A STUDY OF FILTERS AS HOUSEHOLD WATER TREATMENT FACILITIES FOR RURAL AREAS

BY

JOHNSON ORECH

A THESIS SUBMITTED FOR THE PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE MASTER OF SCIENCE DEGREE IN ENVIRONMENTAL HEALTH ENGINEERING OF THE UNIVERSITY OF NAIROBI, KENYA.

JUNE 1978

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

CANDIDATE

This thesis has been submitted for examination with my approval as University Supervisor.

SUPERVISOR

ACKNOWLEDGEMENTS

This work was supported by the University of Nairobi, in part, through funds made available from the Commonwealth Fund for Technical Cooperation by the Office of the Commonwealth Secretariat, to which I am grateful.

I wish to thank my supervisor, Dr. C.H. Geisler and the entire Academic and Technical Staff of the Department of Civil Engineering, particularly those of the Environmental Health Section, for the assistance and support that they rendered to me during the course of this study.

My thanks also go to Mr. P. Scrivener, and Mr. Stapleton both of UNICEF, Nairobi, who assisted me a lot during this work.

CONTENTS

SYMBOLS

Af	Cross sectional area of filter
Ap	Cross sectional area of pipe
Cal/gm	Calories per gram
Cl^-	Chlorine ion
Cl_2	Chlorine molecule
df	Diameter of filter
dp	Diameter of pipe
FTU	Formazin Turbidity Unit
H^+	A proton
H_2O	Water Molecule
HOCl	Hypochlorous Acid
KShs.	Kenya Shillings
MPN	Most probable number
pH_F	Filtered water pH
pH_R	Raw water pH
PVC	Poly vinyl chloride
Q	Total flow to all the filters
Q_1	Flow into each filter
V	Velocity of flow
Vf	Rate of filtration

CHAPTER 1

INTRODUCTION

The importance of enough supply of good quality water cannot be overemphasised. It is the basis for the promotion of environmental health and a high standard of living. And yet, in all under-developed parts of the world, particularly in the tropical areas, enough and good quality water supply still poses one of the biggest problems for the responsible authorities. Raising water from its source and making it more readily available for domestic and other uses, is particularly a problem in the rural areas.

In this country, Kenya, the long term objective of the Government is to provide practically everyone in the country with a safe and sufficient water supply by the year 2000. Data available for the year 1974 indicate that the majority of the urban population, which constiutes approximately ten per cent of the total population, has access to safe water supply. Of the total rural population, about ten per cent are served. The rest of the rural supplies have no treatment facilities and less than half of the supplies deliver water safe from a bacterial point of view. Among the major duties during the life of most rural women and children is still the problem of carrying all the water that is used over long distances and in many cases uphill.

The reasons attributed to the current impossibility to provide safe and adequate water for millions of the rural inhabitants in many countries of the world are many and varied. On one hand, they may be purely financial or political and on the other, they may be only geographical or lack of suitable manpower.

So it becomes important that any organisation responsible for water supply, like the Water Apportionment Board in this country, limits the use of water treatment under rural conditions to only those cases where such treatments are absolutely required and where proper plant operation and maintenance can be secured and supervised. For instance, in this country, with the assistance of UNICEF, the Ministry of Health together with the community concerned, constructed a number of slow sand filters in the recent years in order to provide safe water to the public. Unfortunately, due to one of the reasons or the other mentioned above, some of them have since, ceased operation. These include the ones built in Mutituni (Machakos) completed in 1971, Gatheru (Murang'a) completed in 1975 and Sigor (Kericho) completed in 1970. The collapse of water treatment processes such as these ones, are known to result into some gross water borne epidemics like cholera, dysentry and others. So that, if the community concerned can all afford to procure, operate and maintain a treatment process because of its limited financial resources or some other reason, the responsible authority usually opposes the use of such a treatment process.

It is true that, there are available, modern equipment, designed to minimise operation and maintenance problems. Yet, it is these equipments which require a lot of money to buy and a lot of skill to operate. Besides, once they are spoiled or damaged are difficult to repair due to lack of local expertise or spares.

This explains, in part, the reasons behind the need for a field of activity in which locally available materials, skills and resources are used to develop a form of cheap technology which is appropriate for application in rural areas of developing countries. It is in this field of activity that this study was carried out.

CHAPTER 2

SOURCES OF WATER SUPPLY

In all tropical countries, the most common sources of water supply include:-

2.1 RIVERS AND STREAMS

These waters are usually soft, containing relatively low concentrations of dissolved salts, although this does not necessarily apply elsewhere in the tropics. They are often affected by feacal pollution, usually greatest in small streams near inhabited areas. If they are used for water supply, they are usually treated, otherwise, they consitute a direct connection between the alimentary canals of those people living upstream and the mouths of those living downstream. The quality of these waters usually vary considerably with the period of the year; although turbidity is normally expected.

2.2 LAKES

Large fresh water lakes and ponds form sufficient reservoirs of water if kept free from pollution with wastes. In general, the water quality is usually fairly good and consistent, but may well be polluted. Near areas of industrial and agricultural developments and sewage and industrial effluent discharges, there is an increasing danger of algal growth. This may affect the water to such an extent that it becomes impractical to consider it as a source of public water supply.

2.3 SWAMPS

Swamp waters include slowly flowing rivers. They usually contain feacal pollution and organic matter in high concentrations. This gives rise to colour, turbidity and sometimes acidity of unacceptable ranges.

2.4 SPRINGS AND BOREHOLES

In areas of impervious strata, water obtained from springs and boreholes is usually of better quality than surface water from the same area. This, however, is only true if they are properly maintained and sufficiently distant from pit privies and soakage pits.

In other areas where the soil is rich in organic matter the water when passing through the soil can take up carbon dioxide which permits dissolution of minerals in the soil and thus rendering the water harder than surface water.

2.5 RAINFALL

Rainfall is collected as run-off from

impervious areas such as rocks, corrugated iron-roofs or artificially formed catchments of concrete or other water tight material. Rain water is normally the purest but in built up areas, it is difficult to collect it in such a way as to render it free from pollution and drinkable.

Work done in the USA, Australia, and Jamaica has also shown that water supplied from rainwater units using artificial catchments in areas of low or average rainfall is not cheap and that this supply is only justified where only a limited amount of water is needed. The units are not suitable for large scale supplies like irrigation schemes.

However, in many rural areas, the economic situation prevents the large capital expenditure associated with big public water supply schemes. So that rain water units may provide a suitable alternative. In situations where the population is widely scattered, rain water units for small communities or single households, is usually a means of providing good quality water.

CHAPTER 3

PURIFICATION OF WATER

3.1 LARGE SCALE PURIFICATION

There are various methods available for making water safe and wholesome to the consumers. These methods, the choice of which depends upon the characteristics of the raw water in consideration, include:-

3.1.1 STORAGE AND SEDIMENTATION

Storage in reservoirs for two days reduces the bacterial content of the water by more than fifty percent and storage for one week reduces up to ninety percent of the bacteria. Besides, it also reduces the oxygen demand of the water. However, storage cannot be relied upon as a sole measure of purification. Because of forces like density currents and wind disturbances, even proper clarification cannot be fully attained.

When a reservoir or tank is used for storage, at the same time it provides for sedimentation. Where the tank or reservoir capacity is limited or where the water contains much finely suspended matter, the rate of sedimentation is usually increased by addition of chemical coagulants, usually alluminium sulphate. The coagulants react with the particles to form flocculent precipitates which are capable of settling much more rapidly.

Even after sedimentation, plain or otherwise, some of the finer particles may still persist in water. A large proportion of these finer particles is usually removed by filtration.

3.1.2 FILTRATION

Filtration, especially through sand, is the oldest and the most widely used method of purification. Basically, there are two types of filtration in common use.

3.1.2.1 Slow Sand Filtration

This consists of a concrete or brickwork box, containing carefully selected and graded sand, supported on gravel or stones and suitably underdrained, so that the movement of water through the filter is as even as possible. At a maximum filtration rate of about 3 m^3/m^2/Day, the slow sand filter depends for its action on a combination of biological degradation, adsorption, mechanical straining and sedimentation of suspended matter. Many forms of animal, vegetable and bacterial life participate in this process which takes place at the top biological film (Schmutcdecke). The biological film gets gradually more dense, until it eventually clogs up the filter. At this point, between 0.5 cm and 2.5 cm (Cox, C.R. (1969)), top layer of sand is scraped off. The usual procedure is to continue to scrape the filters until the remaining depth of sand is about 0.8 m, after which about 15 cm of washed sand is replaced to restore the original depth.

3.1.2.2 Rapid Sand Filtration

A rapid filter consists of a layer of sand and some other granular medium, usually gravel, supported on an under drainage system. The entire system is open and the water flows through the filter bed by gravitation. With the entire sand depth being used for filtration, the rapid sand filter is dependent on straining, sedimentation and adsorption for its action. If the raw water for filtration has not been pretreated, the effect of the rapid sand filter is small, compared to that of the slow sand filter. With pretreatment, however, the bacterial removal can be as high as 99%. The rapid sand filter gets dirty quickly and is then backwashed approximately daily.

3.1.3 DISINFECTION

Even after sedimentation and filtration, some of the pathogenic bacteria still persists in the water. This calls for the final stage of purification, namely disinfection. Used to mean the removal of pathogenic bacteria, disinfection can be effected using gases, metals, chamicals as well as radiations.

By far, the most commonly used agent is chlorine and its compounds, whose reaction in water proceeds in the order:-

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^- \text{ (Hydrolysis).}$$

$$HOCl \rightarrow H^+ + OCl^- \text{ (Ionization)}$$

Chlorination itself, takes certain forms, namely prechlorination and breakpoint or super - chlorination.

3.1.3.1 Prechlorination.

This is the addition of chlorine or chlorine compounds to water prior to both sedimentation and filtration. It is usually done so as to effect the oxidation of organic and bacterial load which would otherwise clog up the filter too early.

3.1.3.2 Breakpoint or Super-Chlorination

This means the application to water of a heavier than usual dosage of chlorine in order to oxidise all the organic matter, iron, mangnese and any other oxidizable substances. The amount of chlorine applied is enough to provide either immediately or within the detention time of the plant, free residual chlorine, which is constituted by the species of Cl_2, HOCl and Ocl^-.

3.2 SMALL SCALE PURIFICATION

The purification methods described before, sometimes become impossible to install. This is especially the case in rural areas of developing countries. This led to a survey, aimed at finding and recommending simpler and small scale means of purifying water, even by the village inhabitant. According to the recommendations, contained in the World Health Organisation Publication (1956) entitled 'The Purification of Water on a Small Scale', three methods are recommended.

3.2.1 BOILING

This is an adequate method of destroying pathogenic bacteria in water. It is equally effective irrespective of the nature or degree of pollution of the raw water. Although the amount of fuel required to boil a certain amount of water varies with the type of fire and vessel used, it usually requires about 1 Kg of wood to boil 1 litre of water. This, the villager should be able to afford.

Boiling however, changes the taste of the water as it drives out most of the dissolved gases. But, this effect is lost if the water is left for a period of time, in a partly filled container.

3.2.2 DISINFECTION

As already mentioned, disinfection can be effected by many different agents, the most common of which being chlorine. This is a useful disinfective agent, especially for drinking water. However, in its usual dose, chlorine is ineffective against certain cysts and ova and against organisms embedded within the solid particles. At the same time, chlorine can react with organic matter in water forming chloro-organic compounds which sometimes are disinfective. Adequate chlorine, usually approximately three drops of one per cent chlorine stock solution per litre of water, is therefore usually added to satisfy the chlorine demand of the water together with that required for bacterial oxidation.

3.2.3 FILTRATION

There are two types of filters in common use for the treatment of household water supplies. These are:-

3.2.3.1 Sand Filter

Figure 1 shows the general layout of a household sand filter. This filter, with a maximum filtration rate of 2.7 litres per square metre per minute, is however, relatively ineffective against bacteria, unless skillfully operated and maintained. It does however, remove cysts, ova, cercariae and other relatively large organisms. It will also remove most of the course and visible matter in suspension, but allowing some fine turbidity through. Its effect is usually increased by first carefully treating the water with a coagulant.

The filter becomes clogged after several weeks or even months. It is then cleaned by scrapping off about 0.5 cm of the top layer. After several such cleanings, the sand is restored to its original level with clean sand after scraping the surface down to clean level.

3.2.3.2 Ceramic Filters

Under the title ceramic filters, are included pressure filters, non-pressure filters and filter pumps. There are a wide range of ceramic media having different pore sizes. The ones with coarse gained filter candles are useful for the removal of suspended matter, ova, cercariae and cysts. Their

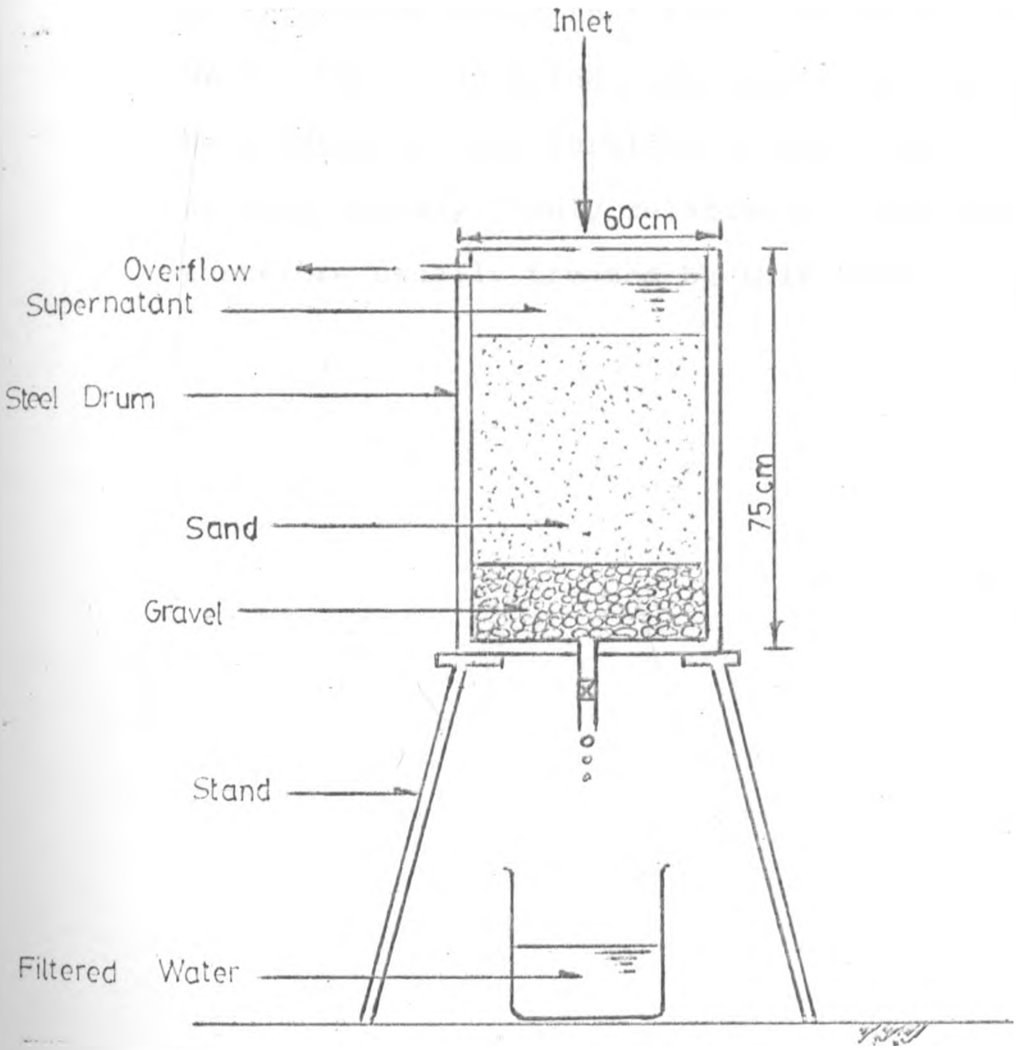


Fig. 1 Sand Filter

failure to remove completely the smaller pathogenic organisms means that the water so treated should be further disinfected. Besides, when the water to be treated is very turbid or cloudy, the filter clogs up very quickly. Only relatively clear water is therefore usually treated by this type of filter.

CHAPTER 4

PURPOSE OF STUDY

The problems of rural areas are usually lack of capital for costly investments, absence of local expertise and lack of spare parts, to name a few. These, among other issues, are great obstacles for both community as well as individual water supplies.

This study was conducted to find simple and cheap methods of water treatment suitable for these areas. In particular, it was tried to develop filters using mainly locally and easily available materials. Construction and operation of the filters was suppo- sedly based on that of the slow sand filter, although kept as simple as possible.

Performance effectiveness was studied by observing the behaviour of the filter box materials while they were under moist conditions for a period of time. Performance was also studied by measuring the effluent quality variation with the length of filter run. The effluent quality variation was also compared, for the same run, with that of the household candle filter.

CHAPTER 5

DESIGN AND CONSTRUCTION OF PILOT PLANT

5.1 PRINCIPLE AND LAYOUT

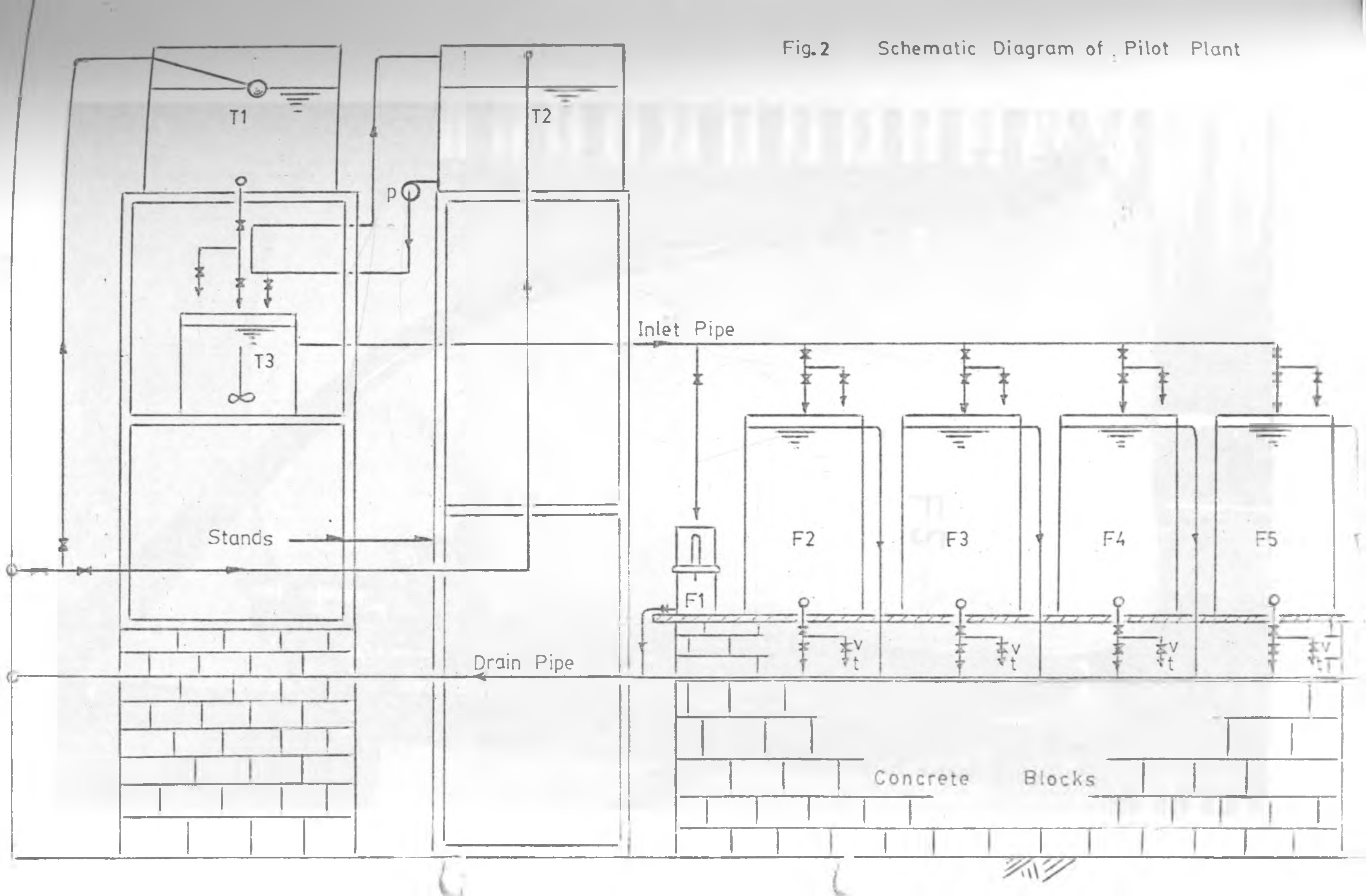
The pilot plant used in the main part of this study was arranged as shown in Figure 2, Pg. 18 Figure 3,4,5,6,7, on pages 19,20,21,22, and 23 show the photographs of the respective components. T1 was a fifty gallon tap water storage tank, T2 was a fifty gallon polluted* water storage tank and T3 was a ten gallon mixing tank. Tap water flowed gravitationally from T1 into T3 where it constantly mixed with polluted water pumped into T3 from T2 by a pump P. Only a small fraction, 50 to 100 mls/min of the polluted water pumped from T2 was tapped into T3. The rest of the water was recirculated back into T2. This was to ensure some degree of mixing.

