THE USE OF GRADED LOCAL SAND IN SLOW SAND FILTRATION

BY

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B.ENG. (CHEMICAL), A.B.U.

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL AHMADU BELLO UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE (WATER RESOURCES AND ENVIRONMENTAL ENGINEERING.

FACULTY OF ENGINEERING

AHMADU BELLO UNIVERSITY, ZARIA.

DECEMBER, 1985

THE USE OF GRADED LOCAL SAND IN SLOW SAND FILTRATION.

DEDICATION

IN THE NAME OF ALLAH THE BENIFICIENT, THE MERCIFUL.

1. READ! IN THE NAME OF THY LORD AND CHERISHER WHO CREATED.

2. CREATED MAN OUT OF (MERE) CLOT OF CONGEALED BLOOD:

3. READ! AND THY LORD IS MOST BOUNTIFUL, -

4. HE WHO TAUGHT (THE USE OF) PEN,

5. TAUGHT MAN THAT WHICH HE KNEW NOT.

(Q: 96, 1-5)

DECLARATION

I hereby declare that this thesis has been written by myself and that it is a record of my own research work. It has not been accepted in any previous application for a higher degree. All sources of information are specially acknowledged by means of reference.

Bello Mohammed

CERTIFICATION

This project thesis entitled "The use of graded local sand in slow sand filtration", by Bello Mohammed, meets the regulation governing the award of the degree of Master of Science (M.Sc.) of Ahmadu Bello University, Zaria, and is approved for its contribution to scientific and literary presentation.

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ABSTRACT

This work was carried out to determine the efficiency of slow sand filtration. Graded sand obtained using BS Sieve Numbers 25, 36, 72, 100 and 200 and another obtained using BS Sieve number 14 constructed locally were used.

Influent and effluent samples were analysed at intervals for pH, turbidity and bacteriology (Coliform test), so as to determine the filter efficiency.

The media obtained using BS set of sieves produced effluent of about 90% removal in coliform, 75% removal in Turbidity and an insignificant change in pH, where as that obtained using BS sieve No, 14 gave an effluent of about 80% removal in coliform, 25% removal in Turbidity and an insignificant change in pH, In the absence of a total coliform removal, disinfection as a measure of safety should be employed.

ACKNOWLEDGEMENTS

My thanks to:- Professor B. Z. Diamant of the World Health Organisation who proposed the work, Professor J. A. Ogunrombi whose interest in the work helped in no small measure for its success, Dr. J. S. Kilani who read, criticised and adviced on the final content of the thesis.

I wish also to thank the Board and Management of Kaduna State Water Board for granting me sponsorship for the period of the study.

Finally to the members of staff of Kaduna State Water Board Zaria, who contributed in one way or the other for the success of the work.

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CHAPTER I

INTRODUCTION

Provision of adequate supply of safe drinking water has been receiving attentions of the various Governments of the world over. However, the water supply to the rural population has remained a challenging task, more especially when the characteristics, cultural habits and socio economic conditions of these settlements are taken into account. According to a World Health Organisation (WHO) report (8) over two-third of the population of the developing countries of the world live in rural areas and only a mere 14 percent of this population have any access to safe water supply. Nigeria being one of the developing countries is also faced with this problem.

This is an alarming situation more especially when factors such as water borne diseases are taken into consideration which day in day out continues to remain a challenging task to the Government.
The urban areas where water supply schemes often involve sophisticated machinery face the problem of spare parts, skilled labour and most importantly treatment chemicals. All these hamper smooth operation, resulting in water shortages in many areas. In cases where the operation is successful production is inadequate to cater for the populace.

This could be attributed to wrong planning or population explosion as a result of rural migration or rapid city development due to provisions of schools, industries and tourism.

This lack of safe drinking water in the rural areas can be tackled by either incorporating the rural water schemes in the urban water supply schemes or establishing water works for the areas. While the former may be un-economical the latter may likely face the problem of skilled labour. However, the rural areas can be supplied with safe drinking water devoid of all the sophistication associated with urban water supply schemes by examining what is readily and locally available of simple operational procedure. Most of our rural areas have abundant surface water, more especially during the rainy season where the daily need is obtained. This accessibility of the rural areas to the surface water encourages this work to be carried out and recommendations made for easy implementation.

In the process of treatment water passes through the following stages:

(i) Screening
(ii) Coagulation
(iii) Sedimentation
(iv) Filtration

(v) Disinfection, before finally distributed.

In the present study only filtration is considered and treated in some details.

Filtration is the purification process, where by water requiring treatment is passed through a porous medium. The quality of the water is improved in three significant ways:-

(i) Removal of suspended and colloidal matter.

(ii) Reduction of the number of bacteria and other organisms and

(iii) Changes in its chemical constituents.

The porous media that could be used for filtration includes:

(i) Granular bed of sand

(ii) Crushed stone

(iii) Antharacite

(iv) Glass

(v) Cinders etc.

Three types of filtration are known:-

(i) Rapid Gravity filtration

(ii) Pressure filtration and

(iii) Slow sand filtration.

Rapid Gravity and Pressure filtrations are employed for big treatment plants where coagulation and sedimentation precedes filtration, while the, slow sand filtration is employed mainly for small community with very little pre-treatment.

It is the aim of this work to develop a simple treatment process that requires unskilled labour for the rural areas of Nigeria. Therefore slow sand filtration was studied closely.

Slow sand filter requires a medium of effective size between 0.15mm and 0.35mm and uniformity coefficient of about 2 to 3. Such a grade could only be obtained by mechanical sieving.

In this work experiments were conducted using two media of graded sand, whose effective sizes are 0.22mm and 0.16mm and uniformity coefficients of 1.93 and 3.6 respectively. The performance of the two media were assessed by measurements of parameters such as turbidity, pH and bacteriological quality of the raw and filtered water.

CHAPTER II

LITERATURE REVIEW

2.1 HISTORICAL BACKGROUND

According to the available information slow sand filtration was initiated and developed in England in the 19th centuary. The success of the operation resulted in the promulgation of an act, that all thames derived water in an area of five miles around St. Paul's Cathedral be slow sand filtered (5).

Today many developing countries have built pilot filters in their urban water works and service filters for small communities in the rural areas. Notable among these countries that have built and developed slow sand filters are:-

(i) Kenya
(ii) Saychelles
(iii) Thailand
(iv) India.

2.1.1. THE KENYA EXPERIENCE

Pilot filters were set up at Kabete Water Works. Coarse media was first used for the pilot plant (effective size 0.68mm and coefficient of uniformity 1.4) (10). The coarse media was later used as a roughing filter for the fine media.

The results showed the filtration of the coarse media as very poor in terms of bacteriological quality, the turbidity and colour removal. The fine media however, gave better results although not satisfying the drinking water standards (8). Disinfection was therefore recommended as post filtration.

In Kenya, now, many slow sand filters exist with the biggest one built in west Karachuonyo in Nyanza province (10). This filter is of three units, each measuring 15m x 8m, and it has settling of the raw water as pre-treatment operation. The filter performance was rated as fair. The media employed for this filter has 0.28mm effective size and uniformity coefficient of 2.3. Most of the slow sand filters in Kenya are fitted with a pre-treatment unit and chlorination as post-treatment (10).

2.1.2. SEYCHELLES

Three slow sand filter units have been reported (10). These filters are sited at the Rochon Dam treatment works. Each filter unit measures 9.45m x 27.8m x 2.74m with 455mm graded stones layer and 730mm sand. The effective size and uniformity coefficient of the media are between 0.3mm and 0.4mm and 1.75 and 2.4 respectively. The filtration rates are $0.095m^3/m^2/hr$

for one unit and 0.122$m^3/m^2/hr$ for two units. The filtered water is subjected to chlorination before distributed to consumers. Another set of filters planned at Ans Royal comprise of settling, filtration and chlorination.

2.1.3. THAILAND

According to information available (13) a study on slow sand filtration was carried out in Thailand with an ultimate aim of providing an acceptable water as cheaply as possible using simple treatment systems. The programme was carried out for the specific purpose of conducting the following investigations:-

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

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

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

The influence of raw water turbidity and filtration rates on the quality of treated water (Turbidity, Coliform removal) and filter run duration based on head loss development was the subject of investigation.

The result of the investigations indicates four alternative method of treatment:-

ALTERNATIVE A. This is a series-filter system composed of coconut fibre as a roughening filter and burnt rice husk as a polishing filter. At a filtration rate of about $0.5m^3/m^2/hr$ the polishing filter was able to remove the residual turbidity in the effluent of the roughening filter and water acceptable for village consumption was produced.

ALTERNATIVE B. This is a dual-media filter consisting of coconut fibres compactly spread on bed of burnt rice husk. The filtration rate is $0.2m^3/m^2/hr$ for a raw water turbidity of about 100 J.T.U. and a continuous filter run of 2 to 3 months. However, it has been observed that inspite of the acceptable quality of treated water in terms of turbidity and long filter run an objectionable odour was detected after a long period of filter operation. Thus in practice, operation should be disrupted at the first sign of odour in the system.

ALTERNATIVE C. This is also a dual-media filter consisting of a burnt-rice-husk bed overlaying sand bed. This combination proved to be reliable for village community water supply. Treated water of excellent clearity and no odour was detected during the period of operation. However, the cleaning process is inconvenient, as the burnt-rice-husk has to be removed before the top layer of the sand bed can be removed.

ALTERNATIVE D. On the basis of alternative C findings, a series-filter system was designed using the media of alternative C. The roughening filter consists of either burnt-rice-husk or coarse sand, and the polishing filter fine sand. The disadvantage of this alternative is high cost incurred in terms of construction.

A conclusion drawn from the findings on the economic point of view, was the adoption of alternative C, that is the dual media filter consisting of burnt rice husk and sand. This is because it seems most appealing and has the greatest potential for treatment of tropical surface waters in rural areas (13).

2.1.4. INDIA

Research work on slow sand filtration was carried out in order to develop practical guidelines for the design, construction and operation (11).

Studies were conducted on the following aspects:-

(i) Effects of different rates of filtration

(ii) Shading

(iii) Discontinuous operation

(iv) High levels of pollution in raw water

(v) The use of builder grade sand.

The following conclusions were drawn from the studies:

(i) Filters treating raw waters with a turbidity up to 30 J.T.U. produced a good quality filtrate of less than 1 JTU at the filtration rates of 0.1, 0.2 and 0.3 m/hr. However, high filtration rates results in decreased filter run and increased filtered water output.

(ii) At filtration rate up to 0.3m/hr reduction of 55 to 70 percent of the COD of the water of initial value of 8-12 mg/l was obtained.

(iii) The filtered water was found to be free of E. Coli on more than 85 percent of the occasions. The filtered water fully satisfies the drinking water quality standards laid down by the Ministry of Health, Government of India. It has been considered quite acceptable for rural and community Water Supplies.

For additional safety and to take care of any possible contamination in the distribution system disinfection of the filtered water was considered desirable.

(iv) Discontinuous operation has been found to be only advantageous for small communities that can afford only a limited number of personnel for operation and maintenance.

(v) High rate of organic and bacterial pollution in raw water seem to upset the performance of the filters resulting in the deterioration of the filtrate quality.

(vi) Slow sand filtration with builder grade sand produces a filtered water of satisfactory quality. Longer filter runs are obtained than with the fine graded sand. However, the fine graded sand produced filtrate of better bacteriological quality.

According to the information available there are about 187 slow sand filter installations in India (11). More than 60 percent of these installations are serving a population in the range of 2,000 - 10,000 persons. About 84 percent of them have pretreatment units incorporated and 95% of them are being operated at a filtration rate of 0.1m/hr. However, detailed information as regard the operation and maintenance of the filters was not available.

A common observation was short filter runs due to excessive algal growth or high turbidity during Monsoon period. Work was carried out to control problems of hydrogen sulphide generation at some of the installation without success. Pre-chlorination and breakpoint chlorination were tried and found to be effective.

2.2. MECHANISM OF FILTRATION

The overall removal of impurities associated with the process of filtration is brought about by a combination of different phenomena, most important of which are:-

(i) Mechanical straining
(ii) Sedimentation
(iii) Adsorption
(iv) Chemical and
(v) Biological activity.

