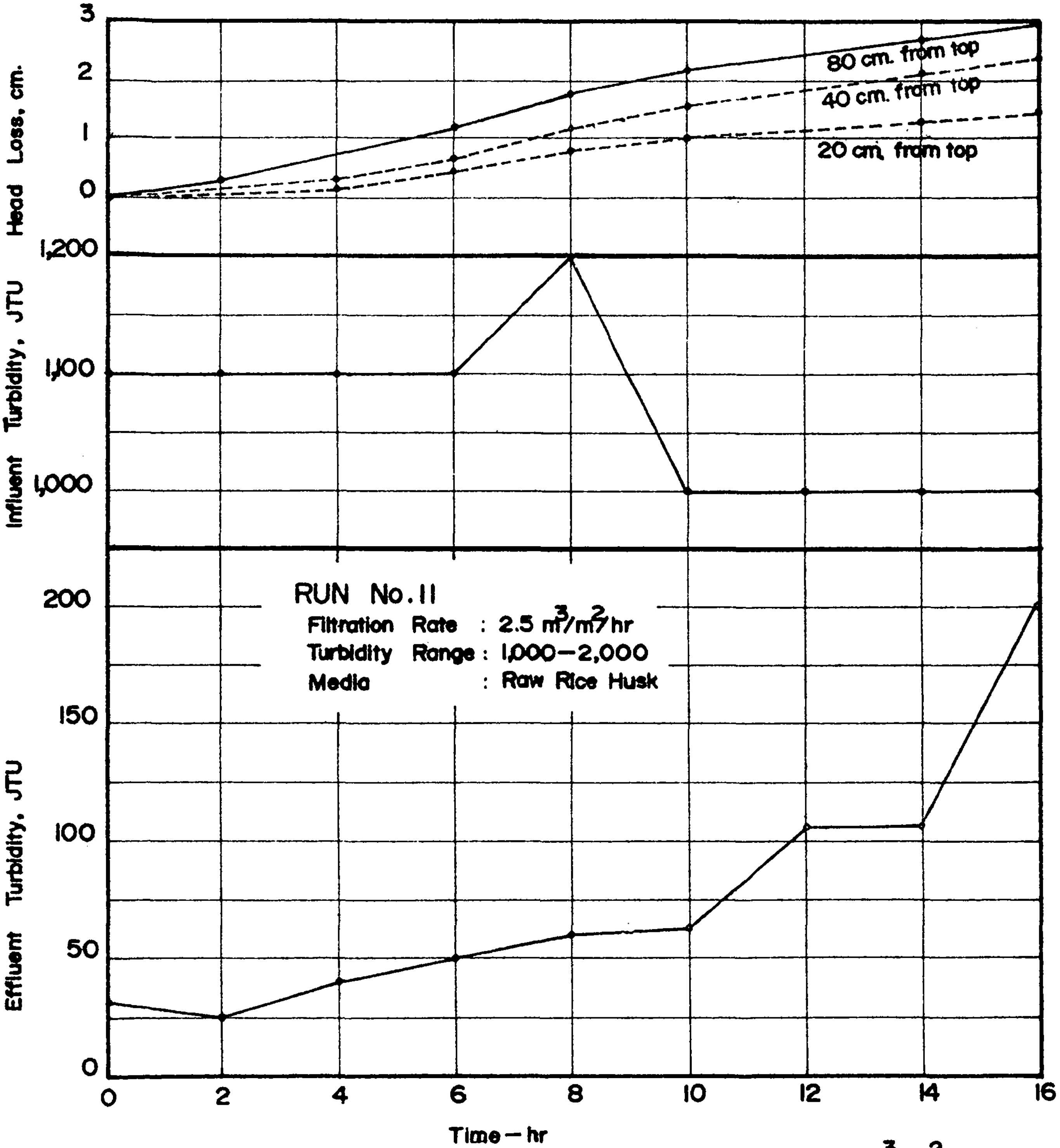


Fig.-31 Filter Performance of Raw Rice Husk at 2.5 $m^3/m^2/hr$.

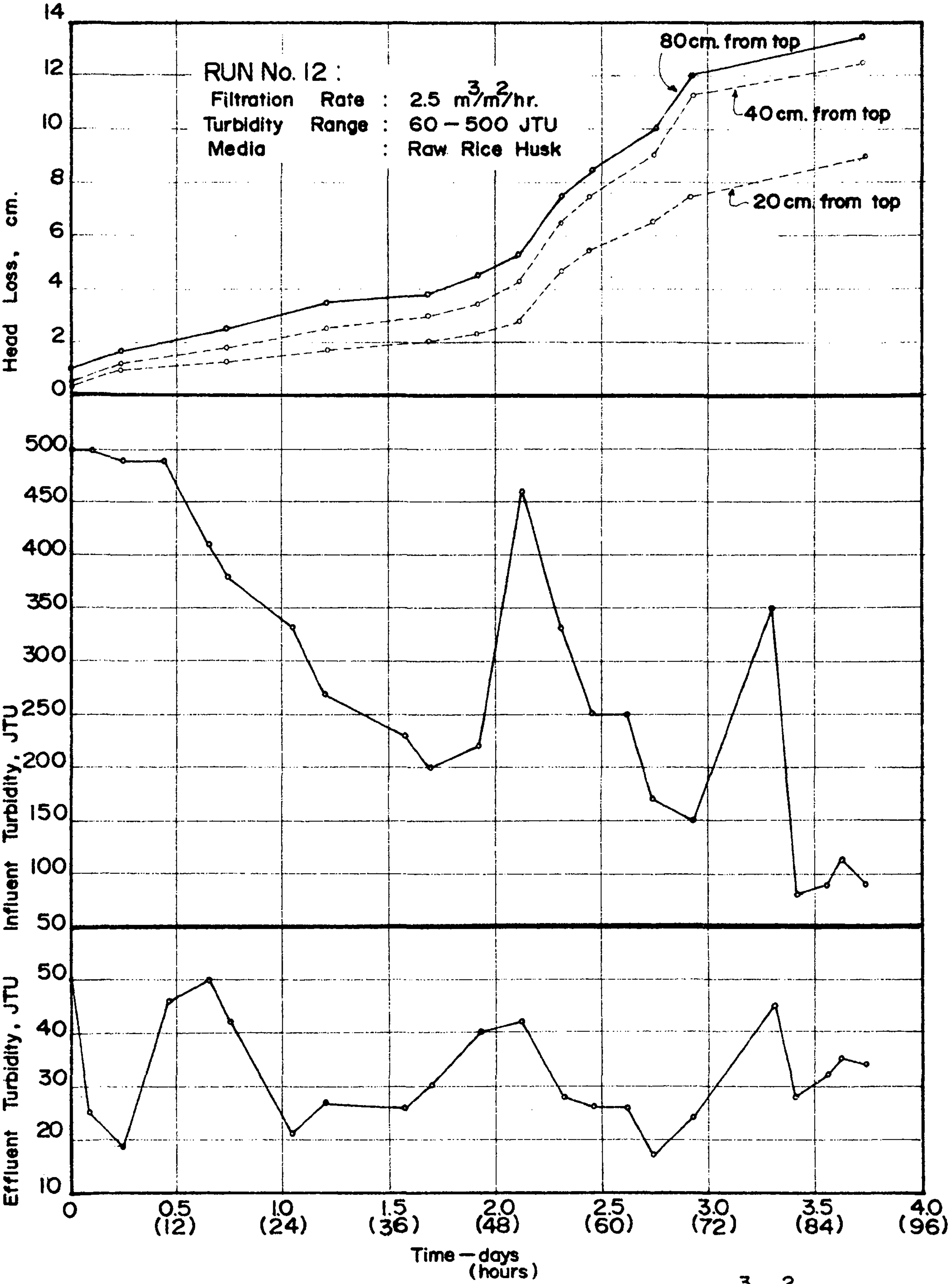


Fig.– 32 Filter Performance of Raw Rice Husk at 2.5 $m^3/m^2/hr$.

deterioration of effluent quality because influent turbidity levels was much higher in Run 11. Breakthrough occurred faster and the effect of influent turbidity was not significantly defined. Particles penetrated throughout the depth of the bed as shown by the change in the hydraulic gradient through the bed. Final head loss was significantly higher than in Run 11 because the initial depositions were found inside the grains. Even cleaning by hand was ineffective.

Summary of results on performances of raw rice husk - As was explained in the summary of results from filter performances of pea gravel, this media seems to have a limit of it s own. Significant head loss did not occur before breakthrough but started to build up only after breakthrough. The hydraulic gradient of the bed changed correspondingly as the filter bed got clogged. Runs were all terminated because of the deterioration of removal capacity of the media.

It is apparent that filtration rates higher than 2.5 $m^3/m^2/hr$ and influent turbidity in the range of 1000 JTU will give shorter filter runs. Filtration rate of about 1.25 $m^3/m^2/hr$ and influent turbidity level of about 100 JTU appears to be the optimum design parameters for this type of media. Results obtained show that effluent turbidity is within the range of 0-50 JTU for the higher rate regardless of the level of influent turbidity and in the range of 0-30 JTU at the lower rate. At the lower rate, there was more clogging of the pores than at higher rate and higher head loss resulted.

Penetration of the particles was deep and use was made of the entire depth before deterioration of filtrate quality occurred as can be seen in Figures 33 and 34. The main drawbacks of this media inspite of efficient removal were the difficulty in cleaning, color during the initial period of operation and the breakthrough of turbidity with no significant headloss which would make it hard to detect whether removal capacity has deteriorated. In cleaning the filter media, it would be necessary to take out the whole bed and wash out by hand the particles caught in the grains. Obviously it would be easier and cheaper to throw the material away after each run. The summary of results obtained from the three runs conducted on this media is given in Table 21.

Table 21

Summary of Results of Raw Rice Husk

Run No.	Filtration rate ($m^3/m^2/hr$)	Influent Turbidity Range	Removal Efficiency Range	Amount of Filtered Water After Breakthrough
10	1.25	800-1600JTU	99.5-87.0	91.4 m^3/m^2 of bed
11	2.5	1000-2000JTU	97.7-80.0	40.0 m^3/m^2 of bed
12	2.5	60-500 JTU	96.7-62.0	223.0 m^3/m^2 of bed

4. Coconut Husk Fiber For this media, two test runs were conducted at two levels of filtration rates with the same influent turbidity level. Figures 35 and 36 illustrate the relative performances of the media at 2.5 and 1.25 $m^3/m^2/hr$, respectively at the same influent turbidity in the range of 1000 JTU. This media appeared

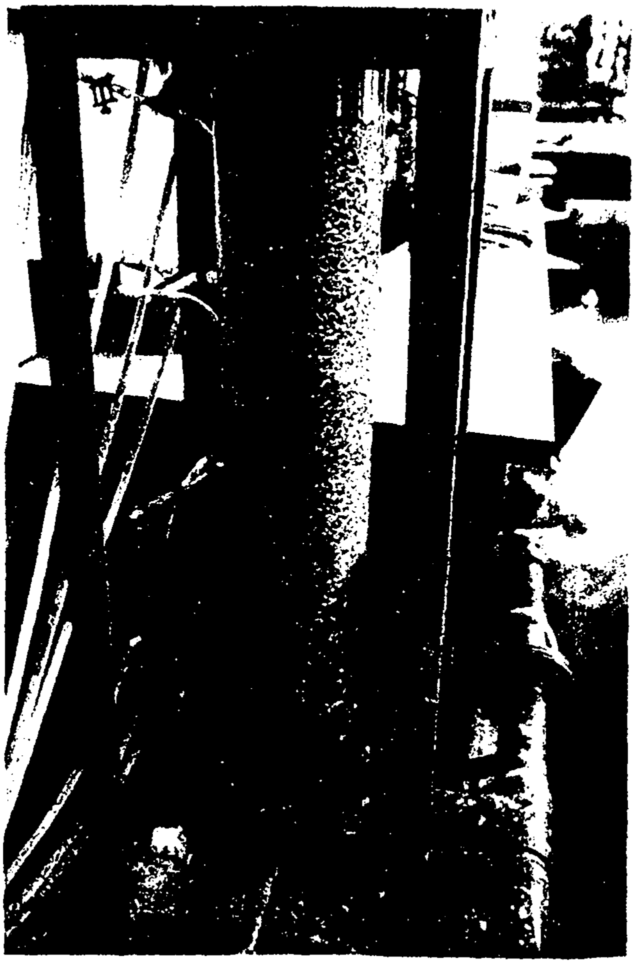


Fig. 33 - Extent of Particle Penetration

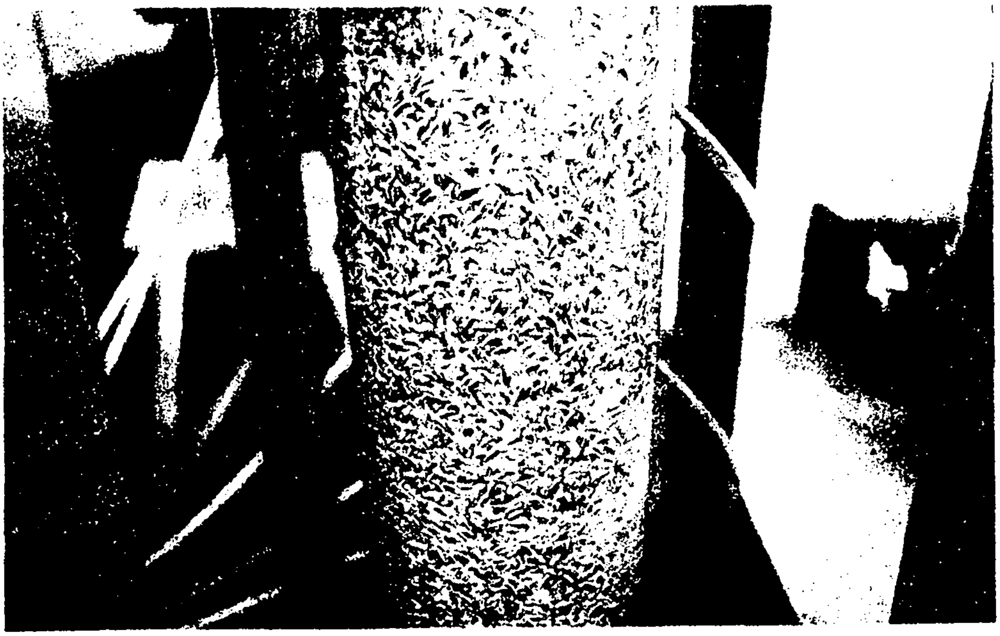


Fig. 34 - Bed Penetration in Raw Rice Husk

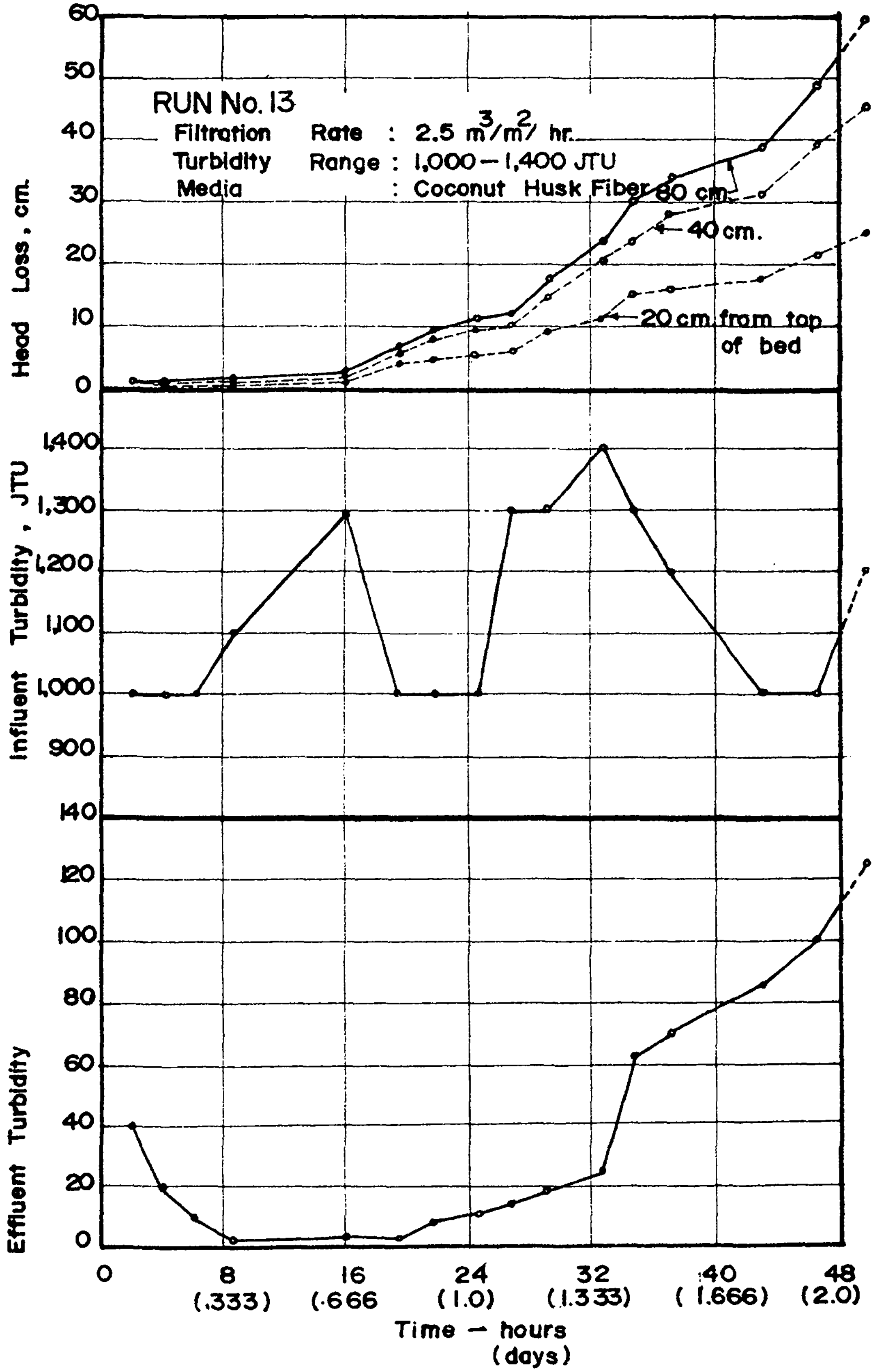


Fig.— 35 Filter Performance of Coconut Husk Fiber at 2.5 m³/m²/ hr.

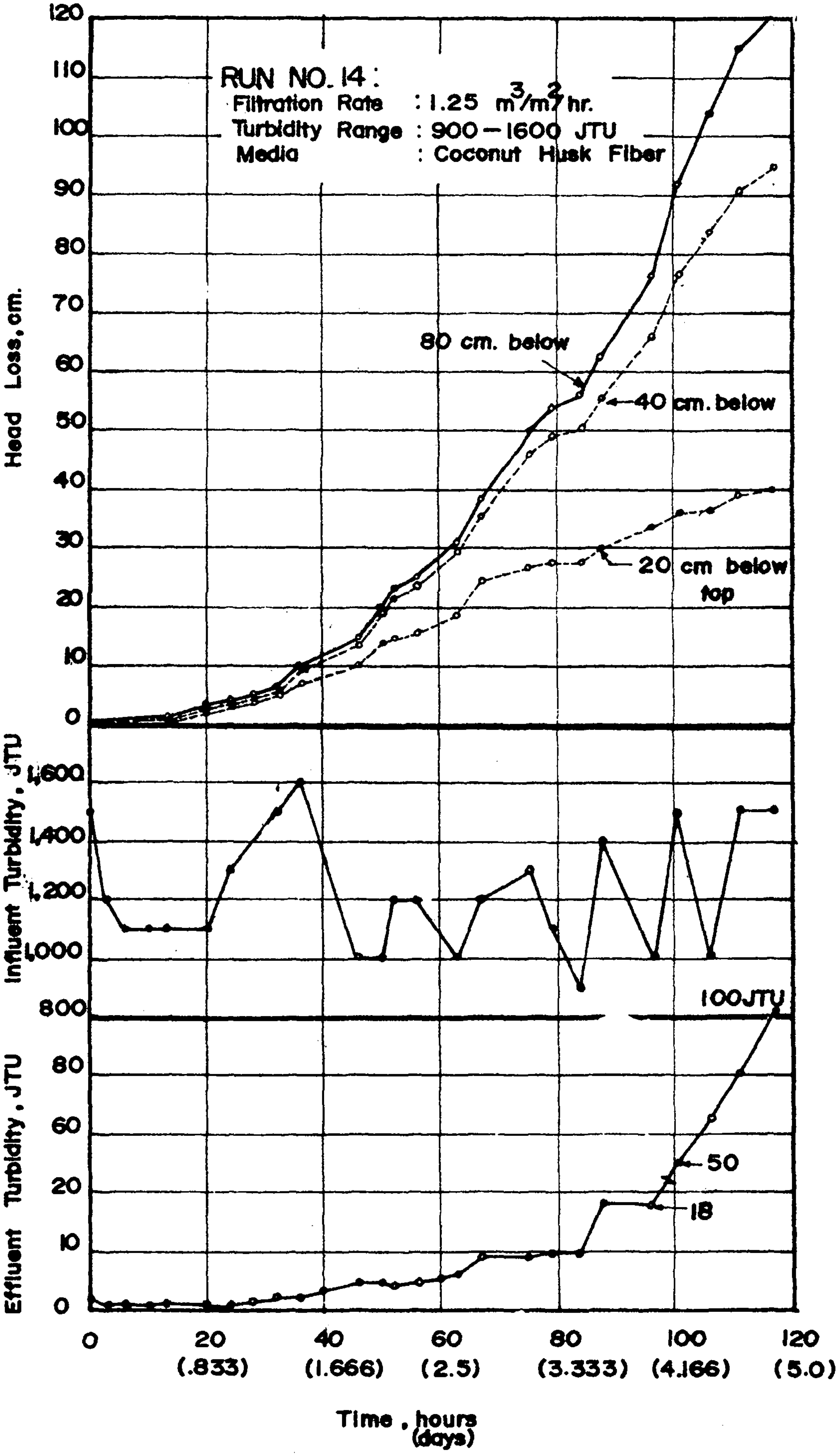


Fig.–36 Filter Performance of Coconut Husk Fibre at 1.25 m³/m²/hr to be very different from the other media investigated. Appearance of the media was more similar to wound fibers or more appropriately like a cotton ball. It could easily be placed with no problem of floating or expansion after water was introduced. After compaction in the column, the media appeared like layers of micromesh fabric unlike the other grain-media. Color in effluent water was also observed in the initial period of operation but disappeared after about six (6) hours. It was also found necessary to soak the media in water before use so that most of the color would disappear and media would be easier to handle.