From the mixing tank T3, the raw water flowed by gravity through the half inch diameter inlet pipe into the five filters labelled F1, F2, F3, F4, and F5. For purposes of comparison, all the five filters were operated in series, except for the first run. A filter run involved putting a fresh media and operating the filters until exhaustion was apparent.

---

*Pollution existed out of turbidity and a small amount of wastewater.

Fig. 2 Schematic Diagram of Pilot Plant



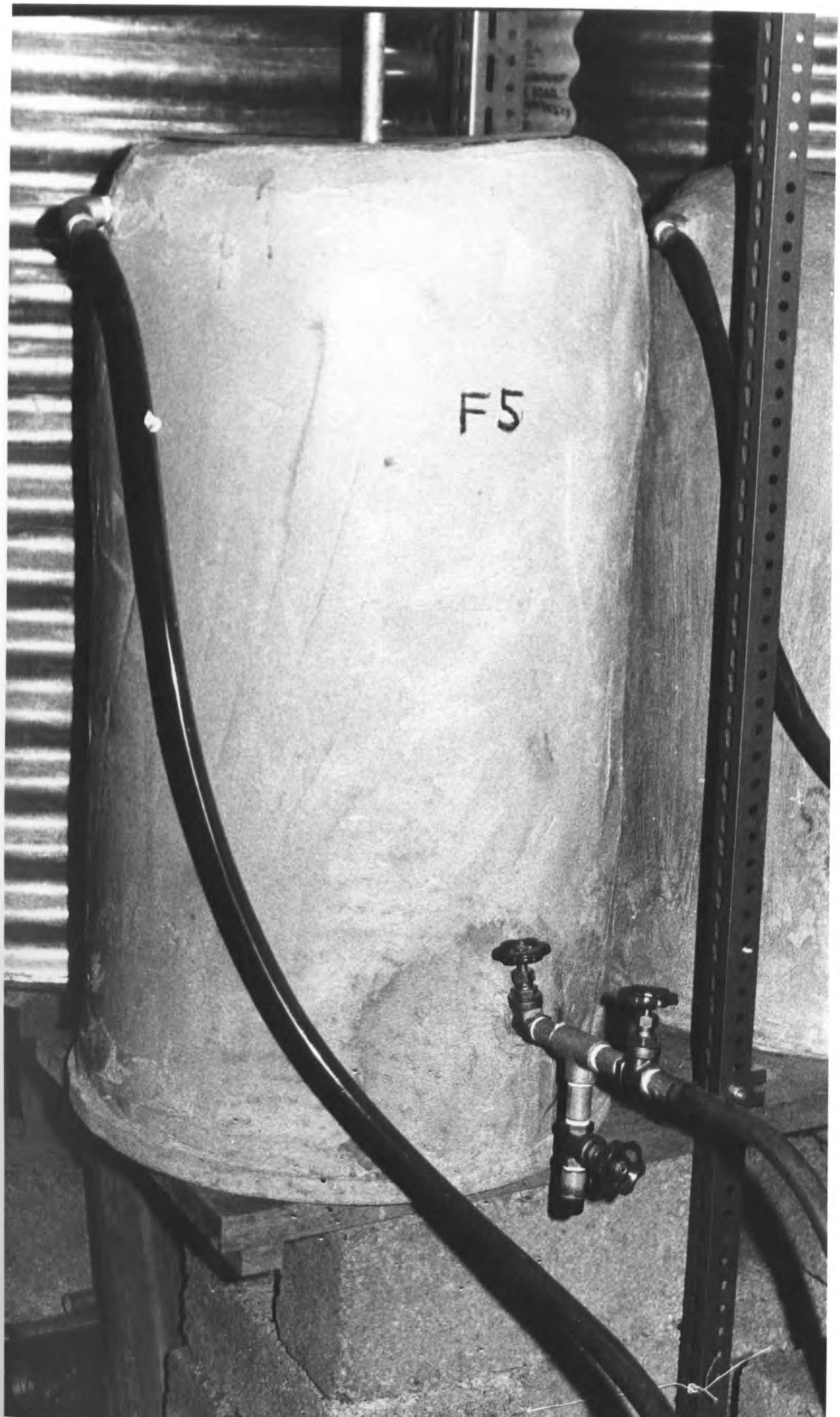


FIG. 3

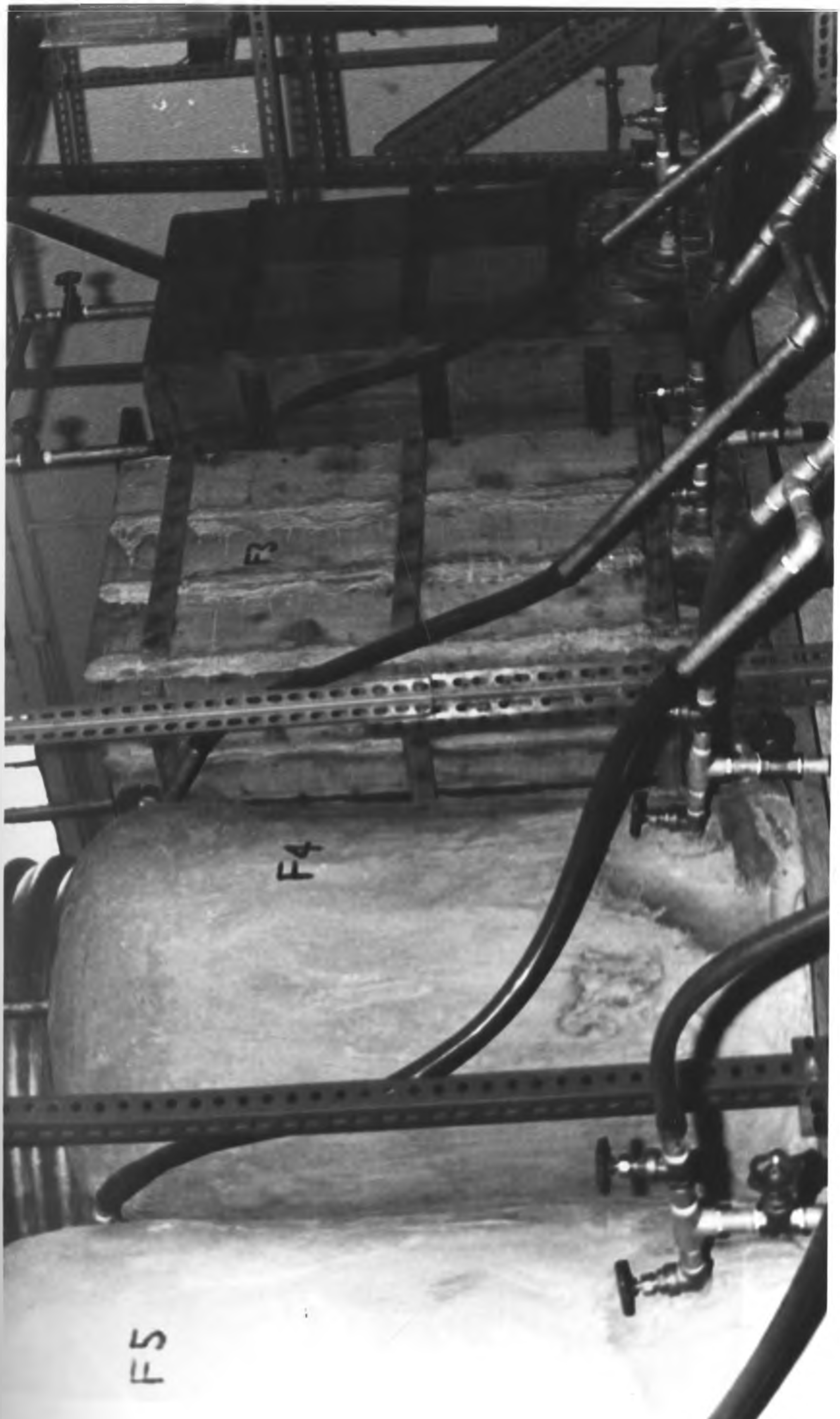


FIG. 4

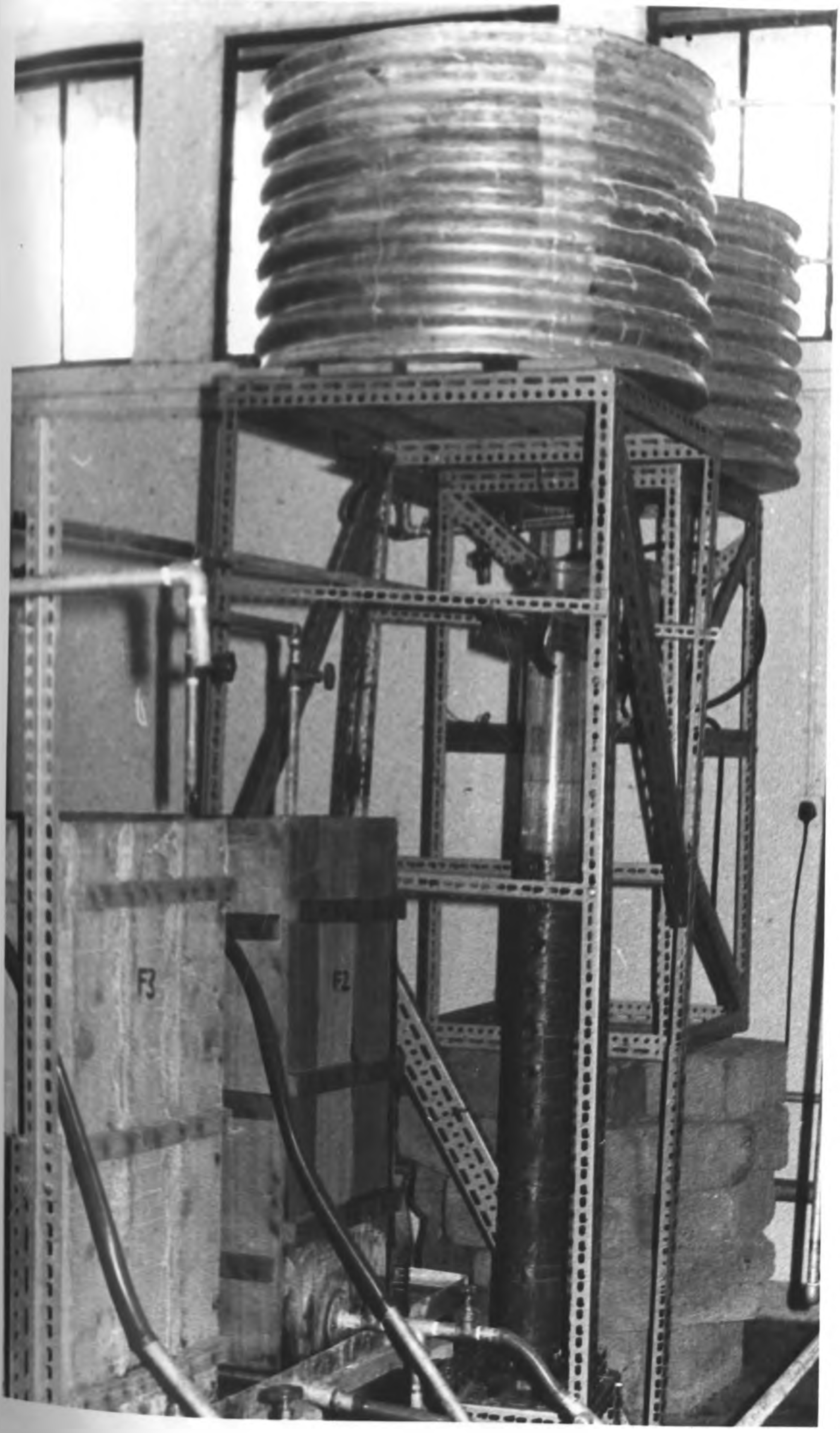


FIG. 5

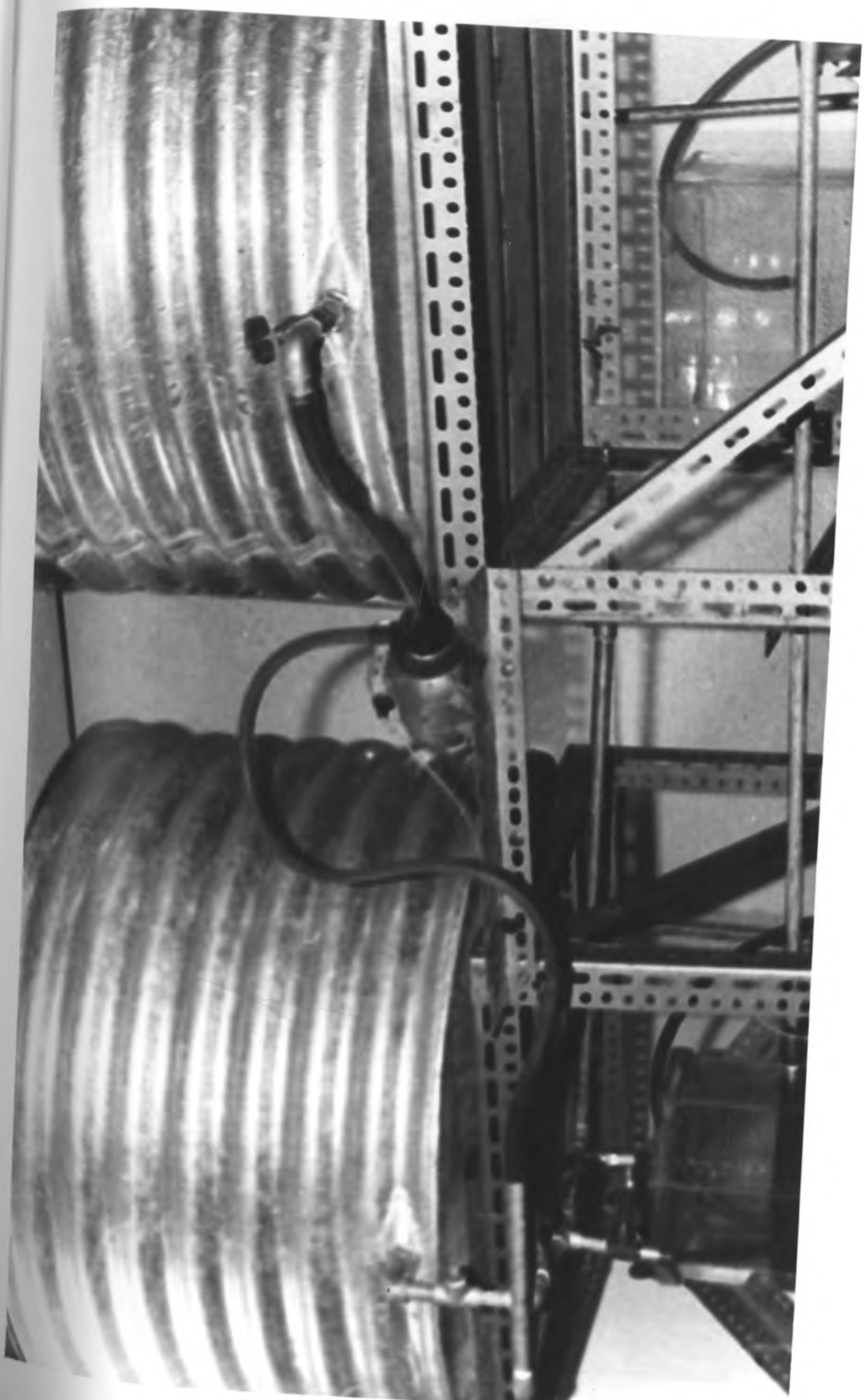


FIG. 6

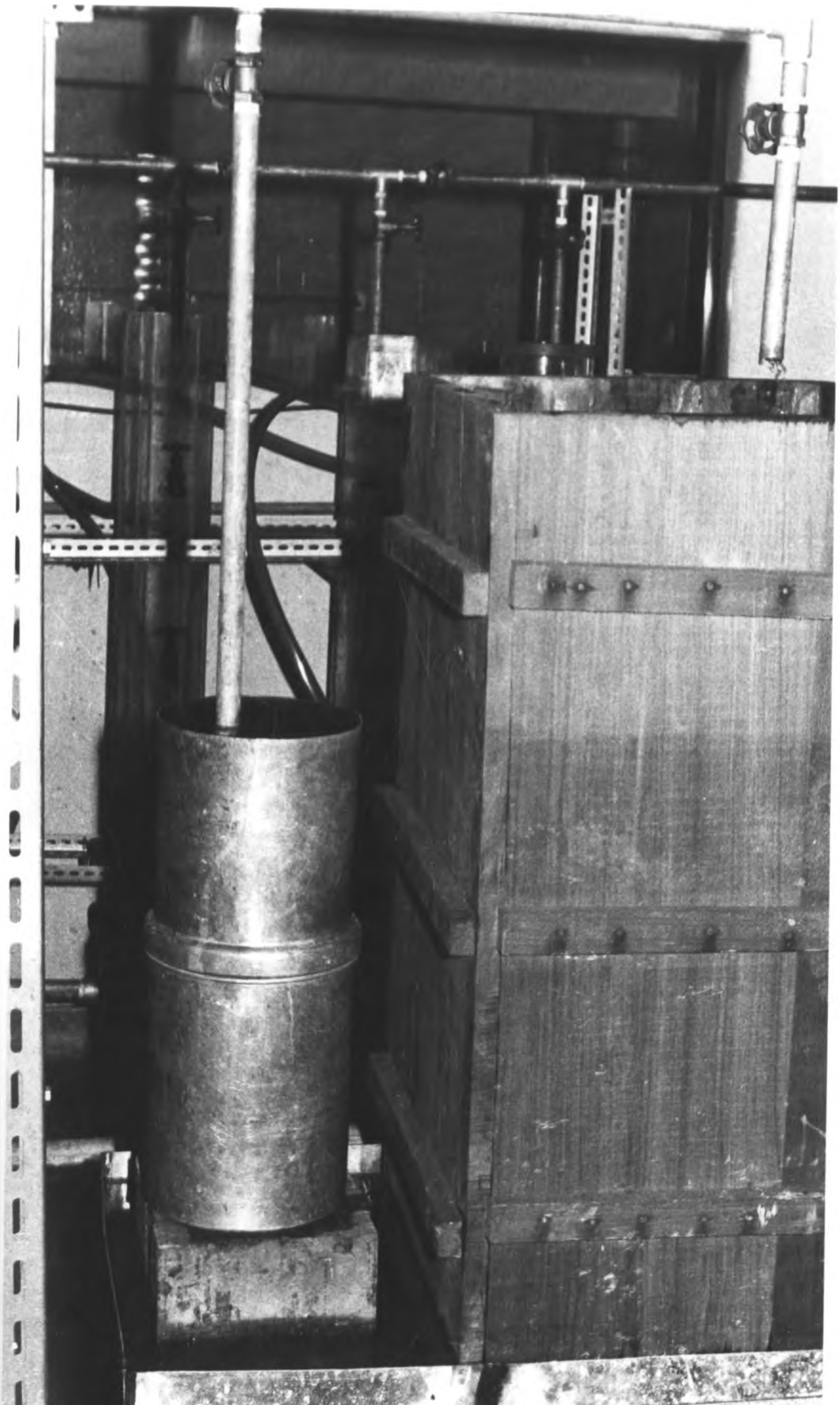


FIG. 7

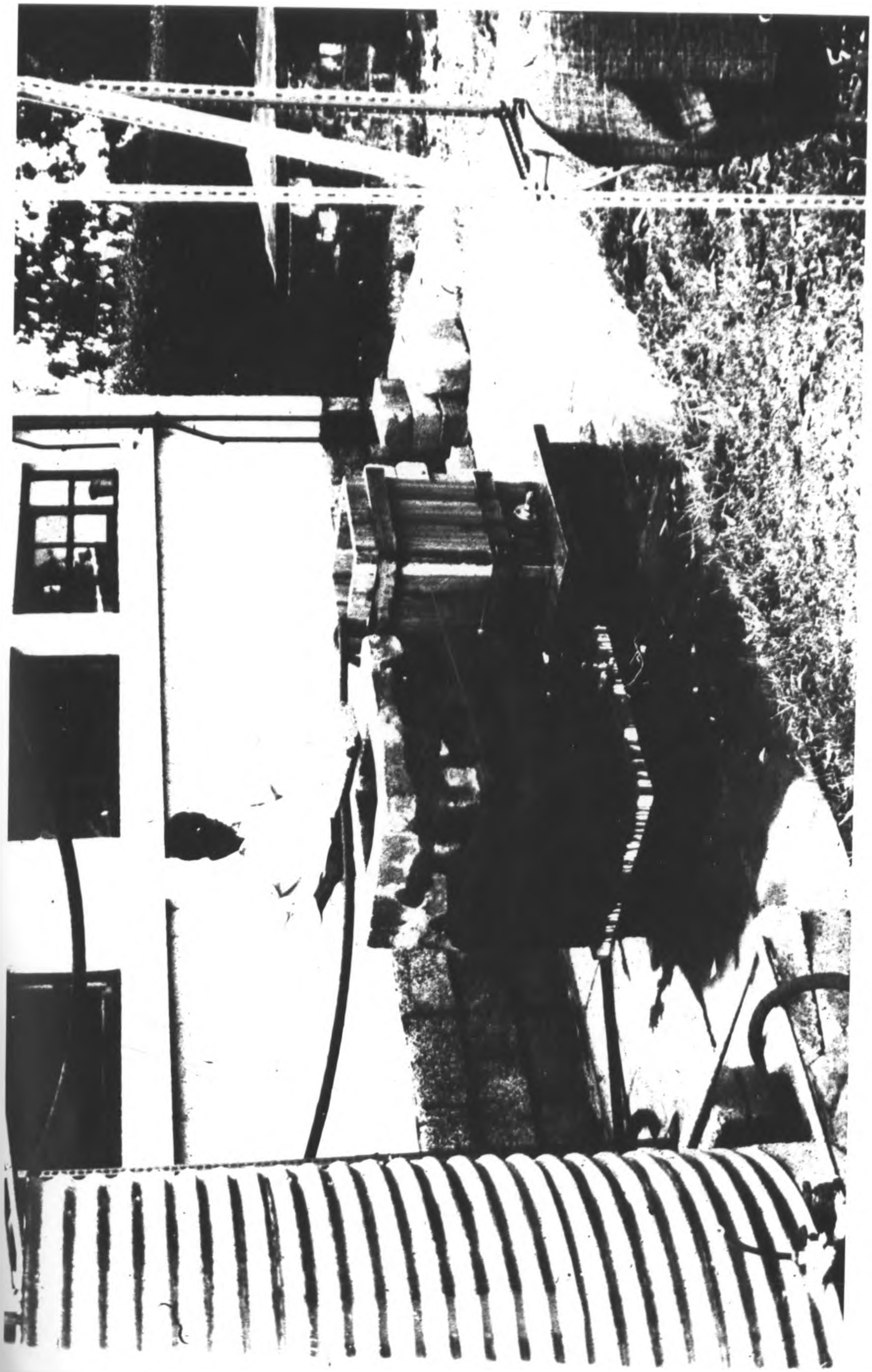


FIG. 8

Filtration was maintained at a constant rate of about 200 litres/day by regularily ajusting the valves shown and measuring the respective flows. The filtered water and overflow from each of the filters collected into the drain pipe. This was a one-inch diameter pipe which led the water into the main drain pipe. Samples of filtered water were taken through the tap, t by opening the valve, V.