2.2.1. MECHANICAL STRAINING

This is the removal of suspended matter that are too large to pass through the interstices between the sand grains. The process takes place almost entirely at the surface of the filter and is independant of the filtration rate. The grain size, D, and the pore size d, as shown in figure 2.1 are related by the formula (5)

$$d = 0{,}155D \qquad - 2.1$$

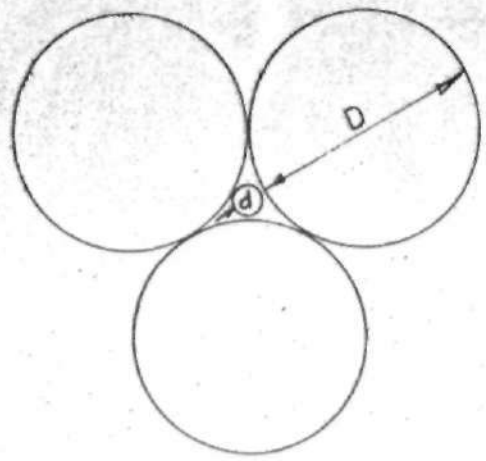
In slow sand filtration the smallest value D can assume is 0.15×10^{-3}m. This shows that the smallest value that d can assume also is a little over 20×10^{-3}mm. It means that colloidal matter (0.001-1μ) and bacteria (up to 15μ in length could not be retained by the pores).

However, as the water passes through the pores of the filter, velocity gradient are created, thus bringing the suspended particles in contact with each other. This leads to aggregation of finely divided particles which are retained at greater depth in the sand bed.

As the retention of these particles continues with the filtration, a ripening period is attained. In this period coarse suspended solids caught at or near the surface of the bed form a very fine porous layer (filter skin) which greatly promotes efficient straining and thus reduces effluent turbidity.

2.2.2. SEDIMENTATION

Sedimentation removes particulate suspended matter of finer sizes as the pore openings (about 20×10^{-3}mm in diameter) by precipitation upon the sides of the sand grains, in exactly the same way as in any ordinary settling tank. The difference,



$d = 0.155D$

$= 0.023$ mm

for $d = 0.15$ mm

FIG 2.1 Relation between grain size and pore size

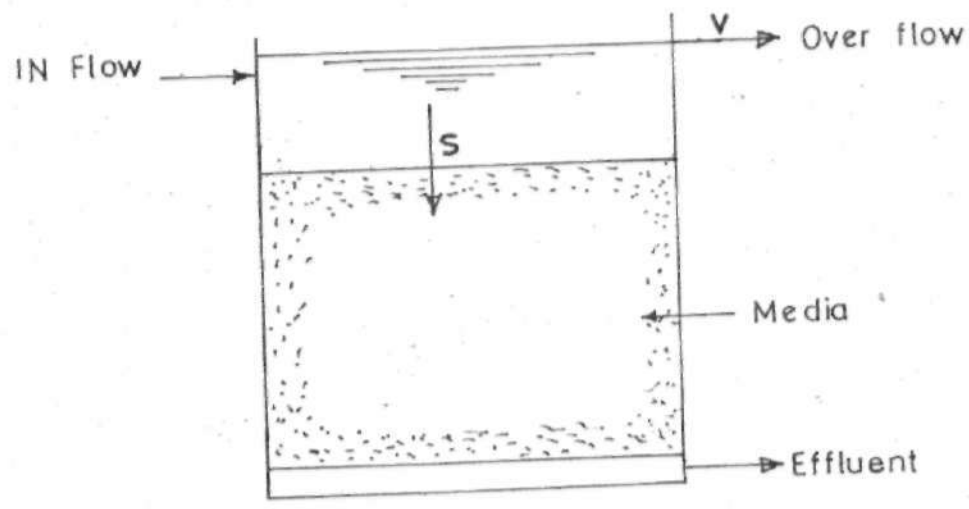


FIG 2.2 Settling of a suspended particle and overflow rate relationship.

however, is that in a tank, deposites can only form on the bottom while in sand filtration the combined surface area of all filter grains is available.

The relationship between surface area and volume of void space is given as (5)

$$\frac{A}{V'} = \frac{(1-f)}{f} \frac{6}{d} \qquad - 2.2$$

$$\text{or} \quad A = \frac{6}{d} \frac{(1-f)}{f} V'$$

Where f = porosity, V' = Volume of voids
= f (Total Volume Spheres)
= fV

$$\therefore \quad A = \frac{6}{d} \frac{(1-f)}{f} fV \qquad - 2.3$$

$$\text{or} \quad A = \frac{6}{d} (1-f) V \qquad - 2.4$$

d = Specific diameter of grain.

For a unit volume of filter sand the gross surface area is given as (5):

$$A = \frac{6}{d} (1-f) \text{ in } m^2$$

For a normal porosity of 38% and grain size of 0.25×10^{-3}m the area of deposition is no less than

15000m^2 per m^3 of filtering material. Even when only the area facing upward is effective, which is a fraction of the area calculated, a value of 1000m^2 which represent the area of deposition will still be obtained (5).

Sedimentation efficiency is a fraction of the ratio of surface loading and the settling velocity of the suspended particles. For a lamina settling, Stokes (4) gives.

$$Vs = \frac{1}{18} \frac{g}{\nu} \frac{\Delta\rho}{\rho} d^2 \qquad - 2.5$$

where d = particle diameter

ρ = density of fluid

$\rho + \Delta\rho$ = mass density of suspended matter.

g acceleration due to gravity (9.81m/sec^2)

ν = Kinematic viscosity of the fluid

Complete removal by sedimentation is expected when the settling velocity is greater than the over flow rate (fig. 2.2).

That is to say

$$Vs = \frac{1}{18} \frac{g}{\nu} \frac{\Delta\rho}{\rho} d^2 > V \qquad - 2.6$$

Where V is the overflow rate. Colloidal particles (0.001-1μ) cannot be extracted by sedimentation as the smallest value that d can attain according to equation 2.6 is 4μ (5).

2.2.3. ADSORPTION

Adsorption is the collision of suspended particles and sand grains after the suspended particle has left the flow line by centrifugal action as shown in figure 2.3 and the subsequent adherence of these impurities to the sticky gelatinous coating formed on the grains by previously deposited bacteria and colloidal matter.

The physical and electrostatical attractions greatly enhance adsorption. Clean quatz sand, by its nature, has a negative charge and is thus able to adsorb positively charged particles in the form of colloidal matter (such as floc of carbonates, Iron and aluminium Hydroxide etc) as well as cations of Iron, Manganese, Aluminium and so on. Colloidal matter of organic origin, bacteria included, mostly have a negative charge and as such are not attracted. This implies that at the initial stage of filtration, such impurities are not removed.

In the process of slow sand filtration a ripening period is attained and during this period positively charged particles are adsorbed, the accumulation of which leads to over saturation and ultimately the charge of the coated particles (bacteria and colloidal matter) reverses and becomes positive.

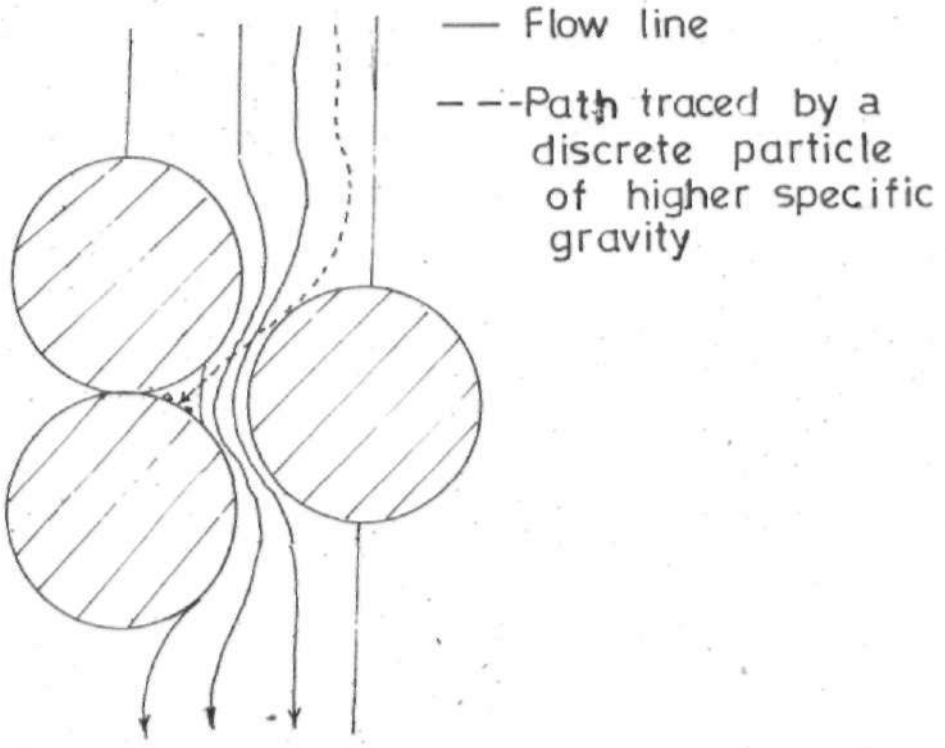


FIG 2·3 Removal of discrete paticles by centrifugal force

The secondary stage of adsorption set in and negatively charged particles as well as colloidal matter of animal and vegetable origin are removed . Over saturation again occurs, the overall charge becomes negative again thus allowing the adsorption of positive charges.

2.2.4. CHEMICAL ACTIVITY

The transfer of impurities from the water to the filter grain surface results in accumulation of so much material. This has to be removed by scouring in the case of rapid sand filters, or scrapping the top layer (1-2cm) in the case of slow sand filter.

However, organic matter adsorbed at greater depth decomposes to mineral salts in the presence of Oxygen. As a result of the Oxidation, dissimilation and assimilation take place, and finally mineralisation at greater depth. The finally librated inorganic salts (water, carbon dioxide, nitrates, phosphates etc.) are discharged with the filter effluent.

The overall reaction is as follows, (5):

$$C_5H_7O_2N + 7O_2 \rightarrow 3H_2O + 5CO_2 + NO^-_3 + H^+ \qquad - 2.7$$

organic matter.

2.2.5. BIOLOGICAL ACTIVITY

This is the action of micro-organisms, living on and in the filter bed. Bacteria from the raw water multiply by using the inorganic and organic matter deposited on the filter grain. Oxidation of the food, as described in section 2.2.4, gives the necessary energy required by the bacteria for its living processes and partly for growth thus colloidal and molecular dissolved impurities are transformed into living particulate matter.

The biochemical oxidation of organic matter is dependant on:-

(i) Time
(ii) Oxygen
(iii) Temperature
(iv) The role of algae.

In slow sand filtration time is not limiting as the water spends about two hours to pass through 1m thick of filter bed at a rate of 0.2 m/hr and 40% pore space (5).

Absence of oxygen results in the setting in of anaerobic decomposition, giving effluent containing hydrogen sulfide, ammonia, manganese, iron and various taste and odour producing substances making the water unfit for drinking and for industrial purposes.

Under all conditions oxygen concentration of the effluent should preferably be above 4mg/l (5). Aeration of the raw water helps to increase the oxygen content.

Efficiency of slow sand filtration is seriously affected by temperature, as it influences the speed at which chemical reactions take place, as well as the metabolism of bacteria and other micro-organisms.

A relationship between temperature, T, and reduction in permanganate consumption Δ by slow sand filtration has been reported (5)

$$\Delta = \frac{T + 11}{9} \qquad - 2.8$$

Where Δ is in mg/l and T in ^{o}C. Any temperature below $6^{o}C$ results in having ammonia in the effluent, and a further fall below $2^{o}C$ for any longer period, requires correction either by covering the filter or by post-disinfection to assure at least the aesthetic quality of the water going into supply.

Presence of algae in the supernatant water brings about most of the changes in Water quality during slow sand filtration. Because they are autotropic organisms, they need light for their photosynthetic processes, as such are not present in covered filters.

Algae are built up from simple minerals such as water, carbon dioxide, mitrates, phosphates etc, with the help of solar energy. The photosynthetic process can be described schematically by the relationship:

$$n(CO_2) + n(H_2O) + \text{Energy} \rightleftharpoons (CH_2O)n + n(O_2) \quad - 2.9$$

organic matter in form of Algal cells.