Deterioration in effluent quality with corresponding increase in head loss was apparent in both runs. Break-in period was more apparent in Run 13 than in Run 14 because the media used for the first run was cleaner. However, both runs suffered from deterioration of removal capacity. Effluent turbidity was independent of influent turbidity before and after breakthrough. There was also considerable change in hydraulic gradient of the bed for both runs attributable to the deep penetration of the particles through the entire depth of the bed.

Head loss accumulated for Run 13 was only about 60 cm whilst that of Run 14 was 1.2 meters. This difference in head loss for different filtration rates was likely to occur because at the higher rate the particles were carried faster and deeper into the bed. Clogging at the top layer was less. At the lower filtration rate, the velocity of the particle was slower and deposition occurred first in the top layer, clogging most of the pores resulting in higher head loss. From visual observations made, it was found that particle penetration at the higher rate was deeper and more saturated up to the bottom of the bed, while at lower rate, penetration was throughout the depth of bed but heavily concentrated up to the top 50 cm only. Inversely, the surface mat formed on the top of the bed was thinner at higher rate, about 2-3 cm thick, compared to 8 cm thick surface mat formed at lower filtration rate.

In Figure 35, it can be seen that termination of the run was due to breakthrough of effluent turbidity with only 60 cm head loss whilst in Figure 36, termination of run was due to a final head loss of 1.2 meters with relatively lower increase in filtrate quality. Effluent quality was higher at 2.5 $m^3/m^2/hr$ filtration rate with corresponding factor deterioration than at 1.25 $m^3/m^2/hr$. The figures indicate also that the build up of head loss becomes faster after breakthrough for both runs.

Summary of results on performances of coconut husk fiber - It is apparent from the results obtained from these runs that at the lower rate, longer filter run, lower effluent turbidity and higher head loss with corresponding breakthrough occurred compared to the higher filtration rate for the same level of influent turbidity. Although, the performance of the medium at lower influent turbidity level was not evaluated, it appears that this will result in longer filter run, especially at filtration rate of 1.25 $m^3/m^2/hr$. If only minimizing the gross turbidity before loading to a secondary filter is the main objective, then this media will suit that purpose. A filtration rate of 1.25 $m^3/m^2/hr$ appears to be the maximum value to be applied to insure high efficiency and longer filter run before breakthrough. However, the selection of this media for actual use will depend on the level of influent turbidity because the length of run was also dependent on this parameter and a compromise must be decided upon. Preparation of the media might negate its universal use at the village level.

Penetration of particles was throughout the bed thus to clean the media effectively, the entire depth must be taken out and cleaned by hand. This was one important criteria in selecting the rate of filtration and influent turbidity load to be applied since the rate of cleaning or the time required before cleaning the media was dependent on these two factors. The amount of surface mat was dependent on the filtration rate and had an increasing effect as it became thicker. Table 22 summarizes the results obtained from these two runs.

Table 22

Summary of Results of Coconut Husk Fiber

Run No.	Filtration Rate ($m^3/m^2/hr$)	Influent Turbidity Range in JTU	Effluent Turbidity Range in JTU	% Removal Range	Amount of Water Filtered in m^3/m^2 of bed
13	2.5	1000-1400	2.5-125	88.50-99.7	125
14	1.25	900-1600	0.7-100	93.30-99.945	146.5

5. Charcoal No test was conducted on this media due to the difficulties encountered during the preparation of sizes to be used for the runs. Locally available charcoal is made from branches and

trunks of trees that can only be secured in chunks of varying sizes. In order to use the charcoal as a filtering media, it had to be reduced in size. Charcoal was so friable and soft that during the grinding process, many of the fine particles went to waste. The resulting sizes had a wide variation and through the sieve analysis made, the uniformity coefficient was about 4.0 and effective size was about .45 mm. Further grinding to reduce the uniformity coefficient resulted in additional wasted particles and if sizes were to be selected properly it would have been a tedious job. An additional problem resulted after the media was placed in the filter column because some of the fine particles penetrated deeper up to the supporting gravel that the filter became inoperative, necessitating to take out the whole filter bed including the gravel to remove the fine particles that clogged the filter. Furthermore, since the media was light and did not easily absorb water, the whole bed expanded and particles floated after the water was introduced. A wire mesh screen, used for the other media, could not prevent the floatation of the filter bed. Because these problems would occur in actual cases, filtration would be difficult and inoperative. Besides, the complicated and tiring process of preparing media aside from its cost made charcoal really unattractive for use in small villages although this material is abundant.

It was decided that the troubles and difficulties encountered were enough to discard this media as an alternative material for the filtration process and no further investigation on its performance was necessary.

6. Control Media - Rapid Sand Filter Coarse sand with effective size of 0.46 mm and uniformity coefficient of 1.45 was prepared from a stock of sand by using Tyler standard sieve number and analyzed from the per cent distribution of each sieve size in the prepared media. Tests were run on a filtration rate of 2.50 m^3/m^2/hr.and influent turbidity level of 1500 JTU. The filter run was significantly short which took only 20 min. with corresponding head loss of 1.2 meters. Effluent turbidity was below 1.0 JTU but the pores of the bed got clogged so fast that a thorough analysis of the performance of the media could not be made. It is apparent however from this result that sand of that effective size is inefficient in terms of head loss and length of run for that level of turbidity inspite of the semi-rapid filtration rate used for the test run. Coarser sand than the one investigated could be more efficient, similar to the one presently in use in most of the waterworks in London.

Comparison and Discussion of Results in Run Series I

Results from Run Series I are presented in Figures 37 to 41 and are summarized in Table 23. Comparison of removal efficiencies and length of runs at different filtration rates and influent turbidity levels are discussed separately below.

Removal Efficiency

It is apparent in Figure 37 that at 1.25 m^3/m^2/hr and influent turbidity of.greater than 1000, coconut husk fiber gave longer filter run than the other three media, although, efficiency was lower than that of burnt rice husk. Deterioration of removal efficiency was significant for both raw rice husk and coconut husk fiber with ry of Results in Run Series I

: y	Average (In JTU)	Removal Efficiency Average	Amount of Water Filtered (m^3/m^2 of bed)	Length of run before Breakthrough or Head Loss of 1.2 m. (in hrs.)	Head Loss Rate (cm/hr.)
	90	46.5	180	72	-
	765	44.5	35	14	-
	8.5	93.8	7	28	-
	715	61.4	50	20	-
)	2150	28.2	44	5.5	-
	80	57.8	160	64	-
7	0.18	99.9	20.6	16.5	7.27
25	0.065	99.0	208	166	0.72
73	0.23	99.9	50	40	3.00
	87	96.5	91.4	73	0.44
	76	92.7	40	16	0.17
	31	89.5	223	89	0.15
	31.8	97.3	125	50	1.20
	16.1	98.8	146.5	117	1.04

resented: PG : Pea Gravel RRH : Raw Rice Husk
BRH : Burnt Rice Husk CHF : Coconut Husk Fiber

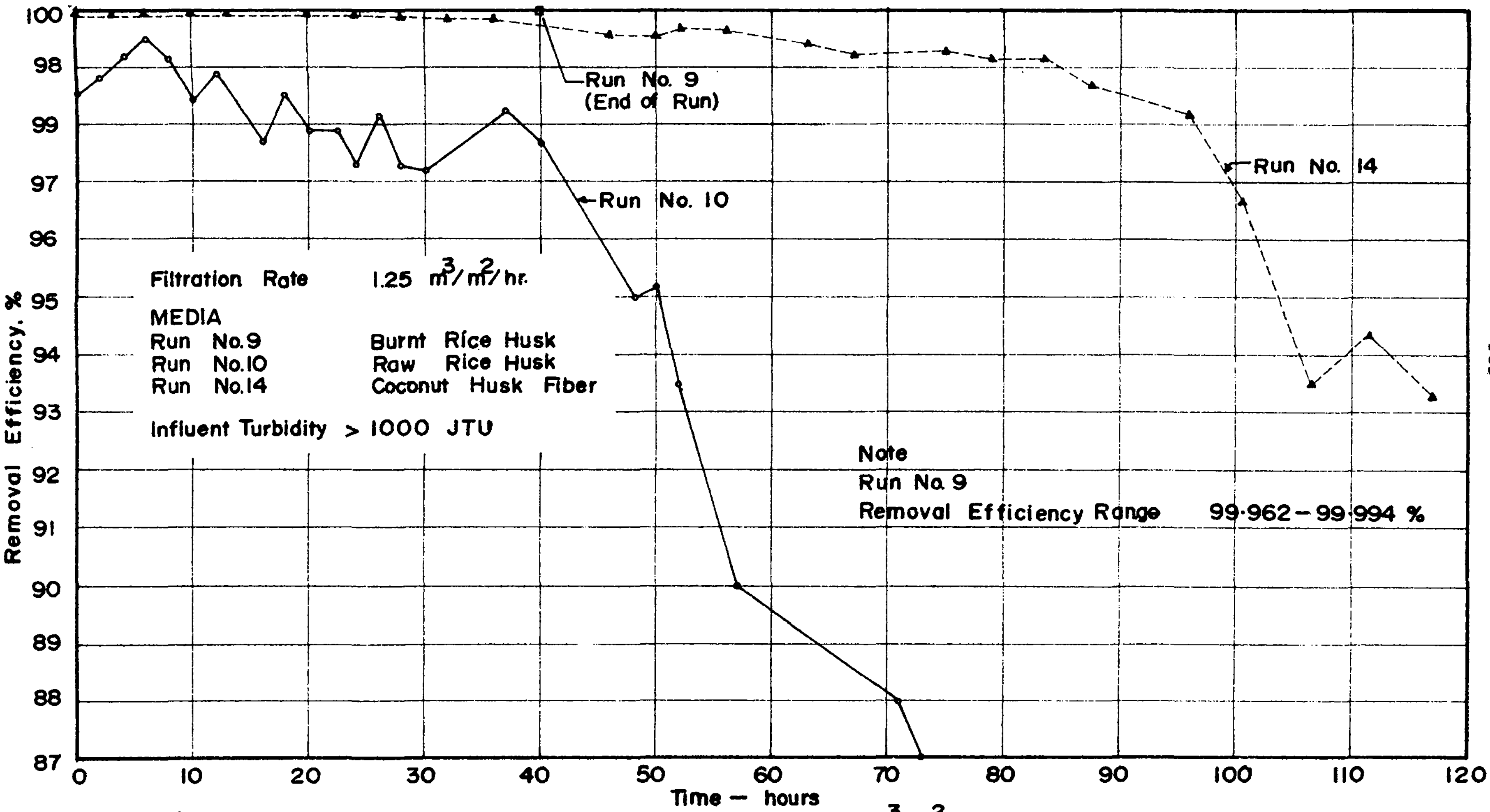


Fig.— 37 Comparison of Removal Efficiency at 1.25 m^3/m^2/hr.

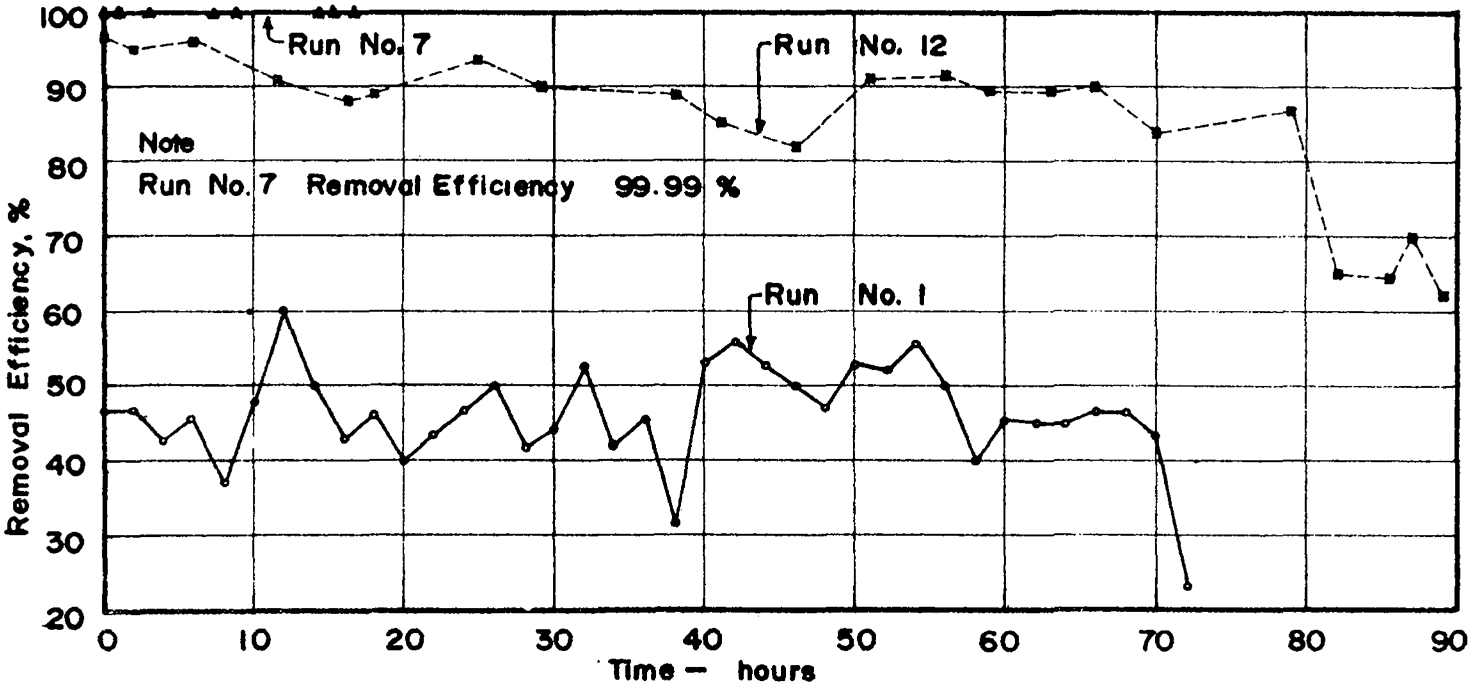


Fig.— 38 Comparision of Removal Efficiency at 2.5 $m^3/m^2/hr$.

MEDIA

Run No. 1	Pea Gravel
Run No. 7	Burnt Rice Husk
Run No. 12	Raw Rice Husk

Influent Turbidity > 100 JTU

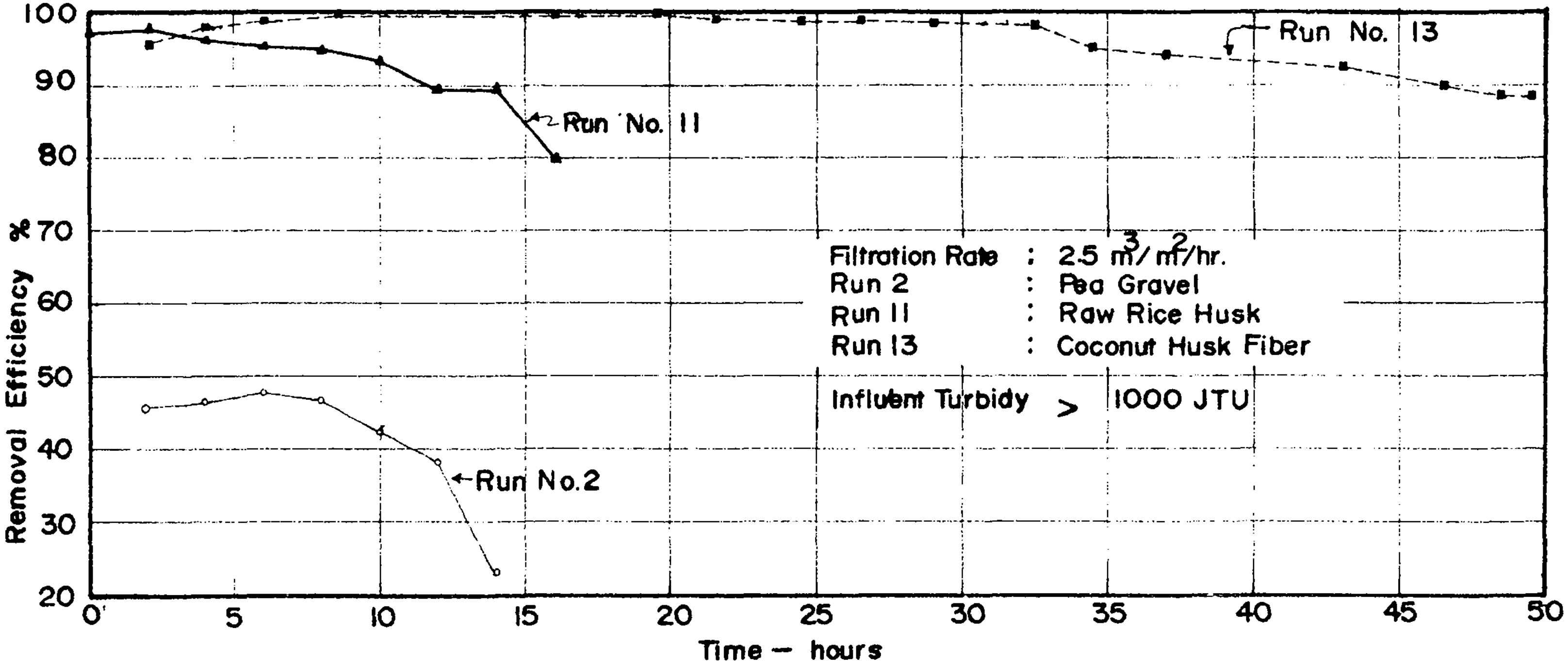


Fig.— 39 Comparison of Removal Efficiency at 2.5 m^3/m^2/hr.

the latter giving a better effluent quality. Removal efficiency of burnt rice husk was nearly 100 per cent but the run had to be terminated after 40 hours due to a head loss of 1.2 meters. Filter runs for the other two media were terminated due to a breakthrough in turbidity with the coconut husk fiber having a corresponding head loss of 1.2 meter also. Run 10 gave inferior performance in terms of removal efficiency compared to the other two. At these loading parameters, burnt rice husk gave the highest removal efficiency with no corresponding deterioration in effluent quality. Coconut husk fiber gave comparable result but a breakthrough in turbidity occurred after some 100 hours of operation.

In Figure 38, removal efficiency of pea gravel, burnt rice husk and raw rice husk are compared at 2.5 $m^3/m^2/hr$ and influent turbidity greater than 100 JTU against time in hours. The end of each curve corresponds to the termination of run either due to a breakthrough or a final head loss of 1.2 meters. Pea gravel did notperform well at this level of flow rate and influent turbidity concentration compared to the other media but gave longer filter run compared to burnt rice husk. Removal efficiency of the rice husk was comparatively good and better than the pea gravel but deterioration in removal capacity occurred with no subsequent head loss. Burnt rice husk again proved most efficient but the length of run was considerably shorter than either of the other two media.

A comparison of removal efficiencies at a filtration rate of 2.5 $m^3/m^2/hr$ and influent turbidity level of greater than 1000 JTU is shown in Figure 39. The coconut husk fiber was most efficient in per cent removal as well as in the length of run before the deterioration occurred. Raw rice husk gave comparable efficiency but the

the filter run was short due to breakthrough. Pea gravel was the least efficient in terms of percent removal and the length of run with corresponding deterioration in effluent quality.

In comparing the relative performances of the three different media in terms of removal efficiency, consideration should be given to (a) desired filtrate quality, (b) influent turbidity level, (c) length of run before deterioration of effluent quality, or a final head loss of 1.2 meters and the (d) characteristics of the filter media. The criteria used in selecting the most efficient media for a roughing filter is the one that can knock down the gross turbidity at any high level to about 10 JTU at a filtration rate that will give the longest filter run with no breakthrough and minimum head loss. In this study, it is apparent that all the media investigated have two limitations: (i) good effluent quality but relatively short filter runs and (ii) relatively long filter runs with lower effluent quality accompanied by a deterioration in removal capacity. Table 24 summarizes the comparison of removal efficiencies of the different media in order of preference with number 1 denoting first choice. Table 25 summarizes the length of run and the average effluent turbidity.