Visible in Fig. 5 is a thin perspex column, 10 cm in diameter and 1.5 m high. This, too, was used as a filter, but at a later stage of the study. Polluted water put in from the top filtered through the media and emerged from the bottom. Samples for quality test were then taken through taps near the top and bottom respectively.

Fig. 8 shows two other filters used in this study. The filter box on the left was made of clay bricks while that on the right was made of wood - Cedar. Here, although no readings were made of the influent and filtrate qualities, observations were made of the behaviour of the filter boxes under those conditions.

5.2 MATERIAL FOR FILTER BOXES

Current practice utilizes mainly concrete, bricks and in some cases steel for construction of filter boxes. In this study, three different materials were considered. These were timber, cement mortar and clay bricks.

5.2.1 TIMBER

The most common types of timber available in this country are cypress, pine, podo, camphor and cedar. Of these, only cypress and cedar were used to construct the filter boxes. Cypress was used in the filter labelled F3 and cedar in that labelled F2.

5.2.1.1 Joints

Figure 9 shows the types of joints considered in making the three timber filter boxes. The filters in F2 and F3 had their joints made as in Figure 9b. Only the one in Fig. 8 had its joints made as in Fig.9a.

5.2.2 CEMENT MORTAR

The idea of making water jars from a mortar of cement and sand was first conceived at the Siam Cement Company, Bangkok by a Mr. Opas and colleagues. The basis for the construction, in this study of filter boxes using this material was not any different from that they used in Bangkok, except for some minor dimensional details.

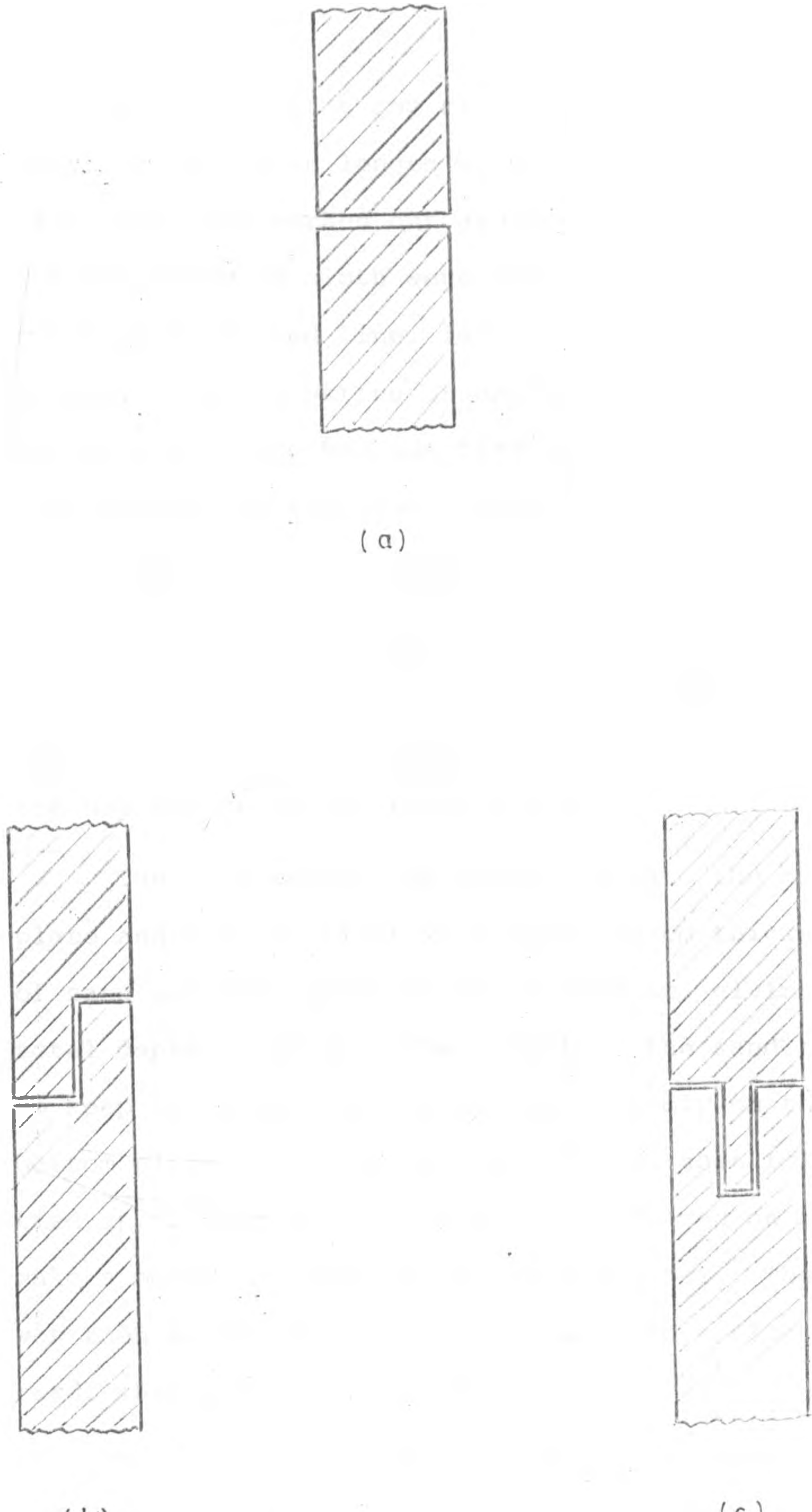


Fig. 9 Joints

Two pieces of gunny cloth, measuring 80 cm in width by 150 cm in length were cut out, placed onto each other and marked out as shown in Figure 10a. The two pieces of cloth were then sawn together along the marked, dotted line, leaving the top and bottom unsawn. Using a string or any hard thread, the bottom end of the bag was tied up as shown in Figure 10b, before the sack was turned inside out.

A mortar, made using a mix of cement and sand in the ratio one to two, was then used to make a bottom plate, about 50 cm in diameter and 1.5 cm thick. This bottom plate was kept under moist conditions for about one day before it was ready for use.

The sack was placed centrally onto the bottom plate and filled, first with about 10 cm thickness of sand and then about 70 cm of sawdust, giving a total depth of 80 cm. The weight of the sand helps to keep the lower edge of the sack firmly on the bottom plate. The top of the sack was then folded and tied up, before a circular ring was placed on it to make a mould for opening of the container. The sack was then tapped with a peice of wood to a nice cylindrical shape, seen in Fig. 4 and 3.

Two holes, each ½ inch in diameter, were then made into the sack one near the base and the other near the top. Into each of these holes, half inch nipples were partially pushed through, as shown in

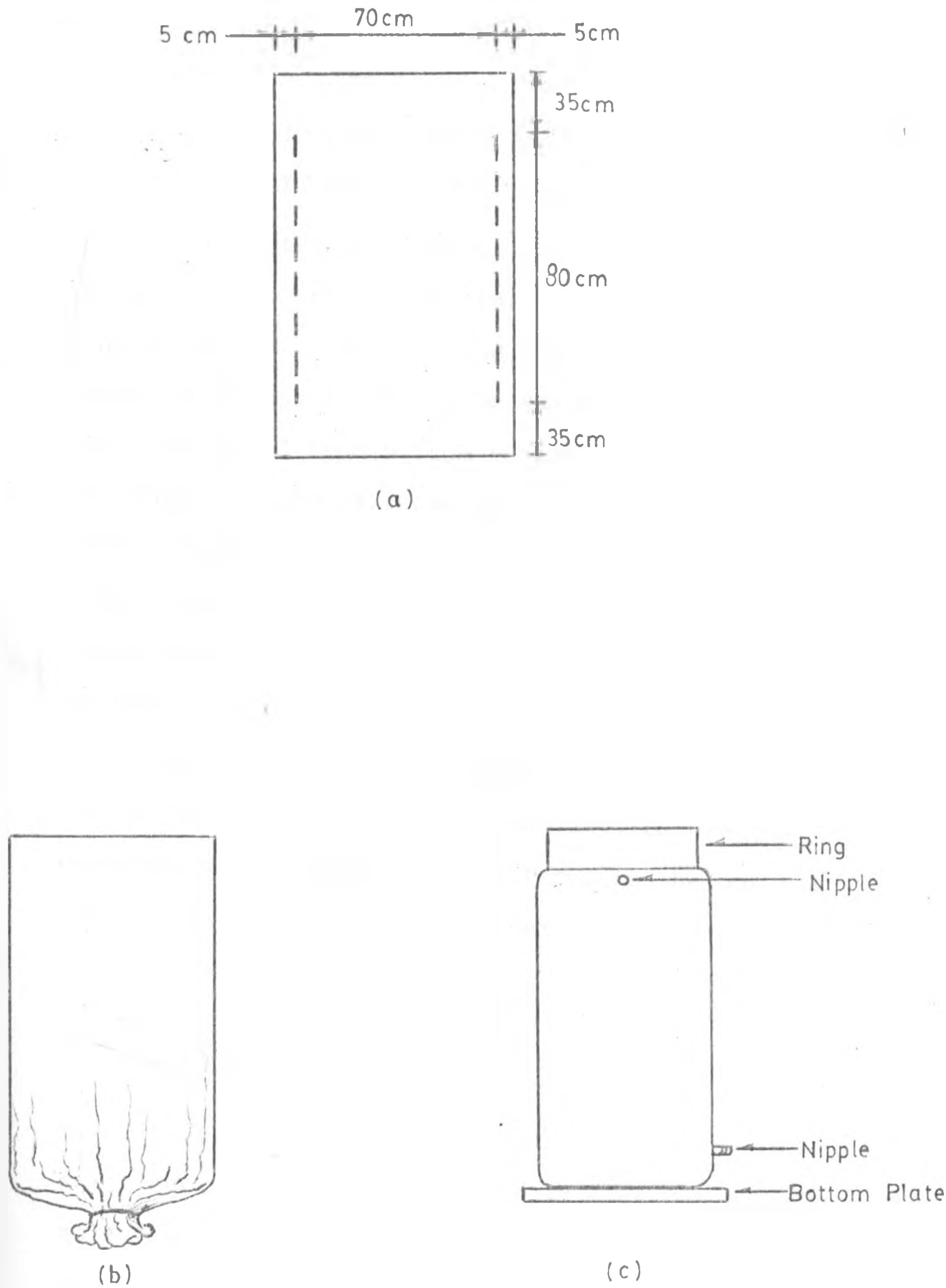


Fig. 10 Cement Mortar Filter Box

Fig. 10c. The nipples used were cast iron made, but for rural purposes, a piece of wood with a hole in the centre could probably suffice.

Some water was then sprayed on the mould to make it damp. Using a mortar with a mix ratio of one of cement to two of sand, as before, the first layer of mortar about 0.5 cm thick was trowelled onto the mould from bottom to top. After some thirty minutes, the second layer of mortar, again 0.5 cm thick, was trowelled in the same manner. At the places where the nipples had been inserted some reinforcement was given by putting slightly more mortar.

The filter boxes so made, were then cured under damp sacking for about one day, before the contents were removed. Any defects in the box was corrected by using cement mortar.

5.2.3 CLAY BRICKS

Filter boxes made of bricks are already in existence. The bricks are usually made out of some selected type of soil. In this study the bricks 15 cm by 15 cm by 30 cm, were made up of clay, sand and cement mixed in the ratio 15.3.1 respectively. They were built into the filter in Fig. 8 by using a thin layer of cement mortar for sticking them tightly together.

5.3 FILTER MEDIA

Two common filter media which have been in use for years now are sand and gravel. For this study, wood charcoal, sand and gravel were used.

5.3.1 CHARCOAL

Figure 11 shows the typical charcoal filter bed used in this study. It consisted of a 20 cm thick layer of gravel at the bottom. This supported a layer of charcoal, 30 cm thick. The sizes of the charcoal used, varied somewhat with the run, as shown below. The layer of charcoal was kept in position by a 10 cm thick layer of either sand or gravel. Whether it was sand or gravel used, depended on which filter and which run, again as shown below.

RUN NUMBER	FILTER	CHARCOAL SIZE (cm)	TOP LAYER
1	F4,F5	0.5-5	Gravel
2	F4,F5	0.05-5	Sand
3,4	F2,F4	0.05-5	Gravel
	F3,F5	0.05-5	Sand

The media used in the 'Column Filter' seen in Fig. 5 was basically the same as that shown in Fig.11. The charcoal varied in size between 0.5 and 50 mm and this was kept down using a 10 cm thick layer of gravel. The fundamental difference

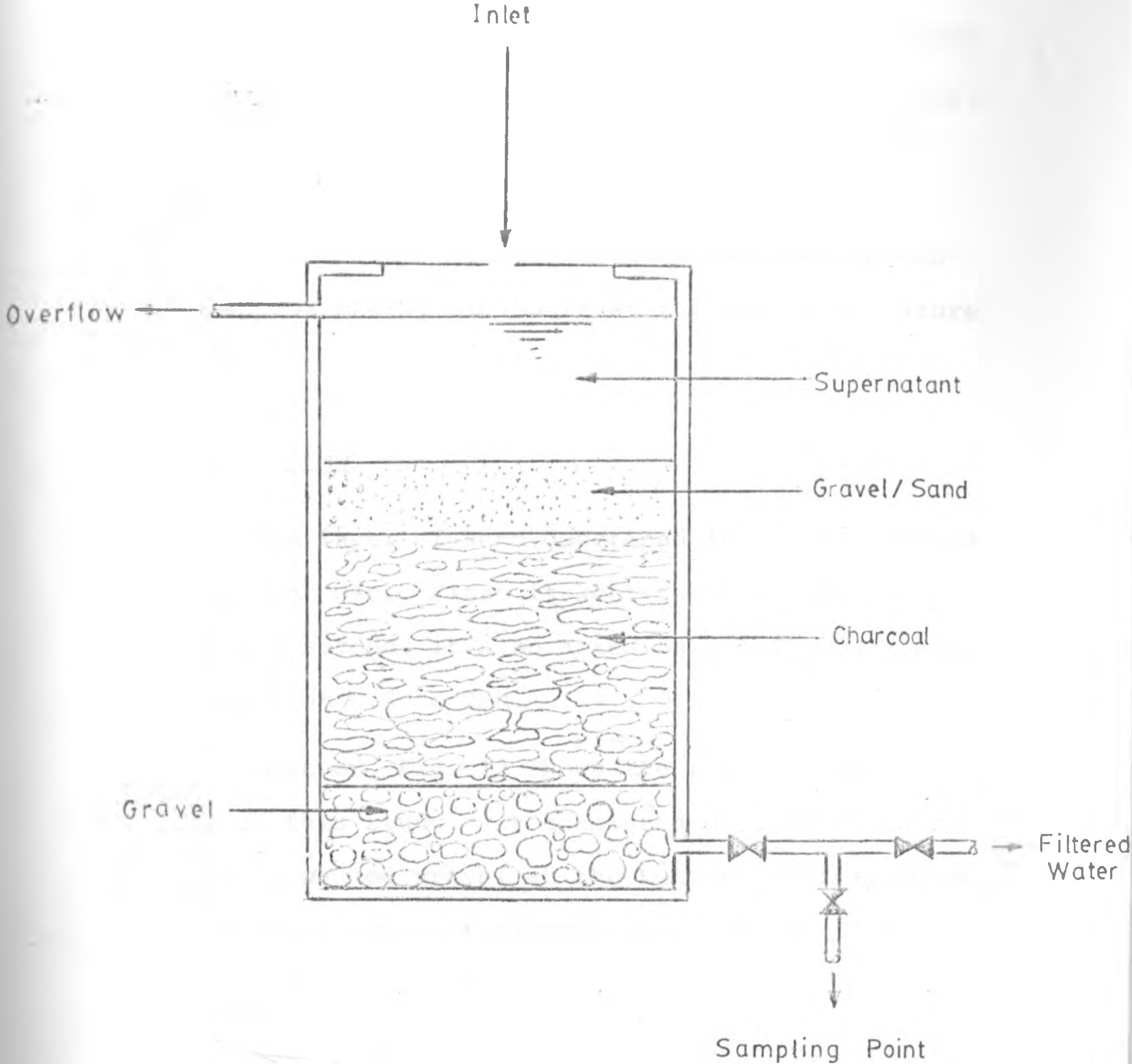


Fig.11 Charcoal Filter

was that the charcoal used here was not only washed as in the other cases. After washing, the charcoal was heated in an oven before use. For run five, the charcoal had been heated for two hours at $200^{o}C$. For run six, the charcoal had been heated for approximately six hours at the same temperature; $200^{o}C$.

5.3.2 SAND

The layer of sand described in Fig. 11 served a dual purpose. First it kept the charcoal layer down and second, it also acted as a media. Its size ranged from 0.5 to 2mm.

However, Fig. 12 shows the typical sand filter used in this study. It consisted of a 20 cm thick layer of washed gravel at the bottom. This supported a 40 cm thick layer of washed sand, varying in size between 0.5 mm and 2mm.

This particular filter bed set up was made during run two for filters F2 and F3 only. The sand filter bed used in the filters in Figure 8 was a little different. While the sand depth remained the same as already described, the depth of the gravel bottom was 30 cm in this case. The sand used had an effective size and coeffient of uniformity of 0.23 mm and 2.48 respectively.

