USE OF LOCAL SAND AS FILTRATION MEDIA FOR RURAL WATER SUPPLY TREATMENT

BY

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CVE/95/7021

A THESIS SUBMITTED TO THE SCHOOL OF POST-GRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF ENGINEERING (M. Eng.) IN CIVIL ENGINEERING (WATER RESOURCES AND ENVIRONMENTAL ENGINEERING)

FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE.

AUGUST 1999.

CERTIFICATION

This is to certify that this is an original and independent research project carried out by Engr. Akinde, A. O. in the Department of Civil Engineering of the Federal University of Technology, Akure, in partial fulfillment of the requirements for the award of Master of Engineering (M.Eng) in Civil Engineering (Water Resources and Environmental Engineering).

....
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Supervisor

DEDICATION

This work is dedicated to my Creator.

ACKNOWLEDGEMENTS

I owe the Almighty God honour and adoration for letting me know this day and the goodness therein.

Many people also have been of great assistance throughout the duration of preparing this thesis. Notable among them are Engr. C.O. Fagoroye from the Ondo State Water Corporation, Mr. G.O. Owoeye from the Chemistry Department, Federal University of Technology, Akure, who helped in the analysis of the water samples. The effect of Engr. B.T. Akindoyin and a host of others from the Ondo State Water and Sanitation (WATSAN) office could not go unnoticed, they assisted in the construction of the model filter.

I am indeed grateful to Dr. A.M. Oguntuase, my supervisor. His demand for thorough jobs has actually enhanced the quality of this thesis.

My appreciation also goes to all the staff of the Civil Engineering Department who made the tenure of my study memorable. Particularly, I appreciate the assistance received from Mr. A.C. Osewa, Mr. J.O. Babatola and Engr. O.A. Owolabi. The contributions of my brother Adelanke and my wife, both financially and morally, are also appreciated.

I acknowledge the contribution and assistance of all my colleagues throughout the experimentation process; their suggestions were very useful.

Finally, I hereby express my heart-felt gratitude to those who in one way or another have contributed to the success of this programme but whose names have not been specifically mentioned. May the Lord of host continue to bless you. Thank you all.

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SYMBOLS AND ABBREVIATIONS

Bs	British Standard
C	Concentration of Suspended Solids in the filtrate
C_0	Solids Concentration at the Inlet Surface
Cu	Coefficient of Uniformity
e, f, η	Porosity
FUTA	Federal University of Technology, Akure
Gs, Sg	Specific Gravity of Sample
g	Gravity Acceleration (m/s^2)
H_L,h	Headloss through a filter (m)
Hcl	Hydrochloric Acid
IRC	International Reference Centre
K	Coeficient of permeability or the hydraulic conductivity
L	Depth from Inlet Surface (m)
Q	flowrate (m^3/s)
R	Reynolds Number
t	Time (s)
V	Volume (m^3)
v	Approach Velocity (m/s)
V_s	Solid Volume (m^3)
V_t	Total Volume (m^3)
V_v	Void Volume (m^3)
WATSAN	Water and Sanitation
Who	World Health Organisation
z	Intrinsic Permeability of Media
ℓ	Mass Density (g/m^3)
Ψ	Particles Shape Factor or Sphericity
μ	Absolute Viscosity (poise)
λ	Constant Characteristic of Bed

ABSTRACT

Over the years, Silica sand has been used as a filter media in both developed and developing countries. However, not until recently when research works showed that locally available sands in Nigeria were useful filter media in rapid sand filters, sand stocks used in filters were imported alongside with the treatment plants.

The essence of this thesis is to revisit earlier work done on local sands and consider its application in slow sand filters. In the light of this, locally available sands were collected from three sources viz: Igbokoda, a location in Ilaje Local Government Area of Ondo State with abundant 'white' coastal sand used for glass sheet manufacturing; River Ala in Akure South Local Government Area and Ayede-Ogbese, a location in Akure North Local Government Area with a typical sand quarry used in local construction works.

The sands collected were analyzed to determine their desirable properties as required in slow sand filters. A model slow sand filter box was constructed in which the analyzed sands were used as media to treat raw water of varying degrees of impurities. The resultant effluent qualities were analyzed to determine the filteration effectiveness achieved, using the sandstokes.

The results show that the three sandstocks studied had negligible solubility in 40% Hcl, indicating that the material is a whole grain, free of fossile. The sands have a specific gravity range of 2.65 to 2.67, indicating that the sandstocks are good silica sands.

Within the specified range of particle sizes for slow sand filters, the Igbokoda sand produced the highest yield of usable sand and a better effluent quality in terms of turbidity removal. However, the Igbokoda sand-bed clogged more rapidly as a result of having higher percentage of fine grains. In order to avoid a need for frequently cleaning of this stock, the percentage fine should be regulated.