Table 24

Comparison of Removal Efficiency

Media	1.25 $m^3/m^2/hr$ @ 1000 JTU	2.5 $m^3/m^2/hr$ @ 100 JTU	2.5 $m^3/m^2/hr$ @ 1000 JTU
Pea Gravel	-	3	3
Burnt Rice Husk	1	1	-
Coconut Husk Fiber	2	-	1
Raw Rice Husk	3	2	2

Table 25

Comparison of Effluent Turbidity (in JTU) and Length of Run (in hours)

Media	1.25 $m^3/m^2/hr$ @ 1000 JTU		2.5 $m^3/m^2/hr$ @ 100 JTU		2.5 $m^3/m^2/hr$ @ 1000 JTU	
	Time	Effluent	Time	Effluent	Time	Effluent
Pea Gravel	-	-	70	54	14	540
Burnt Rice Husk	40	.06-0.4	16	.01	-	-
Coconut Husk Fiber	117	0.7-18.0*	-	-	49	2.5-25*
Raw Rice Husk	74	8.0-60.0*	88	20-45	16	25-65*

* Effluent values were after break-in and before occurrence of breakthrough.

It is evident from the tables presented above that in terms of removal efficiency alone, burnt rice husk is the most efficient, followed by coconut husk fiber, raw rice husk and pea gravel. However, based on effluent turbidity levels and length of run, coconut husk filter appears to be best, followed by raw rice husk, burnt rice husk and pea gravel. The table below compares the performances of the media based on several selected criteria.

Table 26

Comparison of Results Based on Selection Criteria

Media	Effluent Turbidity 10 JTU	Length of run*	Breakthrough Occurrence	Head Loss of 1.2 m
Pea Gravel	No @2.5 $m^3/m^2/hr$	3	Yes	No
Burnt Rice Husk	Yes	4	No	Yes
Coconut Husk Fiber	Yes @1.25 $m^3/m^2/hr$	1	Yes	Yes
Raw Rice Husk	No @2.5 $m^3/m^2/hr$	2	Yes	No

* Value denotes the longest filter run as 1 and so on in decreasing order.

There appears to be a compromise between good effluent quality and shorter filter runs and longer filter runs with poorer effluent quality at this stage of comparison. No one medium appears superior to the others. One thing is evident though, burnt rice husk will definitely give very good effluent quality no matter how high the influent turbidity level and the filtration rate applied. At a rate of 1.25 $m^3/m^2/hr$ a longer filter run at 10 times higher the influent turbidity was obtained. Coconut husk fiber performed optimally at the same filtration rate and influent turbidity level with a filter run almost three times thelength of run of the burnt rice husk but effluent quality significantly lower.

Conclusions drawn at this point indicate that rice husk was too efficient as a primary filter medium. Even at very high turbidity. A secondary filter might not be needed or the burnt rice husk could possibly be subsituted for sand in a secondary filter. Coconut husk fiber can act well as a primary filter since it reduced the incoming turbidity to about 10 JTU with considerably longer filter runs. The relative merit of the other two media were not yet established from this preliminary analysis. One definite conclusion that can be made at this point is that sand is not the only media that can remove turbidity from raw water efficiently and at a long filter run.

Endurance or Length of Run of Filter

Figures 40 and 41 illustrate the difference in the length of run of all the media investigated.

In selecting a media or the operating conditions to be used,

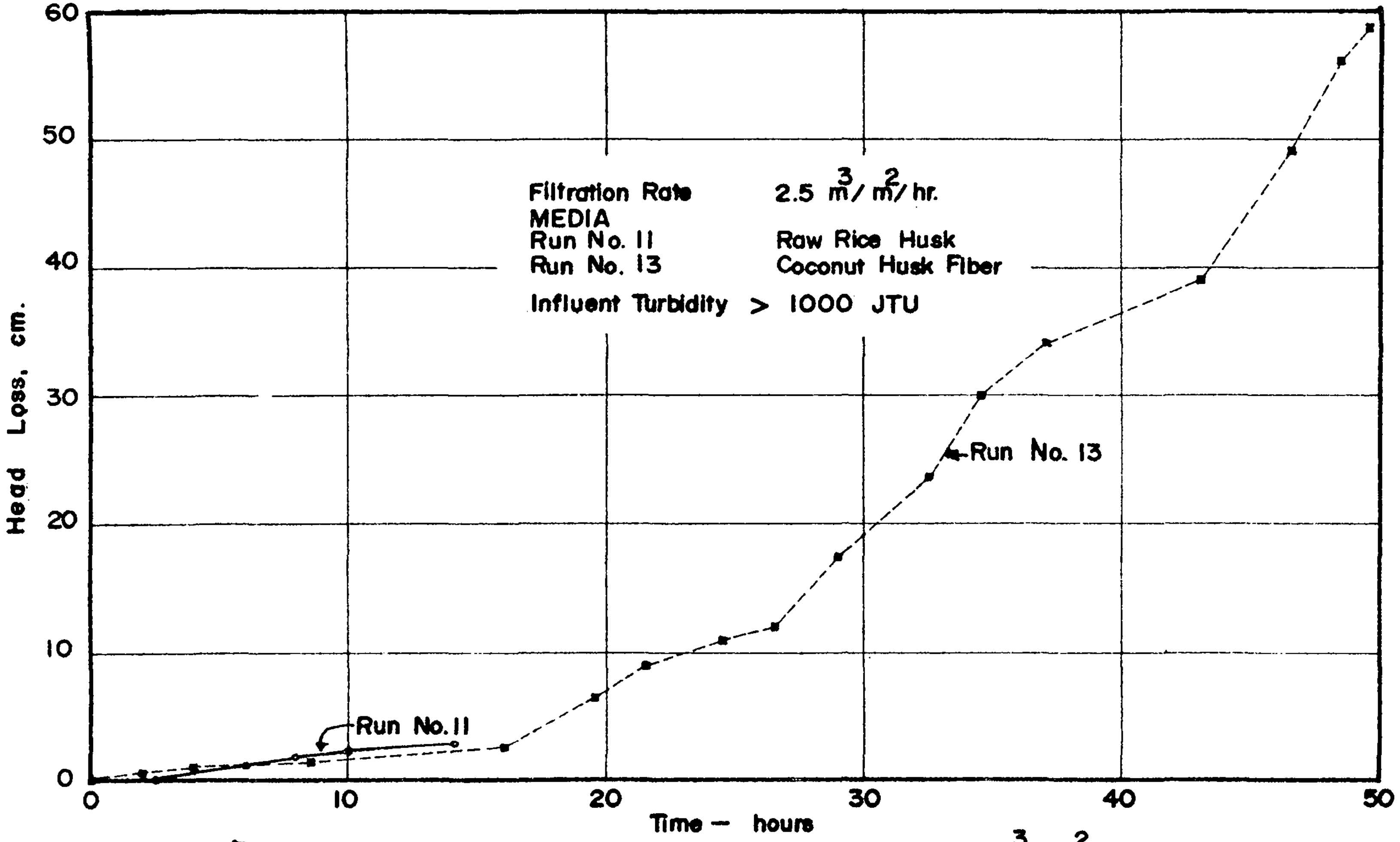


Fig.—40 Endurance Run of Different Media at 2.5 $m^3/m^2/hr$.

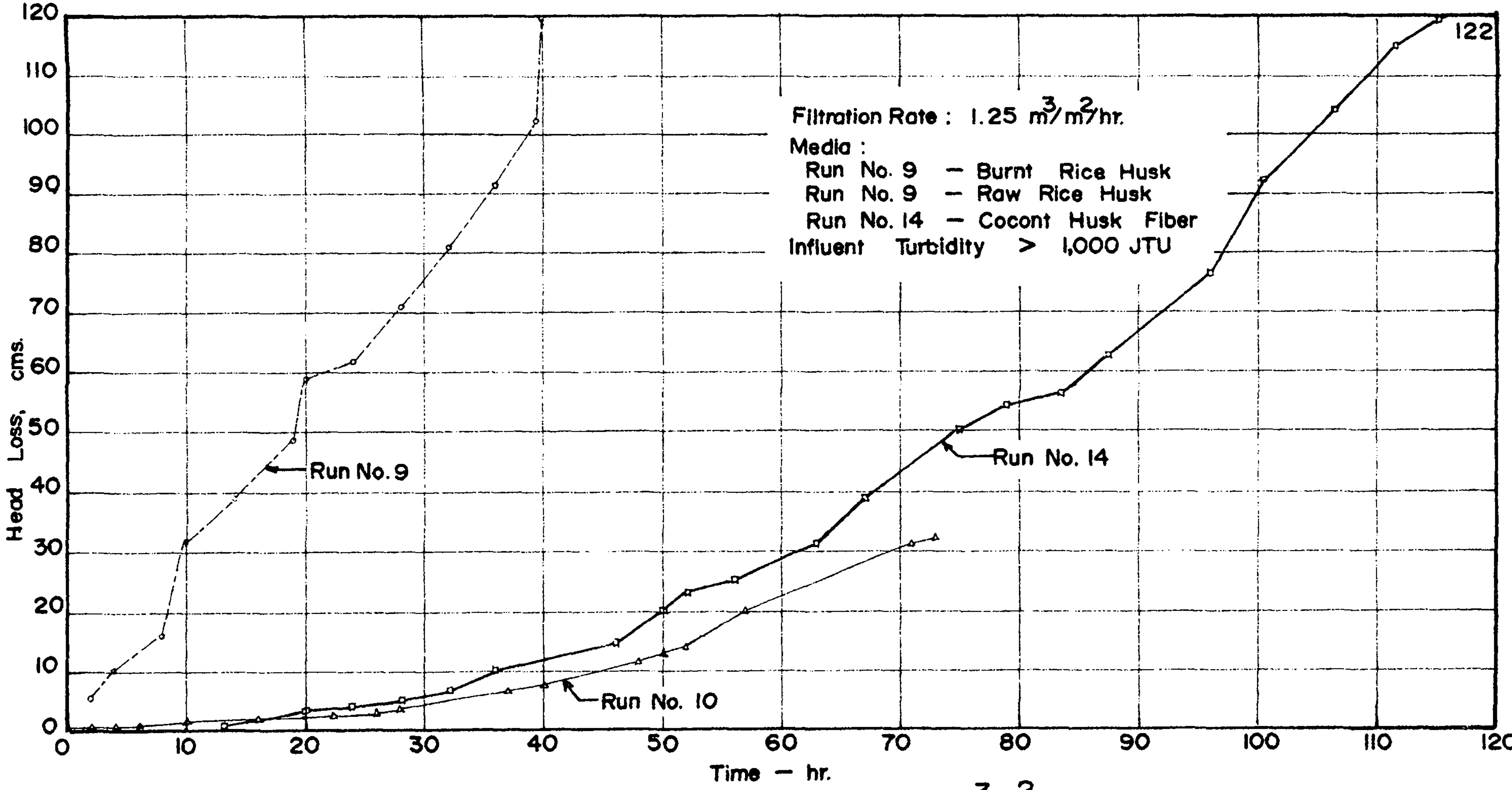


Fig.- 41 Endurance Run of Different Media at 1.25 $m^3/m^2/hr.$

the guide that CLEASBY and OKUN (1965) gave was that a head loss occurrence before a breakthrough was a surer way of detecting when to terminate a filter run than a deterioration of effluent quality. This holds true especially when no device for measuring turbidity is available, thus, a simple manometer tube attached to the filter is sufficient enough to detect the head loss through the bed. Relaxing this rule, a media would be considered efficient as long as the breakthrough of turbidity was accompanied by a head loss for easy detection.

It is apparent from thedata in Figure 40 that coconut husk fiber was significantly better than raw rice husk because the former lasted longer with a detectable head loss of almost 60 cm inspite of a breakthrough. The filter run of raw rice husk was terminated with almost negligible head loss and corresponding deterioration in effluent quality. If this occurrence of 60 cm head loss in coconut fiber will hold true for actual performance, then this media could be efficient enough to be used at this filtration rate and influent turbidity level.

At 1.25 $m^3/m^2/hr$ filtration rate and the same turbidity level as the above, the filter run of coconut fiber was three times longer than that of burnt rice husk although with a different effluent turbidity level. Although the rate of head loss of raw rice husk was lower than the other two media, the filter run had to be terminated due to a breakthrough. It is believed that a more definite head loss (easily measurable) is more important than a lower rate of head loss build-up for selecting operating rules.

From this comparison, it appears that the filtration rate of 1.25 $m^3/m^2/hr$ at any level of influent turbidity is the maximum or optimum value that can be used for burnt rice husk and coconut fiber to give efficient removal and a well defined head loss. For raw rice husk, filtration rate was still too high for efficient performance and if the optimum filtration rate were determined, the filter run was projected to be significantly longer than these other two media. Differences between head loss rate were due to initial deposition and rate of clogging and was evidently more dependent on filtration rate than turbidity.

At this point, it is now clearer that selection of media cannot depend solely on removal efficiency but also on the length of run which makes definite selection complicated. A general statement that can be made based on findings is that: if effluent quality is more important, burnt rice husk is the answer but if length of run is the basis and consequently the rate of cleaning is considered more, than coconut fiber is more attractive.

Method of Cleaning and Washwater Requirement

Observations made revealed that those media with deeper particle penetration in the filter bed were more complicated to clean than if penetration was superficial. Both coconut husk fibers and raw rice husk would require complicated cleaning methods and removal of the media so that the media could be cleaned effectively. Backwash water would also be required. For burnt rice husks where the penetration was superficial, cleaning would require only scraping off of the top of the bed down to the point of penetration. Pea gravel required backwash water to remove the particles caught within the pores and since it did not expand with the backwashing alone, compressed air was necessary to scour the bed. For some of the media, wasting the media after clogging was more practical than cleaning because of their availability and low economic value of the media. Raw rice husk was the hardest to clean because of the penetration of the particles inside the bowl-like grains. Pea gravel would be better washed, coconut husks and raw rice husks better thrown away. Burnt rice husks were more easily cleaned because of superficial penetration only. Since cost is involved in selecting the best media, availability and worth of these materials would need to be balanced against the cost of labor and washwater.

Run Series II: Exploratory Study of Performance of Media at Low Turbidity Loading and Filtration Rate

Test runs were continued for media that proved to be efficient in the first run series. Although raw rice husk was more efficient in terms ofperformance than pea gravel, the simplicity in handling and using the latter offered more advantages. Two test runs were conducted on sand to determine the effect of size on turbidity removal as compared to burnt rice husk. Based on the performances in the previous run series, pea gravel and coconut husk fiber appeared to be less efficient than burnt rice husk. Test runs on this media were conducted for purposes of evaluating the performances at low filtration rate and low turbidity loading.

Control Media

Results of the two runs conducted are illustrated in Figures

42 and 43 and performances are compared in Figure 44. It is apparent from Figure 42 that the filter run was short due to build-up of head loss resulting from the clogging of the top layer of the bed. Clogging of the pores occurred faster when the grain size was finer and the uniformity coefficient approached unity. Effluent turbidity stayed constant throughout the run between .10-.20 JTU and was independent of the changes in influent turbidity. Particle penetration was in the top 1.0 cm with a thin surface mat of about 1.0 mm thickness. The formation of surface mat on the top of the bed was responsible for the exponential increase in head loss. The constant difference in head loss between the bottom of the bed and the top 10 cm of the filter indicated that very little penetration occurred up to this point.

Figure 43 showed a longer filter run when using an effective size of 0.34 mm and uniformity coefficient of 1.35. It is apparent from the trend that after break-in, effluent turbidity was independent of the incoming turbidity, staying relatively constant between 0.10-0.20 JTU. In this filter run, penetration was in the top 1.5 cm, deeper than the other size of media used which indicated that coarser media allowed deeper penetration. Consequently, the longer the time to clog the pores of the bed, the longer the timefor the formation of surface mat. The effect of the time for the formation of surface mat is on the build-up of head loss, resulting in longer filter run. The exponential increase in head loss was also due to this mat forming on top.

The comparison of the effect on filtration by different sizes

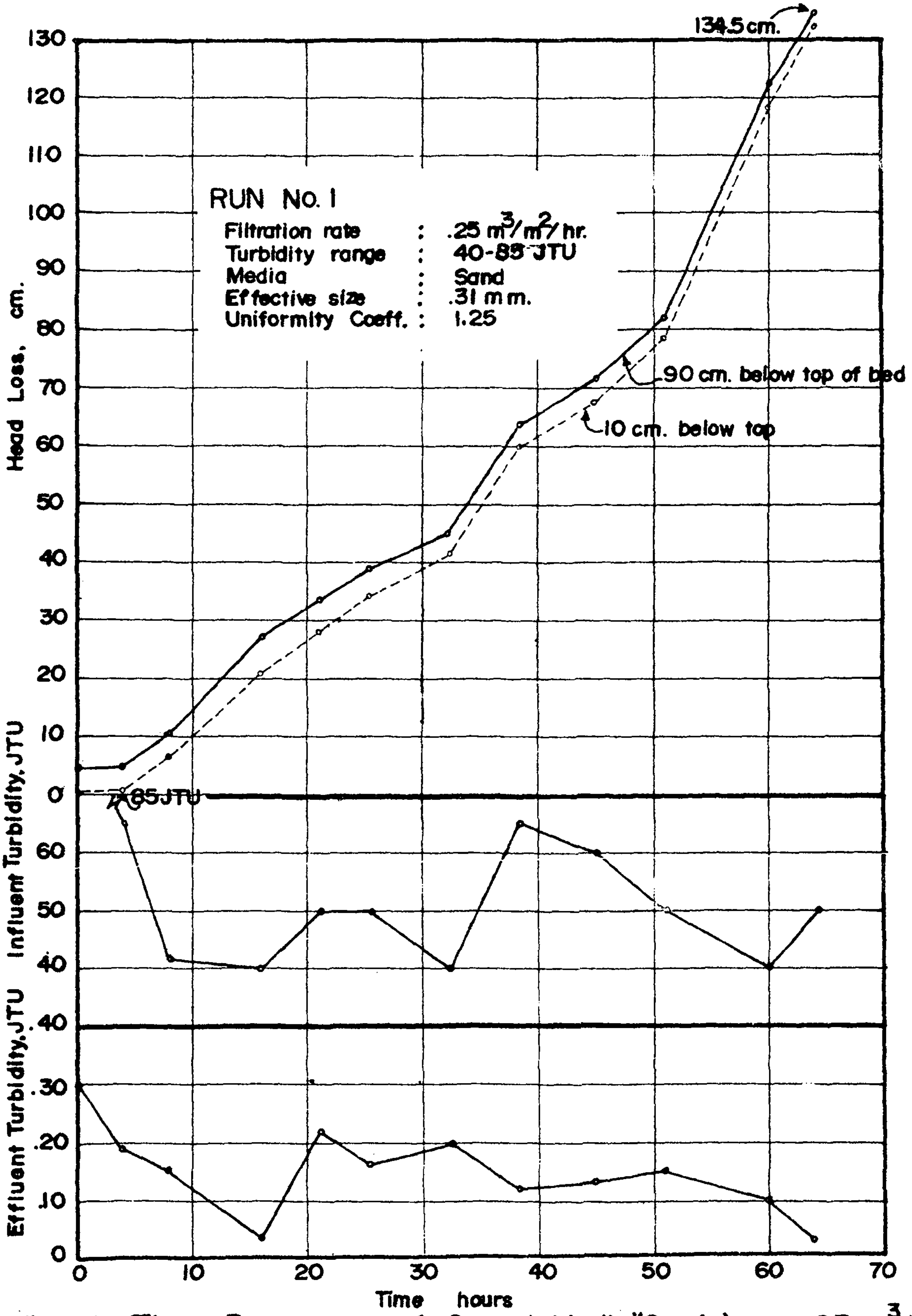


Fig.—42 Filter Performance of Control Media (Sand) at .25 $m^3/m^2/hr.$

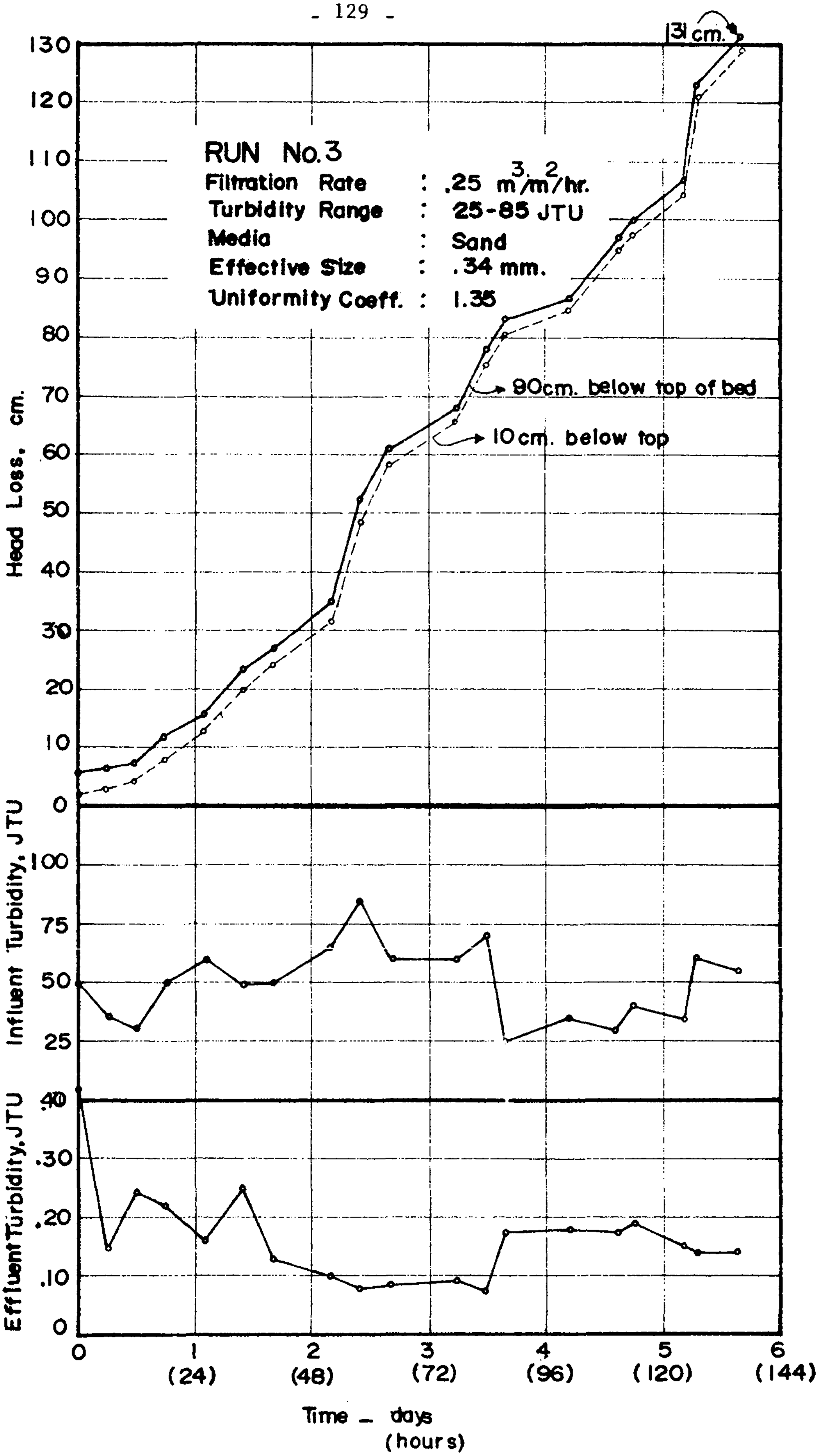


Fig.— 43 Filter Performance of Control Media (Sand) of the control sand media is illustrated in Figure 44. It is shown that a significant difference in filtration efficiency is due to the size of the filter media. The major effect is in the length of filter run with an increase of about 100 per cent. The effect on effluent quality is not so significant but it can be noted that there was a small decrease in effluent quality in Run 3 compared to Run 1 inspite of the fact that a coarser media was used in Run 3. This effect was due to the uniformity coefficient and the level of influent turbidity rather than the effective size of the media. According to the revision made by AWWA on filtering material standard in 1953, "... as the uniformity coefficient of a filter sand approached unity, the proportion of voids in the sand-layer becomes greater and the ability of the sand to remove finely divided material is reduced." It must be noted also that the filtration rate used in these runs was twice the standard rate of slow sand filtration. According to CLEASBY and BAUMANN (1954), the effect of filration rate is a function of the type of influent water. If most of the turbidity present is silt or suspended solids rather than colloidal, formation of surface mat is enhanced resulting in the rapid clogging of the top layer ending in short filter runs. This further suggested that no definite effect of filtration rate can be stated without giving reference to the kind of influent water used.