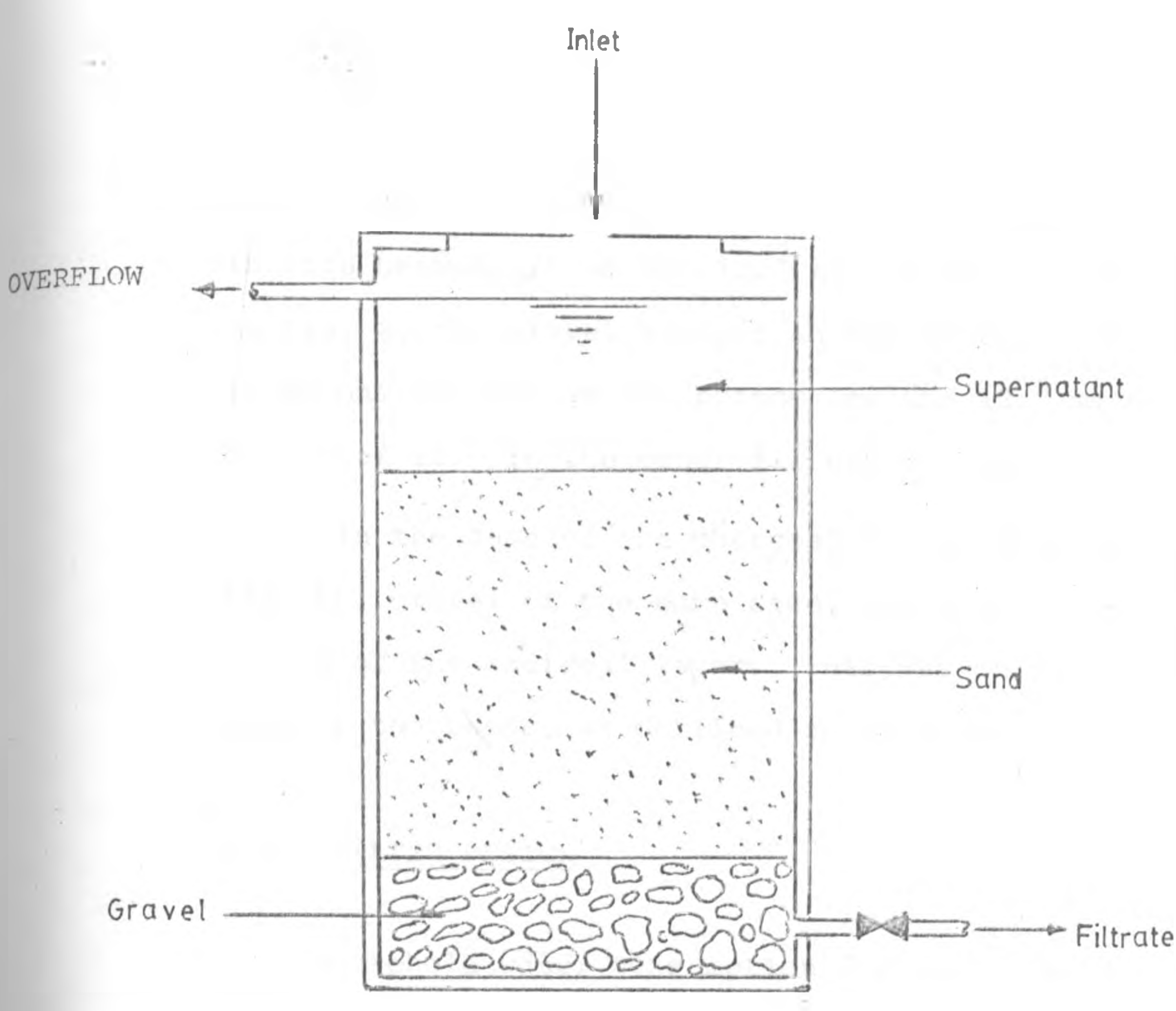


Fig.12 Sand Filter

5.3.3 GRAVEL

The filters described under both the titles, charcoal and sand filter, all contained gravel at the bottom. In all these cases, the gravel varied in size between 19 mm and 12.7 mm. In the filters in Fig. 8, the gravel was put in two layers. The 19 mm one was put at the bottom and the 12.7 mm one on top of it. In the other filters, it was random.

In the case of the charcoal filter described in Fig. 11, gravel of the same size, was also placed on top of the charcoal layer. This was only in some of the cases, as outlined on Page 31.

5.4 FILTER DESIGN

Household water consumption for rural areas

= 20 litres/person/Day

Number of persons per household = 10, assumed

Water demand per household = 200 litres per day

Assume a square filter of sides 0.4 x 0.4 m.

Therefore, cross sectional area A

$$= 0.4 \times 0.4\ m^2$$

$$= 0.16\ m^2.$$

Filter Loading Vf = Q_1/A where

Q_1 - water to be filtered per day, 200 litres

A - Area of filter, 0.16 m^2.

$\therefore$ Vf = Q_1/A

$= 200/0.16\ l/m^2D$

$= 0.2/0.16\ m^3m^2/D$

$= 1.25\ m^3/m^2/D$

$< 2.8\ m^3/m^2/D$, therefore okay.

Assuming a circular filter of diameter, df

Then, the cross sectional area Af

$= \pi df^2/4$

$= 0.16\ m^2$.

$\therefore \pi df^2/4 = 0.16$

$df^2 = 4 \times 0.16/\pi$

$df = \sqrt{4 \times 0.16/\pi}$

$= 0.45$ m.

So, filters were constructed either of side dimensions 0.4m by 0.4m or of diameter 0.45 m. The depth in each case was kept at approximately 0.8 m.

5.5 PIPE DESIGN

5.5.1 INLET AND OUTLET PIPES TO AND FROM FILTERS

Assume a velocity of flow in the pipes,

$v = 1$ m/s

Total Flow $Q = 10^{-6}\ m^3/s$

Therefore, area of pipe, Ap

$= Q/v$

$= 10^{-6}/1\ m^2$.

$$= 10^{-6} m^2$$

$$= 10^{-2} cm^2.$$

Let diameter of pipe be dp.

$$\text{Therefore } \pi dp^2/4 = 10^{-2}$$

$$\pi dp^2 = 4 \times 10^{-2}$$

$$dp^2 = 4/\pi \times 10^{-2}$$

$$dp = \sqrt{4/\pi \times 10^{-2}}$$

$$= 1.13 \times 10^{-1} \text{ cm}$$

$$= 0.113 \text{ cm}$$

$$= 0.045 \text{ in.}$$

The smallest available pipes were of half inch in diameter. Since these are bigger than 0.045 inch, they were used as inlet and outlet pipes.

5.6 SOURCE OF WATER

At the start of this study, although tap water was always readily available, raw water of known and consistent quality was not. This therefore, called for steps towards a creation of some form of artificial raw water.

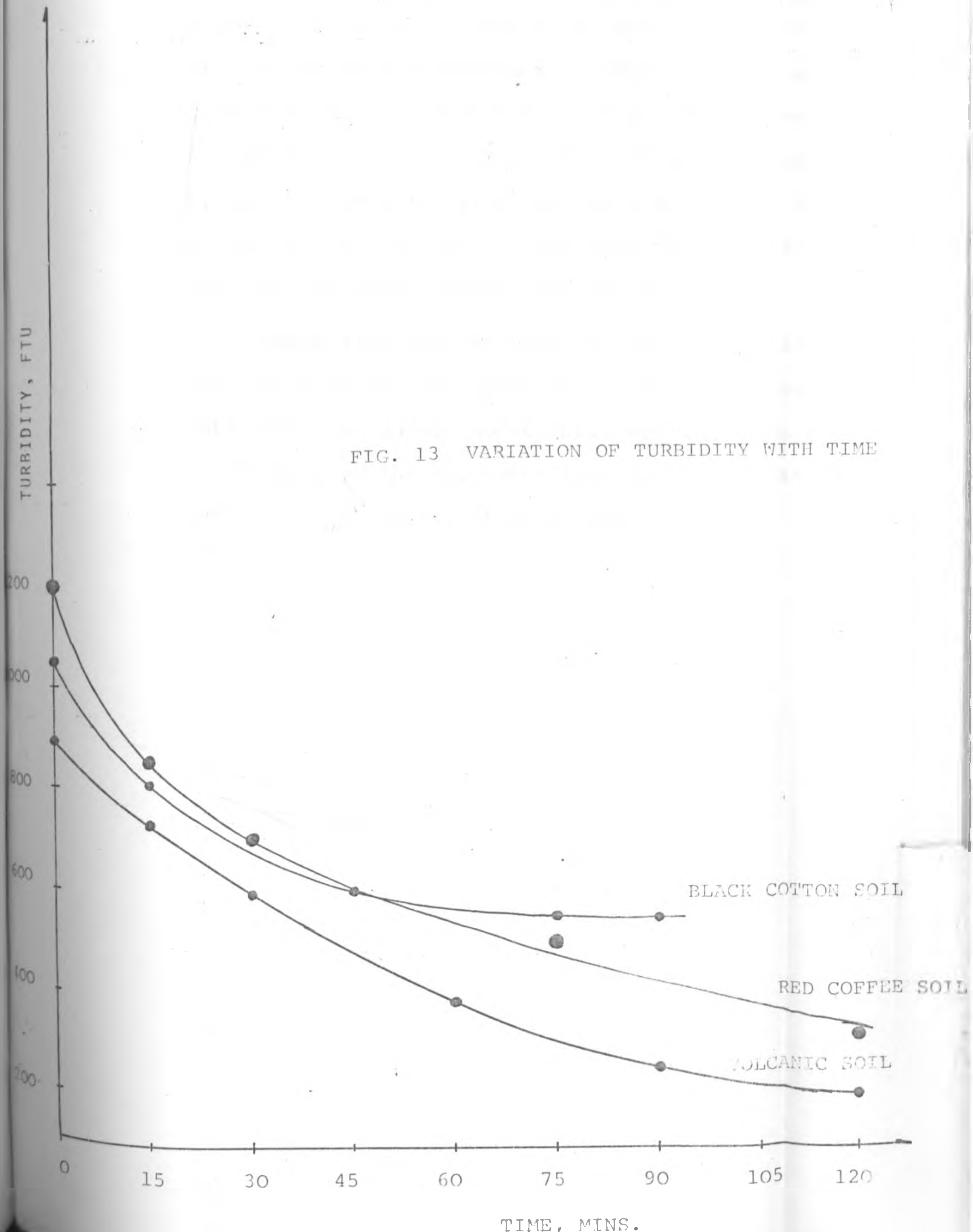
Three different types of soils were considered responsible or at least partly responsible for the turbidity in most of our waters. These were red coffee soil, black cotton soil and volcanic soil. To find the amount of turbidity that can be caused by these soils, the following procedure was adopted:- Equal weights, 5 grams, each of the soils were taken, moistened and crushed in a mortar. Each of these was then taken and put into a flask, containing one litre of distilled water, before shaking thoroughly to dissolve. At intervals, samples for turbidity measurement were taken from the top, making sure that the flask and contents were not disturbed. The results obtained are presented in Table 1 and Fig. 13. From these results, it was considered that while the same weight of red coffee soil gives the greatest initial turbidity, that due to black cotton soil falls off at the slowest rate. This would be an advantage for balck cotton soil in the circumstances as it would then be possible to produce raw water of fairly constant turbidity using this soil.

However, the situation was such that only red coffee soil was readily and abundantly available. A decision was therefore taken in favour of red coffee soil as the source of turbidity to use in this study.

TABLE 1. TURBIDITY VARIATION WITH TIME

SOIL / TIME MIN	RED COFFEE	BLACK COTTON	VOLCANIC
0	1200	1050	900
15	850	800	750
30	700	680	620
45	600	600	500
60	545	560	400
75	500	545	330
90	430	550	270
120	300	-	200

FIG. 13 VARIATION OF TURBIDITY WITH TIME



So after every 5-7 successive days, between 100-1000 grams of the red coffee soil was weighed out, moistened and crushed in a mortar. This was then disolved in 50 gallons of tap water contained in tank T2. The flow from this tank was diluted by that of tap water from the clear water tank T1 in the mixing tank T3. It was from this tank T3 that the raw water flowed into the filters.

Apart from the addition of red coffee soil into the tank T2, one litre of concentrated waste water was also added, about twice weekly. This was to ensure that the raw water flow into the filters had a constant source of microorganisms.

CHAPTER 6

EXPERIMENTAL METHODS

6.1 MICROBIOLOGICAL TESTS

Two microbiological parameters were monitored during this study. These were colony counts and coliform counts.

6.1.1 COLONY COUNTS

Colony counts were conducted according to 'Standard methods for Examination of Water and Wastewater'. Incubation was carried for twenty four hours at 37°C and on yeast extract agar as the growth medium.

6.1.2 COLIFORM COUNTS

Like colony counts, coliform counts were conducted according to 'Standard Methods for Examination of Water and Wastewater.' Samples were incubated on MacConkey's broth- purple for 48 hours at 37°C.

6.2 PHYSICO-CHEMICAL TESTS

Four different physico-chemical parameters were measured during this study. These were turbidity, pH and calorific value (of the coarcoal used).

6.2.1 TURBIDITY

One liquid turbidimeter, model 2100A made by Hach Chemical Company, Iowa, was used to measure turbidity in this study. The calibration of the turbidimeter was done using prepared standards of formazin polymers also prepared by Hach. The detailed procedure for the measurements was in accordance with 'Standard Methods for Examination of Water and Waste Water'.

6.2.2 COLOUR

Colour was measured using a Lavibond Nessleriser, also according to 'Standard Methods for Examination of Water and Waste Water'.

6.2.3 pH

In this study, pH was measured using a pH-meter The procedure adopted was in accordance with 'Standard Methods for Examination of Water and Waste Water.'

6.2.4 CALORIFIC VALUE

The calorific value determination was carried out using a bomb calorimeter. A small quantity of the sample under test was burnt at constant volume in a high pressure container. Oxygen was admitted to the bomb under pressure in order that the fuel may burn. The energy liberated was measured and hence, the calorific value of the fuel determined.

6.3 MECHANICAL TESTS

Two mechanical tests were conducted in this study. These were to determine the bending strength and the compressive strength, respectively.

6.3.1 BENDING STRENGTH

Figure 14 shows a diagram of the Hounsfield Tensometer. This was the machine used for the determination of bending strengths. The test piece, held in suitable chunks fixed to the spherically seated nose pieces by chuck attachment pins, was loaded by means of a motor driven unit through a worm gear box. This caused the operating screw to move to the right and so transmit the bending pull to the test piece.

6.3.2 COMPRESSIVE STRENGTH

Compressive strength was measured using the universal compression test machine. The test piece, held between the lower movable and the upper fixed platens was loaded using a valve system. This set on a pump, which pumped oil underneath a piston. The raising piston then raised the lower platen and compressed the test piece.

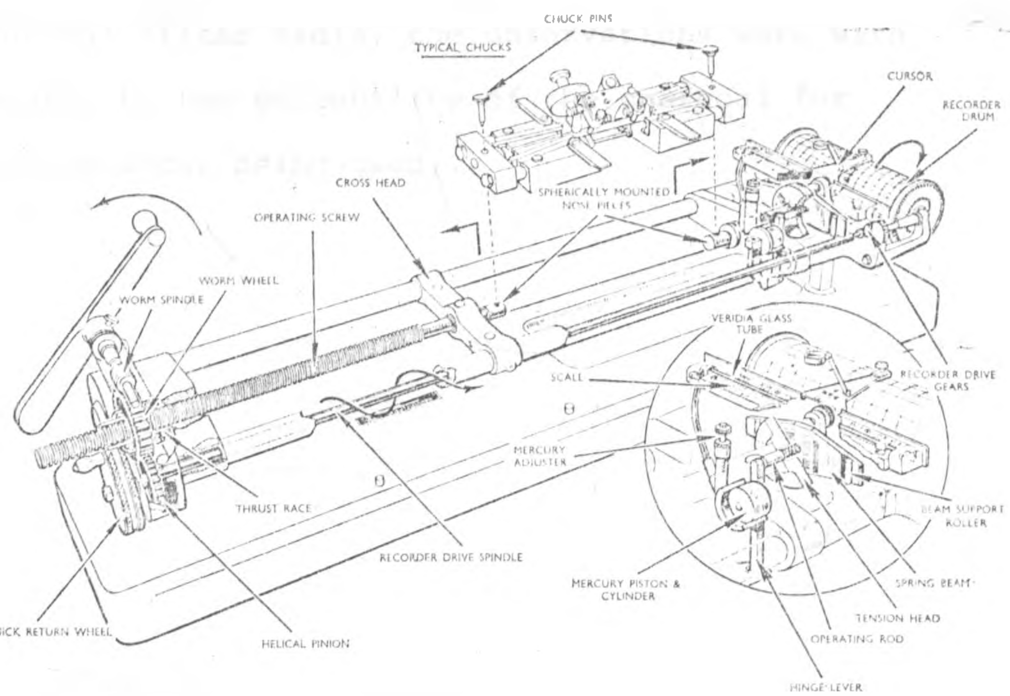


FIG. 14 HOUNSFIELD TENSOMETER

6.4 OTHER OBSERVATIONS

In addition to the above tests, visual observations and microscopic studies were also carried out on the filter boxes, the material of the filter boxes and the filter media. These were with regards to seeing any leakages, and cracks, slimy, algal and plant growths. For the charcoal filter media, the observations were with regards to the suitability of the charcoal for cooking after being used.

CHAPTER 7

RESULTS

7.1 MICROBIOLOGICAL RESULTS

7.1.1 COLONY COUNTS

Samples for colony counts were taken from the filter effluents and influents once every two to four days. Samples were taken only during runs number three and four each of which went for about a month. The results for filters F1, F2, F3, F4, and F5 given in Tables 2 and 3 are expressed in the number of microorganisms per millilitre of sample.

FILTER	F1		F2		F3		F4		F5	
LENGTH OF FILTER RUN, DAYS	RAW WATER COUNT	FILTERED WATER COUNT	RAW WATER COUNT	FILT. WATER COUNT	RAW WATER COUNT	FILT. WATER COUNT	RAW WATER COUNT	FILT. WATER COUNT	RAW WATER COUNT	FILT. WATER COUNT
1	140	6	200	277	20	177	102	43	40	172
3	72	10	36	50	7	80	131	190	170	48
5	87	37	43	194	32	51	100	330	46	27
9	354	101	290	441	1	35	36	41	35	34
11	211	157	158	239	66	144	29	40	200	411
16	186	95	100	396	48	86	12	31	50	190
18	278	161	24	78	3	43	234	491	30	223
20	201	47	51	172	83	190	90	203	115	279
22	94	5	21	40	20	189	120	261	204	394
24	63	35	79	130	112	216	102	156	142	300
27	120	20	120	251	80	304	19	119	35	141
29	70	31	50	193	20	50	42	100	63	90

TABLE 2. COLONY COUNTS, RUN 3

TABLE 3 COLONY COUNTS, RUN 4

FILTER	F1		F2		F3		F4		F5	
LENGTH OF FILTER RUN DAYS	RAW WATER COUNT	FILT. WATER COUNT	RAW WATER COUNT	FILT. WATER COUNT	RAW WATER COUNT	FILT. WATER COUNT	RAW WATER COUNT	FILT. WATER COUNT	RAW WATER COUNT	FILT. WATER COUNT
1	450	88	96	157	46	112	211	148	35	410
3	157	59	0	70	0	392	75	160	10	300
6	320	53	31	98	20	117	30	154	1	121
7	23	0	11	81	0	20	37	360	101	134
9	80	35	94	153	100	169	90	96	40	162
15	266	20	40	138	32	97	41	163	52	177
16	29	0	35	49	94	169	50	62	42	96
19	41	37	98	153	110	200	0	96	39	84
21	264	36	78	143	30	100	61	49	100	200
23	300	198	2	390	90	180	101	198	140	150
25	150	70	314	450	37	167	172	312	111	184
27	213	186	211	300	40	143	184	110	84	220
28	183	160	94	175	55	322	19	83	69	214
29	7	41	56	210	14	216	32	42	45	320
30	296	30	38	50	7	181	3	490	29	460

7.1.2 COLIFORM COUNTS

Coliform counts were conducted on samples taken from the filter influents and effluents, respectively. For the filters F1,F2,F3,F4 and F5, samples were taken at least once a week for about one month of each of the runs three and four. For the column filter, samples were taken daily during the one week of run five and every one to four days during the two weeks of run six. The results for the filters F1-5 are presented in tables 4 and 5 while that for the column filter are presented in tables 6 and 7. In each case, the results are reported as the 'most probable number, MPN, of coliform organisms per one hundred millilitre of sample'.