Algae need energy for their metabolism which is produced as a result of the oxidation of organic matter.

$$(CH_2O)n + n(O_2) \rightleftharpoons n(CO_2) + n(H_2O) + \text{Energy} \quad - 2.10$$

Thus when algae die their cell materials is liberated which is subsequently consumed by bacteria in the filter bed.

The role of algae in slow sand filters can be classified into three distinctive stages:

(i) In the active growth stage of algae, oxygen concentration increases and at the same time carbon dioxide content decreases. This decrease in the carbon dioxide content results in the breaking down of Bicarbonates into carbonates and carbon dioxide.

$$Ca(HCO_3)_2 \rightleftharpoons CaCO_3 + CO_2 + H_2O. \quad - 2.11$$

Thus the temporary hardness is decreased

while the insoluble carbonates precipitate promoting filter clogging. This implies that continuous growth of algae brings about hindering of water movement, as such have to be removed by filter cleaning.

(ii) When the algae are in a steady state, equations 2.9 and 2.10 balance each other and the net results seems to be zero. However, the overall effect is an increase in oxygen content during the day and decrease in oxygen content during the night. This may lead to setting in of anaerobic condition during the night which may results in producing effluent rich in iron and manganese contents and of unpleasant taste and odour.

(iii) Fall in water temperature during autumn (in temprate climates) results in less favourable living conditions for algae, as such they die away. This leads to liberation of organic matter and subsequent oxygen consumption by bio-chemical degradation. Carbondioxide is now produced, the danger of anaerobic conditions increases and there is a drop in water pH.

As a result of massive die-away of algae decay sets in and the filter must be taken out of service to remove the dead organic matter by filter cleaning.

However, as a result of the growth of algae (filamentous specie) a gelatinous mat is formed on the surface of the filter, thereby enhancing straining efficiency and adsorption of bacteria. The formation of this gelatinous mat (Schmutzdecke) (5) results in less suspended matter in the effluent. In the day time bubbles of oxygen produced stick to the surface of the algae, thereby increasing their buoyancy. The Schmutzdecke layer is then lifted and the filter resistance drops with constant filtration rate.

When on the other hand small algae such as diatoms predominate, a separate mat is not formed and the resistance of filter skin is materially increased. Blooms of such algae results in rapid clogging which results in a short filter run.

The formation of schmutzdecke layer results in a favourable environment for protozoa and higher organisms, which feeds on bacteria, thus reducing the number of E.Coli and pathogens in the effluent.

The advantages and disadvantages of Algae in slow sand filtration can only be weighed when the following factors are taken into account:

(i) Composition of the raw Water

(ii) Climate

(iii) Economic and

(iv) Sociological factors.

Algae are only important when they are present in large number, this means that sufficient light and nutrients will be in greater demand. Presence of algae brings with it the danger that frequent filter cleanings must be effected at short intervals, in periods of higher temperature because of algae blooms and in periods of decreasing temperature because of a massive die - away. As a result of these problems maintenance cost increases. Covering the slow filters solves part of these problems (11).

2.3. GRANULAR FILTERING MATERIALS

Filtering materials may be composed of natural silica sand, crushed anthracite, crushed magnetite, and garnet sands, as applied to rapid filters. The natural granular sands and crushed minerals employed normally differ in size and size distribution, shape and shape variation, density and chemical composition. The mean values and variances of these differences provides acceptable parameters for:-

(i) Describing the geometry of the materials

(ii) Rational prediction of their hydraulic behaviour

(iii) Assessing the removal of impurities by filtration.

2.3.1. GRAIN SIZE AND SIZE DISTRIBUTION

Sieving a representative sample of filter grains through a set of calibrated sieves will determine parameters like grain size and size variation. A summation Curve is plotted after the sieve analysis as shown in figure 2.4.

From the summation curve, parameters such as the hazen's effective size E or P10 (10 percentile) and coefficient of uniformity U which is the ratio of the 60 percentile to the 10 percentile (P_{60}/P_{10}) can easily be read.

Hazen (4) chose 10 percentile as the effective size because he had observed that the hydraulic resistance of unstratified sand bed was relatively unaffected by size variation (up to a value of U of about 5.0) as long as the 10 percentile remained unchanged.

2.3.2. GRAIN SHAPE AND SHAPE VARIATION

The size characteristics, surface area A of grains relative to the volume of water in the pore space as a

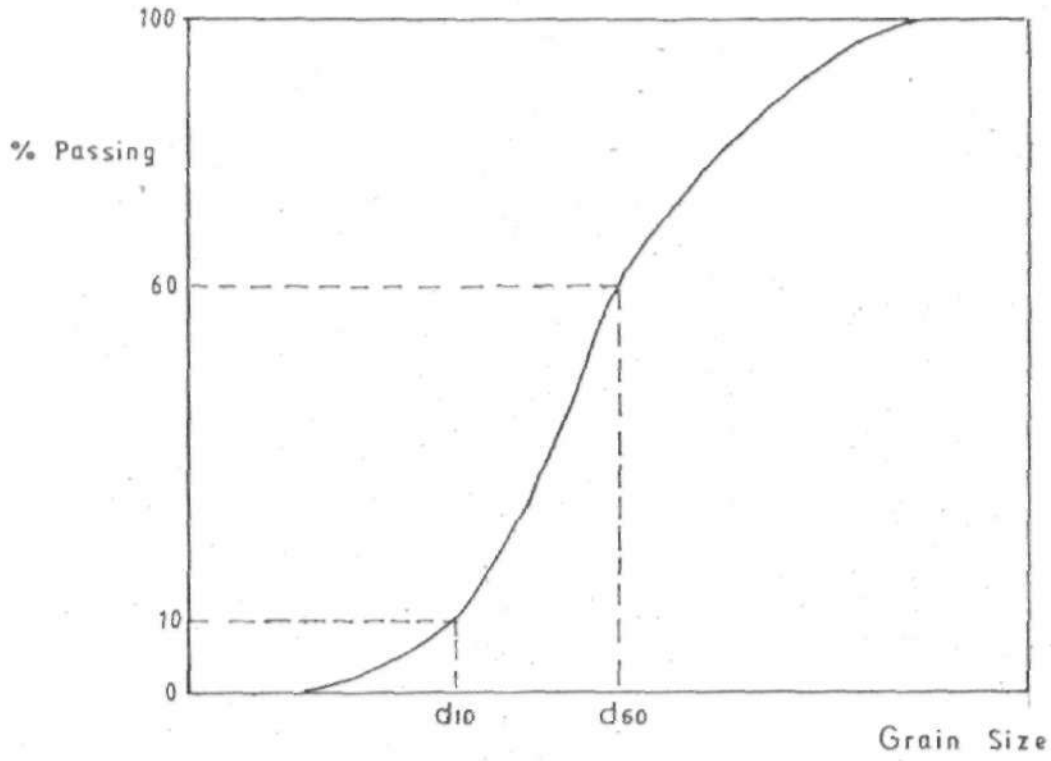


FIG. 2.4 Sieve Analysis

function of A/V (with V representing sand volume) is normally employed in formulations of filter performance and shape identification.

Useful measures of shape are:

(i) The sphericity, Ψ , and

(ii) The shape factor, φ , often defined as the ratio of the surface area of the equivalent - volume sphere to the actual or true surface area. Ψ Assumes values such as those listed in table 2.1. (4). For a spherical grain of diameter d, Ψ = 1 and by definition

$$\frac{A}{V} = \frac{\pi d^2}{\frac{1}{6}\pi d^3} = \frac{6}{d} \qquad - 2.12$$

for true spheres Ψ = 1.0 and the shape factor

$$\varphi = \frac{6.0}{\Psi} = 6.0 \qquad - 2.13$$

TABLE 2.1

Sphericity, shape factors and typical porosities of granular materials.

S/NO	DESCRIPTION	SPHERICITY Ψ	SHAPE FACTOR φ	POROSITY f
1.	Spherical	1.00	6.0	0.38
2.	Rounded	0.98	6.1	0.38
3.	Worn	0.94	6.4	0.39
4.	Sharp	0.81	7.4	0.40
5.	Angular	0.78	7.7	0.43
6.	Crushed	0.70	8.5	0.48

The hydraulic properties of a bed or a layer of granular material depend on the ratio of surface area to volume of void space, A/V'

In a cube of given number of spheres, n, porosity, f, the total volume of spheres is thus given by (4)

$$V = (1-f)\,(\text{volume of given cube}) \qquad - 2.14$$

$$= (1-f)\,\frac{1}{6}\,n\pi\,d^3 \qquad - 2.15$$

Volume of a given cube is thus given by $\frac{V}{1-f}$,

$$\text{Volume of voids} = f(\text{volume of given cube})$$

$$= f\left(\frac{V}{1-f}\right) \qquad - 2.16$$

$$= \left(\frac{f}{1-f}\right)V \qquad - 2.17$$

the surface area, A, of the sand grains with $\Psi = 1.0$ is given by $n\pi d^2$, and their volume, V, by $\frac{1}{6} n \pi d^3$.

substituting V into equation 2.17 gives the volume of void, V', as $\frac{1}{6}\left(\frac{f}{1-f}\right) n\pi d^3$

$$\therefore \quad \frac{A}{V'} = \frac{n\pi d^2}{\frac{1}{6} n\pi d^3 \left(\frac{f}{1-f}\right)} \qquad - 2.18$$

$$= \frac{(1-f)}{f} \quad \frac{6}{d} \qquad - 2.19$$

2.3.3. FILTER SAND PREPARATION

The most important characteristic to be considered in selecting a suitable filter media are the effective size and the uniformity coefficient of the media.

The natural sand may be too coarse, too fine or non - uniform as a media in a filter. However, the desired grade could be obtained through screening in selected set of sieves. The following formulae can be employed (4):

(i) The percentage usable or simply

$$\text{Pusable} = 2(P_{60} - P_{10}) \qquad 2.20$$

(ii) $$P_{too\ fine} = P_{10} - 0.2\ (P_{60} - P_{10}) \qquad - 2.21$$

(iii) $$P_{too\ coarse} = \text{Pusable} + P_{too\ fine} \qquad - 2.22$$

$$= P_{10} + 1.8\ (P_{60} - P_{10}) \qquad - 2.23$$

where P_{10} = 10% of the media passing through selected sieves

P_{60} = 60% passing.

2.4. HYDRAULICS OF FILTRATION

Flows in filters has been shown to follow Darcy's law, which is given as:

$$V = K \frac{H}{L} \qquad - 2.24$$

Where V = Velocity of the water above sand bed (m/hr)

K = Coefficient of permeability (m/hr)

L = Filter bed thickness (m)

H = Initial head loss (m)

The components of K as identified according to Darcy's law are the density ρ, and viscosity, μ, of the water, the porosity, f, of the bed and the size and shape of the sand grains, the grains surface area A and their volume within the bed.

The resistance of a clean bed of sand to filtration of clean water is given by the Blake - Kozeny Equation (4).

$$\frac{h}{L} = \left(\frac{k}{g}\right) \left(\frac{\mu}{\rho}\right) v \frac{(1-f)^2}{f^3} (A/V)^2 \qquad - 2.25$$

Where k is dimensionless coefficient with magnitude close to 5.0 under all condition of water filtration and h is the depth below filter bed surface.

In the filtration process, impurities from the raw water are deposited on top and in the first centimeter depth of the filter bed, producing a filter skin and reducing the pore space available for the flow of water. As a result of which the filter clogs and negative pressures may set in. When negative pressures are created, dissolved gases will be released and subsequently accumulates within the pore openings and the filtration rate decreases. Accumulated gas bubbles are then forced upwards through the filter skin, due to insufficient time to dissolve thereby creating openings. The result is imperfect treatment. Thus negative pressures in slow sand filtration should always be avoided.

2.5. EFFECTS OF FILTRATION ON QUALITY OF INFLUENT WATER

The quality of effluent as well as filter run length in slow sand filtration depends on four factors:

(i) Raw Water quality
(ii) Temperature
(iii) Filtration rate applied
(iv) Composition of the filter bed.

In a particular season, raw water quality and temperature are constant, thus only filtration rate and filtering material are chosen at will. In general the effluent quality is better when the filter is built of finer grained materials (11).