Burnt Rice Husk A run was conducted with burnt rice husk simultaneously with a run on the control media to compare the effect of influent turbidity level on the length of run and effluent turbidity for both types of media.

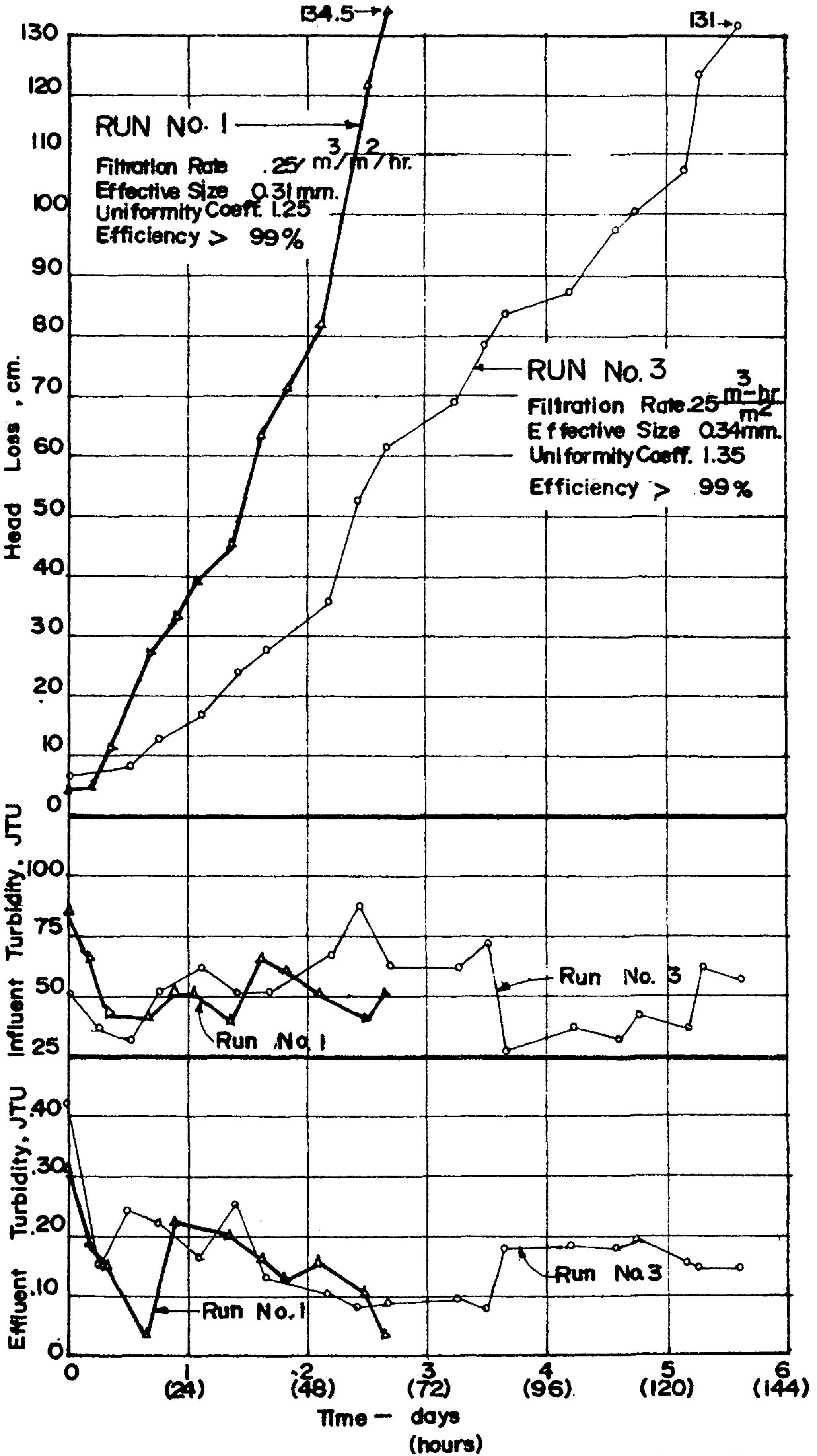


Fig.-44 Comparison of Different Size of Control Media

Figure 45 illustrates the data obtained from the first run on burnt rice husk. It is evident that effluent turbidity was fairly constant at about 0.10 JTU regardless of influent turbidity after breakthrough. Penetration of the bed was superficial, only in the top 1-2 cm with a corresponding formation of a surface mat. The exponential increase in head loss was attributable to this mat formation and it is believed this was also due to this formation that the filter run was relatively short. The constant hydraulic gradient of the bed is attributable to the superficial penetration. Compared to the performance of this media as shown in Figure 28, higher rate appears to be more efficient in terms of turbidity which could be due to the deeper penetration of particles and longer time for the formation of surface mat.

In the second filter run on the same media, it was apparent that filter run was longer than the first run, but the effluent was not significantly different. Depth of penetration was a little deeper than the first one but surface mat was thinner as observed visually. This could be the factor behind the increase in the length of filter run or it could be due to the longer time of mat formation. It is evident from Figure 46 that the head loss seemed to increase linearly which is attributable to deposition of particles within the pores of the filter. The hydraulic gradient in the filter bed was evidently constant through the length of run until termination at a head loss of 1.3 meters.

Comparison of the two filter runs are illustrated in Figure 48. The increase in the length of run was about 50 per cent with relatively

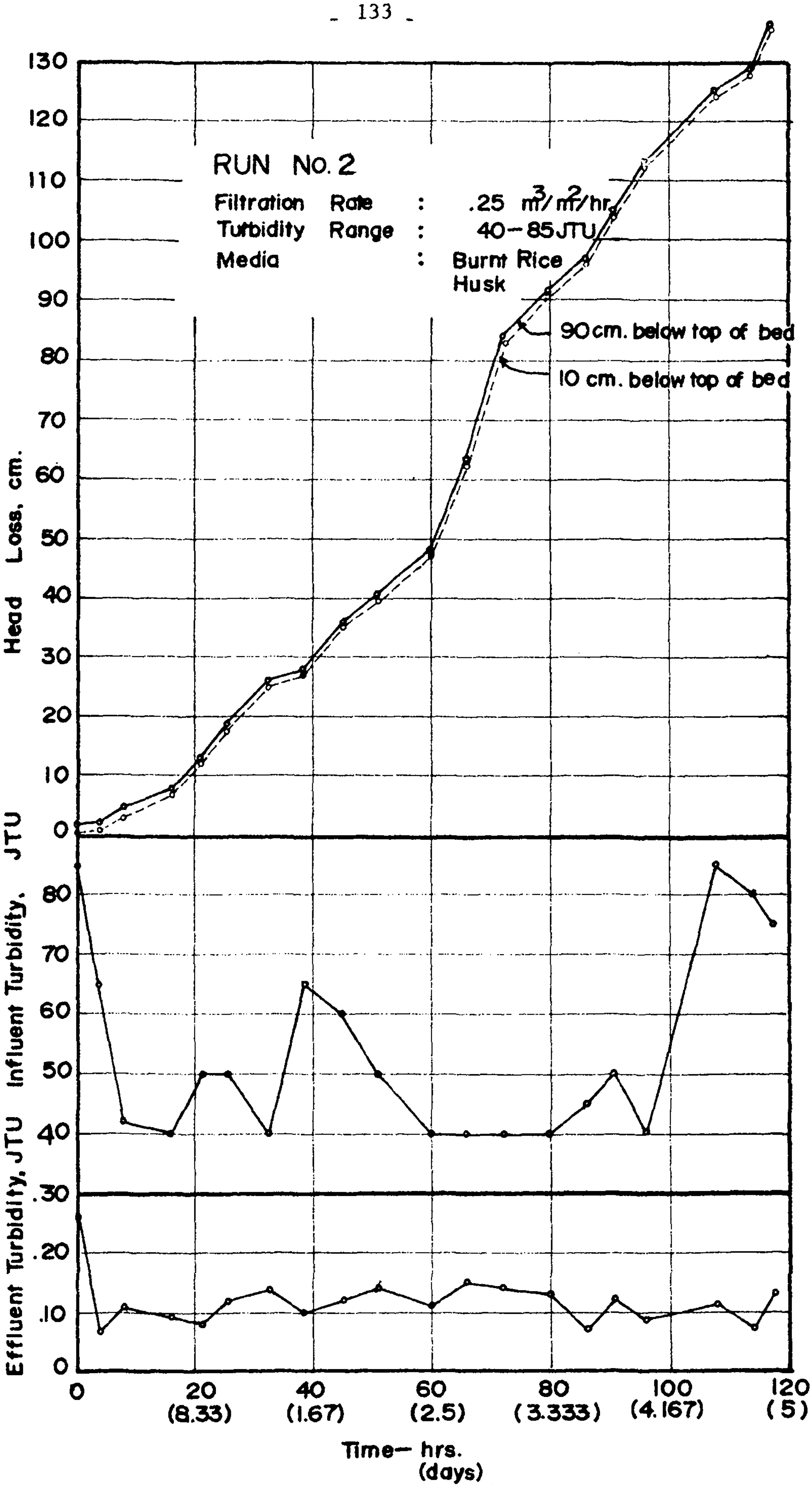


Fig.-45 Filter Performance of Burnt Rice Husk at Slow Rate

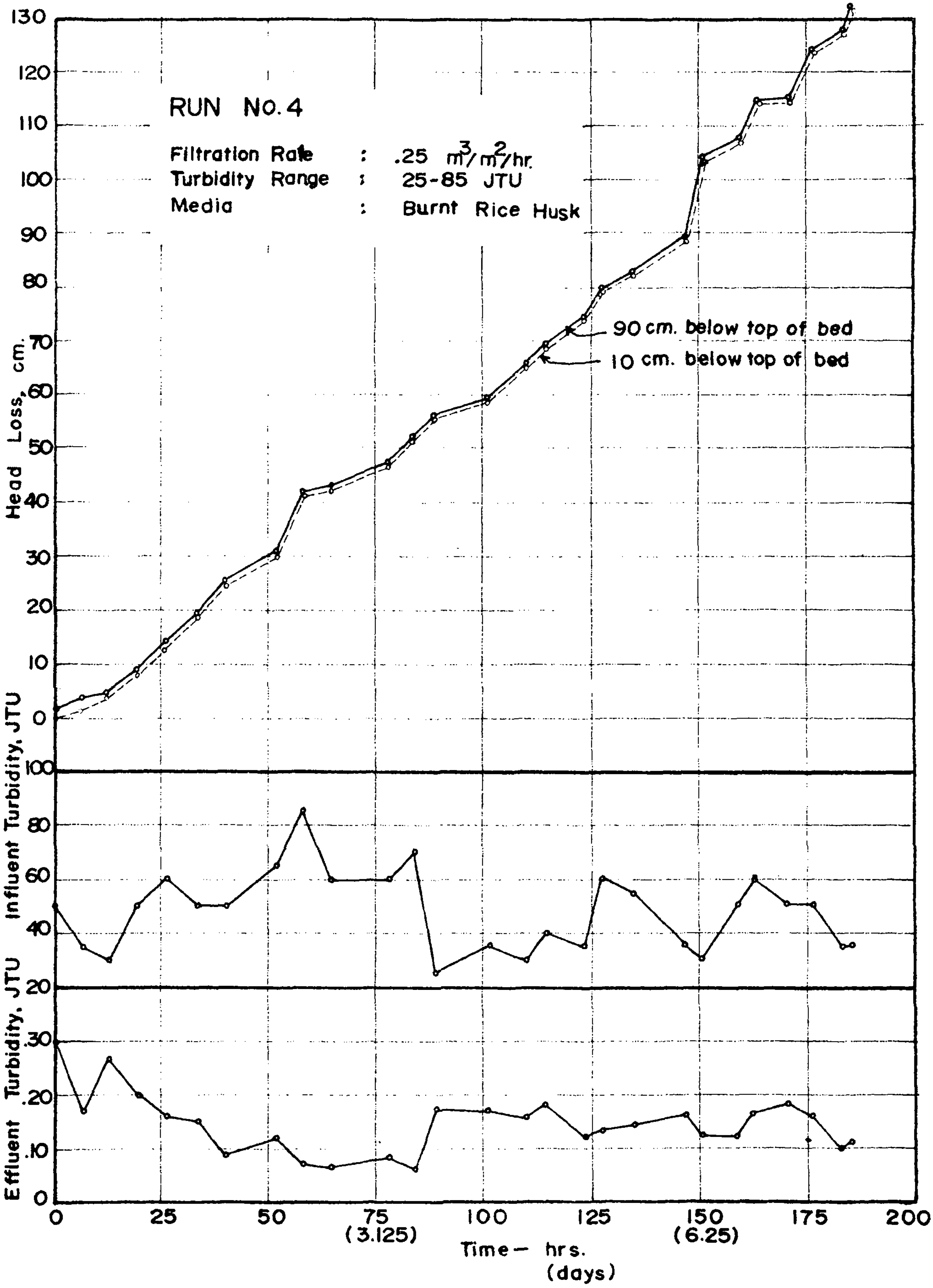


Fig.—46 Filter Performance of Burnt Rice Husk at Slow Rate the same effluent level. It is now more evident that the level of turbidity affects the length of run of this media rather than a deterioration of the effluent quality. It is believed that the slower rate of head loss build-up was due to the inherent characteristics of the media to absorb water. Unlike sand particles which are spherical and are not porous in themselves, burnt rice husk is flake-like and highly porous. Filtration through a sand bed depends on the porosity of the media or the pores between the grains while in burnt rice husk, there is another factor aside from porosity that affects filtration and that is the permeability of the media itself. This point was further clarified through visual observations which showed that the hydraulic gradient in the bed was nearly linear and as long as penetration did not go deeper, the head loss would be constant through the bed. Figure 47 shows the nearly linear head loss through the bed.

Coconut Husk Fiber Termination of the filter run was due to the limited time of study available. As shown in Figure 49 after 18 days, the filter was still performing efficiently with no corresponding headloss. Effluent turbidity was still decreasing inspite of the fluctuation in influent turbidity. Break-in period appears to have ended at the 300th hour but had performed relatively efficient since the 10th hour with the effluent turbidity continually decreasing below 0.50 JTU. The significant increase in effluent turbidity did not result in corresponding increase in effluent turbidity which clarified that the break-in period ended at this point.

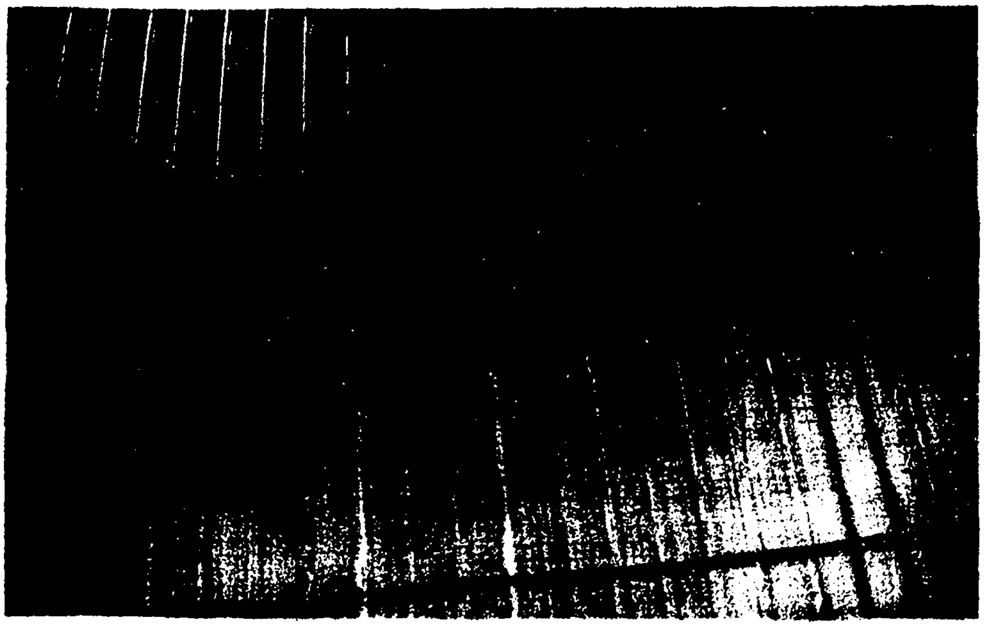


Fig. 47 - Hydraulic Gradient Through the Bed

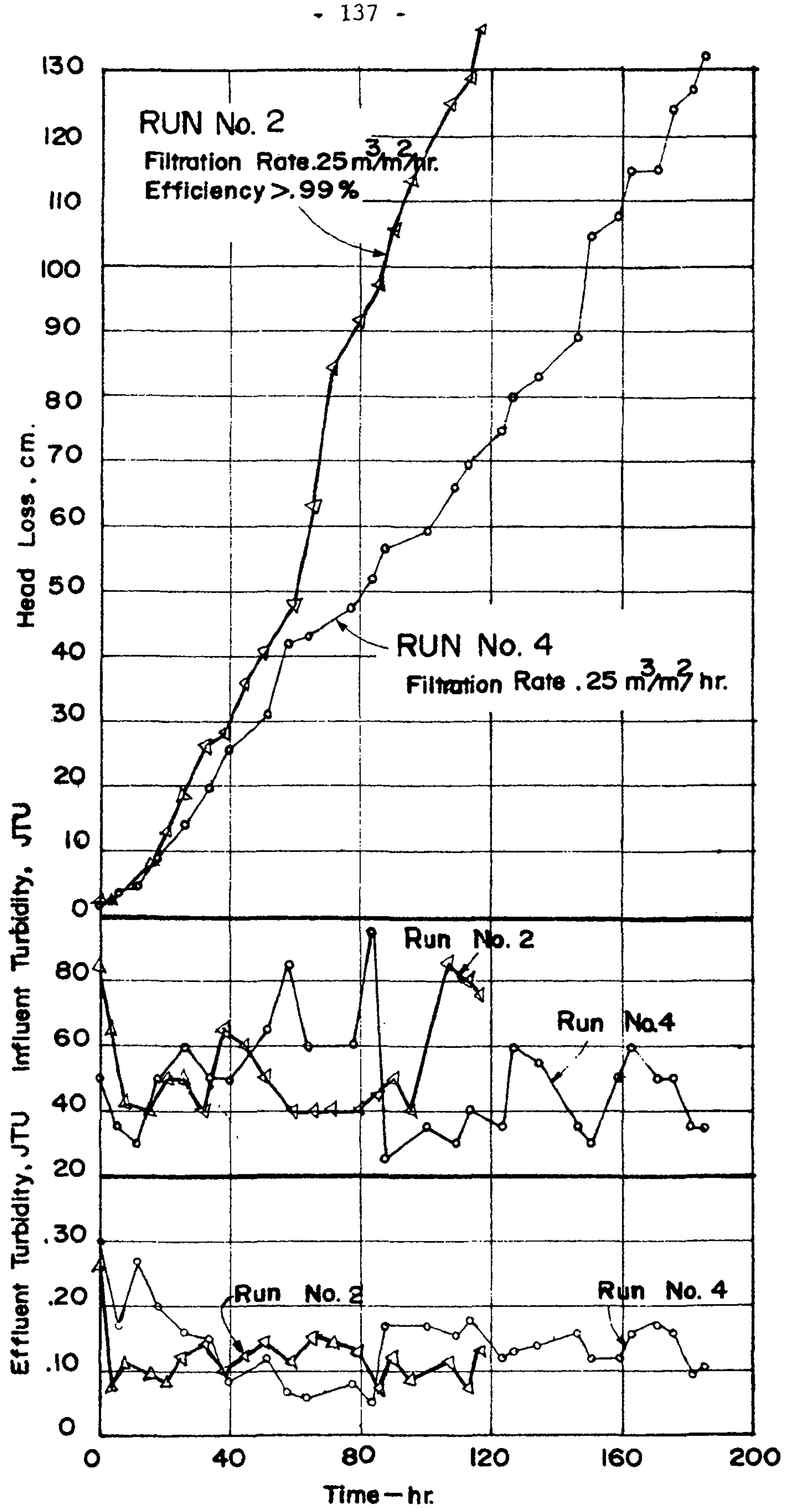


Fig.-48 Comparison of Burnt Rice Husk at.25 m³/m²/hr.