LENGTH OF FILTER RUN, DAYS		1				3				9				16			
VOLUME OF WATER/ MPN		50 mls	10 mls	1 mls	MPN	50 mls	10 mls	1 mls	MPN	50 mls	10 mls	1 mls	MPN	50 mls	10 mls	1 mls	MPN
F1	RAW	1	3	0	8	0	3	0	3	1	5	3	90	1	5	5	180+
	FILTERED	1	0	1	3	1	1	0	3	1	1	2	9	1	5	5	180+
F2	RAW	0	0	0	0	0	0	0	0	1	5	3	90	1	5	5	180+
	FILTERED	1	5	3	90	1	5	2	50	1	5	4	160	1	5	5	180+
F3	RAW	0	0	0	0	0	0	0	0	1	5	1	35	1	5	5	180+
	FILTERED	1	5	0	25	1	5	1	35	1	5	4	160	1	5	5	180+
F3	RAW	0	0	0	0	0	1	0	1	1	5	2	50	1	5	5	180+
	FILTERED	1	5	4	160	1	3	0	8	1	5	0	25	1	5	5	180+
F5	RAW	0	1	0	1	0	1	0	1	1	5	3	90	1	5	5	180+
	FILTERED	1	5	5	180+	1	5	3	90	1	5	3	90	1	5	4	160

TABLE 4 COLIFORM COUNT, RUN 3

LENGTH OF FILTER RUN, DAYS		21				27				29			
VOLUME OF WATER/MPN		50	10	1	MPN	50	10	1	MPN	50	10	1	MPN
F1	RAW	1	5	5	180+	1	5	5	180+	1	5	5	180+
	FILTERED	1	4	5	40	1	5	5	180+	1	5	5	180+
F2	RAW	1	5	5	180+	1	5	5	180+	1	5	3	90
	FILTERED	1	5	5	130+	1	5	5	180+	1	5	5	180+
F3	RAW	1	5	4	160	1	5	5	180+	1	5	5	180+
	FILTERED	1	5	5	180+	1	5	5	180+	1	5	5	180+
F4	RAW	1	5	5	180+	1	5	5	180+	1	5	4	160
	FILTERED	1	5	5	180+	1	5	5	180+	1	5	4	160
F5	RAW	1	5	4	160	1	5	5	180+	1	5	5	180
	FILTERED	1	5	5	180+	1	5	5	180+	1	5	4	160

TABLE 4 CONT. COLIFORM COUNT, RUN 3

LENGTH OF FILTER RUN, DAYS		1				3				9				16			
VOLUME OF WATER/MPN		10 mls	1 mls	0.1 mls	MPN	10 mls	1 mls	0.1 mls	MPN	10 mls	1 mls	0.1 mls	MPN	10 mls	1 mls	0.1 mls	MPN
F1	RAW	5	5	4	1600	5	5	4	1600	5	2	0	50	4	0	1	17
	FILTERED	5	5	1	350	5	5	3	900	5	0	0	25	3	0	0	8
F2	RAW	5	4	0	130	5	5	4	1600	5	2	0	50	4	0	2	20
	FILTERED	5	5	5	1800+	5	5	5	1800+	5	5	4	1600	5	5	1	350
F3	RAW	5	3	2	140	5	5	5	1800+	4	3	0	25	4	1	0	17
	FILTERED	5	5	4	1600	5	5	5	1800+	5	5	1	350	5	5	2	550
F4	RAW	5	4	0	130	5	5	4	1600	5	1	1	45	3	3	0	17
	FILTERED	5	5	3	900	5	5	5	1800+	5	5	2	550	5	4	2	225
F5	RAW	5	3	3	175	4	4	0	35	5	0	0	25	1	0	0	2
	FILTERED	5	5	4	1600	5	5	2	550	5	4	3	275	5	4	3	375

TABLE 5 COLIFORM COUNT, RUN 4

LENGTH OF FILTER RUN, DAYS		21				28			
VOLUME OF WATER/MPN		10 mls	1 mls	0.1 mls	MPN	10 mls	1 mls	0.1 mls	MPN
F1	RAW	0	1	1	4	4	0	0	13
	FILTERED	1	0	0	2	0	3	0	6
F2	RAW	0	2	0	4	3	0	2	13
	FILTERED	5	5	1	350	5	5	0	250
F3	RAW	0	0	0	0	3	1	1	14
	FILTERED	5	5	2	550	5	5	0	250
F4	RAW	1	1	0	4	4	3	0	25
	FILTERED	5	5	3	900	5	4	4	350
F5	RAW	5	5	4	1600	1	1	1	6
	FILTERED	5	5	5	1800+	5	4	3	275

TABLE 5 COLIFORM COUNT, RUN 4 (CONT.)

TABLE 6 COLIFORM COUNTS, RUN 5

LENGTH OF FILTER RUN, DAYS	VOLUME OF WATER, mls/ AND MPN	RAW WATER	FILTERED WATER	COLIFORM REMOVAL %
1	10	5	5	
	1	5	5	
	0.1	5	3	
	MPN	1800+	900	> 50
2	10	5	5	
	1	5	5	
	0.1	5	3	
	MPN	1800	900	> 50
3	10	5	5	
	1	5	4	
	0.1	3	5	
	MPN	900	425	53
4	10	5	5	
	1	5	5	
	0.1	5	3	
	MPN	1800+	900	> 50
5	10	5	5	
	1	5	5	
	0.1	4	3	
	MPN	1600	900	44
6	10	5	5	
	1	5	5	
	0.1	4	3	
	MPN	1600	900	44
7	10	5	5	
	1	5	5	
	0.1	3	2	
	MPN	900	550	39

TABLE 7 COLIFORM COUNTS, RUN 6

LENGTH OF FILTER RUN, DAYS	VOLUME OF WATER, mls/ MPN	RAW WATER	FILTERED WATER	COLIFORM REMOVAL %
1	10	5	2	
	1	1	2	
	0.1	1	0	
	MPN	45	9	80
3	10	5	5	
	1	3	2	
	0.1	1	1	
	MPN	110	70	36
5	10	5	5	
	1	3	0	
	0.1	0	2	
	MPN	80	45	44
7	10	5	5	
	1	5	5	
	0.1	2	1	
	MPN	550	350	36
10	10	4	5	
	1	5	2	
	0.1	0	2	
	MPN	40	95	-
14	10	5	5	
	1	3	4	
	0.1	0	5	
	MPN	80	425	-

7.2 PHYSICO-CHEMICAL PARAMETERS

7.2.1 TURBIDITY

Samples for turbidity measurement were taken on the average daily from the influent and effluent pipes of the filters F1, F2, F3, F4 and F5. The filters were run in series and continously for roughly one month before the media was changed. Turbidity readings were taken during runs number 1, 2 and 4 only. Tables 8 to 19 give the results obtained.

Fig. 15 to 24 show the graphs of turbidity removal versus the length of filter run for the filters. In Fig. 17-24, the graphs of turbidity removal versus length of filter run, for the same run, of filter F1 are superimposed.

LENGTH OF FILTER RUN, DAYS	RAW WATER TURBIDITY, FTU	FILTERED WATER TURBIDITY FTU	TURBIDITY REMOVAL %
1	17.5	9.0	48.6
2	16.0	9.0	43.8
3	19.0	13.5	29.0
4	19.3	10.1	47.7
5	18.3	11.8	35.6
6	19.3	10.0	47.6
7	19.0	13.0	31.6
8	18.0	11.5	36.1
9	17.5	8.5	51.5
10	15.0	8.0	46.6
11	19.0	10.1	47.0
12	19.0	10.0	47.3
13	18.0	11.3	37.3
14	19.3	10.0	48.2
15	12.8	8.5	33.6
16	11.5	6.8	40.9
18	24.5	14.0	42.5
19	27.0	15.0	44.5
20	27.0	15.5	42.5
21	27.0	18.0	33.4
22	26.0	15.0	42.3
23	25.0	14.0	44.0
24	26.0	15.0	42.3
25	26.0	16.0	38.5
26	34.0	16.0	23.5
27	34.5	28.3	18.0
28	33.8	22.5	33.5
29	36.0	27.0	25.0

TABLE 8 <u>TURBIDITY READINGS FOR FILTER F4, RUN ONE</u>

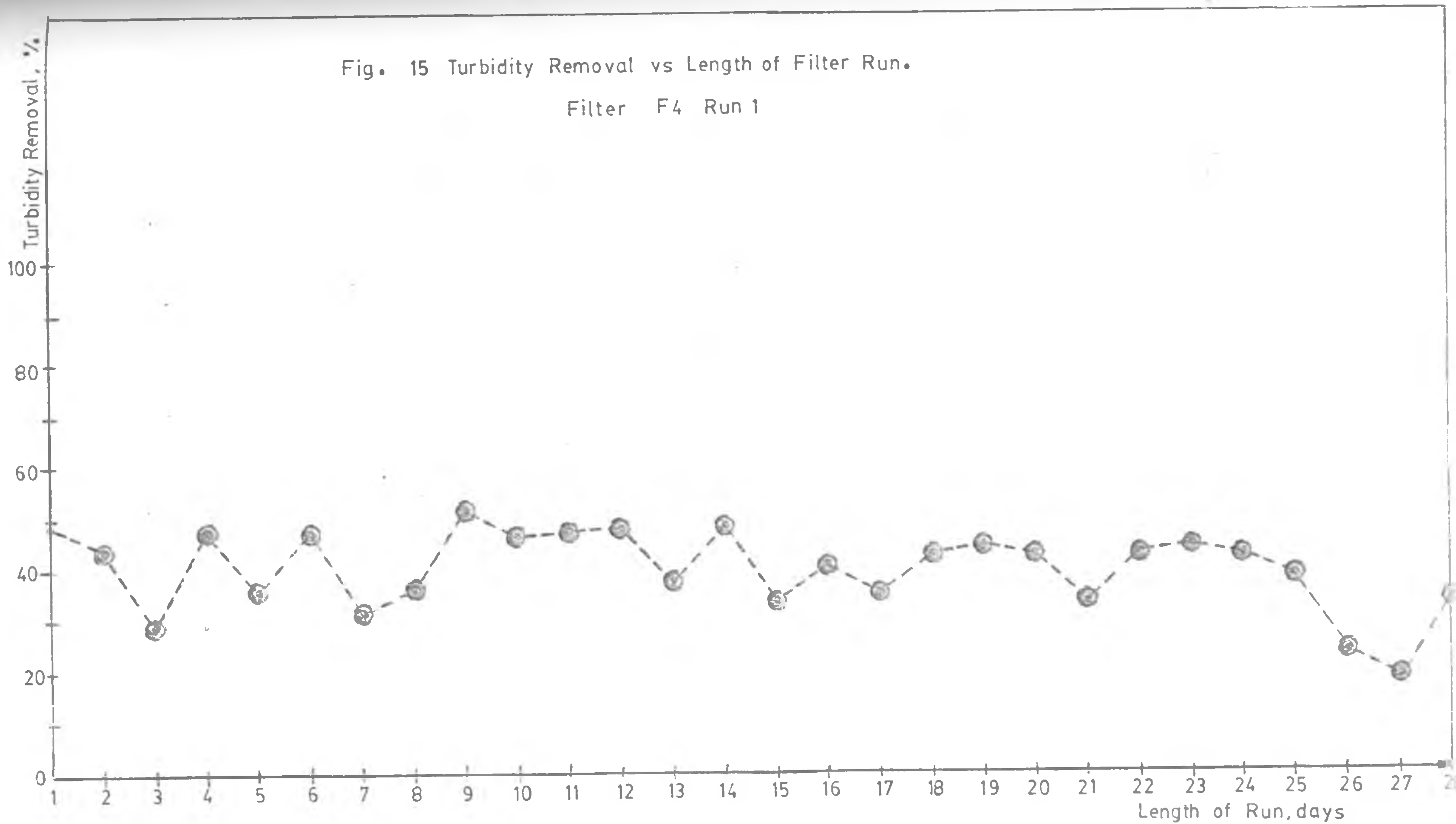


Fig. 15 Turbidity Removal vs Length of Filter Run.
Filter F4 Run 1
Turbidity Removal, %
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
Length of Run, days

LENGTH OF FILTER RUN, DAYS	RAW WATER TURBIDITY, FTU	FILTERED WATER TURBIDITY FTU	TURBIDITY REMOVAL %
1	13.0	7.0	46.0
2	14.5	9.0	38.0
3	14.0	9.0	35.8
4	19.0	10.0	47.4
5	15.0	9.0	40.0
6	17.0	10.0	37.5
7	16.5	10.5	36.4
8	14.5	9.0	38.0
9	13.0	8.0	38.5
10	13.5	9.0	33.4
11	17.5	10.5	40.0
12	17.5	10.0	43.0
13	16.0	10.0	37.5
14	15.5	9.5	38.7
15	12.8	6.8	47.0
16	12.0	6.8	43.4
17	15.0	9.0	40.0
18	22.0	16.0	27.3
19	27.5	18.5	32.8
20	27.0	18.0	33.3
21	23.8	17.8	25.2
22	23.0	18.0	21.8
23	24.0	18.0	25.0
24	23.0	17.5	22.0
25	31.0	26.0	16.1
26	30.0	24.5	18.4
27	35.0	29.8	14.8
28	31.8	29.0	8.8
29	35.8	27.8	22.3
30	34.0	29.0	14.7

TABLE 9 TURBIDITY READINGS FOR FILTER F5, RUN ONE

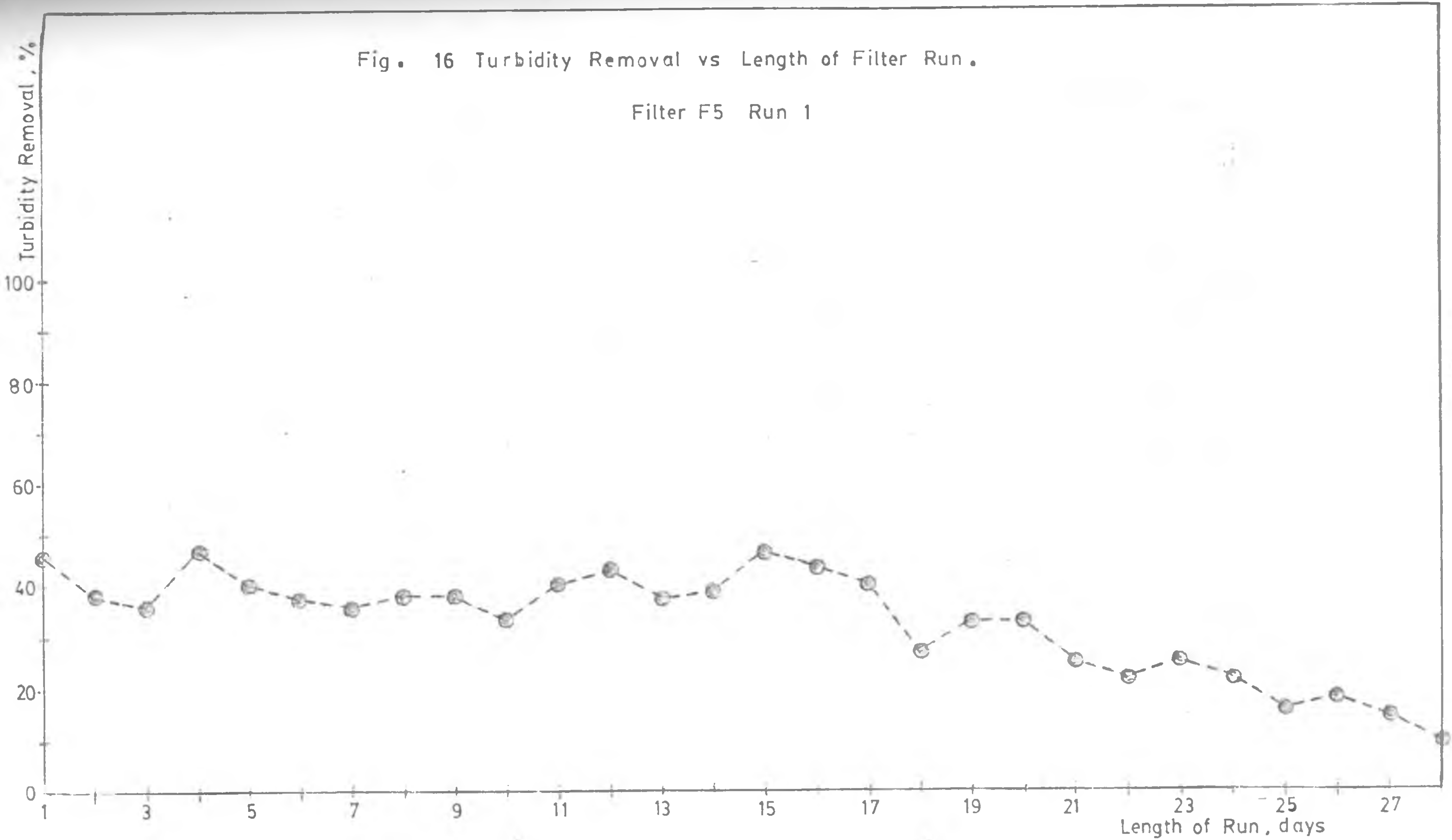


Fig. 16 Turbidity Removal vs Length of Filter Run.
Filter F5 Run 1
Turbidity Removal, %
100
80
60
40
20
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
Length of Run, days

LENGTH OF FILTER RUN, DAYS	RAW WATER TURBIDITY FTU	FILTERED WATER TURBIDITY FTU	TURBIDITY REMOVAL %
2	20.0	9.0	55.0
3	21.0	8.0	62.0
4	21.0	7.5	64.5
5	26.0	8.5	67.5
6	26.0	9.0	65.4
7	26.0	4.0	84.5
8	25.0	4.0	84.0
9	23.5	3.5	85.0
10	25.0	4.5	82.0
11	29.0	9.0	69.0
12	27.5	4.5	83.6
13	36.5	4.0	89.0
14	32.0	7.0	78.0
15	39.0	8.0	79.5
16	32.0	7.6	76.3
17	36.5	13.5	63.0
18	37.0	14.0	62.0
19	39.0	14.0	64.0
20	39.0	14.0	64.0
21	31.0	16.0	48.4
22	38.0	19.5	48.6
23	39.0	19.0	51.3
24	31.0	15.0	51.7
25	38.0	18.5	51.4
26	39.5	18.0	54.5
27	37.0	22.0	40.5

TABLE 10 <u>TURBIDITY, READINGS FOR FILTER F1, RUN 2</u>

LENGTH OF FILTER RUN, DAYS	RAW WATER TURBIDITY FTU	FILTERED WATER TURBIDITY FTU	TURBIDITY REMOVAL %
1	36.5	28.0	23.3
2	39.5	30.0	24.0
3	38.5	31.0	19.5
4	37.5	26.0	30.7
5	39.0	25.0	35.9
6	34.0	24.0	29.5
7	30.5	20.5	32.8
8	39.5	27.0	31.8
9	39.5	26.0	34.2
10	34.0	24.0	19.4
11	41.0	26.0	36.6
12	42.0	26.0	38.1
13	49.0	24.0	51.0
14	45.0	23.0	48.8
15	44.0	22.0	50.0
16	46.0	24.0	48.0
17	57.0	30.0	47.5
18	51.0	26.0	49.0
19	58.0	30.0	48.3
20	51.0	27.0	47.0
21	58.0	26.0	55.0
22	59	19.0	51.0
23	59.0	30.0	49.0
24	54.0	26.0	52.0
25	50.0	24.0	52.0
26	51.0	26.0	49.0
27	58.0	29.0	50.0
28	51.0	25.0	51.0
29	57.0	27.0	52.5

TABLE 11 TURBIDITY READINGS, FILTER F2 RUN 2

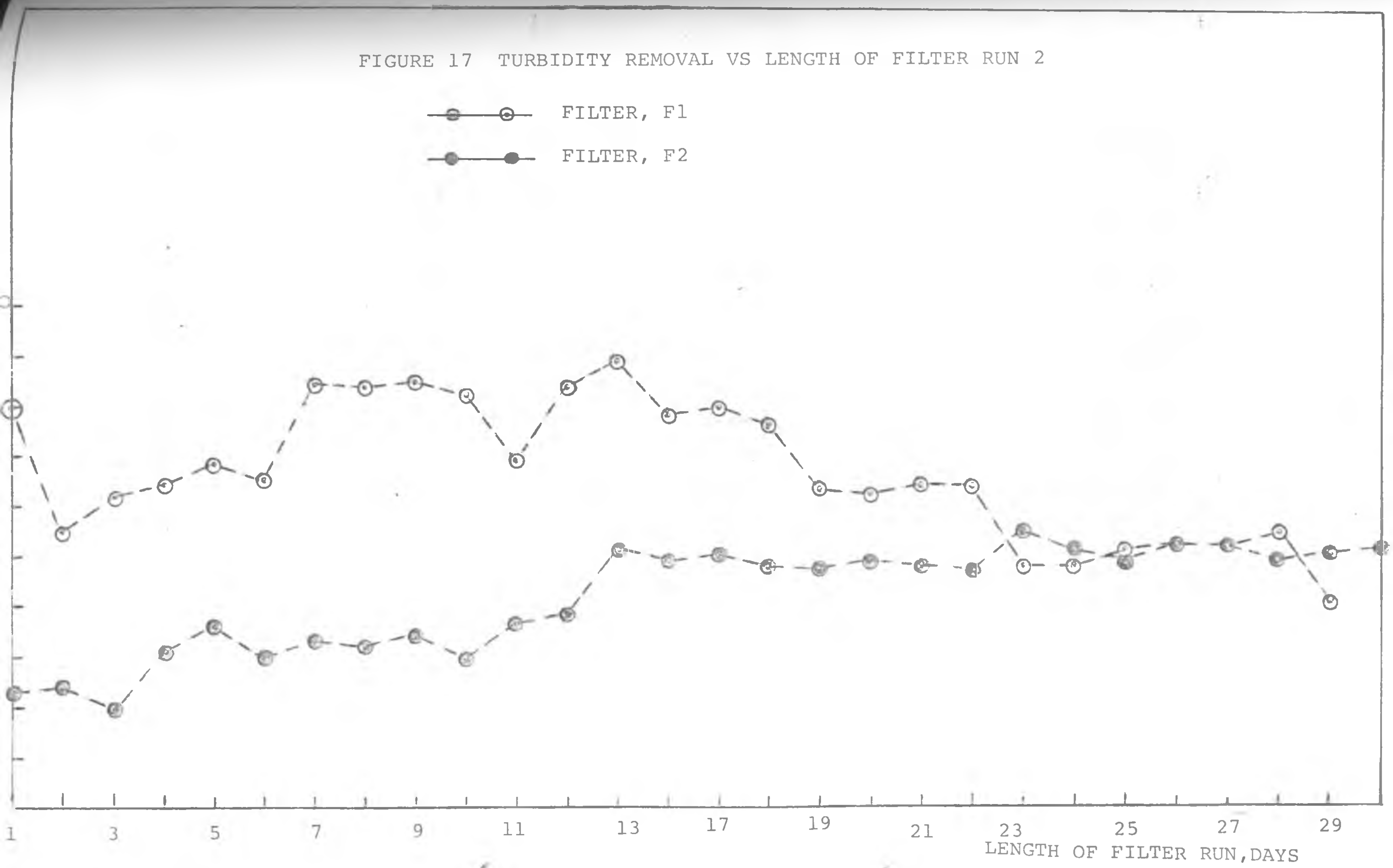


FIGURE 17 TURBIDITY REMOVAL VS LENGTH OF FILTER RUN 2
FILTER, F1
FILTER, F2
1
3
5
7
9
11
13
17
19
21
23
25
27
29
LENGTH OF FILTER RUN, DAYS