Filtration rate has a small influence on the effluent quality (5). The reasons advanced are as follows:

(i) Mechanical straining is independant of filtration rate.

(ii) Increase in filtration rate will only have little influence on the turbidity of the effluent.

(iii) Adsorption phenomena is a matter of electrical forces.

However, biological activity, because of its dependance on time, is, slightly affected more especially in open filter with abundant algae growth as earlier discussed in section 2.3. As a result of algae metabolism, decrease in filtration rate will result in discharge of by-products in high concentration resulting in bad taste and odour of the effluent. Effluent quality has been shown to be independent of filtration rate in covered filters (10).

2.6. DESIGN OF SLOW SAND FILTERS

In designing slow sand filter from the foregoing discussions the following are clear.

2.6.1. GRAIN SIZE DISTRIBUTION

This should be chosen well within the theoritical values, of 0.15-0.35mm effective size and 2.0 - 3.0 uniformity coefficient, so as to satisfy the effluent quality requirements (4,5).

2.6.2. FILTRATION RATE

The filtration rate, should as much as possible be between 0.1 and 0.3 m/hr, this is to allow a minimum filter run of two weeks under the most unfavourable conditions (10).

2.6.3. THICKNESS OF THE FILTER BED

The thickness of the filter bed normally employed is between 0.8 and 1.0 meter, However, when an additional margin of safety is required, the thickness of the filter bed can be increased to 1.5m (5).

2.6.4. PRE - TREATMENT

This is incorporated when the water to be filtered exceeds turbidity of 50 units (J.T.U) which can

result in short filter runs (12).

It is also incorporated if the filtration rate of 0.1 m/hr is increased by about 20% and 0.2 m/hr by about 60% (5). It is advisable to pretreat when the raw water quality drops for very short periods. Pre-treatment is a necessity when the oxygen demand of the raw water is so high, in order to disallow anaerobic conditions in the effluent.

Examples of pre-treatment units are:-

(i) Rapid filtration
(ii) Chemical co-agulation
(iii) Plain sedimentation
(iv) Micro-strainers
(v) Storage and
(vi) Chemical oxidation.

Of these rapid filtration is the most popular one being practiced in developing countries (9) although other systems may prove more effective or more economical.

2.6.5. POST - TREATMENT

This is incoporated in order to sterilise the finally filtered water. Post - chlorination is always preferred in order to ensure the safety of the drinking water (10, 11, 12, 13).

CHAPTER III

EXPERIMENTAL INVESTIGATIONS

3.1. MATERIAL

The pilot filter used was set up at the New water Works, Zaria, in Kaduna State. The site was selected because of its ease of access, availability of raw water and laboratory facilities.

The filter box used was rectangular in shape of dimensions 1.1m x 1.0m x 1.6m. It was made of galvanised iron sheets and was properly painted in and out in order to prevent rust. The filter box was fitted with an inlet, outlet and an overflow control devices. A gullet was also provided to ensure that the influent does not fall directly on the sand bed and to prevent scouring of the bed surface The effluent outlet was raised to a height above the development of a negative pressure. The filter was set up as shown in figure 3.1.

The sand media used was obtained from the River Galma in Zaria. A set of B S Sieves Nos 14, 25, 36, 72, 100 and 200 were used in order to obtain the required sizes. The raw water was obtained from the Zaria Dam.

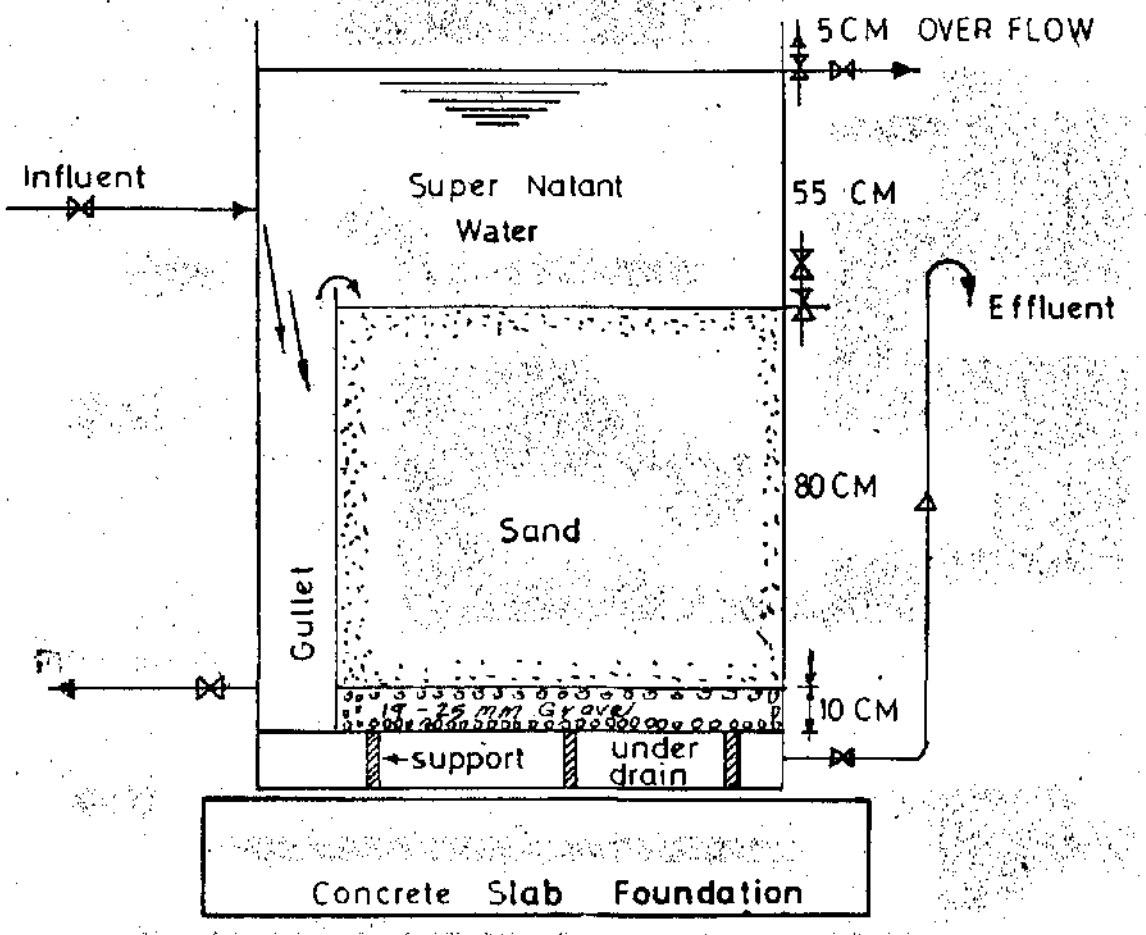


FIG 3·1 FILTER SET UP

3.2. METHOD

Two sets of filter media were used. Investigation was first carried out using a medium obtained as a result of mechanical sieving using BS set of sieves Nos. 25, 36, 72, 100 and 200. The size of this media ranges between 0.15mm and 0.60mm and the effective size is 0.22mm with uniformity coefficient of 1.93. These compare favourably with the values cited in literature. This media was later replaced with another obtained by using BS sieve No. 14 to separate bigger particles. The sand was washed prior to putting it into operation in order to remove the silty material. At the end of the filtration a representative sample was taken and sieved mechanically in order to determine the effective size of this medium and its uniformity coefficient. BS sieve Nos. 25, 36, 72, 100 and 200 were used. The effective size obtained is 0.16mm and the uniformity coefficient 3.6.

Two filter runs were investigated. The runs were started by filling the gullet provided, the water then overflowed to the filter bed via a weir. The reason for this was to prevent the scouring of the bed surface. Raw water from the Zaria Dam through a 60cm diameter A.C. pipe was intercepted before reaching the mixing chamber where chemicals are added and directed to the pilot filter as shown in figure 3.2.

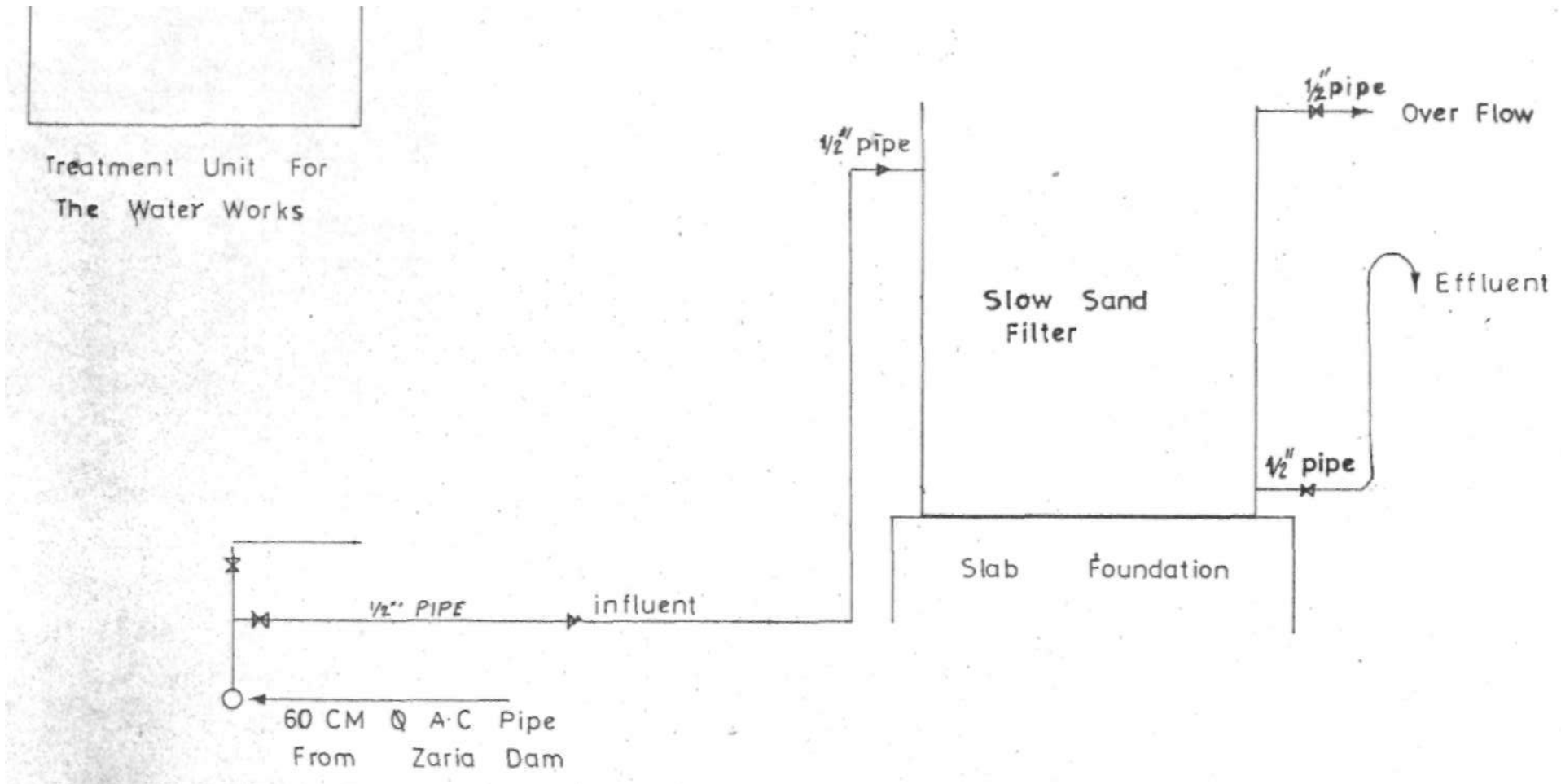


FIG 3·2 Schematic diagram showing Raw water interception to the Slow sand Filter

The flow rate was initially maintained at 0.15m/hr. When the sand surface was completely covered with water and the overflow level was reached the rate of flow into the filter was reduced to avoid waste through the overflow. The filtration rates were measured at intervals throughout the filter runs. The first run was stopped at the end of 36 days when the filtration rate was falling below the minimum of 0,1 m/hr. The second filter was stopped temporarily on the 9th day of operation when a high coliform count was observed in the filtrate. The top layer was then scrapped off and the operation was continued for another 6 days.