CHAPTER ONE

INTRODUCTION

1.1 General

Water, a substance found abundantly in nature occurs in three phases of matter; solid (ice), liquid (water) and gas (vapour and steam). The purest form in which the substance can be obtained is vapour. But its use in this phase is limited. The most convenient phase of water for man's use is the liquid state.

Water is classified as either fresh or salty. Fresh water which occurs as surface water is found in lakes, rivers and ponds. It also occurs as precipitation water and groundwater from wells of various categories, springs and infiltration galleries. Salt water occurs in oceans and seas, estuaries and coastal soils. Usually, it is heavier than fresh water, with an average specific gravity of about 1.025 (Linsley, et al. 1972).

Although, it is said that water covers about 75% of the surface of the earth (Olasupo, 1982), only a very small proportion of this is available for use, a major percentage is tied up in the polar region and oceans.

In an attempt to improve water quality, series of processes are involved, the complexity of which depends on the level of technology, quality of the raw water, and socio-economic status of the consumers. Among the known processes of treatment to improve water quality are the unit operations of screening, aeration, flocculation, sedimentation and filtration, and the unit processes of coagulation, disinfection, precipitation, ion exchange, absorption and chemical oxidation.

Impurities in water normally are either suspended or dissolved. Surface waters are characterized by both the suspended and dissolved types of impurities whereas groundwater is generally free from the suspended matters but is likely to contain a large amount of the dissolved impurities gathered during the travel in the underground strata comprising rocks and minerals. The suspended matters found in surface water often contain pathogen which are disease - causing bacteria. This makes it necessary to treat surface water for potability.

Sand and gravel used in rapid filters in water works of many Third World Countries were once routinely imported along with the treatment plants from developed countries, with the attendant foreign exchange and economic problems, however, in Nigeria, researches have shown that locally available sands are suitable as filter media rapid sand filters (Ogedengbe, 1985).

Filter sand is specified on the basis of effective size and uniformity co-efficient. The effective size (D_{10}) is derived from test (Hirsch, 1945), indicating the size which separates the coarse and the fine in the ratio of 90 percent to 10 percent respectively (Ogedengbe, 1982). These parameters of sand, in essence, control the hydraulic behaviour of the filter. The uniformity coefficient (Uc) is a constant that indicates the ratio of the sand size separating the coarse, 40 percent from the finer 60 percent to the effective size given by (D_{60}/D_{10}). Uc is a measure of dispersion.

It should be noted that water of good quality plays an important role in human existence in relation to health. There is a tremendous interest in various researches that could enhance the production of water of acceptable quality at low cost and with systems that can be easily adapted and operated in developing countries. Water treatment technology dates back to as early as 2000 BC (ASCE/AWWA, 1990) and efforts to improve it continue till the present day.

1.2 Objective of the Project

The objective of this project is to determine the suitability of sand samples collected from different locations in Ondo State, for slow sand filter media on the basis of their physical properties. Moreover, this project equally aimed at revalidating the available facts and applying them to slow sand filtration technique, which can be more easily adapted for providing potable water in rural communities in Nigeria. The water quality parameters before and after filtration are analyzed to determine the efficiency of the filtration technique chosen to provide safe water for consumption. Subsequently, the information obtained from the experiments are used to design an appropriate filter unit of water treatment plant.

1.3 Justification for the Project

As stated by Schulz and Okun (1978), while engineers in the industrialised world are taught to use technology that are capital intensive with supporting high mechanization, instrumentation and automation, the reverse is the case in the developing world where the aforementioned are difficult if not impossible to obtain. Therefore, this project focuses on low skill technology in relation to surface water treatment for rural communities in Nigeria.

The success of this project would further discourage the importation of sand for water treatment, thereby eliminating problems associated with such importation and would facilitate potable water production, since the aspect of chemical pre-treatment is eliminated in slow sand filtration, thereby causing a reduction in operational cost. The experience of this author as an engineer in rural setting makes it a worthwhile venture to inquire into simple engineering systems that could enhance the provision of quality water with a low-level technological know-how; to improve the quality of rural life.

1.4 Scope of the Project

The project encompasses the determination of physical properties of local sand such as its particle size analysis, shape, solubility and specific gravity. A model filter box was designed, using the sand sample. Flow rates, qualities of influent and effluent water through the sand media were measured to predict the filter behaviour. Hydraulic analysis required for effective media was conducted.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Filtration is one of the main processes of water treatment, which makes it possible to improve the quality of water to the standard of potability. The act of filtration is a solid-liquid separation in which the liquid passes through porous media to remove as much of fine suspended solids as possible. The substances to be removed include suspended silt, clay and colloids. The micro-organisms to be removed include algae and bacteria.

Filtration of water through sand was one of the earliest methods employed in water treatment, but with time and advancement in technology, other materials other than sand came to fore (Holden, 1970). The early sand filters were constructed as small sand beds in 1804 by John Gibb in Paisley, Scotland and as large beds in 1828 by James Simpson, for the clarification of Thames river water by the Chelsea Water Company of London, England (Fair, et al 1971).