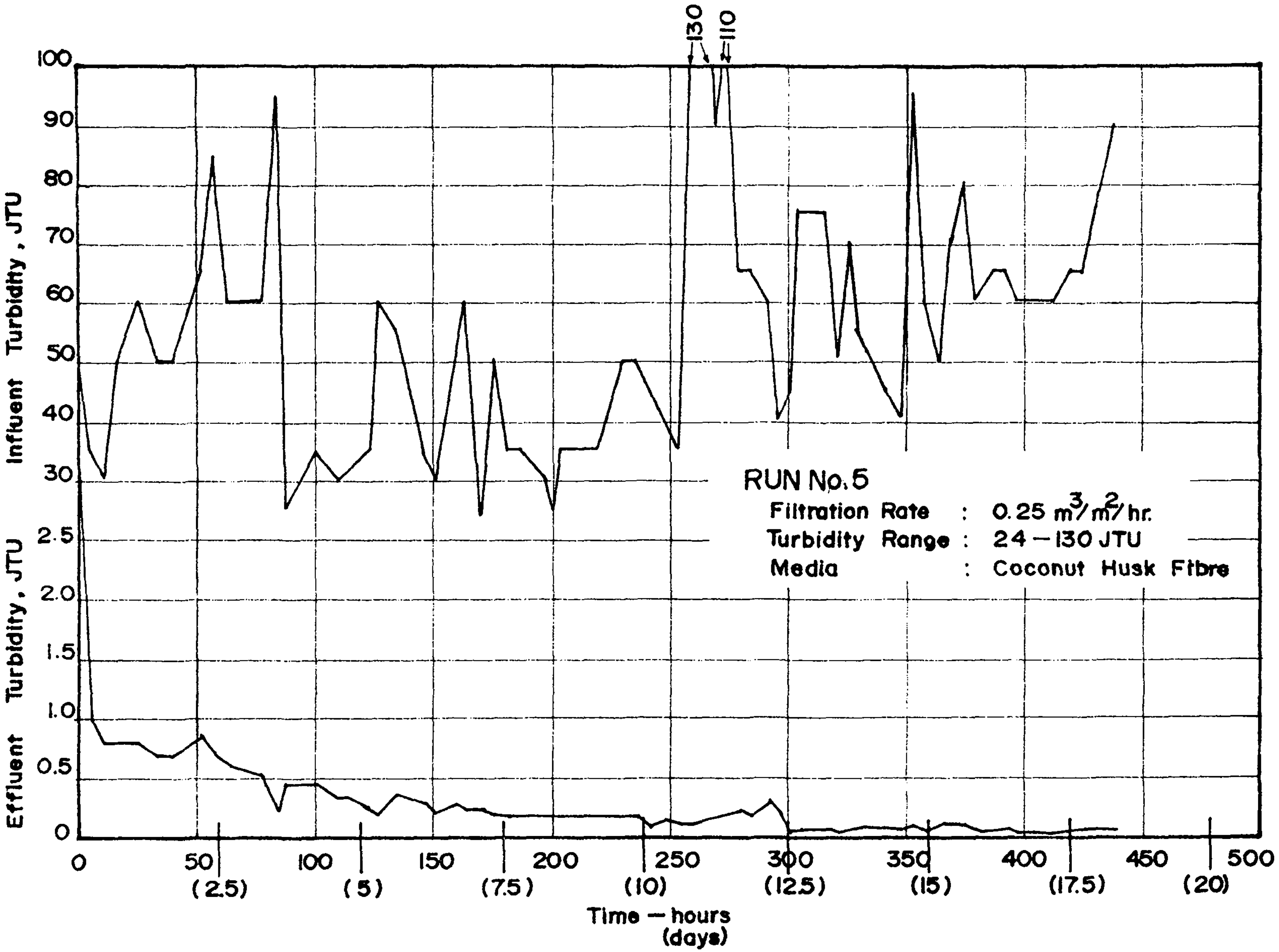


Fig.— 49 Filter Performance of Coconut Husk Fibre at Slow Rate

Penetration of particles extended down to 10 cm but the top 5 cm was well saturated as shown in Figure 50. This initial deposition was mainly responsible for the increasing effect on effluent quality. This result further verified the statement made earlier in the discussion in Run Series I, that at lower rate, clogging starts at the top layer and once this is saturated, it penetrates deeper. Consequently, head loss builds up only when this penetration gets deeper. It is evident that the filter run would have lasted a long time before the whole bed would be penetrated and a corresponding head loss built up.

Pea Gravel It is now evident that pea gravel can remove turbidity more efficiently at low rate than higher rate as shown in Figure 51. Performance of the filter was more clearly defined as to what really takes palce during the initial period of operation. During the break-in period, effluent quality was highly dependent on influent turbidity and the extent of dependency decreased as the filter run progressed. After the 300th hour, efficiency increased and was still dependent on influent turbidity although not significantly. Effluent turbidity was fairly constant at 1.0 JTU after the break-in period inspite of the significant fluctuation in influent turbidity. As was found before, no significant head loss occurred throughout the length of run. Termination of the run was due to the limited time available but it is evident that no breakthrough occurred after 28 days of continuous filter run. In fact, removal capacity seemed to increase.

Penetration and deposition started at the top layer of the bed

Fig. 50 - Particle Penetration in Coconut Husk Fiber

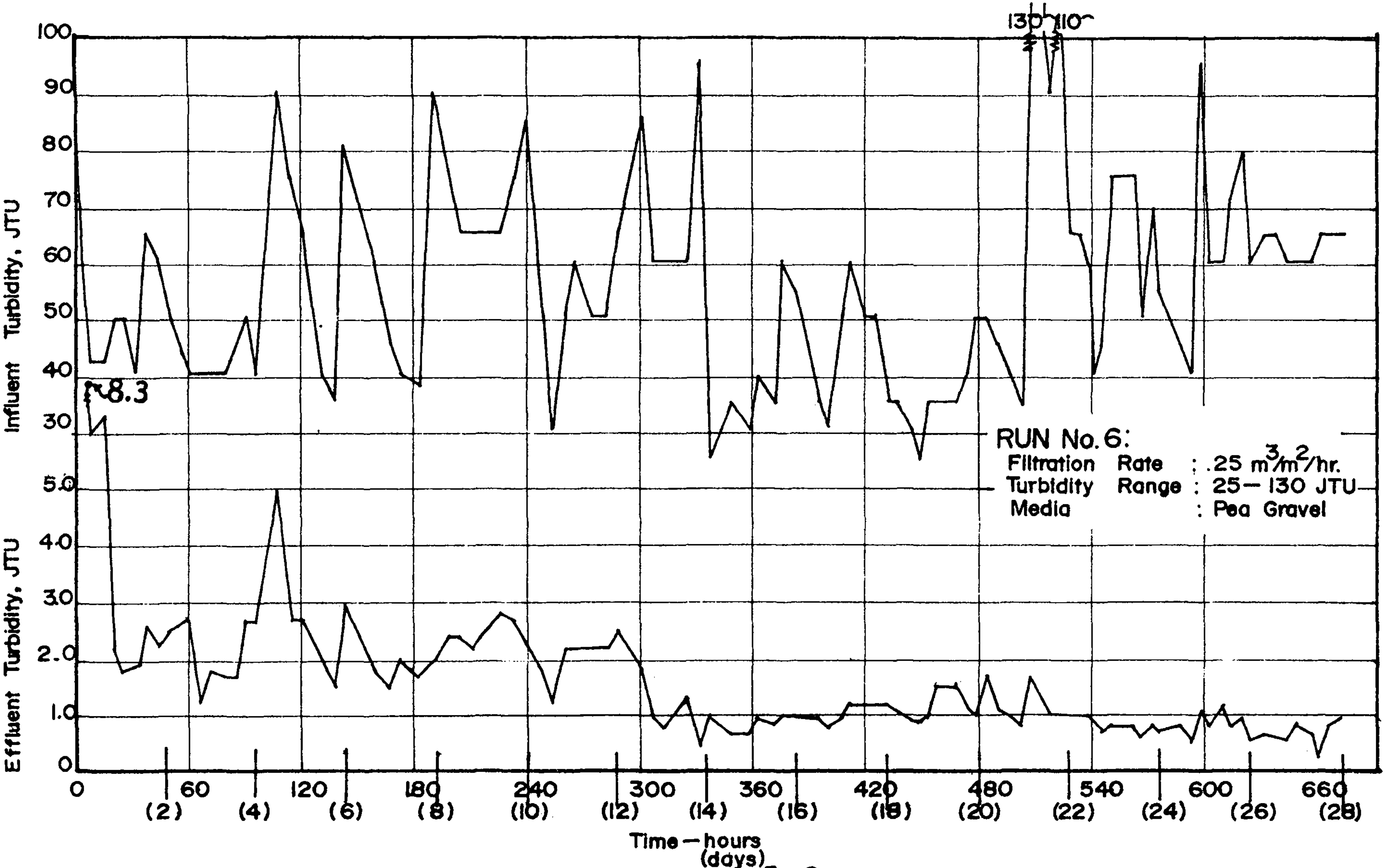


Fig.—51 Filter Performance of Pea Gravel at .25 m^3/m^2/hr. and Low Turbidity and solids passed through only when extreme clogging started to occur. As was observed visually, heavy deposition was in the top 30 cm and had begun to move to the lower 30 cm at the time the filter run was terminated. There was no observed surface mat formation throughout the run exceptfor some particles that had settled on top of the bed. It is presumed that the filter run would have lasted a longer time before deterioration in removal capacity would occur.

Comparison and Discussion of Performances in Run Series II

Burnt rice husk is compared as a substitute media for slow type filtration against sand of two different effective sizes and uniformity coefficients. The performances of four media investigated are compared in terms of effluent quality versus filter run as a function of influent turbidity.

Burnt Rice Husk vs. Sand   Figure 52 illustrates the comparison of filter performances of the two media at the same filtration rate and influent turbidity level, using sand with effective size of 0.34 mm and uniformity coefficient of 1.35. Both media produced relatively the same effluent quality throughout the length of runs. Both media did not respond accordingly to the change in incoming turbidity and appeared to have the same trend of head loss rate towards the end of the break-in period but significantly differed thereafter. The significant feature in this comparison is the longer filter run of the burnt rice husk by almost 30 per cent than the filter run using sand.

It is apparent that if the effective size of the media is reduced and uniformity coefficient apparoaches unity, filter perfor-

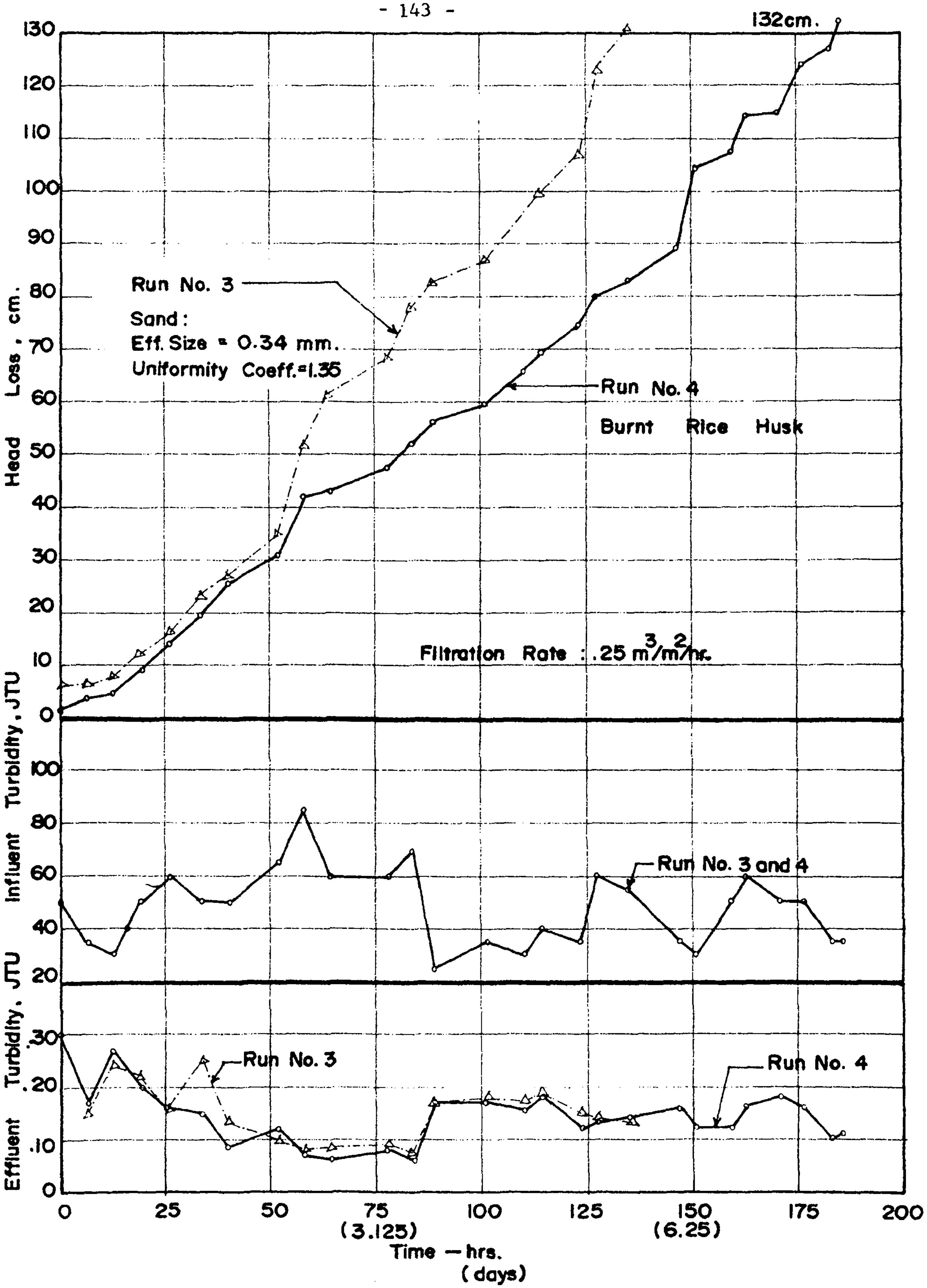


Fig.— 52 Comparison of Sand and Burnt Rice Husk at the same Filtration Rate and Influent Turbidity mance correspondingly decrease in terms of length of run and increase in effluent turbidity. The effect of influent turbidity is on the length of filter run rather than the effluent quality. In Figure 53 it is evident that the performance of burnt rice husk was significantly more efficient than sand with an increase of about 85 percent in the length of run and relaaively better filtrate quality. The significant difference in the increase in the length of runs of the two media is attributable to the change in effective size and uniformity coefficient of sand. However, it is also evident that further increase in uniformity coefficient leads to longer run because the grain size becomes coarser while maintaining the same effective size. The accepted normal uniformity coefficient must not be greater than 2.0 with an effective size of 0.3-0.4 mm. This grain size however, will lead to higher effluent turbidity. It is believed that the length of run of the two media being compared would be equal at a certain effective size and uniformity coefficient of sand but the resulting effluent quality would be lower than that of burnt rice husk. This hypothesis was however not fully investigated. There appears to be a compromise in using sand, coarser sand with resulting longer filter run and lower effluent quality or finer sand with shorter filter run but higher effluent quality. For the purposes of comparison, it is believed that the grain size of sand used was sufficient enough since the resulting effluent quality was comparatively the same as that of the burbt rice husk. Furthermore, it was evident in this comparison that the difference was in the length of run with both giving the same effluent turbidity.

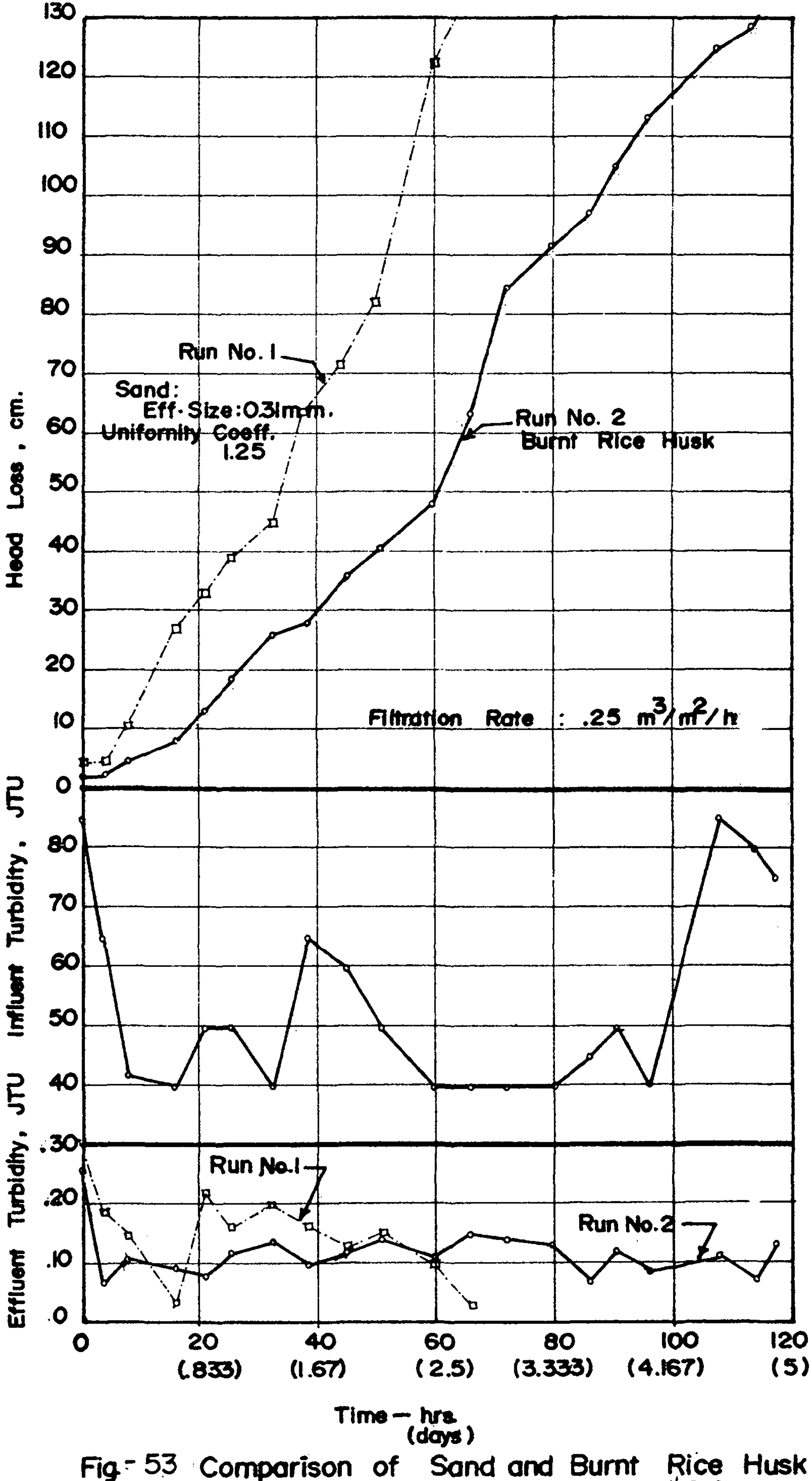


Fig - 53 Comparison of Sand and Burnt Rice Husk at the same filtration Rate and Influent Turbidity

A general statement that could be derived from this comparison of performance is: burnt rice husk would give comparable effluent quality at a longer filter run with sand of effective size, 0.34 mm and uniformity coefficient of 1.35.