The performance of the filter media was determined by the analysis of the raw and the filtered water for the pH, turbidity and the coliform counts. The pH was measured by using comparator method with Bromothymol Blue as an indicator. This was in accordance with the "standard method" (8). The comparator method of pH determination was chosen because of its simplicity. The turbidity measurement was carried out by using a turbidimeter model DRT 100. The coliform counts were carried out in accordance with the "standard method" (8) at an incubation period of 48 hours at $37^{o}C$.

CHAPTER IV

RESULTS AND DISCUSSION OF RESULTS

4.1. FILTER MEDIA

The results of the sieve analysis are shown in tables 4.1 and 4.2. and particle Distribution Curves are shown in figures 4.1. and 4.2. From these results the effective sizes for the two media were calculated as 0.22mm and 0.16mm respectively. The effective sizes used are in comformity with the suggested values of 0.15 - 0.35mm (5). The Uniformity Coefficient for the first filter media which is 1.93, compares with the suggested values of 2-3 (4,10, 11) while it is slightly higher for the second filter media. The very low effective size of the second filter media and the high coefficient of uniformity must have contributed to the turning out of poor quality filtration, in terms of the investigated parameters (5).

4.2. TREATMENT PARAMETERS

4.2.1. pH

Table 4.3 shows the pH of both the raw and the filtered water. It is observed that there is no significant changes in the pH values. This result is expected as there was no chemical used as pre-treatment which may influence the pH changes.

TABLE 4.1

SIEVE ANALYSIS OF THE SAND
USED FOR FILTER RUN ONE

BS SIEVE NO	APERTURE (mm)	PERCENTAGE RETAINED	CUMULATIVE % RETAINED	PERCENTAGE PASSING
25	0.600	10.15	10.15	89.85
36	0.425	24.10	34.25	65.75
52	0.300	40.40	74.65	25.35
72	0.212	19.30	93.95	6.05
100	0.125	4.65	98.60	1.40
200	0.075	0.35	98.95	1.05
PAN	-	1.05	100.00	0.00

From figure 4.1.

P_{10} = 0.22 = E.S.

P_{60} = 0.42

$U.C = \frac{0.425}{0.22}$

= 1.93

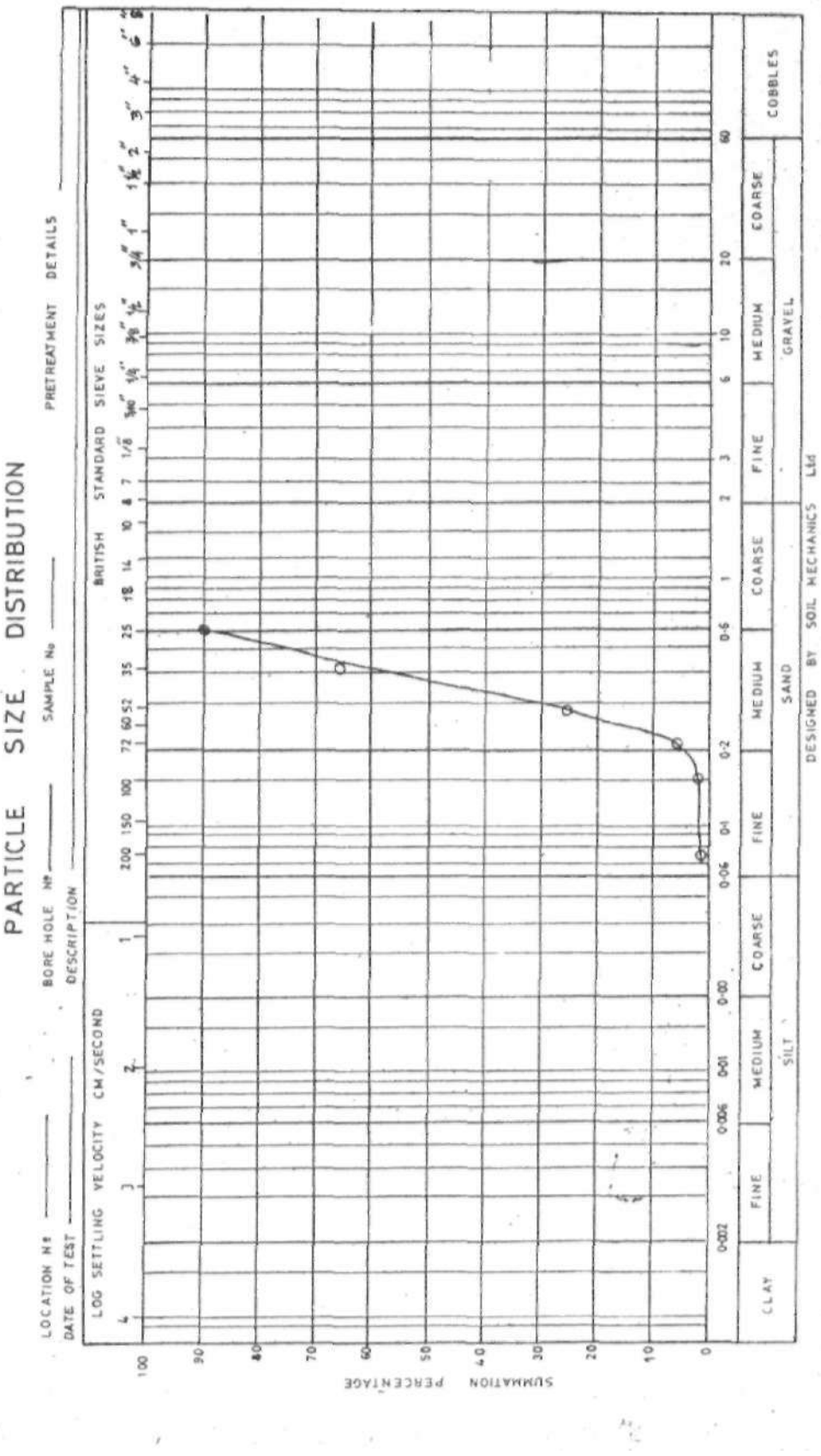

PARTICLE SIZE DISTRIBUTION
LOCATION No
DATE OF TEST
BORE HOLE No
DESCRIPTION
SAMPLE No
PRETREATMENT
DETAILS
LOG SETTLING VELOCITY CM/SECOND
BRITISH STANDARD SIEVE SIZES
SUMMATION PERCENTAGE
CLAY
SILT
SAND
GRAVEL
COBBLES
FINE
MEDIUM
COARSE
DESIGNED BY SOIL MECHANICS Ltd

Fig. 4.1.

TABLE 4.2.

SIEVE ANALYSIS OF THE SAND

USED FOR FILTER RUN TWO

BS SIEVE NO	APERTURE (MM)	PERCENTAGE RETAINED	CUMULATIVE % RETAINED	PERCENT-AGE PASSING
25	0.600	39.50	39.50	60.50
36	0.435	18.22	57.72	42.28
52	0.300	16.49	74.21	25.79
72	0.212	11.15	85.36	14.64
100	0.125	5.09	90.45	9.55
200	0.075	1.14	91.59	8.41
PAN	-	8.41	100.00	0

From figure 4.2.

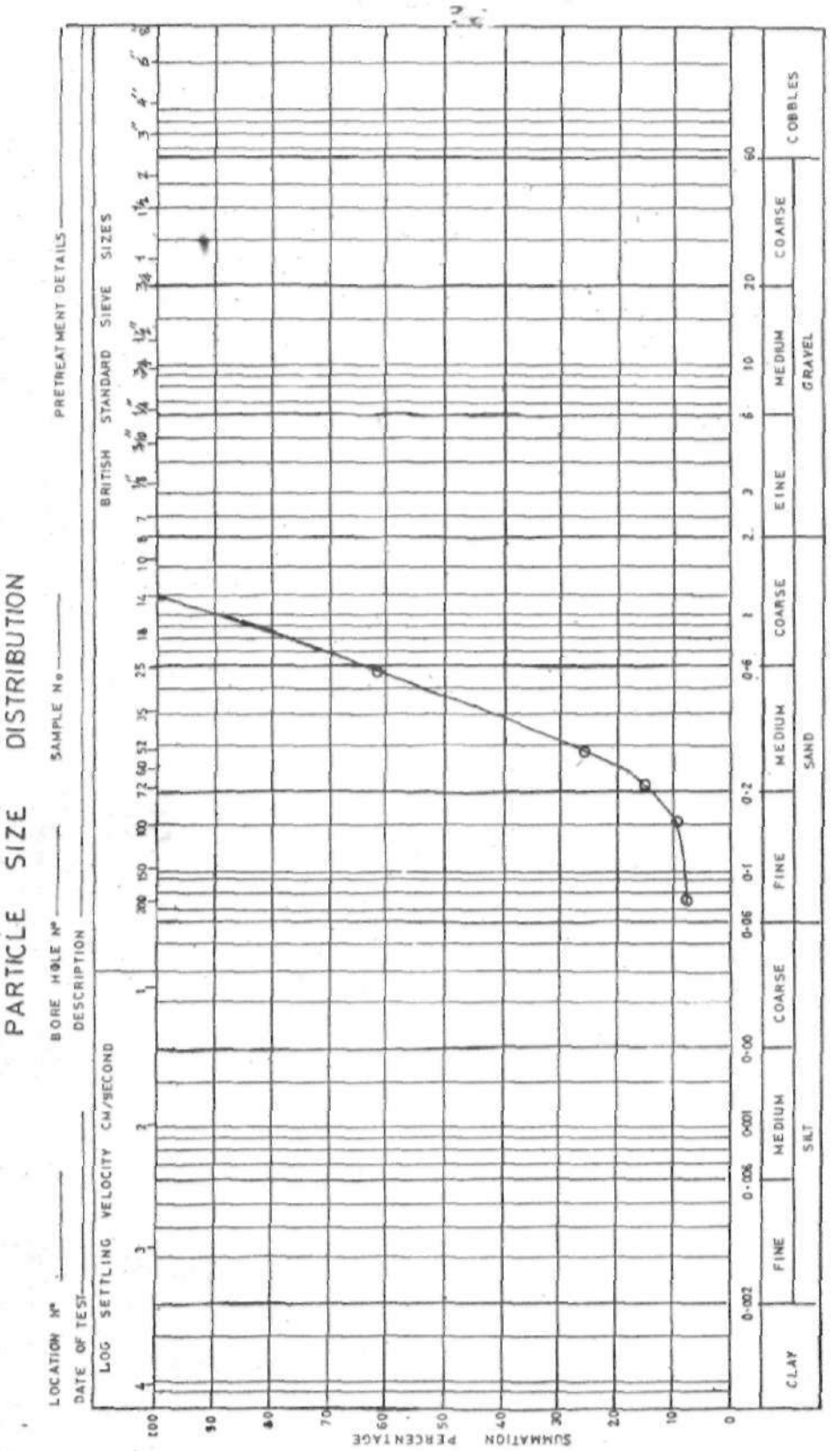
P_{10} = E.S. = 0.16mm

P_{60} = 0.58mm

$$U.C. = \frac{P_{60}}{P_{10}}$$

$$= \frac{0.58}{0.16}$$

$$= 3.6$$


PARTICLE SIZE DISTRIBUTION
LOCATION N°
DATE OF TEST
SAMPLE N°
BORE HOLE N°
DESCRIPTION
PRETREATMENT DETAILS
BRITISH STANDARD SIEVE SIZES
LOG SETTLING VELOCITY CM/SECOND
PERCENTAGE SUMMATION
COBBLES
GRAVEL
COARSE
MEDIUM
FINE
SAND
SILT
CLAY

Also the Alkalinity of the raw water was rather low (table 4.4.). Though the filtered water is slightly acidic, it is still within the WHO-maximum permissible limit (8).

4.2.2. TURBIDITY

Table 4.5. shows the result of turbidity measurements. Results indicate that the turbidity of the filtered water was higher than that of the raw water during the 1st week, when the first filter was in operation. This is attributed to the silty material in the media which was not washed off prior to putting it into service. This media was not washed as it was assumed that all the silt accompanying the original smaple has been removed as a result of the mechanical sieving. However, the filter performance there after improved considerably. At the end of the filter run the turbidity of the raw water was reduced to about 50%.