LENGTH OF FILTER RUN, DAYS	RAW WATER TURBIDITY FTU	FILTERED WATER TURBIDITY FTU	TURBIDITY REMOVAL %
1	30.0	22.5	25
2	31.0	21.0	31.8
3	37.5	25.0	33.4
4	31.0	22.5	27.4
5	37.0	24.0	35.2
6	33.5	21.0	37.4
7	30.0	19.5	35.0
8	35.0	22.0	37.2
9	39.0	26.5	32.1
10	35.5	23.0	35.2
11	45.0	29.0	35.6
12	42.0	29.0	31.0
13	46.0	30.0	34.8
14	45.0	26.0	42.3
15	43.5	24.0	45.0
16	42.0	22.0	47.6
17	52.5	26.0	50.5
18	58.0	29.0	50.0
19	54.0	29.0	44.4
20	50.0	24.0	52.0
21	55.0	24.5	55.4
22	58.0	29.0	50.0
23	54.0	30.0	44.0
24	50.0	24.0	52.0
25	55.0	24.5	55.4
26	58.0	27.0	52.5
27	55.0	24.0	56.4

TABLE 12 · TURBIDITY READINGS, FILTER F3 RUN 2

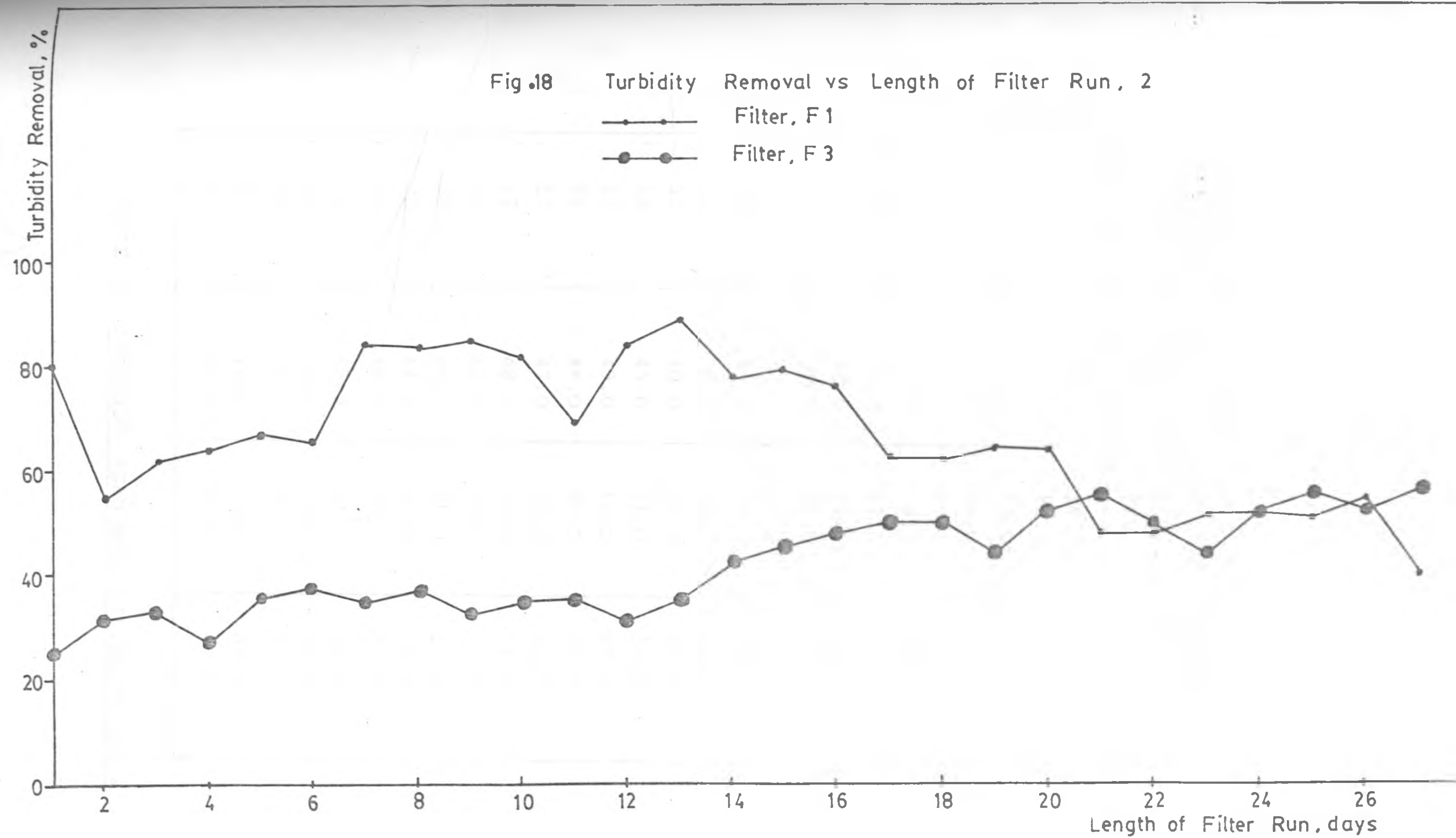


Fig .18 Turbidity Removal vs Length of Filter Run, 2
Filter, F 1
Filter, F 3
Turbidity Removal, %
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
22
24
26
Length of Filter Run, days

LENGTH OF FILTER RUN, DAYS	RAW WATER TURBIDITY FTU	FILTERED WATER TURBIDITY FTU	TURBIDITY REMOVAL %
1	33.0	15.0	54.5
2	34.0	16.0	53.0
3	30.0	13.0	56.6
4	34.5	16.0	53.5
5	39.0	19.5	50.0
6	39.0	19.5	50.0
7	30.0	16.5	45.0
8	39.0	20.0	48.8
9	31.0	13.0	58.0
10	37.0	17.0	54.0
11	33.0	14.0	56.0
12	34.0	17.0	50.0
13	40.0	22.5	43.7
14	45.0	21.0	53.5
15	49.0	18.0	63.3
16	46.0	21.0	54.4
17	47.0	22.0	53.3
18	48.0	22.0	54.0
19	42.0	20.0	52.4
20	40.0	21.0	47.5
21	44.0	21.0	52.0
22	40.0	20.0	50.0
23	45.5	23.5	49.4
24	49.0	23.0	53.0
25	49.5	24.5	50.5
26	42.5	20.0	53.0
27	41.0	22.0	46.4

TABLE 13 <u>TURBIDITY READINGS, FILTER F4 RUN 2</u>

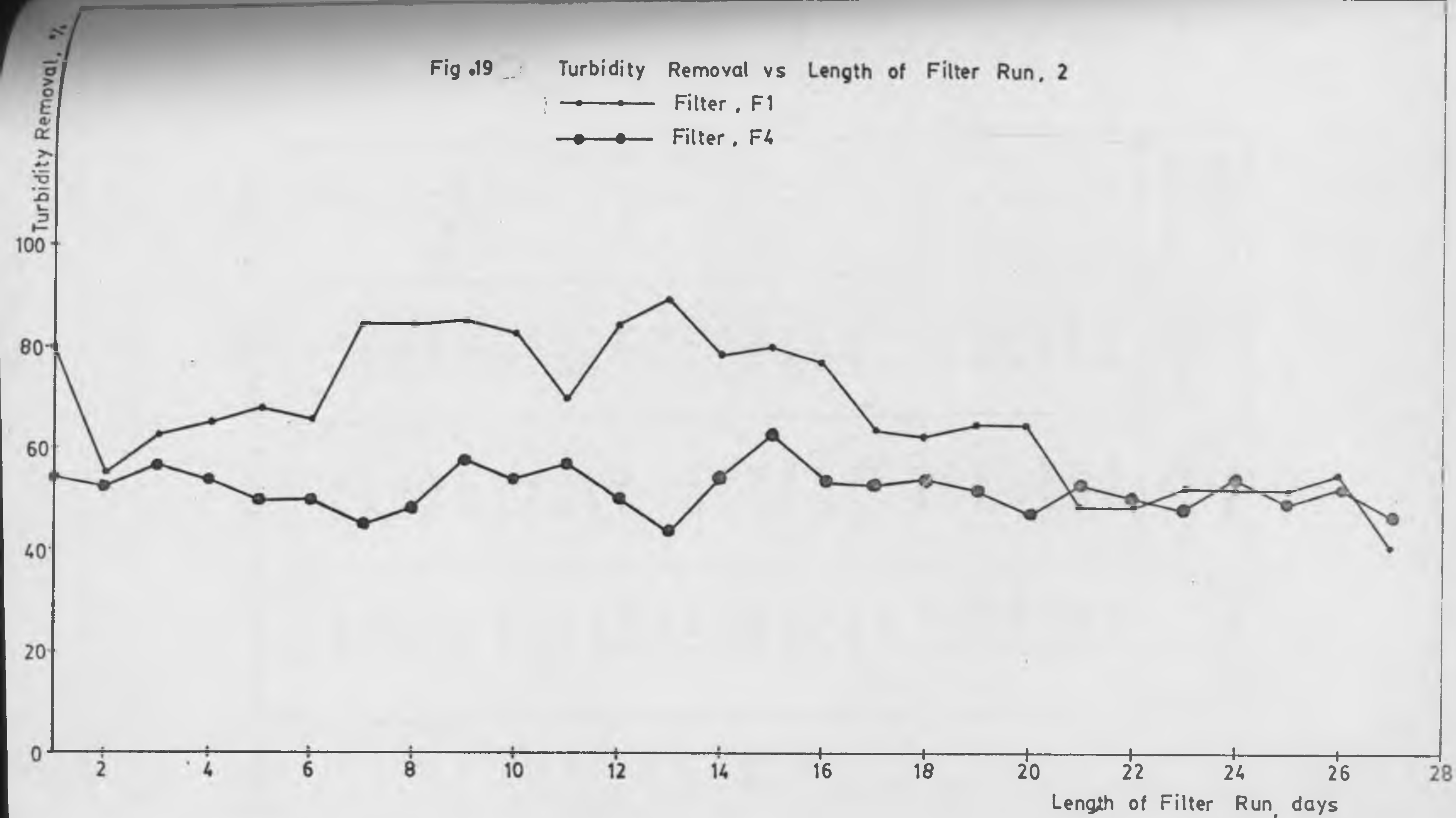
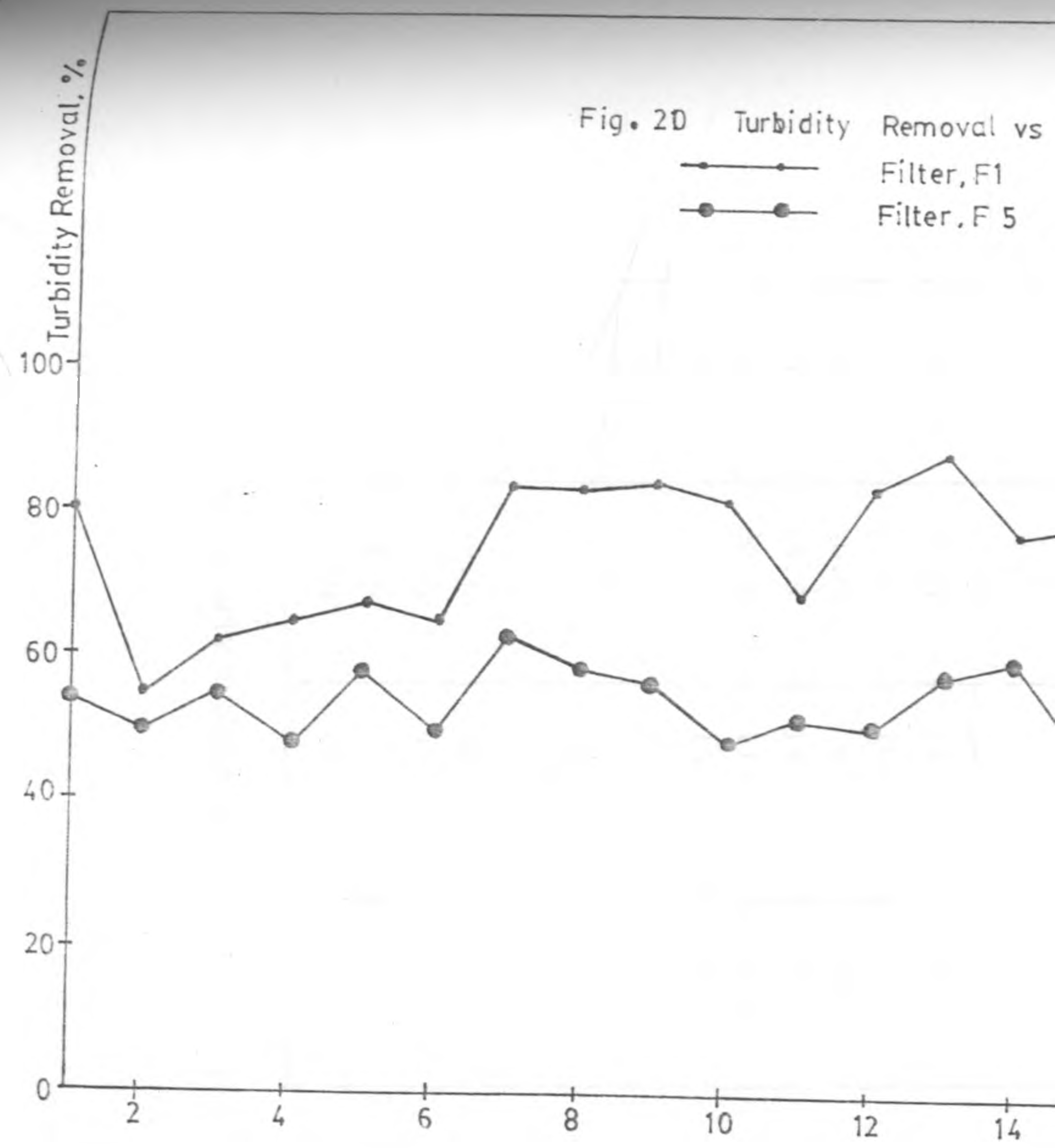


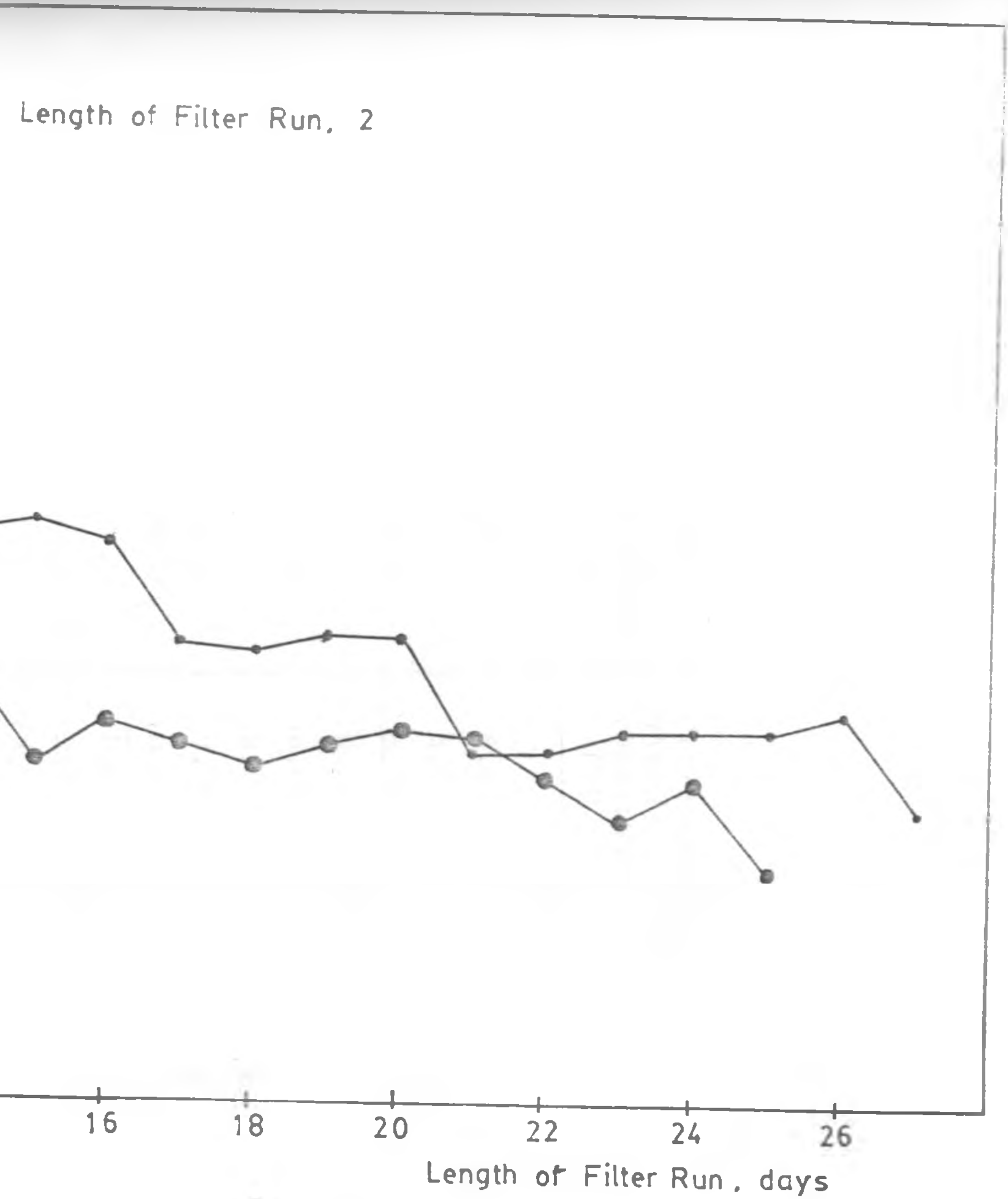
Fig .19 Turbidity Removal vs Length of Filter Run, 2
Filter , F1
Filter , F4
Turbidity Removal, %
0
20
40
60
80
100
2
4
6
8
10
12
14
16
18
20
22
24
26
28
Length of Filter Run, days

LENGTH OF FILTER RUN, DAYS	RAW WATER TURBIDITY FTU	FILTERED WATER TURBIDITY FTU	TURBIDITY REMOVAL %
1	26.5	12.0	54.8
2	20.0	10.0	50.0
3	22.0	10.0	55.0
4	26.0	13.5	48.0
5	31.0	13.0	58.0
6	24.0	12.0	50.0
7	30.0	11.0	63.3
8	29.0	12.0	58.5
9	26.0	11.0	57.6
10	35.0	18.0	48.5
11	30.0	24.0	52.0
12	39.5	19.5	50.6
13	45.0	19.0	57.8
14	44.0	17.5	60.2
15	34.5	18.5	46.4
16	47.5	23.0	51.5
17	47.0	24.0	49.0
18	51.0	27.5	46.0
19	51.0	26.0	49.0
20	55.0	27.0	51.0
21	52.0	26.0	50.0
22	45.0	25.0	44.4
23	49.0	30.0	38.8
24	43.0	24.0	44.4
25	41.0	28.0	31.7

TABLE 14 TURBIDITY READINGS FOR FILTER F5, RUN 2



Turbidity Removal, %
Fig. 2D Turbidity Removal vs
Filter, F1
Filter, F 5
100
80
60
40
20
0
2
4
6
8
10
12
14