Pea Gravel and Coconut Husk Fiber as a Substitute Media

According to the International Standards for Drinking water, thepermissible concentration of turbidity mustbe 5 JTU (mg/l as SiO_2) and excessive if it exceeds th evel of 25 JTU. It is evident that pea gravel can be substituted as a media for slow rate filtration due to the relatively good effluent quality. Figure 54 shows that effluent turbidity was already well below 5 JTU even during the break-in period and decreased to about 1.0 JTU. The main drawback of this media was its apparent dependency on influent turbidity that if turbidity is higher than the level studied, effluent turbidity will consequently increase also. Furthermore, there are other factors and effects that need detailed evaluation, like, the length of run before it deteriorates in efficiency, bacteriological action in the bed, and effect of other types of influent turbidity. Coconut husk fiber removed influent turbidity more efficiently than pea gravel, that is, effluent quality was more acceptable for drinking water. Again, other factors need to be evaluated. This medium has more potential as a substitute for sand than pea gravel since higher effluent quality was obtained and the filter run was longer than the other media evaluated.

Effluent Turbidity vs. Time and Influent Turbidity

Figure 54 illustrates the comparison of effluent turbidities

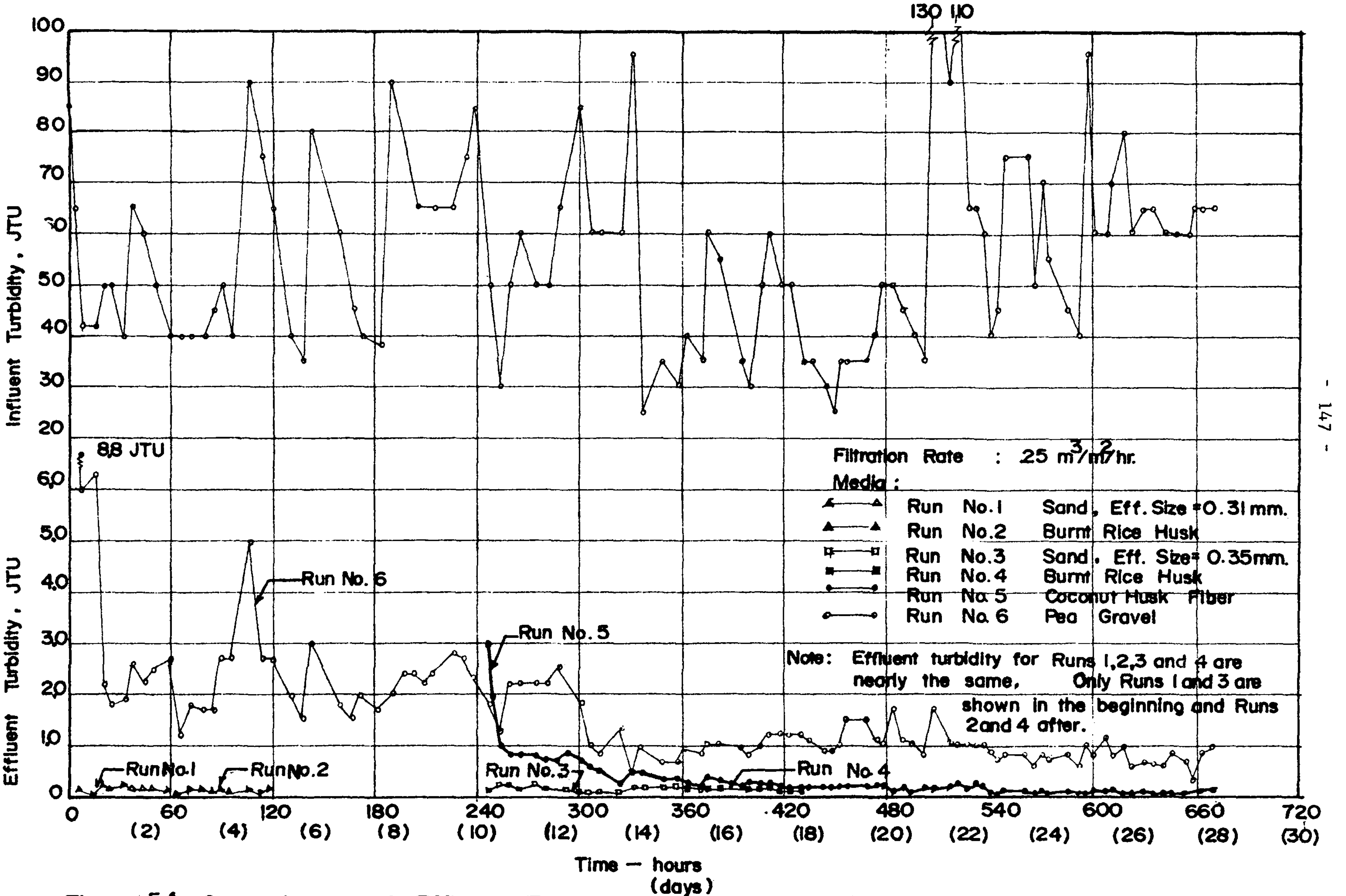


Fig. — 54 Comparison of Effluent Turbidity of Different Media versus Time and Influent Turbidity of all the media studied in this run series. Run 1, 2 and 6 were all conducted at the same time but Run 1 and 2 had to be terminated after an occurrence of 1.3 meters had loss. Effluent turbidities of the first two runs were apparently stable while Run 6 was highly dependent on the influent turbidity. After 5 days, three more media were run simultaneously with pea gravel. It is evident that at this time, pea gravel was still in the break-in period while coconut husk was only in the initial stage. After 5 days, the filter run of sand had to be terminated due to head loss in the bed with still efficient removal of turbidity. The filter run of burnt rice husk, however, lasted for another three days with the same head loss occurring. With the two runs already terminated, coconut husk fiber was still in the break-in period when terminated on the 23rd day, 300 hours after the run started. Simultaneously, pea gravel had passed the break-in period already but the quality of the effluent was still dependent on influent turbidity.

In Figure 55, relative penetration of particles are shown. This photograph verified the statements made earlier, that at the lower rate, clogging occurs in the top layer of the bed first for coarse and highly porous media. (Refer to filter column 1 and 3 in the photograph from the left). The second and last filter column shows the superficial penetration of the particles in the finer and less porous media, i.e. sand and burnt rice husk in this instance.

In terms of the relative efficiency of the media to remove turbidity, pea gravel had performed the least efficient. Sand and burnt rice husk had relatively high similar efficiency but the filter runs were short owing to the occurrence of a 1.3-m lead loss.

Fig. 55 - Comparison of Bed Penetration

Coconut husk fiber after the break-in performed efficiently in reducing the gross turbidity to about 0.20 JTU even after 18 days of continuous filtration at which point the run was terminated due to limited time.

It is apparent in these comparisons that the most efficeint media in knowcking down the influent turbidity was burnt rice husk, followed by sand, coconut husk fiber and pea gravel. The observed differences in the performance of the four media in knocking the gross turbidity are attributed to the differences in grain size and porosity of the four media rather than the media itself. However, the relative significance of these two factors were not and cannot be established from this work. Results obtained indicated that with finer and less porous media like sand and burnt rice husk, head loss occurred with no apparent change in filtrate turbidity inspite of the change in influent turbidity. It appears that comparison of performance based on removal efficiency alone was not realistic without considering the length of run. No media seemed to be superior than the other.

Run Series III: Evaluation of Filter Performances using Typical River Water

A test run was conducted at a filtration rate of 2.5 $m^3/m^2/hr$ on burnt rice husk using river water. The breakthrough curve corresponding to the increase in head loss is shown in Figure 56. Head loss was due to rapid clogging of the top layer and the nearly linear head loss was attributable to deeper penetration of the particles into the bed.

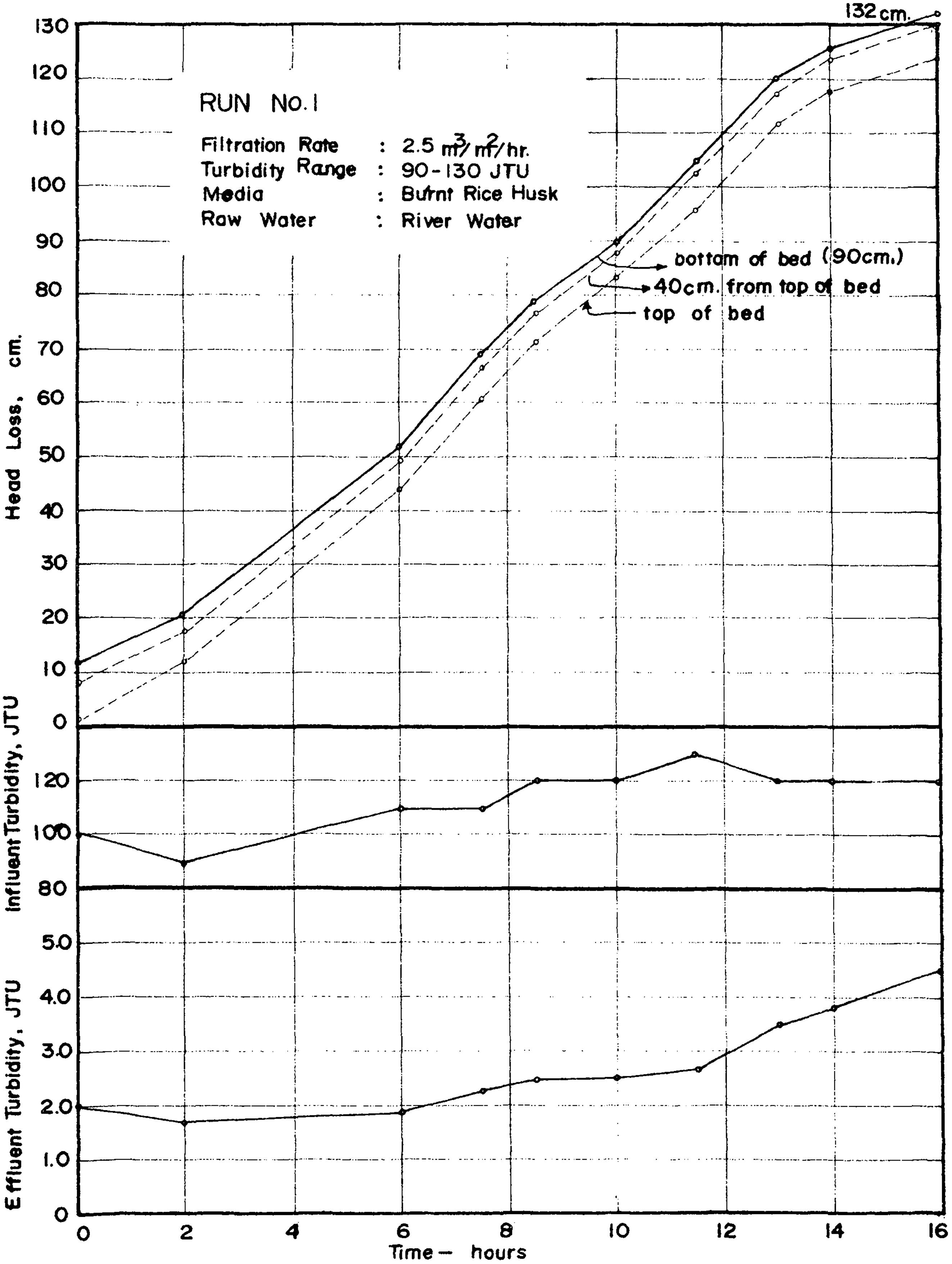


Fig.— 56 Filter Performance of Burnt Rice Husk using River Water

Figure 57 is a comparison of head loss and effluent quality using synthetic turbidity water versus actual river water. The effect of type of influent turbidity is clearly seen. Although the rate of head loss development was not significantly different for the two runs, effect was significant on effluent turbidity. It is apparent that inspite of the higher influent turbidity level of the synthetic water, effluent quality was far better than effluent from river water. The river water did contain organic and inorganic colloids, smaller than the pore size of the media, which were not completely removed at the high filtration rate. The synthetic water, which was purely a coarse dispersion of particles, was easily arrested by the media. A thicker surface mat helped remove most of the synthetic turbidity.

Results obtained from the filter run using synthetic water at this filtration rate cannot be said to under or over-estimate performance of the filtering medium because efficiency does depend on the type of turbidity present. The performance using synthetic water representative of the performance of the filter if most of the turbidity present were of the inorganic, coarse dispersion type, that is, silts and suspended solids.

Slow Rate Filtration   The four media that were evaluated in Run Series II were evaluated again using typical river water from the Chao Phraya River at a slow filtration rate of 0.25 $m^3/m^2/hr$. Sand and burnt rice husk were run simultaneously to evaluate their performance at the same level of influent turbidity using a different type of raw water.

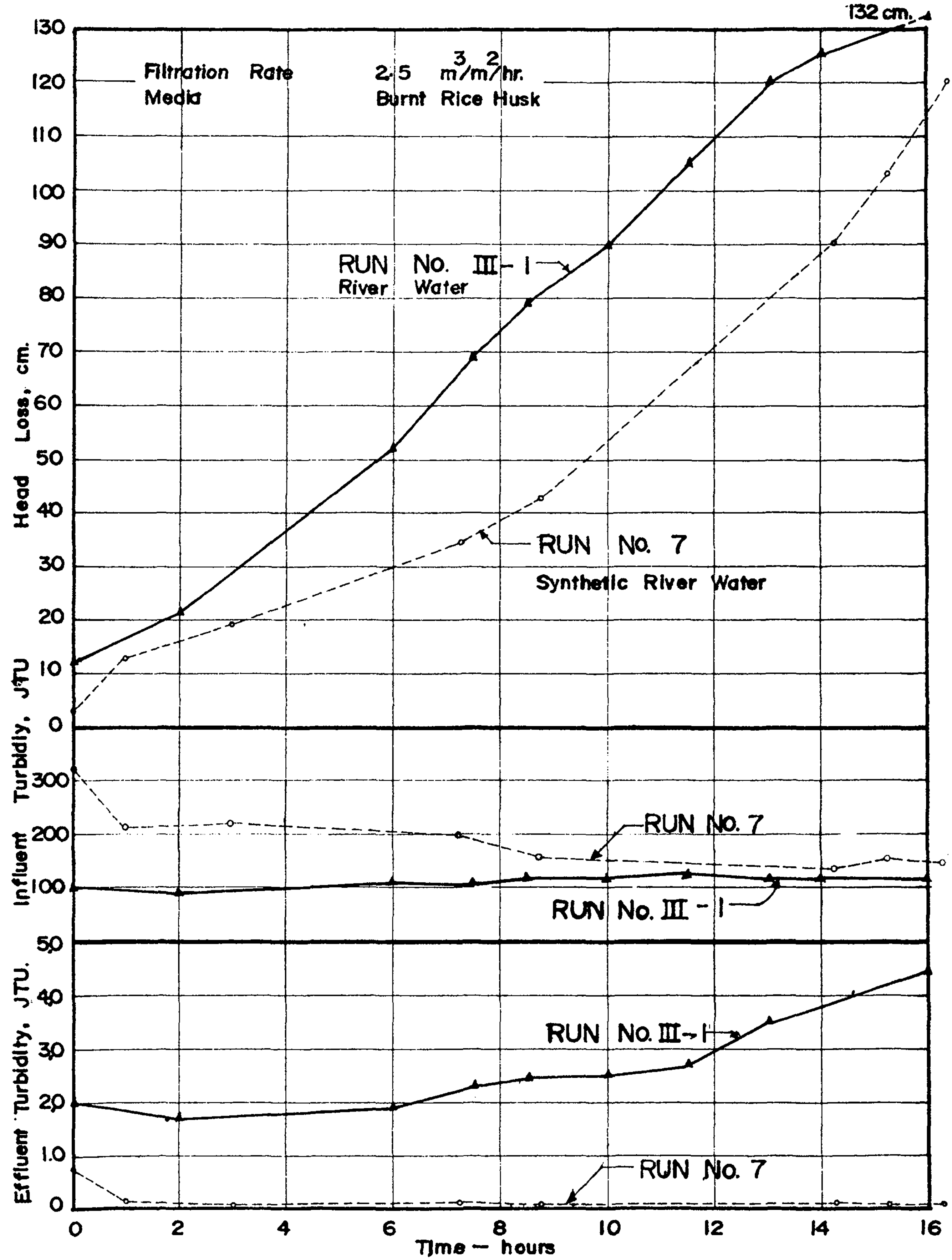


Fig.- 57 Comparison of Filter Performance using different Raw Water at 2.5 $m^3/m^2/hr.$

1. Control Media In Figure 58, head loss development and the length of filter run for sand using different types of influent turbidity was not significantly different. What appears to be significant was the length of time of break-in. In Run III-2 the gradual decrease in effluent turbidity appears to be due to the slow clogging of the surface of the bed with the corresponding increase in head loss. If the turbidity present were composed of coarse particles and organic colloids, the clogging of the top layer would take longer, leading to a gradual increase in effluent quality. Whilst if all the turbidity present were suspended matters (similar to synthetic turbidity) and particle sizes are relatively coarse, clogging occurs faster with decrease in effluent turbidity. Effluent quality of sand using river water was comparable but the run was terminated owing to the initial deposition on the top layer. Penetration was superficial and the exponential increase in head loss of filter run III-2 indicates the formation of a surface cake.

The performance of the control media using synthetic raw water can be said to be realistic in terms of head loss rate and turbidity removal. In fact, using river water gave a better performance, that is, inspite of higher influent turbidity level, effluent quality was comparatively better after break-in and towards the end of the run.

2. Burnt Rice Husk As shown in Figure 59, a significantly lower head loss developed in Run III-3. At the time Run II-4 was terminated, the head loss of Run III-3 was only about 45cm, a difference of 85 cm between the two runs. It is projected that the

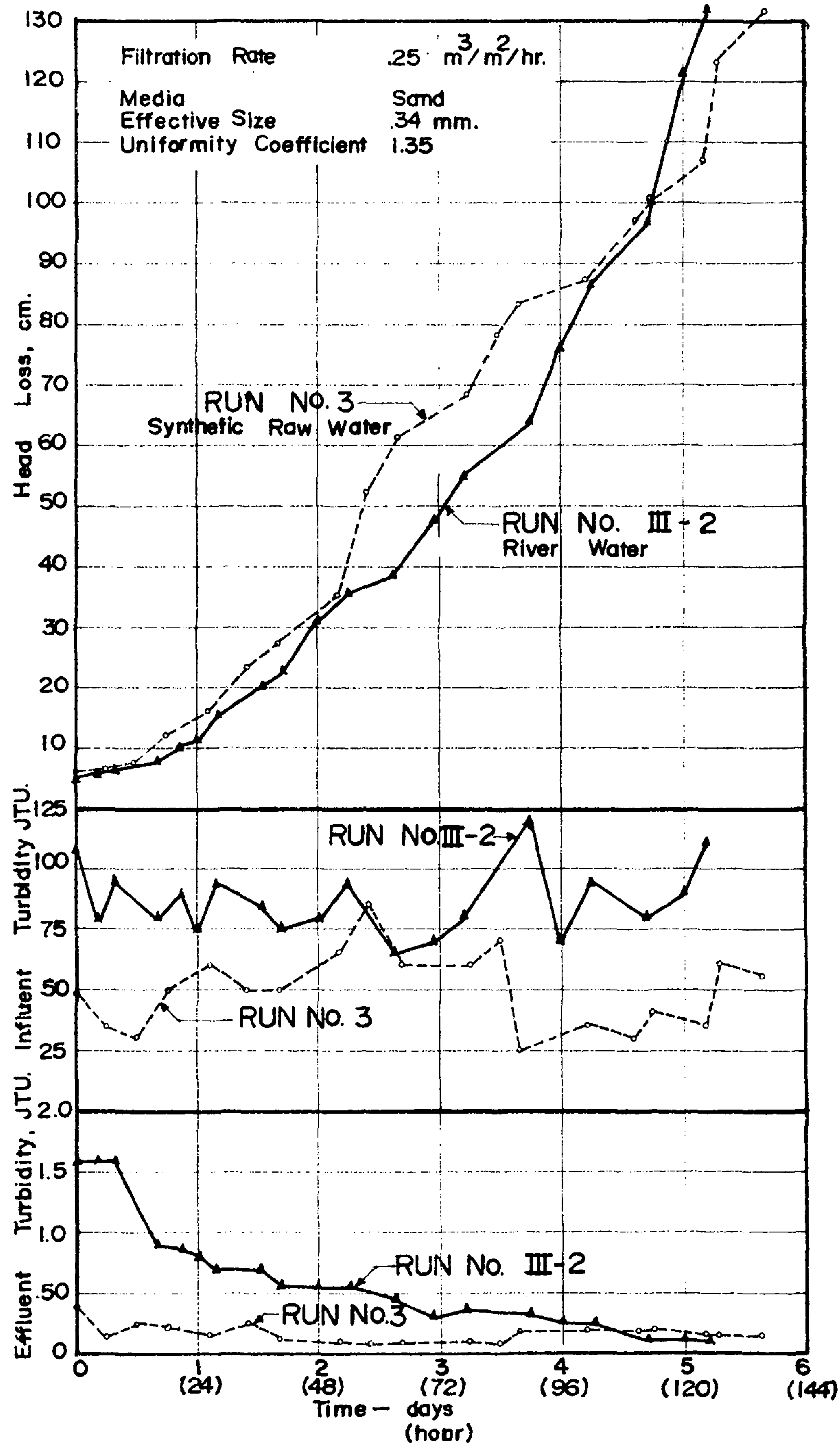


Fig.-58 Comparison of Sand Performance using different Raw Water at .25 $m^3/m^2/hr$.