In the case of filter No. 2, even when the media was washed before it was put into operation, the turbidity removal was not appreciable. This was probably due to the nature of the media employed (about 60% is greater than 0.40mm in size and this is outside the range of recommended media size) as straining and sedimentation efficiencies of suspended particles are inversely proportional to the media

size (5). However, for the two media the effluent turbidity are found to be below the maximum allowable (50 J.T.U.) (8).

TABLE 4.3.

PH MEASUREMENT

FILTER RUN 1			FILTER RUN 2		
DATE	pH		DATE	pH	
	R.W.	F.W.		R.W.	F. W.
28/03/84	6.4	6.4	10/07/84	6.6	6.4
29/03/84	6.4	6.2	11/07/84	6.6	6.4
30/03/84	6.4	6 2	12/07/84	6.4	6.4
04/04/84	6.6	6.4	14/07/84	6.4	6.4
09/04/84	6.4	6.4	17/07/84	6.4	6.2
10/04/84	6.4	6.4	18/07/84	6.6	6.4
13/04/84	6.4	6.4	20/07/84	6.4	6.4
16/04/84	6.4	6.4	23/07/84	6.6	6.4
17/04/84	6.2	6.2	24/07/84	6.6	6.4
24/04/84	6.4	6.4			
25/04/84	6.4	6.4			
26/04/84	6.2	6.2			
02/05/84	6.2	6.2			

LEGEND:

R.W. = Raw Water

F.W. = Filtered water

TABLE 4.4.

PHYSICAL AND CHEMICAL ANALYSIS

OF ZARIA DAM RAW WATER

S/NO	DATE OF SMAPLING	HCO^-_3 ALKALINITY mg/l	CO^-_3 ALKALINITY mg/l	TOTAL HARDNESS mg/l as $CaCO_3$	Fe mg/l
1.	5/11/81	38.0	NIL	33.00	1.42
2.	3/12/82	38.0	NIL	24.00	0.32
3.	9/6/83	55.0	NIL	41.00	1.62
4.	4/8/83	45.0	NIL	21.0	4.48
5.	29/9/83	54.0	NIL	40.00	3.28
6.	11/1/84	43.0	NIL	30.00	1.12
7.	30/3/84	47.0	NIL	26.00	1.94
8.	3/01/84	26.0	NIL	19.00	0.90
9.	29/8/84	26.0	NIL	16.00	1.97

STANDARD

Hardness:- 100 mg/l as ($CaCO_3$) - Desirable

500 mg/l as ($CaCO_3$) - Max permissible

Iron, Fe: 50 mg/l Max allowable (Raw Water)

: 1.0 mg/l Max allowable (treated water)

TABLE 4.5

TURBIDITY MEASUREMENT

FILTER RUN NO. 1				FILTER RUN NO. 2			
DATE	FILTRATION RATE m/hr	TURBIDITY J.T.U R.W	F.W	DATE	FILTRATION RATE m/hr	TURBIDITY J.T.U. R.W	F.W
28/03/84	0.15	18	50	10/07/84	0.15	16	13
03/04/84	0.17	14	36	13/07/84	0.15	19	23
09/04/84	0.18	7.0	8.5	16/07/84	0.12	26	20
16/04/84	0.16	8.8	6.0	17/07/84	0.12	20	23
24/04/84	0.10	70	18	18/07/84	0.13	25	19
26/04/84	0.10	60	16	20/07/84	0.12	42	34
02/05/84	0.089	30	14	24/07/84	0.095	40	36

4.2.3. COLIFORM COUNT

The results of the coliform counts for both the raw and filtered water are shown in Table 4.6. During the period of study the coliform count of the raw water ranged from 28 - 1,100 MPN/100 ml in the case of filter No. 1 and 43 -93 MPN/100 ml for filter No. 2. The coliform counts for the filtered water ranged from 9 - 150 MPN/100 ml and 9 - 240 MPN/100 ml for filters No. 1 and 2 respectively.

4.2.3a. FILTER NO. 1

For filter No 1 the quality of the filtrate at the initial stage was very poor. This could be attributed to the non pre-treatment of the media before use (10, 11, 12, 13). However, an improvement was noticed after the second week of operation. This is expected because at the attainment of the repening period filtrate quality improves due to greater adsorption activity taking place at that period (5). The need to take the filter out of service clearly became evident after the fourth week of operation. During this period, there was an abundant algal growth which must have contributed to the leterioration of the effluent quality. Judging from the 95% confidence limit (8) it is quite clear that disinfection of the filter water is necessary in order to ensure the safety of the water,

TABLE 4.6

COLIFORM COUNTS

FILTER NO. 1								FILTER NO. 2							
DATE	RATE m/hr	COLIFORM COUNT (MPN/100ML)		95% CONFIDENCE LIMITS R.W.		F.W.		DATE	RATE m/hr	COLIFORM COUNT (MPN/100ML)		95% CONFIDENCE LIMITS R.W.		F.W.	
		R.W	F.W	LOWER	UPPER	LOWER	UPPER			R.W.	F.W	LOWER	UPPER	LOWER	UPPER
28/03/84	0.15	43	150	7	210	30	440	10/07/84	0.15	75	43	15	230	7	210
09/04/84	0.18	28	43	10	150	7	150	13/07/84	0.15	64	28	150	380	10	150
16/04/84	0.16	43	9	7	210	1	36	16/07/84	0.12	43	9	7	210	1	36
24/04/84	0.10	460	39	71	2,400	7	130	18/07/84	0.13	93	240	15	380	36	1,300
26/04/84	0.10	1,100	150	150	4,800	30	440	24/07/84	0.095	75	28	14	230	15	380
2/05/84	0.089	240	120	36	1,300	30	380								

4.2.3b. FILTER NO. 2

For this filter the quality of the filtrate was found to improve from the beginning of the operation. This could be attributed to the fact that the media was washed before it was put into operation. However, after nine days of operation the filtrate quality deteriorated. This may be due to the presence of dead insects on the filter bed, as the filter was not provided with a cover. When the filter bed was cleaned the quality of the filtrate improved considerably. However, it is desirable to disinfect the filtered water as a measure of safety.

4.2. FILTRATION RATE

As the unit was not attached with a head loss measuring device the flow rate development was measured on daily basis.

4.3.1. FILTER RUN 1

At the beginning of the filtration a constant flow rate of 0.15m/hr was maintained after about one week of operation the flow rate value increased to 0.19m/hr and after about five weeks the value came down to 0.089 m/hr (Table 4.7).

TABLE 4.7

FILTRATION RATE ON DAILY

BASIS FOR FILTER RUN NO.1

DATE	TIME IN DAYS	FILTRATION RATE m/hr
28/03/84	1	0.15
29/03/84	2	0.15
30/03/84	3	0.17
03/04/84	7	0.17
04/04/84	8	0.19
05/04/84	9	0.18
09/04/84	13	0.18
10/04/84	14	0.17
13/04/84	17	0.18
16/04/84	20	0.16
17/04/84	21	0.14
24/04/84	28	0.10
25/04/84	29	0.10
26/04/84	30	0.10
2/05/84	36	0.089

Three factors may be attributed to this observations:

(i) Silt blocked the path of flow at the initial stage of filtration if the media employed was not pre-treated (9, 11). The high turbidity value recorded for the effluent at the initial stage of operation clearly explains this.

(ii) The clearing of the flow path result in an increase of flow as most of the blocked pores are opened as the filtration continues.

(iii) As a result of deposition of suspended particles on the filter bed as the filtration continues couple with sharp increase in raw water turbidity, reduction of the flow rate was to be expected at later stages. The high turbidity value recorded in the influent may be due to the first heavy rain recorded in the year (see app.1). As a result of which silt at the river bank may be transported into the reservoir along with the river flow. High velocity of the river also helps to create turbulancy within the reservoir thereby making the already

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settled silt to go in suspension. The result is sharp increase in the water turbidity.

4.3.2. FILTER RUN 2

Judging from past experience the media employed for this was first subjected to an upward flow version using clear water. The flow was later reversed. A lot of silt was removed as a result of this action. This must have contributed to the non blockage of the pores. As a result of this variation in the flow rate did not show any discrepancy (Table 4.8).

TABLE 4.8

FILTRATION RATE ON DAILY BASIS FOR FILTER RUN NO.2

DATE	FILTRATION RATE m/hr
10/07/84	0.15
11/07/84	0.15
12/07/84	0.15
13/07/84	0.15
14/07/84	0.15
16/07/84	0.12
17/07/84	0.12
18/07/84	0.13
20/07/84	0.12
23/07/84	0.10
24/07/84	0.095

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSION

Results of the foregoing research have indicated that slow sand filtration, as a means for water treatment, can at least be set up for the small communities living around the Zaria Dam reservoir. However, in setting up such facility the usual media size (effective size 0.15 - 0.35mm, Uniformity coefficient between 2 and 3) should always be used for slow sand filters. This is because the carefully graded media performed better in terms of turbidity and coliform removal. Disinfection of the finally filtered water should also be employed, as a measure of safety, judging from the coliform count result obtained.

5.2. RECOMMENDATION

Now that a pilot filter has been set up at the Zaria New Water Works further research should continue in order to arrive at more conclusions. Since it has been recommended that local sands can be used as a medium in Water treatment (1) future work should be undertaken to identify which of those recommended local sands should best be used for slow sand filtration.

The Kaduna State Water Board, should as a matter of urgency set up pilot filters for slow sand filtration in all its Water Works so as to counter water shortage as a result of non-treatment Chemicals and Electricity failures.

Finally the department of Water Resources and Environmental Engineering Ahmadu Bello University Zaria should make use of the pilot filter set up in the Zaria New Water Works for further investigation in the following areas:-

(i) Incorporation of a pre-treatment unit to determine how the quality of the effluent will improve as a result of the pretreatment unit.

(ii) The performance of the filter under different filtration rates.

(iii) The filter performance under intermittant operation.

(iv) Covering of the filter may prevent insects falling in the filter. However, the effect of cover on the performance of the filter should be investigated.

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APPENDIX

APPENDIX 1

RAIN FALL DATA (13)