Length of Filter Run, 2
16
18
20
22
24
26
Length of Filter Run, days

LENGTH OF FILTER RUN, DAYS	RAW WATER TURBIDITY FTU	FILTERED WATER TURBIDITY FTU	TURBIDITY REMOVAL %
1	28.0	6.0	78.5
2	23.0	5.5	76.0
3	24.0	5.0	79.0
4	25.0	6.0	76.0
5	26.0	6.0	77.0
6	27.5	8.0	71.0
7	26.0	9.0	65.5
8	30.0	10.0	66.8
9	38.0	18.0	52.5
10	33.0	12.0	63.5
11	35.0	13.5	61.4
12	36.5	17.5	52.0
13	29.5	10.5	64.5
14	31.0	11.0	64.0
15	29.0	10.0	65.5
16	30.0	9.5	68.3
17	28.5	14.5	49.0
18	22.0	11.0	50.0
19	23.5	15.5	34.1
20	31.0	17.5	43.5
21	32.0	25.5	20.3
22	32.5	25.0	21.9
23	40.5	30.0	26.5
24	39.5	30.0	24.0
25	41.0	32.5	20.8
26	41.5	35.0	15.6
27	35.0	28.5	18.6

TABLE 15 TURBIDITY READINGS FOR FILTER F1 RUN 4

LENGTH OF FILTER RUN, DAYS	RAW WATER TURBIDITY FTU	FILTERED WATER TURBIDITY FTU	TURBIDITY REMOVAL %
1	33.5	20.0	40.3
2	28.5	14.0	50.9
3	29.0	16.0	45.0
4	21.0	13.0	38.1
5	25.0	15.0	40.0
6	20.5	12.0	41.5
7	37.0	24.5	33.8
8	38.0	24.0	42.0
9	20.0	14.0	30.0
10	29.0	18.0	38.0
11	28.5	21.0	26.5
12	20.0	14.5	27.5
13	21.0	14.0	33.3
14	23.5	16.0	31.9
15	28.0	20.0	28.6
16	33.0	25.5	22.8
17	38.0	30.5	19.5
18	38.5	30.5	20.8
19	44.0	33.0	24.0
20	31.0	26.0	16.1
21	36.5	27.0	26.0
22	32.0	26.0	18.8
23	40.0	30.0	25.0
24	44.5	36.5	18.0
25	39.0	31.0	20.5
26	30.5	28.5	9.9
27	32.0	28.0	12.5

TABLE 16 TURBIDITY READINGS FOR FILTER F2, RUN 4

FIG. 21 TURBIDITY REMOVAL VS LENGTH OF FILTER RUN, 4

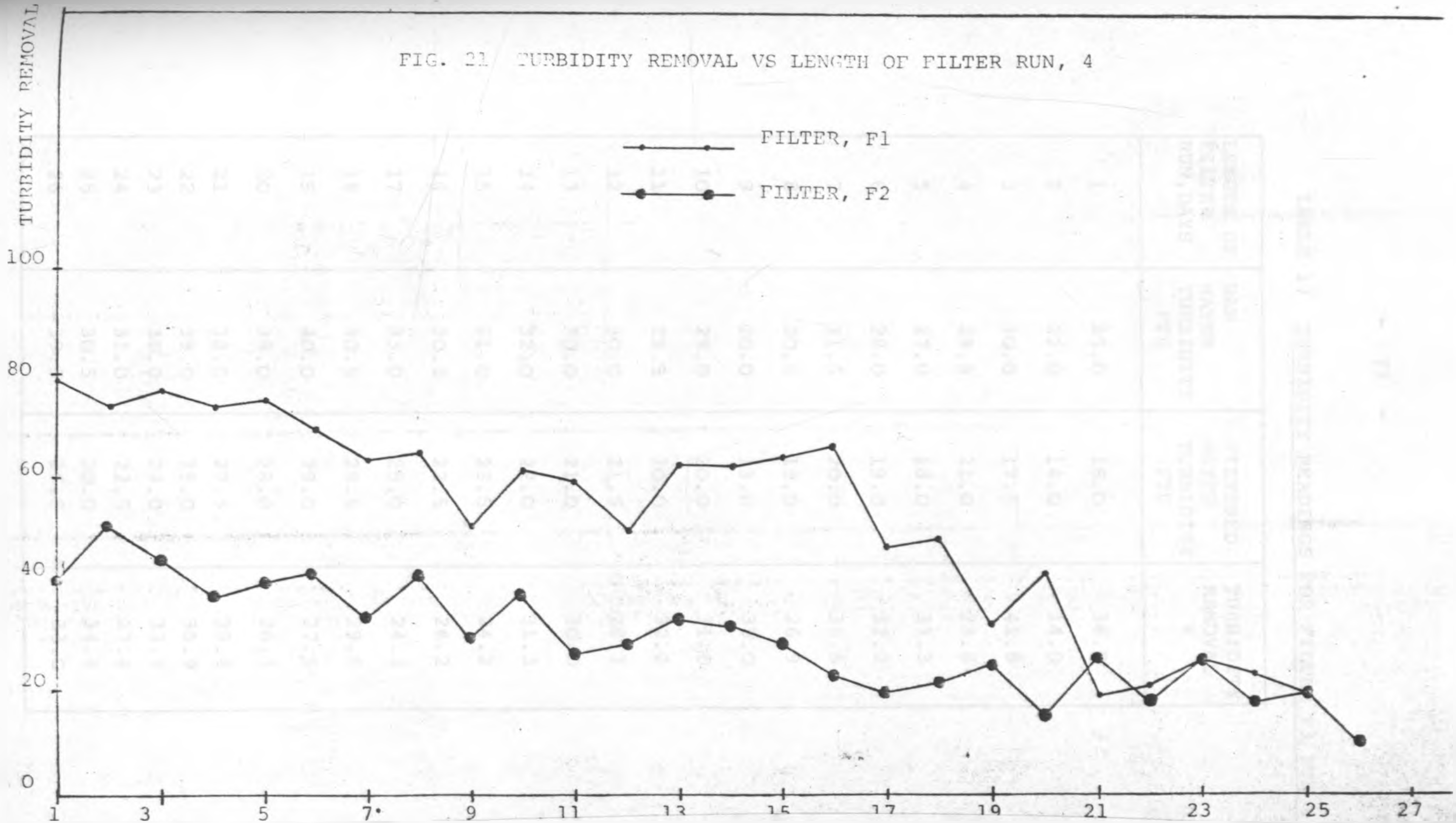


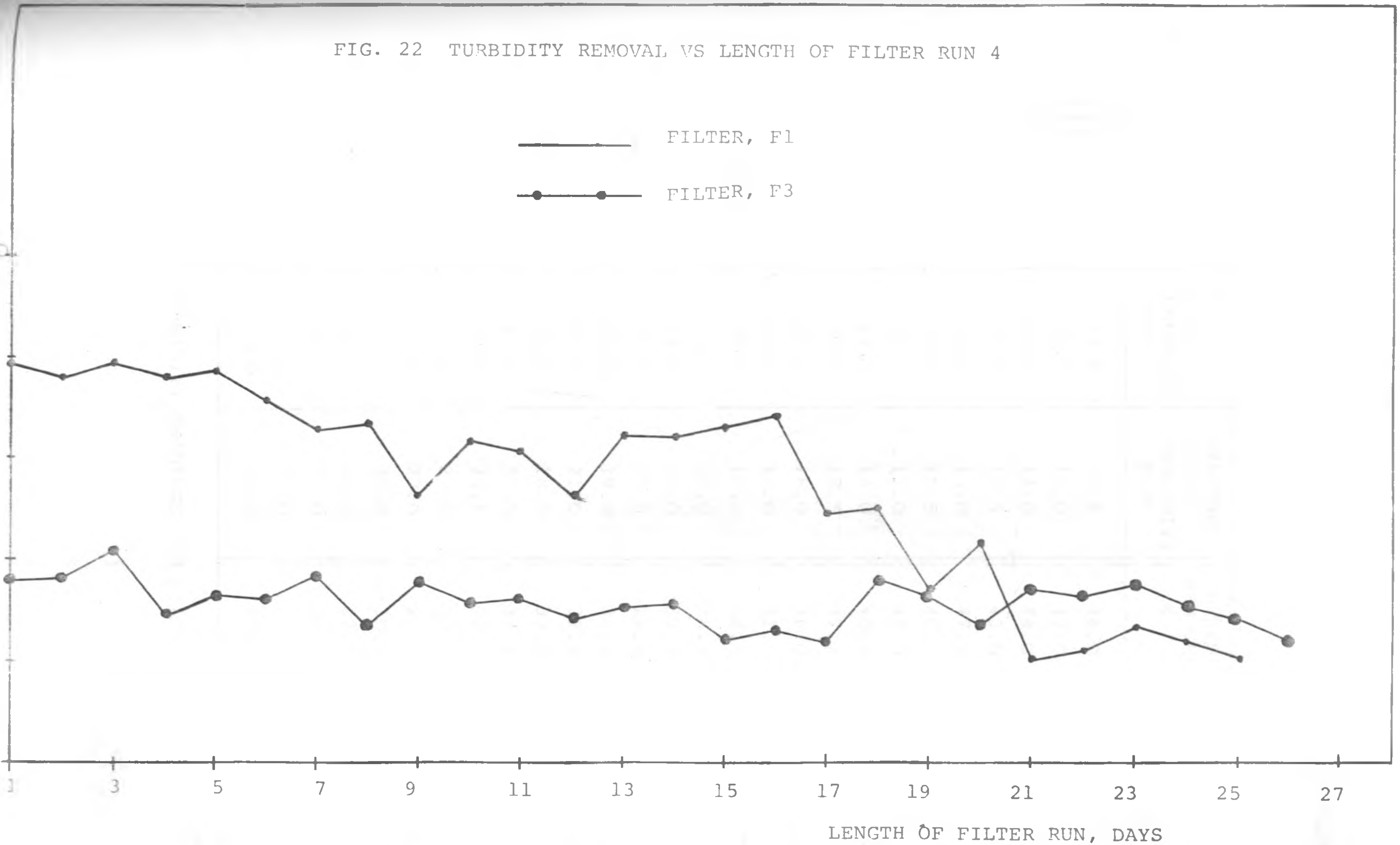
TABLE 17 TURBIDITY READINGS FOR FILTER F3. RUN 4

LENGTH OF FILTER RUN,DAYS	RAW WATER TURBIDITY FTU	FILTERED WATER TURBIDITY FTU	TURBIDITY REMOVAL %
1	25.0	16.0	36.0
2	22.0	14.0	14.0
3	30.0	17.5	41.8
4	29.5	21.0	28.8
5	27.0	18.0	33.3
6	28.0	19.0	32.2
7	31.5	20.0	36.5
8	20.5	15.0	26.9
9	20.0	13.0	35.0
10	29.0	20.0	31.0
11	29.5	20.0	32.2
12	30.0	21.5	28.3
13	30.0	21.0	30.0
14	32.0	22.0	31.3
15	31.0	23.5	24.2
16	30.5	22.5	26.2
17	33.0	25.0	24.3
18	40.5	28.5	29.6
19	40.0	29.0	27.5
20	38.0	28.0	26.3
21	38.5	29.5	23.4
22	39.0	25.0	35.9
23	36.0	24.0	33.3
24	31.0	22.5	27.4
25	30.5	20.0	34.4
26	39.5	26.5	33.0

LENGTH OF FILTER RUN, DAYS	RAW WATER TURBIDITY FTU	FILTERED WATER TURBIDITY FTU	TURBIDITY REMOVAL %
27	35.5	23.0	35.2
28	32.0	22.0	31.3
29	31.5	22.5	28.6
30	29.0	22.0	24.2

CONT. TABLE 17 TURBIDITY READINGS FOR FILTER F3, RUN 4

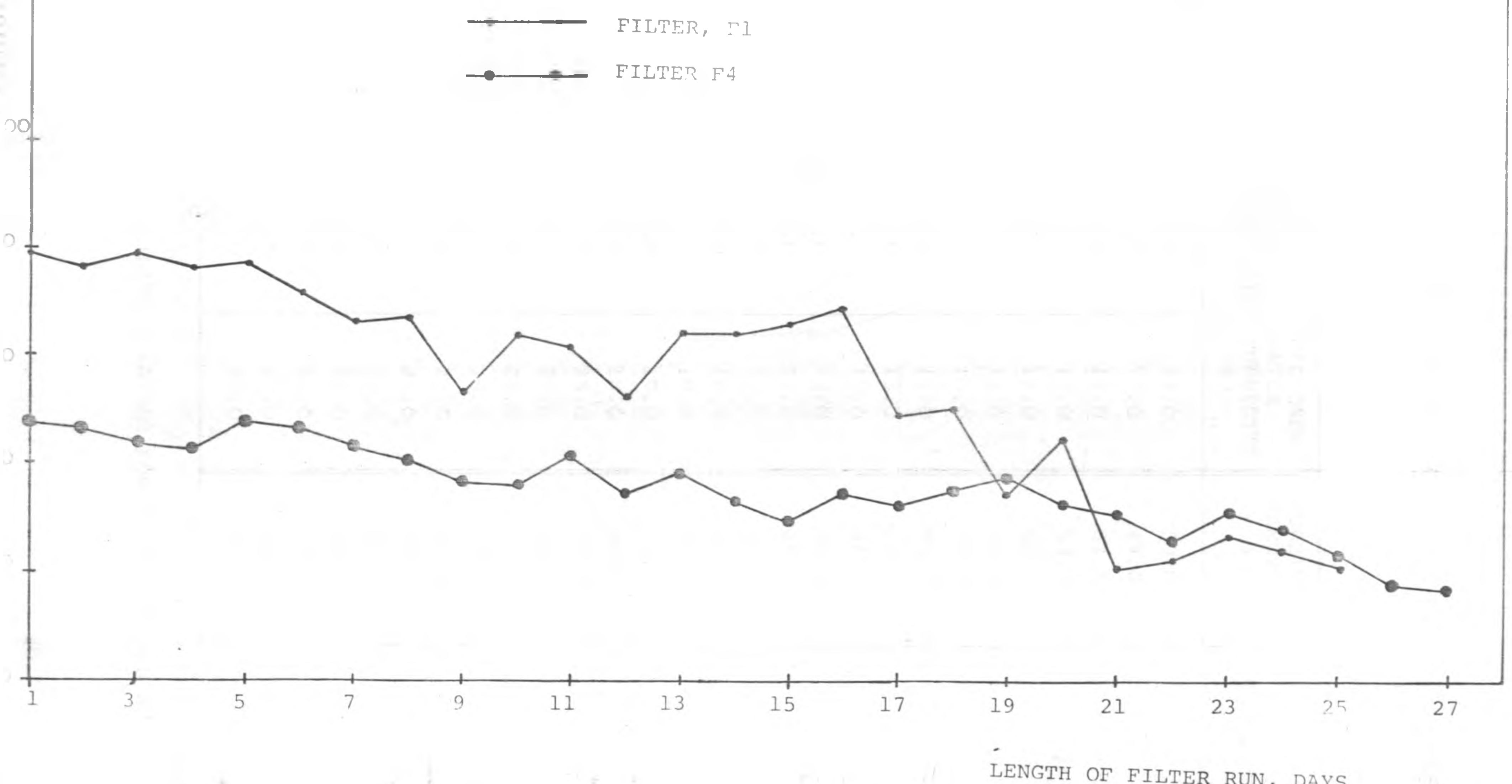
FIG. 22 TURBIDITY REMOVAL VS LENGTH OF FILTER RUN 4



LENGTH OF FILTER RUN, DAYS	RAW WATER TURBIDITY FTU	FILTERED WATER TURBIDITY FTU	TURBIDITY REMOVAL %
1	24.0	12.5	48.0
2	24.5	13.0	47.0
3	25.0	14.0	44.0
4	22.0	13.5	43.0
5	28.0	15.0	47.5
6	29.0	15.5	46.5
7	21.0	12.0	43.0
8	24.5	14.0	40.8
9	29.5	18.5	37.2
10	25.0	16.0	36.0
11	20.5	12.0	41.5
12	26.0	17.0	34.7
13	27.5	17.0	38.2
14	27.0	18.0	33.4
15	22.0	15.5	29.6
16	29.0	19.0	34.5
17	31.0	21.0	32.3
18	28.5	18.5	35.0
19	35.0	22.0	37.1
20	38.0	25.5	32.9
21	39.0	27.0	30.8
22	31.0	23.0	25.8
23	37.5	26.0	30.5
24	39.0	28.0	28.2
25	40.5	31.0	23.4
26	37.0	29.0	21.6
27	38.0	29.0	23.7

TABLE 18 TURBIDITY READINGS FOR FILTER F4, RUN 4

FIG. 23 TURBIDITY REMOVAL VS LENGTH OF FILTER RUN 4

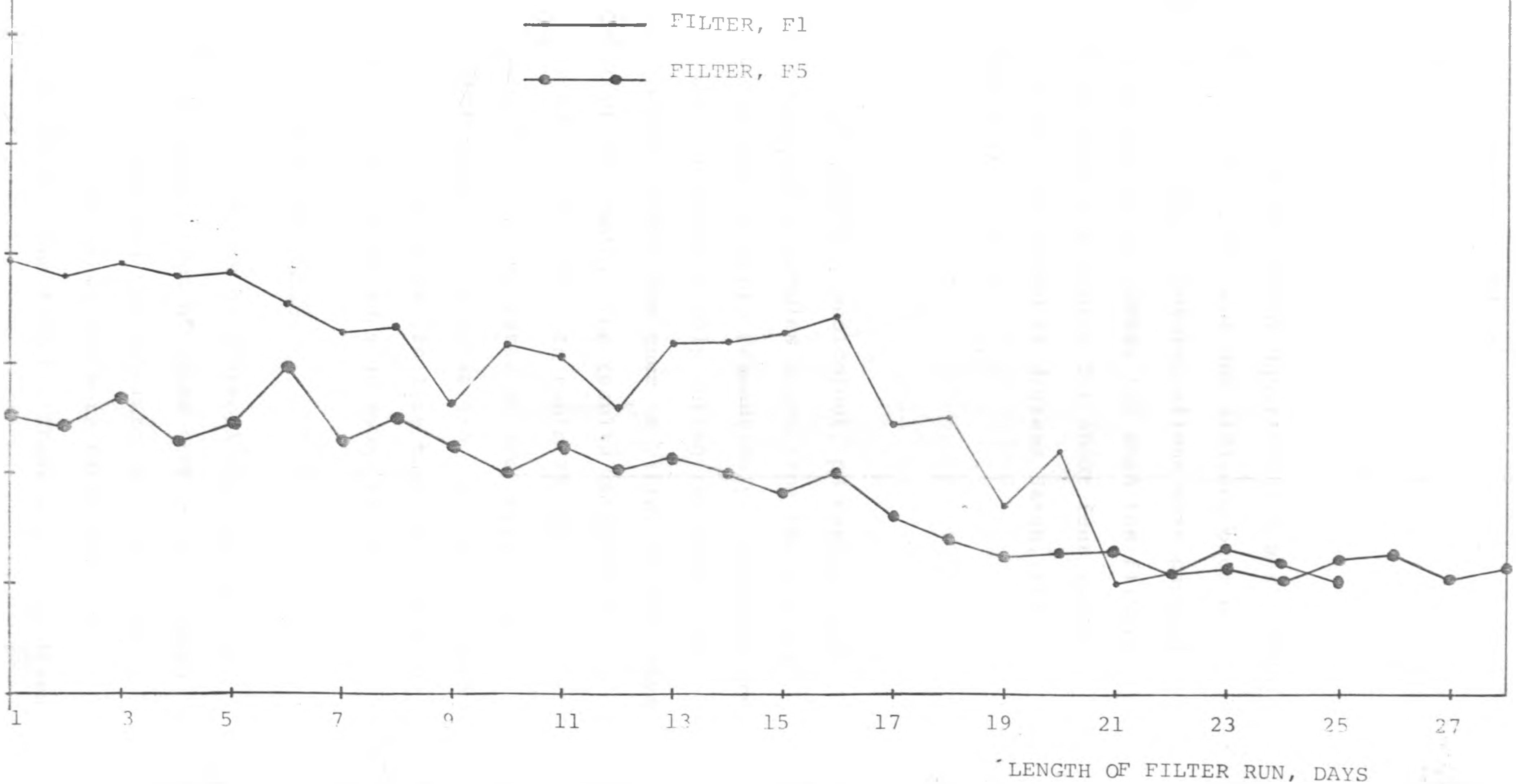


- 77 -

LENGTH OF FILTER RUN, DAYS	RAW WATER TURBIDITY FTU	FILTERED WATER TURBIDITY FTU	TURBIDITY REMOVAL %
1	24.0	12.0	50.0
2	21.0	11.0	49.0
3	28.0	13.0	53.6
4	24.0	12.0	50.0
5	24.0	13.0	45.7
6	21.0	11.0	49.0
7	21.5	10.0	59.8
8	24.0	13.0	45.8
9	26.0	13.0	50.0
10	20.0	11.0	45.0
11	20.0	12.0	40.0
12	21.0	12.0	45.0
13	27.0	16.0	40.7
14	28.0	16.0	42.9
15	25.0	10.0	40.0
16	30.0	19.0	36.7
17	30.0	18.0	40.0
18	37.0	25.0	32.4
19	32.0	23.0	28.1
20	37.0	28.0	24.3
21	35.0	26.0	25.9
22	31.0	23.0	25.8
23	35.0	27.0	22.9
24	39.0	30.0	23.0
25	39.0	31.0	20.5
26	37.0	28.0	24.3
27	36.0	27.0	25.0
28	38.0	30.0	21.1

TABLE 19 TURBIDITY READINGS FOR FILTER F5, RUN 4

FIG. 24 TURBIDITY REMOVAL VS LENGTH OF FILTER RUN, 4



7.2.2 COLOUR

Samples for colour determination were taken from the filter influent and effluent once every two to three days. Determinations were carried out only during run number two when the filters were operated continously for about four weeks. The results, expressed in degrees Hazen, are presented in table 20.