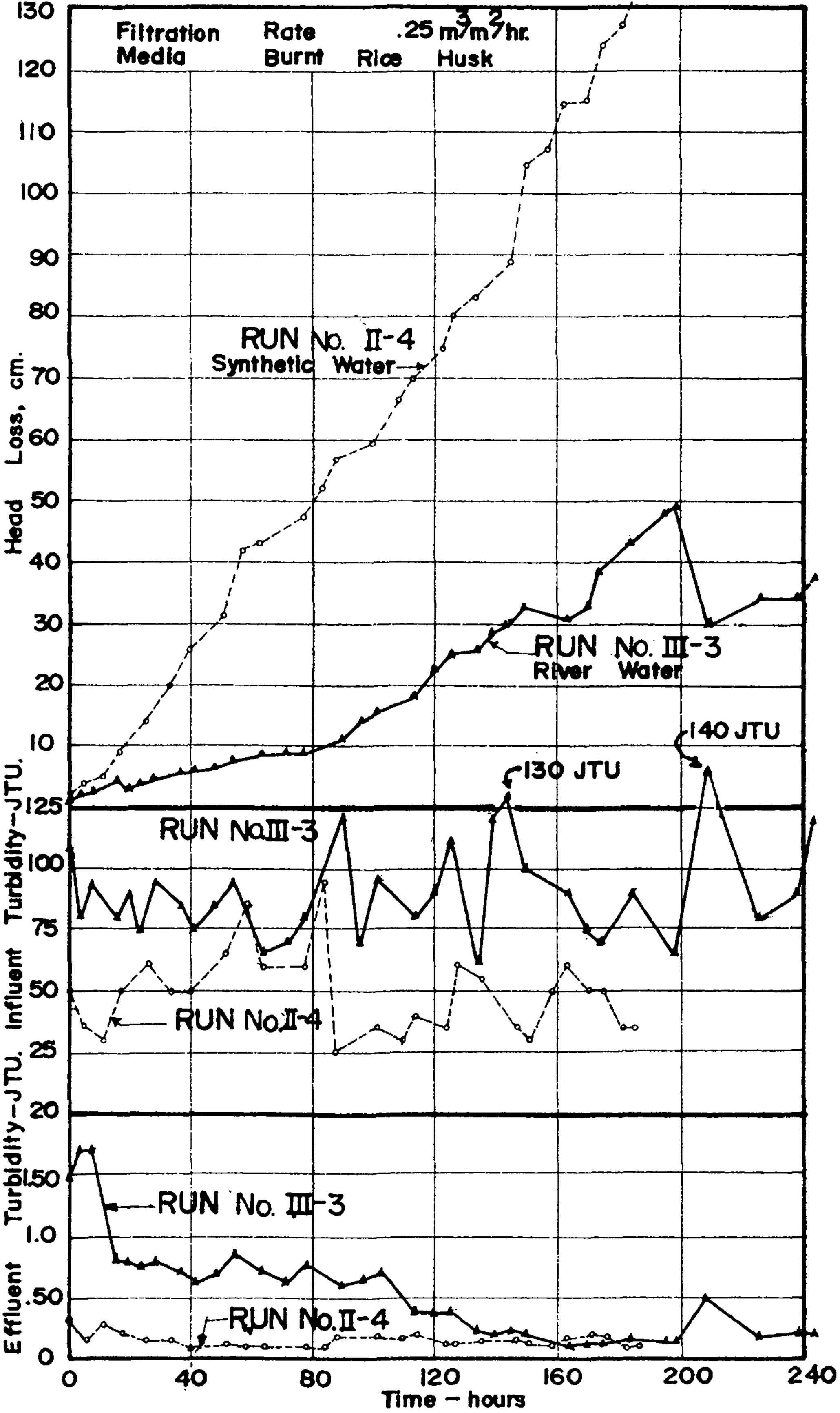


Fig:– 59 Comparison of Filter Performance of Burnt Rice Husk using different Raw Water at same Filtration Rate filter run using river water would last 100 per cent more than the other filter run. The sudden change is head loss of Run III-3 was due to the termination of the run at the 200th hours because the raw water supply ran out and the filter stagnant for 8 hours allowing settlement and compaction of the bed to occur.

Effluent turbidity appeared to be increasing already before the filter run using river water was temporarily terminated. The sudden rise in the effluent turbidity after resuming the run corresponds to an increase in influent turbidity. After that period, effluent turbidity appeared to be constant and independent of the incoming turbidity. The gradual ending of the break-in period in the beginning of the filter run was significantly different in Run II-4. Effluent turbidity of river water was comparatively similar to that of synthetic turbidity except at the sudden termination of the run. It should be noted that the river water influent turbidity was higher than that of the synthetic turbidity.

Burnt rice husk appears to have performed better with river water than synthetic raw water at lower filtration rate which could due to the gradual clogging of the top layer and deeper penetration of the finely divided particles. It appears also that organic colloids gave efficient performance in terms of length of run than inorganic and coarser particles. Due to the inherent characteristic of this media, the fine particles that are smaller than the pores of the media are removed by adhering to the grains. Penetration was superficial with a surface mat formation responsible for the exponential increase in head loss. The filter run was terminated before reaching the final head loss of 1.3 m.

From the results obtained and comparisons made, it appears that the performance of the media using synthetic water was an under estimation of the real capacity of the media to remove relatively fine particles. Furthermore, synthetic turbidity which represents coarse dispersion rather than organic colloids, was usually the cause of rapid clogging of fine media such as sand and burnt rice husk, necessitating termination of the filter runs at a relatively short period due to head loss development.

3. Coconut Husk Fiber The filter run was conducted for only a relatively short period for purposes of comparison and not for a detailed analysis of the filter capacity to remove turbidity. The filter run on coconut husk fiber using river water at a filtration rate of .25 $m^3/m^2/hr$ was conducted for 80 hours only and compared with the first 80 hours of run using synthetic water as shown in Figure 60. The sudden rise in effluent turbidity corresponding to the increase in influent turbidity occurred during the temporary termination of run due to lack of raw water supply. It is apparent that the effluent turbidity had started to decrease and remained fairly constant during the first 30 hours after which the run was temporarily terminated. After the filter run was resumed, break-in seemed to have started again as can be seen in the dependency of effluent to influent turbisity levels.

It is apparent that the trend of break-in during the first 30 hours were similar for both filter runs and differed due to the sudden termination of run. For 8 hours of stagnancy, particles were

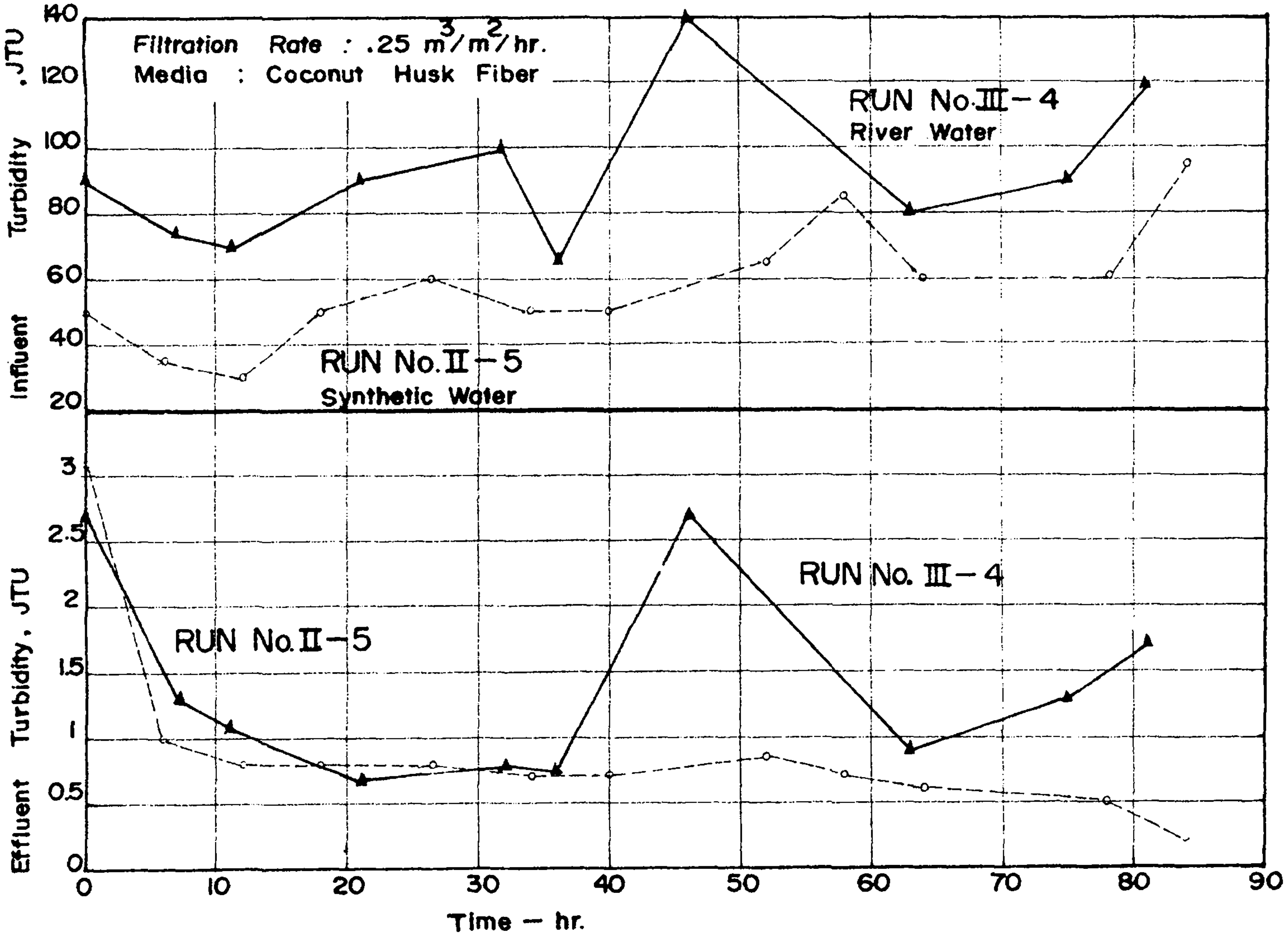


Fig.—60 Comparison of Filter Performance of Coconut Husk Fiber using different Raw Water at .25 $m^3/m^2/hr$.

allowed to settle, coalesce and go deeper through the bed, with corresponding reduction in downward force. When the filter run was started again, there was a sudden downward force applied to the particles that the finer ones were carried faster, resulting to a decrease in effluent quality.

From the results obtained from this filter run using river water, no deductions can be made. It appears that a longer time study on the effect of typical river water is needed before a more detailed comparison could be made. However, some findings could be deduced from the figure presented. The removal efficiency of the media was well over 98 per cent which could mean that this media had a capability to arrest fine particles or colloids and was not limited to coarse dispersions only. The initial deposition on the surface layer was responsible for decreasing the porosity of the media, consequently leading to a more efficient removal. If the filter run was not temporarily terminated, there was a great possibility that the effluent quality would continue to increase as can be seen from the trend during the first 30 hours. It is also apparent that the removal efficiency of the media using river water was higher than the run using sybthetic water but this is not well established because comparison was made only during the break-in period.

4. Pea Gravel Results obtained are illustrated in Figure 61 and show the significant difference in effluent quality of both filter runs at the same filtration rate. It is apparent that the effluent quality of filter run using river water is much more dependent

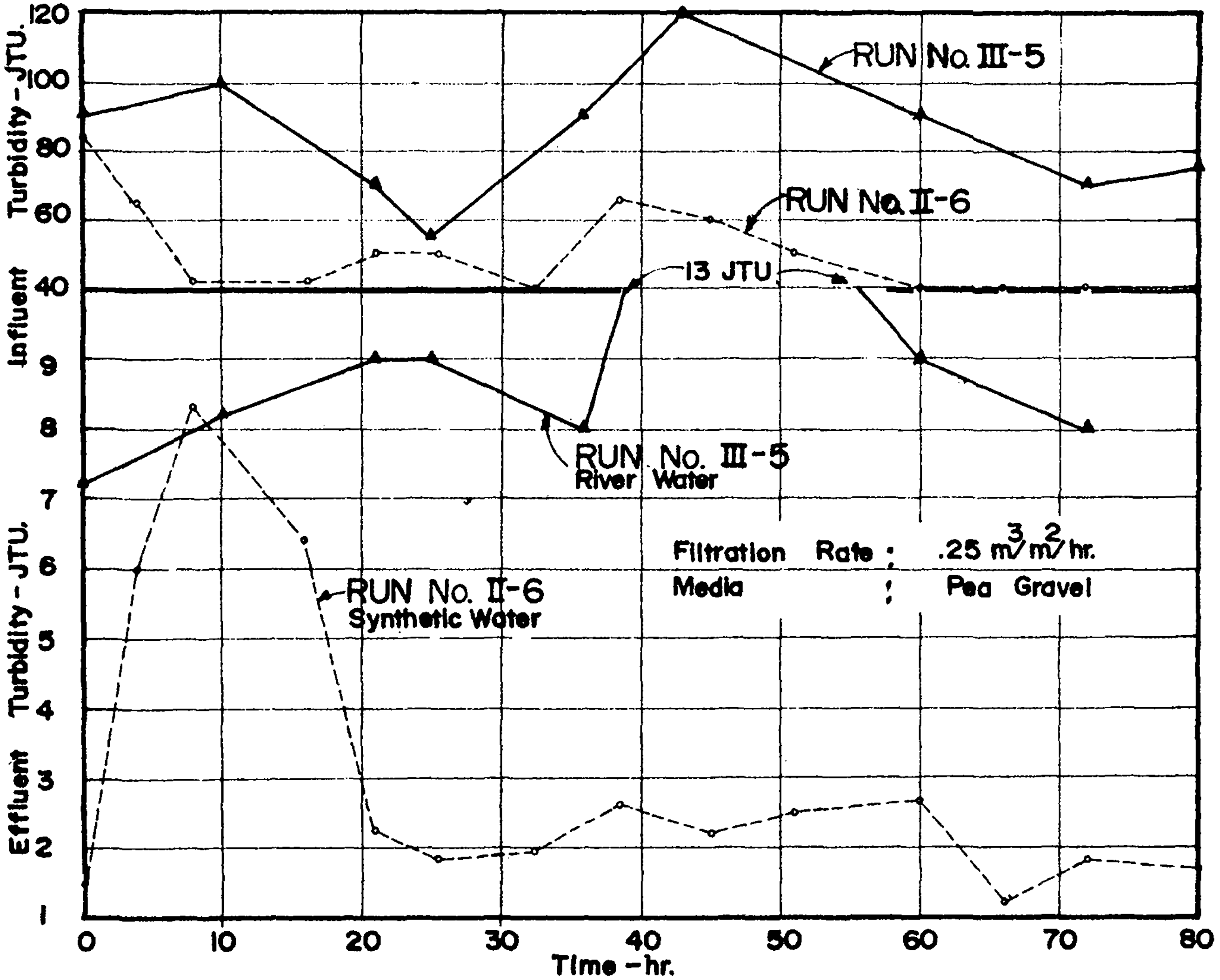


Fig.— 61 Comparison of Filter Performance of Pea Gravel using different Raw Water at same Filtration on influent turbidity level than when using synthetic turbidity. The rate of break-in occurrence in Run II-6 was much faster than in Run III-5. Evidently, this was due to the difference in the type of turbidity present. Although the length of filter run was relatively short for comparison of performance, it can be well seen that the time required for break-in period when using river water will take a longer time than when using synthetic turbidity. It must be noted that it took 300 hours before break-in terminated in the filter run using synthetic water but effluent turbidity was still dependent on influent turbidity inspite of efficient removal.

The effect of the type of influent turbidity on the performance of the media is significant on this comparison. It is evident that if coarser and heavier particles are present rather than organic colloids and fine matters, clogging of the top layers is faster enhancing more particles to be arrested. In Run III-5, the river water used had comparatively higher turbidity than the synthetic water used for the other run, yet the removal efficiency of the former was lower than the latter run. It can be deduced from this evaluation of performance that pea gravel would not give efficient removal if most of the turbidity present are fine dispersions rather than colloids and coarse dispersions and that break-in of the filter will take longer time to terminate. But inspite of the size of this media, removal of this type of turbidity at a high level was comparatively good and obviously has a capacity for long-term filter run with no occurrence head loss except deterioration of effluent quality.

Color Removal A comparison of the ability of the four media studied to remove color is shown in Table 27.

Table 27

Effect of Media on Color Removal
Value in Hazen Units

Media	Initial	Final
Pea Gravel	20	5 - 10
Burnt Rice Husk	20 - 40	nil
Coconut Husk Fiber	20 - 40	0 - 5
Sand	20 - 40	nil

It was observed however that most of the apparent color present was due to the turbidity of the raw water. This was the inherent color of the inorganic particles themselves when in despersion. Figure 62 shows the comparison of river and synthetic raw water and effluent water, Bottle #118 was the river water used and #23 was the synthetic water used. They were of the same turbidity level but the apparent color in Bottle #118 is noticeable. Bottle #120 is a typical sample of filtered water with relatively no turbidity present.

The table presented herein shows that the finer media gave a colorless water while the coarser media even though with relatively clear effluent, color was apparent at a lower level. However, the resulting color in the effluent still meets the drinking water standard of 5 units (platinum-cobalt scale). If influent water contains

Fig. 62 - Comparison of Influent and Effluent Waters. Shown from Left to Right Are River Water Influent, Filtered Water Effluent, and Synthetic Water Influent Respectively

high color, pea gravel and coconut husk fiber might not perform well in removing the color, especially if color is organic in nature.

The general deduction that could be derived from this series of run was: Performance of a media highly depends on the type of influent turbidity and is a function of filtration rates. Preliminary runs using synthetic turbidity cannot generally be said to be underestimated because the kaolin clay used for the influent water is representative of the effect of coarse idspersion and inorganic turbidity present on the performance of the media. It is evident that coarser dispersion give shorter filter runs because they are easily arrested and correspondingly pores get clogged easily. Filter runs using river water gave more general performance of the media when different kinds of turbidity are present in water. It also revealed the relative response of the different media to the different type of influent turbidity and consequently, it was also found out that the four media did not perform relatively the same as in the previous run.

For instance, burnt rice husk performed longer and better with river water than with synthetic turbidity, while pea gravel seemed to have performed with synthetic water better than with river water. It is relevant at this point that in order to determine the relative merit of each media, a more detailed analysis of performance with different type of influent turbidity is needed.

Summary of Results

Run Series I

a) The following were the maximum or optimum filtration rates for different media at the highest turbidity loading of about 1000 JTU:

Pea Gravel : less than 2.5 $m^3/m^2/hr$
Burnt Rice Husk : 1.25 $m^3/m^2/hr$
Raw Rice Husk : less than 1.25 $m^3/m^2/hr$
Coconut Husk Fiber : 1.25 $m^3/m^2/hrs$ or a little lower.

b) Compared to rapid-sand filtration, burnt rice husk gave the highest removal efficient at any level of turbidity and filtration rate but the filter run was relatively short, compared to coconut husk fiber.

c) Coconut husk gave the longest filter run with comparable effluent quality at any level of influent turbidity and filtration rate, but head loss build-up was accompanied by a deterioration in effluent quality.

d) Pea gravel and raw rice husk did not respond efficiently at any level of high turbidity loading and filtration rate investigated.

e) It was evident in all the runs except burnt rice husk that occurrence of breakthrough with or without a definite head loss was highly dependent on filtration rates and porosity of media rather than influent turbidity loadings. These were more particularly true with more porous media like pea gravel and raw rice husk.

f) One important finding that needs verification was: Burnt rice husk removed turbidity so efficiently at any level with a defined head loss that if found reliable in terms of chemical and bacteriological effects, a secondary filter might not be needed. In other words, this medium alone can give effluent quality better or comparatively better than any other single medium or possibly even series filtration.

g) Observations revealed that it was more practical to discard the media of raw rice husks, burnt rice husks, and coconut husk fibers after use than attempting to clean them.

Run Series II

a) Pea gravel performed quite efficiently at low turbidity loading and filtration rate. It appears that for this media, filtration rate and effluent turbidity loading must not exceed .25 $m^3/m^2/hr$ and average of 50 JTU respectively.

b) Coconut husk performed comparatively efficient in removing turbidity with longer filter runs and no appreciable head loss after 18 days.

c) Burnt rice husk was the most efficient compared with sand of 0.34-mm effective size and uniformity coefficient of 1.35. Filter run was longer than sand but shorter than the other two media due to a faster head loss development, terminating at 1.3 meters.

d) Pea gravel and coconut husk fiber have a possibility of being a substitute media for sand because of the capacity for long term operation with no appreciable head loss. There are, however, other factors and effects that need a detailed evaluation such as: Bacteriological action in the bed, and the length of run before deterioration of effluent quality occurs.

e) Burnt rice husk has the highest possibility of being a substitute media for slow sand filtration because at the same level of turbidity loadings and filtration rate, burnt rice husk gave the same effluent turbidity as sand but filter run was significantly longer.