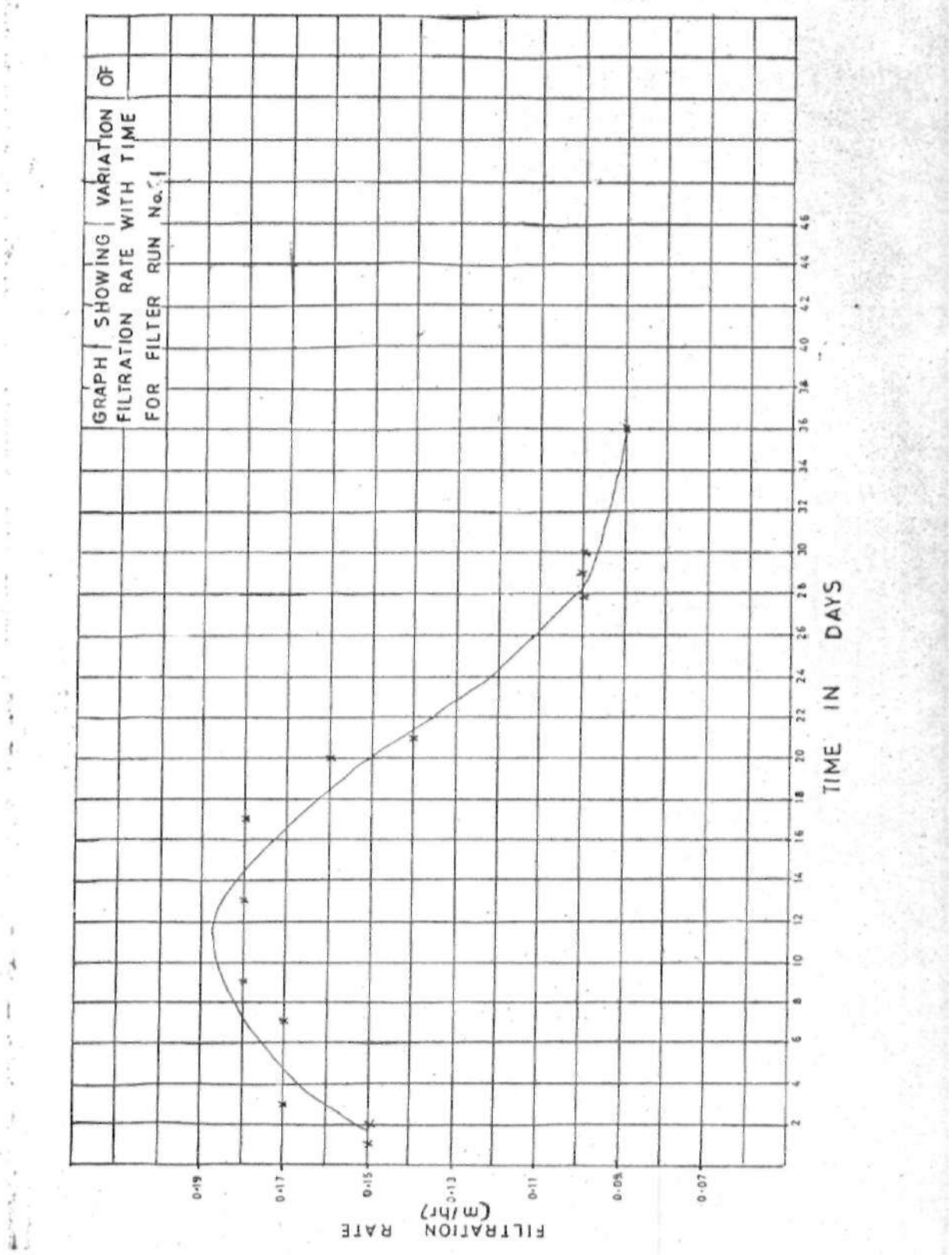
DATE	RAINFALL mm
10/03/84	8.0
22/04/84	4.2
24/04/84	12.5
25/04/84	1.0
29/04/84	8.9
1/05/84	2.9
6/05/84	72.5
9/05/84	9.6
2/05/84	14.9
25/05/84	11.7
26/05/84	7.5
27/05/84	16.5
29/05/84	12.4
2/06/84	14.5
6/06/84	10.5
13/06/84	12.4

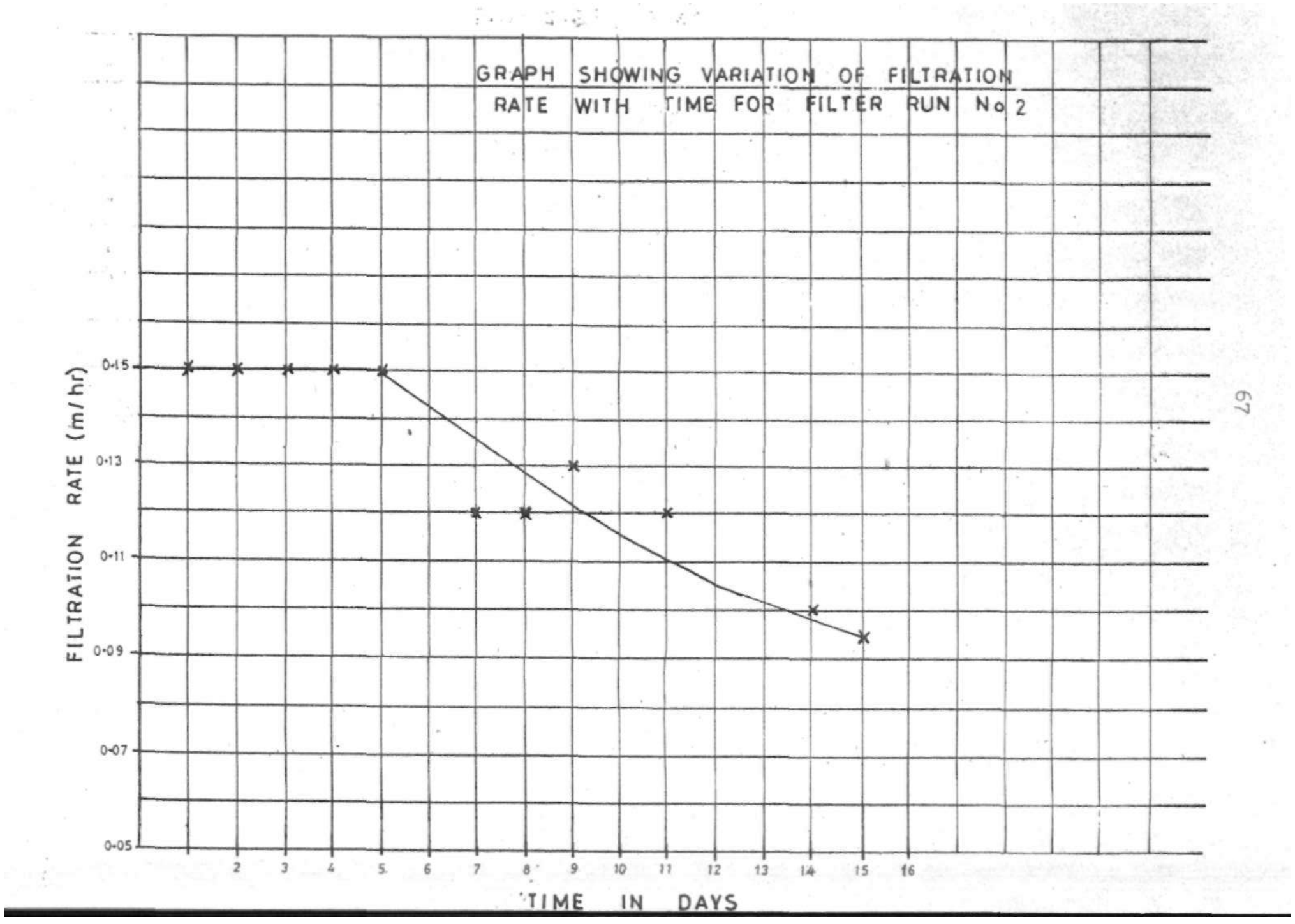
APPENDIX 1 (Cont'd)

DATE	RAIN IN MM
14/06/84	32.4
20/06/84	2.5
23/06/84	16.0
24/06/84	5.7
2/07/84	17.0
5/07/84	10.0
6/07/84	13.9
7/07/84	5.4
12/07/84	12.1
13/07/84	2.3
14/07/84	3.7
15/07/84	11.5
20/07/84	11.0
21/07/84	7.5
23/07/84	15.1
24/07/84	10.2
25/07/84	9.8
26/07/84	5.2
26/07/84	1.4
29/07/84	18.5

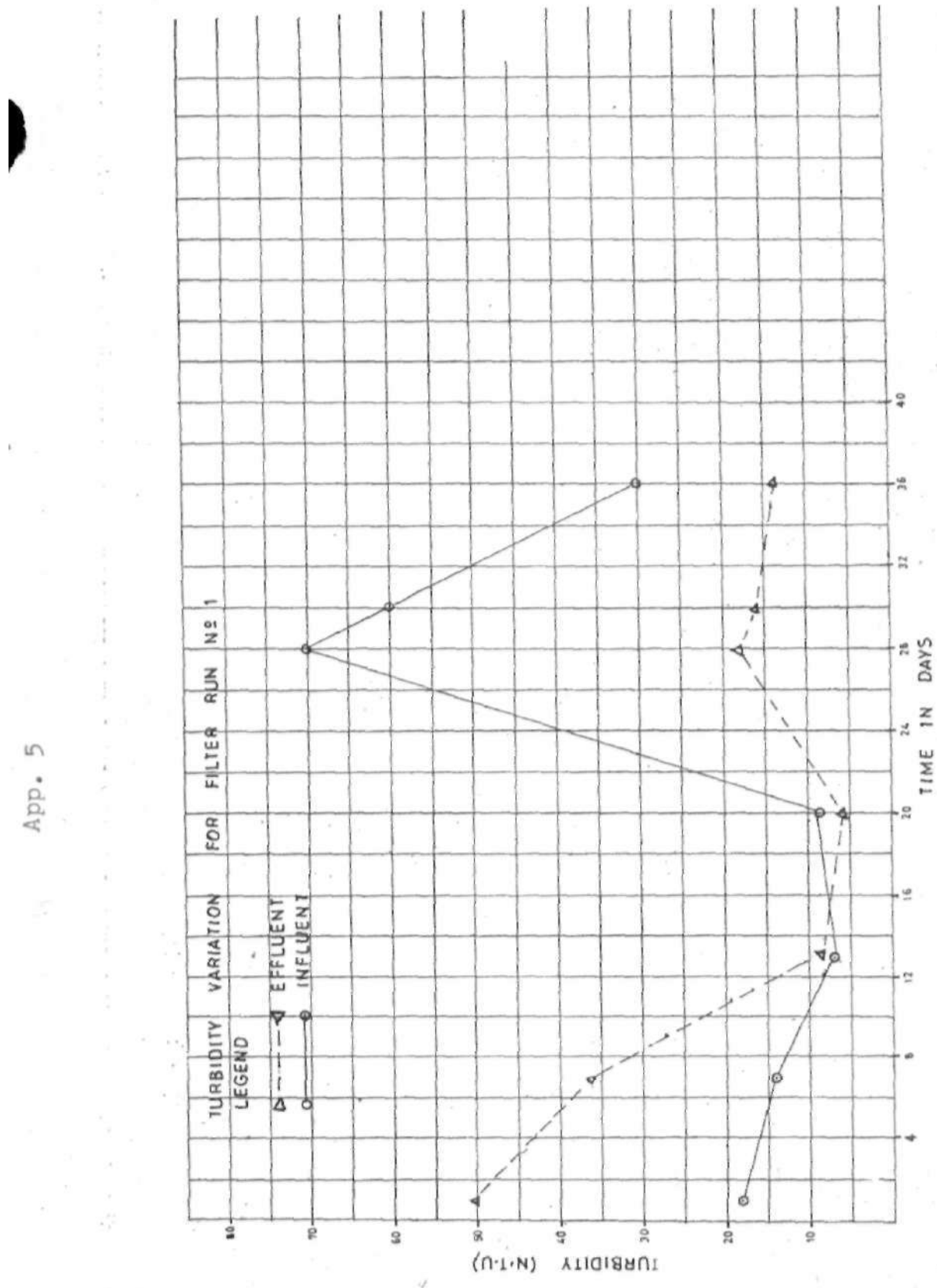
NUMBER OF TUBES GIVING POSITIVE REACTION OUT OF			MPN INDEX	95% CONFIDENCE LIMITS	
3 of 10ml Each	3 of 1ml Each	3 of 0.1ml Each	PER 100ml	LOWER	UPPER
0	0	1	3	<0.5	9
0	1	0	3	<0.5	13
1	0	0	4	<0.5	20
1	0	1	7	1	21
1	1	0	7	1	23
1	1	1	11	3	36
1	2	0	11	3	36
2	0	0	9	1	36
2	0	1	14	3	37
2	1	0	15	3	44
2	1	1	30	7	89
2	2	0	21	4	47
2	2	1	28	10	150
3	0	0	23	4	120
3	0	1	39	7	130
3	0	2	64	15	380
3	1	0	43	7	210
3	1	1	75	14	230
3	1	2	120	30	380
3	2	0	93	15	380
3	2	1	150	30	440
3	2	2	210	35	470
3	3	0	240	36	1,300
3	3	1	460	71	2,400
3	3	2	1,100	150	4,800