7.2.3 pH

Like turbidity and colour, pH measurements were conducted on samples taken from the filters effluents and influents respectively. Measurements were also carried out only during run number two when samples were taken once in three to four days for about one month. The results obtained are presented in table 21. In table 22, the raw water pH minus the filtered water pH are represented by either positives or negatives. A positive sign means the raw water pH is less than the filtered water pH and a negative sign means the reverse.

7.2.4 CALORIFIC VALUE

Twenty samples of charcoal were tested for calorific value. Ten of these samples were taken before the charcoal was put into the filter as media, while the other ten were taken after it had been used in the filter. These were then dried in the sun for the same period of time, one day, before being tested. The results, given in table 23 are expressed in calories/gram of charcoal.

FILTER	F1			F2			F3			F4			F5		
LENGTH OF FILTER RUN DAYS	RAW WATER	FILT. WATER	% REMOVAL	RAW WATER	FILT. WATER	% REMOVAL	RAW WATER	FILT. WATER	% REMOVAL	RAW WATER	FILT. WATER	% REMOVAL	RAW WATER	FILT WATER	% REM VAL
1	150	10	93	240	150	38	250	100	60	250	100	60	100	75	25
3	120	15	88	210	160	24	120	40	67	100	40	60	100	40	60
5	160	5	96	200	150	25	120	50	58	110	40	63.5	210	160	64
7	100	15	85	100	80	20	200	95	53	200	150	25	80	40	50
9	90	20	78	110	95	14	250	100	60	200	140	30	140	75	46
11	95	15	84	120	80	33	160	100	38	100	40	60	160	120	25
13	130	15	89	120	80	33	120	80	33	120	80	33	80	60	25
15	150	10	93	160	120	25	250	50	40	240	100	58	100	80	20
17	100	20	80	140	100	29	250	90	64	160	80	50	100	75	25
19	140	10	93	150	95	37	240	80	67	200	120	40	210	140	33
21	110	5	95	200	150	25	160	100	38	250	80	68	160	80	50
23	150	15	90	200	100	50	200	120	40	240	95	60	200	75	63
25	100	25	75	170	150	12	250	95	62	150	100	33	240	95	60
28	90	5	95	180	140	22	250	80	68	240	120	50	100	80	20

TABLE 20 COLOUR READINGS RUN 2

FILTER	F1		F2		F3		F4		F5	
LENGTH OF FILTER RUN,DAYS	RAW WATER pH	FILTERED WATER pH	RAW WATER pH	FILTERED WATER pH	RAW WATER pH	FILTERED WATER pH	RAW WATER Ph	FILTERED WATER Ph	RAW WATER pH	FILTERED WATER pH
1	7.1	7.7	7.5	8.1	7.85	8.1	7.9	8.0	7.9	8.0
4	7.2	7.1	7.2	7.6	7.2	7.8	7.8	8.0	7.7	7.9
9	7.1	7.2	7.1	7.1	7.1	7.4	7.2	7.0	7.4	7.4
12	7.4	7.7	7.5	7.9	7.8	8.0	7.5	7.6	7.6	7.5
15	7.6	7.6	7.9	7.9	7.7	7.8	7.7	7.6	7.6	7.7
19	7.8	7.5	7.3	7.4	7.3	7.9	7.9	8.1	7.8	8.0
22	7.4	7.6	8.0	7.8	7.2	7.5	7.3	7.1	7.2	7.5
25	7.3	7.1	7.6	7.7	7.9	8.1	7.7	7.8	7.7	7.6
27	7.0	7.2	7.0	6.9	7.8	7.9	7.8	7.7	7.9	7.8
29	7.8	7.3	7.3	7.5	7.6	7.7	7.7	7.6	7.7	7.6

TABLE 21 pH READINGS, RUN 2

FILTER / LENGTH OF FILTER RUN, DAYS	F1	F2	F3	F4	F5
	pH CHANGE (pH_R- pH_F)	pH CHANGE (pH_R- pH_F)	pH CHANGE (pH_R- pH_F)	pH CHANGE (pH_R- pH_F)	pH CHANGE (pH_R- p_{HF})
1	+	+	+	+	+
4	-	+	+	+	+
9	+	O	+	-	O
12	+	+	+	+	-
15	O	O	+	-	+
19	-	+	+	+	+
22	+	-	+	-	+
25	-	+	+	+	-
27	+	-	+	-	-
29	-	+	+	-	-

TABLE 22 pH CHANGE, RUN 2

SAMPLES TAKEN	CALORIFIC VALUE, Cal/gm x 10^3
Before use After use	7.85 7.25
Reduction in Calorific value, %	8

TABLE 23 CALORIFIC VALUE

7.3 MECHANICAL PARAMETERS

7.3.1 BENDING STRENGTH

Bending strength tests were carried out on a total of 60 specimens of wood, 20 x 20 x 300 mm in size, which were kept moist in the curing room for four weeks. 30 of these specimens were cypress and the other 30 were cedar. Six specimens of each type of wood were tested every week for about one month. The results, given in table 24 are expressed in N/mm^2.

SPECIMEN / DURATION IN CURING ROOM WEEKS	CYPRESS ($N/mm^2 x 10^{-2}$)	CEDAR ($N/mm^2 x 10^{-2}$
0	6.90	9.75
1	5.45	7.30
2	5.40	7.16
3	4.84	6.80
4	4.40	6.35
Reduction in strength %	36	35

TABLE 24 BENDING STRENGTH

7.3.2 COMPRESSIVE STRENGTH

Compressive strength tests were carried on ten different clay bricks. Five of these were tested soon after they had been made and the other five were tested after keeping them moist in the curing for a period of one year. The average results, expressed in N/mm^2 are given in Table 25 below

Time when Tested	Compressive Strength, N/mm^2
Soon after being made	14.5
After 1 year in curing room	1.0
Reduction in strength %	93

TABLE 25 COMPRESSIVE STRENGTH

7.4 OTHER RESULTS

The cement mortar filter boxes did not reveal any leakages, cracks nor any slimy, algal and plant growths. The wooden filter boxes in F2 and F3, however leaked all the water put in, at the start. When they were then soaked in a tank of water for about one month, the leakage only decreased. On sealing all the joints with cement paste, however, the leakage ceased. Like those in F2 and F3, the wooden filter box in Fig. 8 leaked a lot of water at the start. With time however, the leakage tended to decrease with the joints becoming smaller when the water level was high and larger when the water level fell. With respect to slimy, algal and plant growths, it was noted that the inside of these wooden filters tended to smell fishy and when small samples from there were viewed under the microscope, some diatoms were observed. Besides, specimens of cypress and cedar wood kept moist in the curing room, felt slippery to the touch after only one month.

The clay bricks filter box in Fig. 8 leaked all the water at the start. However, when the inside was plastered with betwen 10 and 15 mm of cement-mortar, the leakage stopped completely.

Clay bricks left outside for one year, showed no visible growths nor deterioration. If, however, exposed to intensive moisture or water pouring down from roofs etc, excessive algal and plant growth developed. In addition, the clay bricks became grossly eroded.

CHAPTER 8

DISCUSSION

8.1 BACTERIOLOGICAL QUALITY IMPROVEMENT

The use of charcoal in water purification is well known. It has been recognised in removing colour, odour, iron, taste and certain dissolved matter from polluted waters in addition to adsorbing some viral particles. While the lump charcoal has been used as a substitute in place of stones and pebbles as a contact medium for aeration, the fine powdered charcoal, with a size range of 50 microns to 100 microns has been found to be a good substitute for diatomaceous earth in pressure filtration using stellar filters (Merchant, N.M. Construction of An Intermittent Water Filter for Villages in Southern Iran & Paramasiram, R. National Environmental Engineering Research Institute, Nehru Marg, Nagpur).

When used as a granular material for filtration, however, charcoal is known to be probably dangerous. The bacterial content of the filtered water is known to be often higher than that of the raw water (Davey, T.H. & Wilson, T. The control of Disease in the Tropics.). The results of plate counts and coliform counts contained in Tables 2,3, 4 and 5 where the charcoal was used without any form of pretreatment, only helped to confirm this. The bacterial content of the filtered water was always more than that of the raw water, even from the start of the runs.

With heating,however, the charcoal showed a considerable improvement. When it had been heated for two hours at 200°C, the charcoal reduced coliforms in the water by more than fifty percent on the first day. This percentage reduction then fell off to about 40, at the end of the week. On heating the charcoal again at 200°C, but this time for about 6 hours, the coliform removal varied from eighty percent to 36 percent after one week. Before two weeks had elapsed, however, the results indicated an increase in the coliform count of up to 80% in the filter effluent.

Limitations in time could not permit any more experiemnts to be carried out along these lines. For any definite quantitative statements, this would be necessary.

8.2 TURBIDITY REMOVAL

The diagrams of turbidity removal versus length of filter run are contained in Figs. 15 to 24. From these, it could be said that for the charcoal filters, turbidity removal tended to decrease from as much as fifty percent to as low as ten percent in one month, with basically no significant difference between using either sand or gravel to keep the charcoal down. With the two sand filters, operated in run number two, the turbidity removal tended to increase, being initially about 20% and reaching up to more than fifty percent in one month.

So, assuming a minimum turbidity of our waters of about 30 FTU the filtrate turbidity, for the charcoal filters, would vary from about 15 FTU on the first day to about 20 FTU at the end of one week and about 27 FTU, at the end of the month. This charcoal filter performance, with respect to turbidity removal, was certainly not the best. The superimposed diagrams of the efficiency of the household candle filter in Figs. 18 to 25, helps to justify this, especially during the first three weeks. After three weeks, the efficiency of the candle filter was sometimes less than that of the charcoal filters. It is true that the output per day from the candle filter never exceeded 40 litres compared to 200 litres from the charcoal filters. In this regard, it seems that one would have to give preference to either quality or quantity.

8.3 FILTER BOXES

8.3.1 AVAILABILITY

A container or tank which can be conveniently adopted for water storage, may as well be used as a filter box. Commercially available in the market these days, are small water tight tanks made of welded or sectional steel, plastic, synthetic rubber and concrete. In certain places like USA and Sudan, water tight tanks have been developed by lining thin gauge steel tanks with polythene or prefabricated PVC bags. The tanks made of synthetic rubber or plastic are not very easily available in the rural areas of a country like Kenya. At least not more readily available than timber, clay or even cement, which were considered in this study.

Cypress and Cedar are two of the five most abundantly occuring species of timber in Kenya, the others being pine, Podo and Camphor. Found in the highland plantations and Aberdares, Maramanet, Mau and Mt. Kenya regions respectively, both cypress and Cedar are readily obtainable as sawn timber, even in the rural areas. Clay occurs in most parts of Kenya. Cement, too, being commercially produced, is easily available.

8.3.2 COSTS AND ECONOMIC IMPACT

The steel and concrete filter boxes, mentioned in section 8.3.1 are relatively expensive, even for the urban situation. The timber filter boxes, too, are not very cheap either. The cost of those made of cypress, however, is about half as much as of those made of cedar. A piece of cedar wood measuring 25 mm x 250 mm currently costs KShs. 13.60 per metre, while the same size of cypress wood costs only KShs. 7.05 per metre.

Clay costs very little. The same holds true even for sand. The cost of making a filter box out of either clay bricks or cement mortar, therefore, comes practically from the labour involved and the cement that is used. The method used for making filter boxes out of cement mortar as described in chapter 5 cannot be said to be very difficult. It is possible to master the whole technique in one or two days, as it was in the case of the writer. Besides, the village Technology Unit in Karen has been training a considerable number of people in the production technics of these cement mortar tanks. These people have been spreading their skills among the rural population.

A similar reasoning would hold true in the case of making the filter boxes out of clay bricks. A difficulty in this direction, however, would probably arise out of the necessity for a suitable device for making the bricks in the first place. These devices might be expensive. But with cooperation among the beneficiaries, an entire village population should be able to afford at least one such device.

The amount of cement in one clay brick is about five per cent by weight, while one bag of cement costing approximately KShs. 30, makes more than ten, 130 litre capacity cement mortar filter boxes. With cement being required in such small quantities, it can be said that the cost of these filter boxes, attributed to cement, is not much, either, meaning that the filter boxes are basically cheap. For instance, the estimated cost of one, 130 litre cement mortar filter box is put at not more than KShs. 10.

8.3.3 BEHAVIOUR AND DURABILITY

As regards the wooden filter boxes, cedar, which costs about twice as much as cypress is also stronger, if tested under the same conditions. Besides, under damp conditions, cedar has more resistance to fungal and termite attack than cypress. This greater strength and durability tends to balance off the extra cost of cedar.

While building the filter boxes using these species of timber, considerations were given towards simplicity with respect to the types of joints used. In Fig.9, the types of joints considered were shown. Fig. 9a was considered the simplest type of joint to make and therefore easily adaptible even by the villager who is not so skilled in woodwork. Simple to make, though it is, this type of joint was considered to never render the tank water tight. The type of joint shown in Fig. 9c was thought to be perhaps the most difficult to make under rural conditions. So that, although it seems to give a good water holding ability, it was disregarded. Under the same standard of workmanship, the joint is Fig. 9b would be midway between those in 9a and 9c. It would be more difficult to make but more water tight than 9a and easier to make but less water tight than 9c.

When the filter boxes were then made with the joints in Figs. 9a and 9b, respectively, there appeared no significant difference in water tightness. The filter boxes leaked all the water put into them. An unsuccessful attmept to close up the filter boxes was made by soaking them in water for as long as one month. Eventually, however, the wooden filter boxes became watertight when the joints were sealed with cement paste. Other waxy materials could have probably been used for sealing or the inner surface of the filter boxes lined with a watertight sheeting.

Like the wooden filter boxes, a serious disadvantage faced by clay bricks filter box was that it leaked a lot of water. After the inner surface was covered with a 15 mm thick mortar, the leakage stopped. Worthwhile to mention here is the fact that the cement mortar filter boxes used in this study were built entirely of 15 mm thick mortar.

These filter boxes did not leak any water and remained intact during the entire period of experimentation.

Under these circumstances, it would appear that a preference for cement mortar to clay bricks would be justifiable. In addition, results of compressive strength tests contained in Table 25, indicate that the strength of clay bricks dropped by nearly ninety percent when constantly subjected to moist conditions for about one year. Besides, under heavy rain and water impact, the results indicate that the bricks wore out. This can certainly accelerate deterioration. That under those same conditions the bricks developed some plant and algal growths is yet another problem. Such growth might contribute to a more rapid filter clogging.

8.4 REUSE OF MEDIA

The results of calorific value tests contained in Table 23 indicate that the amount of heat produced by wood charcoal decreased by eight percent when it had been used as a filter media. This decrease in the amount of heat produced was accompanied by a slightly more development of smoke, than is usually the case. These changes were, however, small and make the charcoal suitable for cooking after serving as filter media. Besides, foods are usually cooked in closed containers, so that the influence of the smoke on the taste of the food should be minimal. With the current price of charcoal being officially as high as KShs. 30 a bag(20kg), the cost saved by putting charcoal to a dual purpose is justified.

No strength, physical or chemical tests were conducted on the sand and gravel after they had been used in the filters. It can be assumed that the qualities of these materials do not change much. This would however be of importance if the water contained chemicals capable of reacting with the substances. Both the sand and gravel can probably be reused for construction, road buildings etc without difficulties.

8.5 OTHER CONSIDERATIONS

The results of colour measurements contained in Table 19 show the candle filter to be very efficient in colour removal, removing always at least 75%. Charcoal, too, was quite efficient. The colour removal was frequently between 60 and 70%, although on other occasions, it was as low as 10%.

The results of pH tests contained in Tables 20 and 21 are rather unclear. On certain days, the pH-value of the filtered water was less than that of the raw water while on other days, it was the reverse. In each case however, the differences were small. In the case of the wooden filters, the pH-value of the filtered water was frequently above that of the raw water. It is possible that the wood had an impact on the pH values of the water. But again, the impact was small.

CHAPTER 9

CONCLUSIONS

9 The following conclusions can be drawn from from this study:-

9.1 Cement mortar filter boxes remained water tight and developed no algal, bacterial, plant or other growths in them.

9.2 Wooden filter boxes smelled fishy and developed slimy and diatomaceous growths on them after several months of continous use.

9.3 Wooden filter boxes leaked considerably through their joints. The boxes became water tight when the joints were sealed, from the inside, with cement paste.

9.4 Clay bricks made of clay, sand and cement in the ration 15:3:1 lost 90% of their strength when continously kept moist for one year.

9.5 Clay bricks became eroded and covered with plants and algae after having been exposed to falling water or heavy rain.

9.6 When built into filter boxes, the clay bricks leaked considerably. The leakage however, diminished after some time. A thin layer of cement mortar, trowelled from the inside, helped to stop the leakage.

9.7 If charcoal, without any form of pretreatment, was used as filter media, the bacterial content of the filtered water was always higher than that of the raw water.

9.8 When the charcoal used was preheated at 200^{o}C for at least 2 hours, the bacterial removal decreased from over fifty percent on the first day to about fourty percent after one week. Before the end of two weeks, the bacterial content of the filtered water again became higher than that of the raw water.

9.9 The turbidity removal of the charcoal filters, decreased from roughly fifty percent during the first days to less than thirty percent after about one month. For the sand filters, the turbidity removal increased from about 20% to over 50% after a period of one month.

9.10 Using sand or gravel to keep the charcoal down did not affect much the efficiency of the filters.

9.11 The household candle filter was more efficient than the charcoal and the sand filters, but only during the first three weeks. After that, the efficiency of the candle filter fell off and approached that of the other filters.

9.12 The calorific value of charcoal after it had been used as a filter media, decreased by 8%. Slightly more smoke than usual was produced.

9.13 The wooden filters increased the pH of the water slightly.

CHAPTER 10

RECOMMENDATIONS

10.1 Charcoal without pretreatment should never be used as a filter media

10.2 Charcoal should first be heated at 200°C for at least 2 hours before being used as filter media.

10.3 The charcoal filter content should be removed and replaced after every one week.

10.4 The charcoal, so removed from the filter, may be dried and used for cooking or heating purposes. The sand and gravel removed, may be washed and used for purposes like building, road construction etc.

10.5 Filter boxes or water storage tanks built from timber should have a seal of cement paste along the joints.

10.6 Filter boxes or storage tanks built from timber should only be used where a high quality of water is not required.

10.7 Filter boxes built of clay bricks, should first be lined on the inside with a 15mm thick layer of cement mortar

10.8 Cement mortar is an excellent material for filter boxes or water storage tanks.

REFERENCES

AMERICAN PUBLIC HEALTH ASS., NEW YORK (1971) Standard Methods for the Examination of Water and Wastewater.

BENGOUGH, C.C. (1971) Commercial Timbers of Kenya.

CLEASBY, J.L. (1975) Effect of Media Intermixing on Dual Media Filtration, Journal of the Environmental Engineering Division.

COX, C.R. (1969) Operation and Control of Water Treatment Processes

DAVEY,T.H. & WILSON, T. (1971) The Control of Disease in the Tropics

DEPARTMENT OF HEALTH AND SOCIAL SECURITY (1974) The Bacteriological Examination of Water Supplies.

DOUGLAS, J.F. (1970) Solution of Problems in Fluid Mechanics.

LINSLEY, R.K. & FRANZINI, J.B. (1972) Water Resources Engineering.

MADDOCKS, D (1975) An Introduction to Methods of Rainwater Collection and Storage, Appropriate Technology, Volume 2, Number 3.

MANN, H.T.and WILLIAMSON, D. Water Treatment and Sanitation.

MERCHANT, N.M. Construction of an Intermittent Water Filter for Villages in Southern Iran.

SIMON, W. (1975) Water Jars from Cement Mortar, Appropriate Technology Volume 2.

STEEL E.W. (1960) Water Supply and Sewerage.

WAGNER, E.G. (1959) Water Supply for Rural Areas and Small Communities.