Run Series III

a) The synthetic turbidity used was similar in characteristics to the colloids and coarse dispersion present in typical river water. Performances using synthetic turbidity revealed that the media showed the same relative efficiency to handle this turbidity as they did with natural river water.

b) Most of the media investigated using this typical river water gave comparable performance with the runs using synthetic turbidity. For fine and less porous media, like sand and burnt rice husk, performance was better because of its capacity to arrest fine particles. For coarser and highly porous media, like pea gravel and coconut husk fiber, performance was less efficient due to the passing through the bed of the fine particles.

c) Color removal was more efficient with finer and less porous media than the coarser media like pea gravel and coconut husk fiber.

d) Effect of filtration was a function of the type of influent turbidity.

e) Burnt rice husk was definitely better than fine sand in terms of turbidity removal and length of run but the bacteriological and chemical effects need to be investigated more fully.

f) At higher filtration rate, 2.5 $m^3/m^2/hr$, there was a tendency of breakthrough in burnt rice husk accompanied by a head loss development. This verified the fact that this filtration rate is too high for burnt rice husk.

V ECONOMIC CONSIDERATIONS

From the laboratory studies conducted and analyzed, there appears to be some important aspects that need further verification and detailed study. However, from the summary of promising results, it appears that some of the media proved comparable, if not better, than sand as filter media. For instance, burnt rice husk was significantly better than sand in removing turbidity and apparently gave longer filter runs than sand of known size. Coconut husk fiber was proven to be a good roughing filter but the effect of breakthrough, bacteriologicl actions in the bed and long storage of media has yet to be evaluated. It is apparent at this stage of study that a detailed economic comparison of the new findings with existing and proven system is unrealistic. However, a general comparison of existing systems with the new development on the basis of cost savings can be made at this point.

ATHIKOMRUNGSARIT (1971) made a study of the benefits and costs of different treatment systems presently being used in villages of Thailand. Table 28 gives the summary of average capital costs for different systems and plant capacities excluding cost of land. It is apparent that there exists some economies of scale. The slow-sand filtration system with aeration had an average capital cost higher than the conventional - rapid sand filtration system by 8-13 per cent for the same plant size. The relatively small difference in capital cost is attributable to the simplicity in construction and design of slow-sand filtration system than the more complex design of rapid-sand filters even though the former requires a larger area of land. In rural villages, seldom do they have limited land area that construction of a slow-sand filter would face any limitation. And if people realize the benefit of a water supply system in their locality, they are more than willing to donate land. The authority of a water supply system usually falls under a government agency where acquiring the required land area is no problem.

Table 28

Average Capital Cost

Type	Plant No.	Capacity 10 m^3/hr	Cost of Plant range in Baht	Average Cost ฿
C-S-RSF-CHL	1	10	73,000-452,000	293,300
	2	20	350,000-570,000	445,500
	3	30	295,000-545,000	477,600
	4	50	275,000-900,000	538,700
A-S-SSF-CHL	5	10	215,088-375,400	331,900
	6	20	270,000-735,000	480,500
	7	30	435,000-603,000	519,000

Source: ATHIKOMRUNGSARIT (1971)

C = Coagulation, S = Sedimentation, RSF = Rapid Sand Filter

SSF = Slow sand filter, A = Aeration, CHL = Chlorination

Table 29 gives the breakdown of the monthly cost of the different treatment systems investigated. The major cost in the conventional water treatment systems was the amortization cost, maintenance, chemical and power costs. Likewise, the same cost components affected the monthly cost of treatment using slow-sand filtration. The significant difference, in the monthly fixed cost between the two systems was due to the amortization cost which is dependent on the capital cost. The slow-sand filtration system has a relatively higher total cost than the rapid-sand filtration system due to amortization cost rather than to the monthly operating and maintenance cost. It is apparent that the operating cost including maintenance was higher for the rapid filter system than the slow-sand system, owing to chemicals, maintenance and power. There however exists a difference between the two systems and that is the type of raw water each is treating and if a more realistic comparison is desired, this must be included and the extent of treatment required from each to give the same effluent quality.

Comparison of Existing Systems and New Developments

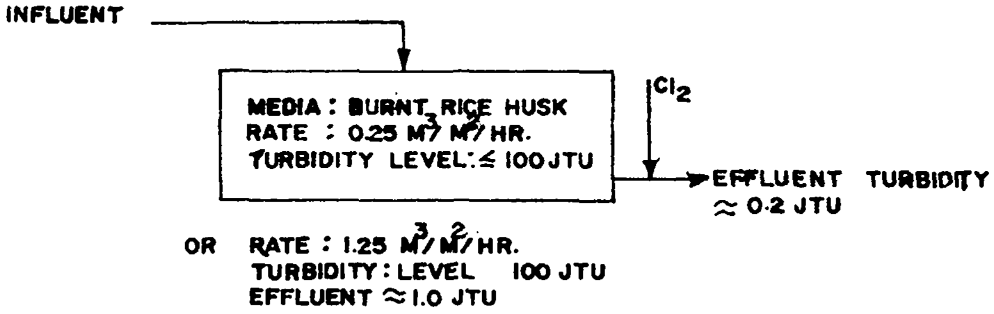
There are three possible system configurations derived from the experimental study conducted. The flow diagrams are shown in Figure 63. The configuration of the system will depend on the level of incoming turbidity and the effluent quality desired. Consequently, the extent of maintenance will depend on the rate of cleaning. Chlorination is a suggested safety precaution in case of any bacterial breakthrough which at this point is not verified.

Capital Cost For System I, the projected cost is much lower than the slow-sand filtration system, maybe by 30 per cent due to the

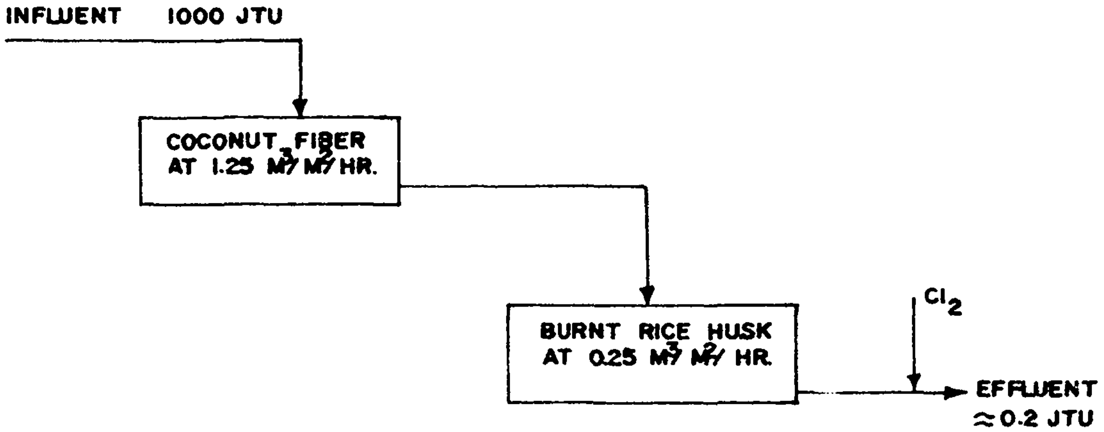
Table 29 - Breakdown of Monthly Cost & Total Cost Based on 8 hrs/day Operation

Plant Type	Plant No.	Monthly Variable Cost in Baht				Total Variable Cost in ฿	Monthly Fixed Cost		Total Fixed Cost in ฿	Total Cost of Water in ฿/cu.m
		Chemical	Power	Maintenance	Spoilage		Labor in Baht	Amortization in ฿		
C-S-RSF-CHL	1	295	435	980	190	1900	450	2780	3230	2.15
	2	475	560	1485	385	2905	500	4230	4730	1.60
	3	640	770	1590	575	3575	550	4540	5090	1.20
	4	995	995	1795	960	4745	650	5120	5770	.90
A-S-SSF-CHL	5	75	395	830	95	1295	650	3550	4200	2.30
	6	155	530	1200	190	2075	500	5130	5630	1.60
	7	230	770	1300	290	2590	550	5540	6090	1.20

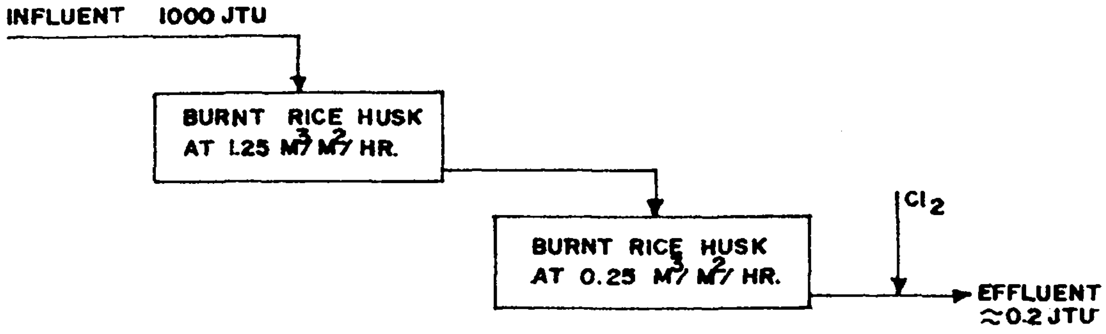
Source: ATHIKOMRUNGSARIT (1971), All values were rounded off.
Capacities of plants given in Table 28.
Amortization based on 10 yrs. service life and cost of money at



SYSTEM I



SYSTEM II



SYSTEM III

Fig. — 63 Proposed System Configerations extreme simplicity of the system and twice the normal filtration rate used for the existing one, reducing the filter area. Only, the influent turbidity must not exceed 100 JTU to ensure longer filter run between periods of cleaning. In System II, capital cost would either be comparatively the same or a little greater, but it can handle extremely turbid water. The last system recommended for future study, will have a capital cost similar to System I but shorter periods between cleaning in the primary filter by scraping off the top. Systems II and III would have higher capital cost than conventional rapid filter system and lower than slow-sand filtration system.

Operation and Maintenance Cost

Possible savings in treatment cost from the three proposed systems are : chemical cost, maintenance and wasted water. It is apparent that proposed systems would not need any chemicals except maybe chlorine, less spoilage or wastage of treated water which might only be used for cleaning the filter itself and less maintenance because of the simplicity of design and operation. Power might be less, since no high lift pump is required for storing water in elevated tanks for backwashing. ATHIKOMRUNGSARIT (1971) assumed the annual maintenance cost of plants for the conventional treatment to be 4 per cent and for the slow sand system to be 3 per cent of the capital investment. It is believed that this assumption could be lowered down to 1 per cent since not much equipment and repair are utilized and if a simple structure and design of units can be found.

Annual Cost

The other cost component of the total treatment cost is the fixed cost, composed of labor and depreciation cost plus any interest cost. The cost of labor is very low that any additional labor force required will not affect the total cost significantly. The depreciation cost is more significant since it depends on the capital investment, rate of interest and depreciation life of treatment units. The lower depreciation life depends not on the structure itself but on the extent of use and misuse. A simple unit with no complicated gadgets and operating procedure is subject to longer service. Consequently, the simplicity of structure leads to less capital cost which further reflects in lower depreciation cost.

Labor Requirements

The projected long filter runs will surely need labor only during times of cleaning, otherwise, no technician is needed when the system is in operation. A minimum supervision is all that is required since no critical factor affecting filtration has to be checked regularly, except possible breakthrough. Unlike, the conventional system where an operator is always required to be on constant guard once the filer is operating.

Required Level of Training for Operators

The simplicity of operating procedure would only require the operator to know how to operate and maintain a pump, control the filtration rate and when to terminate a filter run. Additional training that may be required is application of chlorine only. Otherwise, physical strength is all that is required to clean and maintain the filter in good operating condition. In simple words, minimum level of training is all that is required unlike operating a rapid-sand-coagulation system where the operators must also know the proper coagulant dosages to be applied for different levels of turbidity to ensure effective coagulation and settling of turbidity. Operators must also be trained on how to backwash a filter, when to start and when to stop. He is required to have the maximim knowledge of operating the system effectively which is highly dependent on the coagulation process.

It is evident from the general comparison that a lot of savings will be incurred once the proposed system is proved to be highly reliable. Savings are not only in monetary form but also the time and supervision required from the plant operator. There are still savings that at this stage are unrealized and overlooked that only a more comprehensive analysis will reveal. One of them is the possible decrease in chlorine demand, consequently, the amount of chlorine, or it is possible that disinfection would be eliminated due to the high degree of bacteria removal, and oxidation of reducing agents present in water.

VI CONCLUSIONS

From the experimental studies conducted using pea gravel, charcoal, raw rice husks, burnt rice husks, shredded coconut husks and sand, and comparative analysis of results made, the following conclusions can be drawn:

No one medium gave a superior perfermances to facilitate selection. Each had its own merits and disadvantages. Additional criteria of comparison are needed for a more detailed evaluation.

The optimum filtration rates for burnt rice husks and coconut husk fiber appeared to be 1.25 $m^3/m^2/hr$ which is in between the standard rapid-sand and slow-sand filtration rates and can be termed as "semi-rapid rate". Performance of coconut husk fiber at 0.25 $m^3/m^2/hr$ twice the normal slow-sand filtration rate, was more efficient than the optimum rate in terms of turbidity removal and longer run.

Coarse-grain filtration such as pea gravel had a capacity for long-term use with no appreciable head loss. Removal efficiency was well over 90 per cent but the effluent turbidity is dependent on the influent turbidity throughout the length of run. Termination was due to a deterioration in effluent quality.

The efficient removal of turbidity by burnt rice husk was similar to that of sand with an effective size of 0.34 mm. and uniformity coefficient of 1.35. The burnt rice husks gave longer filter run for a filtration rate of 0.25 $m^3/m^2/hr$. This media can well be substituted for sand as a polishing media or as a single filter with no pretreatment necessary as long as the influent turbidity average less than 100 JTU.

Coconut husk fiber has potential as a roughing filter media with a detectable head loss accompanied by a breakthrough at the optimum filtration rate of 1.25 $m^3/m^2/hr$. Removal efficiency was over 99 per cent and as low as 90 per cent, that is the medium can reduce the level of incoming water to a level that will not upset the performance of the secondary filter due to rapid clogging. However, the performance of this medium at lower filtration rate of .25 $m^3/m^2/hr$ was satisfactory and has the capacity for long-term use also. The effect of long use and long storage in water accompanied by bacteriological actions has yet to be established.

Raw rice husk offers some potential use but the difficulties encountered during initial period of operation and deterioration in effluent quality with no appreciable head loss for detection eliminates the possible use of this media in filtration. Furthermore, the effect of long use and storage in water might be undesirable.

The synthetic turbidity that was used throughout the series of preliminary runs was found to be realistic when compared with performances of media using river water. However, it is more representative of actual filter performance when the type of turbidity present in raw water is colloidal and coarse dispersions and not when turbidity is preponderantly fine suspension of the organic type as it is with synthetic turbidity made from koalin clay.

In using river water for comparison of performance, apparent color was observed to be noticeable in the influent water. For purposes of comparison, relative efficiency of the media to remove color was found to be better with fine and less porous media than with the coarser and more porous media like pea gravel and coconut husk fiber. Color was removed efficiently and was down to 0 level by the burnt rice husk and the sand control media. Pea gravel reduced color down to 50 percent only while coconut husk removed about 80 per cent of the influent color.

The difficulties encountered in the preparation of the proper filter size of the media were enough to eliminate charcoal as a possible substitute media for filtration in the rural villages. Besides, although it is locally available and abundant, charcoal has to be purchased and the wasted particles during preparation will increase the cost of maintenance and operation.

From the general economic comparisons made, savings from using the new development will be realized in the elimination of coagulation and reduction in chlorine demand, lower maintenance cost, simple design and structure of the filter units, less labor requirement and level of traning required for the operator. The capital cost of either of the new systems will greatly depend on the materials and design of units to be used. Land value is no limitation to the design of units and so is the availability of cheap labor.

At this stage of preliminary investigation, there are still a number of factors to be considered thoroughly before a detailed and realistic comparison with the existing systems can be made. Among these are: (s) bacteriological action in and on the bed; (b) effect of the media under investigation on other qualities of water; (c) long term use and possible re-use of media; (d) simple structures; (e) pilot-plant study to evaluate the performance on a bigger scale.

VII RECOMMENDATIONS FOR FUTURE WORKS

In order that the new system can be put to use, a number of factors need evaluation:

1. The effect of the media on the filtrate needs to be evaluated to determine whether it affects the quality of the water.

2. Bacteriological action in the bed is one of the most important characteristics of a slow-sand filter. Bacteriological tests needs to be performed with the new media.

3. The use of multi-media filtration using the media investigated if found efficient could decrease the size of the unit and consequently lead to a lower capital cost.

4. The effective size of sand that will give comparable results and performance with that of burnt rice husk.

5. More detailed study on the effect of filtration rate and different types of influent turbidity on the performance of the media.

6. A pilot-plant study to a determine whether the proposed system configurations would be able to give a high quality potable water that meets drinking water standards.

REFERENCES

ARCEIVALA, S.J., *Rural Sanitation*, Research at Control Public Health Engineering Research Institute, Nogpur, India.

ATHIKOMRUNGSARIT, C. (1971) Benefits and Costs of Providing Potable Water to Small Communities in Thailand, *Master's Thesis*, Asian Institute of Technology, May, 1971.

AWWA (1965), *Water Quality & Treatment*, 2nd Edition, The AWWA Inc. pp. 253-288.

BAILEY, A.C. (1937) Use of Anthrafilt in a Slow Sand Filter, *J. Amer. Wat. Wks Ass.*, Vol. 29 No. 12, pp. 1909-1916

BODY, W.M.T. and ALPE, G. (19), Practical Experiences using Upward Flow Filtration, *Date and publication unknown*.

BOUCHER, P.L., (1961) Micro-Straining, *Presented to a meeting of the Edinburgh and East of Scotland District at Edinburgh, Scotland March 20, 1961*, pp. 294-312.

BROWN, J.C. & OKUN, D.A. (1965), European Practice in Water Filtration, Publication No. 10, *Conference on Filtration*, Civil Engineering Division, University of Missouri, pp. 5-11.

CLEASBY, J.L. and BAUMANN, E.R., (1954), Selection of Sand Filtration rates, *J. Amer. Wat. Wks Ass.*, 54: 579-602.

DANIELS, F. & ALBERTY, R. (1966), *Physical Chemistry*, John Wiley & Sons, Inc., New York, 3rd Edition.

DIETERICHE, B.H. & HENDERSON, J.M. (1963), *Urban Water Supply Conditions and Needs in Seventy-Five Developing Countries*. Public Health Papers #23, WHO, Geneva, pp. 9-13, 63, 69-78.

ENCYCLOPEDIA BRITANNICA, (1965), Vol. 2, Encyclopedia Britannica, Inc., William Benton Publisher, U.S.A. pp. 603.

FAIR, G.M. GEYER, J.C. and OKUN, D.A. (1968) Water & Washwater Engineering, Vol. 2, John Wiley & Sons, Inc., U.S.A., pp. 27-1-49.

HAMANN, C.L. and McKINNEY, R.E. (1968), Upflow Filtration Process, J. Amer. Wat. Wks. Ass., Vol ____, No. ____, pp. 1023-1039.

HAZEN, R. (1953), Application of Microstrainer to Water Treatment In Great Britain, J. Amer. Wat. Wks. Ass., Vol. 45, No. 6, pp. 723-

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

HOUGHTON, G.U. (1970), Slow Sand Filtration and Biological Processes, Paper presented at the Symposium on "Water Treatment in the Seventies".

HUDSON, H.E. (1958), Factors Affecting Filtration Rates, J. Amer. Wat. Wks. Ass., Vol. 51, No. 6,

HUISMAN (1969), Biological or Slow-Sand Filters, Background Paper #70.1 WHO, pp. 2-15.

McGRAW-HILL ENCYCLOPEDIA OF SCIENCE AND TECHNOLOGY, (1966), Vol. 3, Mc-Graw-Hill Book Company, pp. 10.

MILLER, D.G., BURLEY, M.F. and NAWER, P.A. (1970), A Survey of Water Supply Costs, Chemistry and Industry, May, 1970, pp. 673-683.

OKUN, D.A. (1962), Water Supply & Treatment in Three European Countries, J. Amer. Wat. Wks. Ass., Vol. 54, June, pp. 650.

PEARSALL, W.H., GARDINER, A.C. and GREESHILEDS, F. (1946), Freshwater Biology and Water Supply in Britain, Fresh Water Biological Association (Windemere).

PESCOD, M.B. (1966), Sand Filtration, Asian Summer Institute of Water Supply and Treatment (Unpublished).

RIDLEY, J.W. (1967), Experiences on the use of Slow-Sand Filtration, Double and Filtration and Micro-Straining, Proc. of the Soc. of Water Treatment & Exam., Vol. 16, Part 3, pp. 170.

RIPPLE, O.J. (1938), Coal vs. Sand as a Filter Medium, J. Amer. Wat. Wks. Ass., Vol. 30, No. 5, pp. 812.

ROEBUCK, G.G. & WOODWARD, R.L. (1959), Pilot Plants for Water Treatment Research, J. San Engng. Div., Proc. Am. Soc. Civ. Engrs., Vol. 85, No. SA4, pp. 1.

SEGALL, B.A. and OKUN, D.A. (1965), Effect of Filtration Rate on Filtrate Quality, Rept. to the 45th Annual Joint Convention, North Carolina Section AWWA and NCWPCA November 8, 1965.

SKEAT, W.O. and DANGERFIELD, B.J. (1969), Manual of British Water Engineering Practice, Vol. III, W. Heffer and Sons Ltd., Cambridge, England, pp. 191-197.

WADINGTON, A.H. (1961), Pilot Plant for Water Treatment, Proc. of the Soc. of Water Treatment and Exam., Vol. 10, pp. 22.

WAGNER, E.G. and LANDIX, J.N. (1959), Water Supply for Rural Areas and Small Communities, WHO, Geneva, pp. 175-178.