App. 3

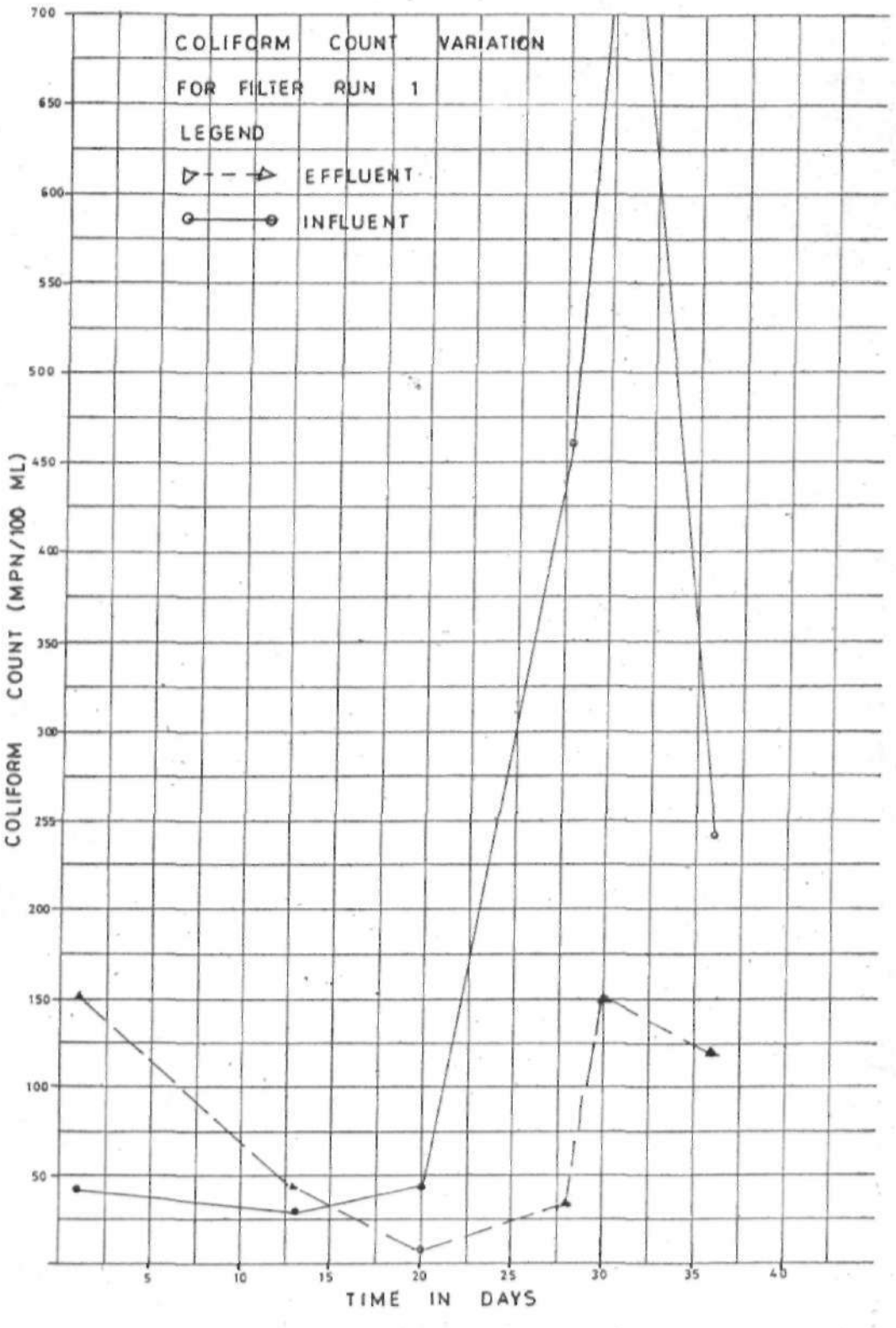

GRAPH SHOWING VARIATION OF FILTRATION RATE WITH TIME FOR FILTER RUN No. 1
FILTRATION RATE (m/hr)
0·19
0·17
0·15
0·13
0·11
0·09
0·07
TIME IN DAYS
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46

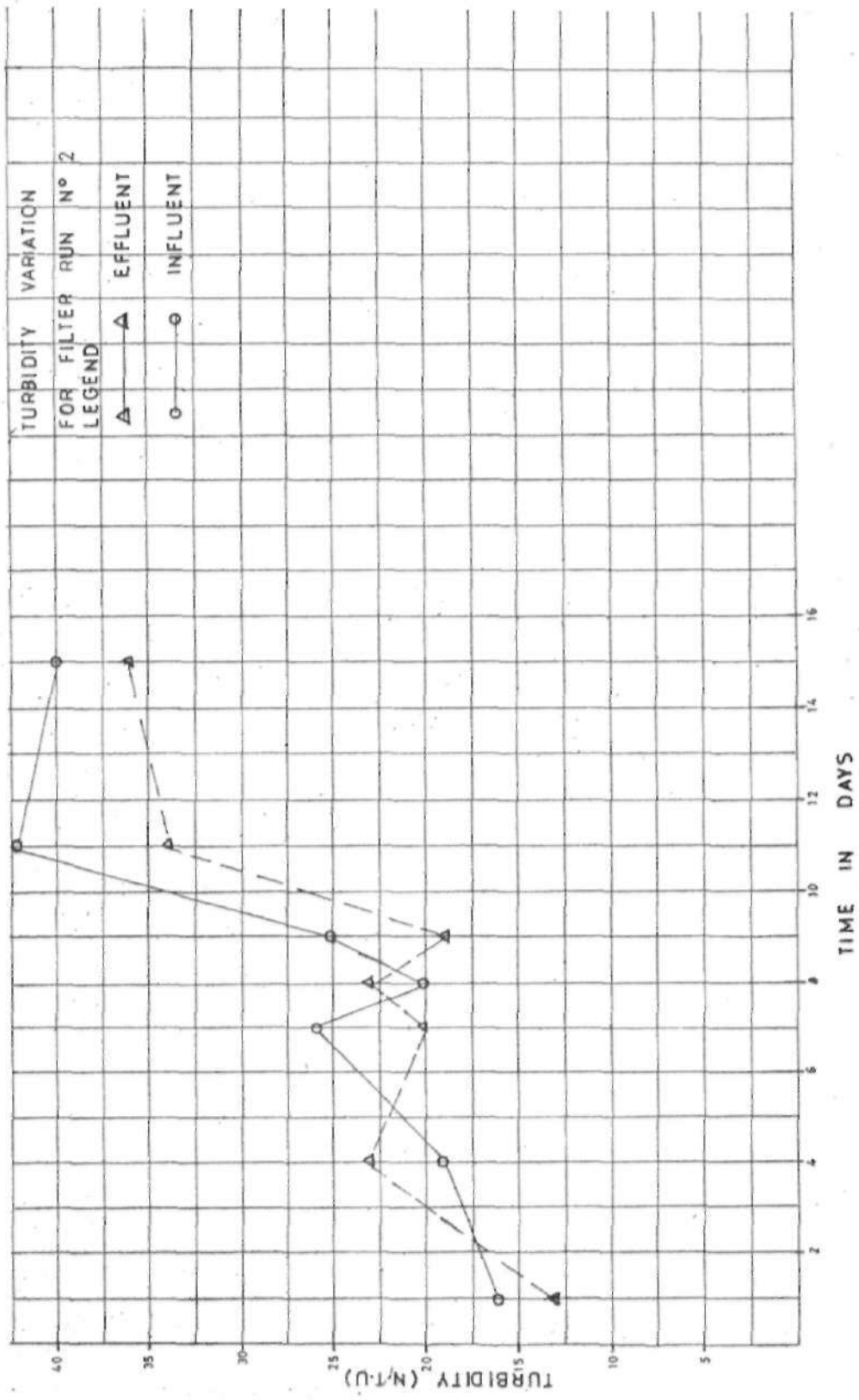

GRAPH SHOWING VARIATION OF FILTRATION RATE WITH TIME FOR FILTER RUN No 2
FILTRATION RATE (m/hr)
0·15
0·13
0·11
0·09
0·07
0·05
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
TIME IN DAYS

App. 5

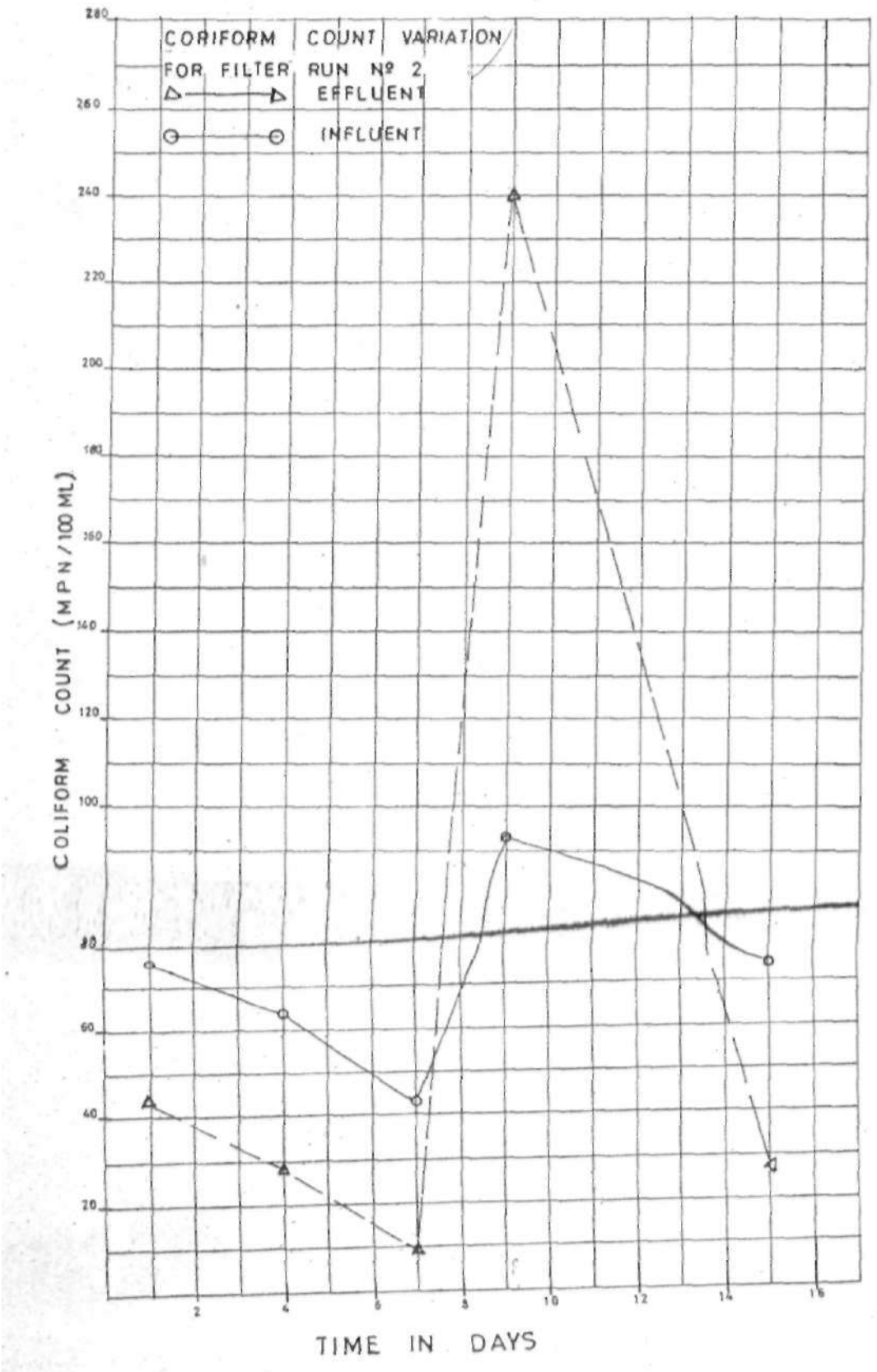

TURBIDITY VARIATION FOR FILTER RUN Nº 1
LEGEND
EFFLUENT
INFLUENT
TURBIDITY (N.T.U)
TIME IN DAYS

App. 6


COLIFORM COUNT VARIATION
FOR FILTER RUN 1
LEGEND
EFFLUENT
INFLUENT
COLIFORM COUNT (MPN/100 ML)
700
650
600
550
500
450
400
350
300
255
200
150
100
50
5
10
15
20
25
30
35
40
TIME IN DAYS


TURBIDITY VARIATION
FOR FILTER RUN N° 2
LEGEND
EFFLUENT
INFLUENT
TURBIDITY (N/T.U)
TIME IN DAYS

App. 8


CORIFORM COUNT VARIATION
FOR FILTER RUN Nº 2
EFFLUENT
INFLUENT
COLIFORM COUNT (M P N / 100 ML)
280
260
240
220
200
180
160
140
120
100
80
60
40
20
2
4
6
8
10
12
14
16
TIME IN DAYS