2.2 Filters and Filter Materials

As used in water treatment, a filter may consist of a thin porous layer of filter and deposited by flow on a support septum, or a bed of granular non-porous materials held in place by the force of gravity or by the direction of flow (AWWA 1971). Series of materials have been tried as filter bed which are usually graded granular materials which satisfy sanitary conditions, and have a sufficiently high chemical stability and mechanical strength. They include quartz sand, silica sand, crushed anthracite, burnt rock, expanded clay, ceramics, blast furnace slag, marble aggregate, polymer magnetite, rice husk, pumice and palm kernel shells to mention a few (Ogedengbe, 1985, Nikoladze, et al 1989).

Many different crushed and angular materials have been used to make up the type of deep beds employed in the large gravity and pressure filters common to water purification and sewage treatment industries. These materials include crushed quartz, crush marble, charcoal, coke and silica sand. Silica sand was used in the first filter of this type when they were introduced to purify water, first in Paris and shortly afterwards in England, towards the end of the 18th century. Experience over the years has confirmed silica sand to be the most satisfactory materials, now used as the standard filter medium in modern practice. Of the other materials, the porous ones are troublesome to clean and consequently give rise to damage from uncontrolled breeding of bacteria. The supporting layer of gravel or crushed stone, of thickness 0.45 - 0.55m and grain size 2-40mm on which the filter filling is laid is required in order that the finer filtering material could not be carried off with water through opening of the distribution system (Nikoladze, et al 1989).

The efficiency of a filter depends on several factors of which filter media characteristics play a prominent role. Table 2.1 shows the properties of some filter media materials. The different types of filter media, as described by Purchas (1971) summarised in Table 2.2. Many other authours, including Cleasby and Baumann (1967), and Holden (1970) have published similar results.

Table 2.1: Properties of some filter Media Materials

Materials	Shapes	Density	Hardness	Porosity	Range of effective size used (mm)
Silica sand	Rounded	2.6	7	42	0.4-1.0
Silica sand	Rough	2.6	7	44	0.4-1.0
Crushed quartz	Angular	2.6	7	53	0.4-1.0
Silica gravel	Rounded	2.6	7	40	1.0-50
Garnet sand	-	3.1-4.3	6.5-7.5	-	0.2-0.4
Crushed -					
Anthracite	Angular	1.5	3	55	0.4-1.4
Alluvia -					
Anthracite	Rounded	1.5	3	50	0.4-1.0

(Source: AWWA, 1971, pp 224)

Table 2.2: Generalized Summary of all types of Filter Media

	Type	Example	Minimum particle size trapped (microns)
1.	Solid Fabrication	Scalloped Washer Wire-wound tupes	5
2.	Rigid Porous media	(i) Ceramic and stone-wire. (ii) Sintered metal.	1 3
3.	Metal Sheets	(i) Perforated (ii) Woven Wire	100 5
4.	Porous Plastic	(i) Plastic pods sheets, etc (ii) Membranes	 3 0.005
5.	Woven fabrics	Cloths, of material and synthetic fibres	10
6.	Cartridges	Yarm-wound spools, graded fibres	2
7.	Non-woven sheets	(i) Felts, lap, etc (ii) Paper (cellulose glass glass (iii) Sheets and mats	10 5 2 0.5
8.	Loose sheets	(i) Fibres, e.g asbestos, cellulose (ii) Powders	Submicron Submicron
9.	Forces	(i) Electrical forces (ii) Dynamic force, e.g gravity, settling centrifuges cyclone	Submicron Submicron

(Source: Purchas, 1971).

2.3 Desirable Properties of Filter Media

No specifications have been made concerning the physico-chemical properties of filter grain surfaces, although some claims have been made that certain media have 'special' surface properties. Ives and Gregory (1966), nevertheless, gave an account of the surface chemical properties of some filter media. They gave measured values of electrokinetic potentials on sands, anthracite and balloting (glass sphere), showing that normally they were less than 20mV, although pretreatment of the grains with acid, or by crushing could change the magnitude (but not the sign) of the potentials. For all practical purposes these values could not be altered significantly for the media as supplied. However changes in the water chemistry, including the addition of polyelectrolyte, can change the media surface during filtration. Ives and Gregory also calculated the other significant surface characteristic, the London-Van der Waal's forces, showing that this value could not be altered to any significant effect. Thus it is not worthwhile to attempt to specify the surface physico-chemical properties of filter media.

Filtration property, which is the ability to remove particles from suspension to produce a clear filtrate, has been subjected to some intensive research, such that no single physical test can ensure the capability other than an actual filtration experiment (Ives, 1964).

A lot may be inferred by analogy with pilot filter installation or from experience in similar circumstances, This might account for why there had not been any BS standard for granular filter media (Ogedengbe, 1985). The specifications which are normally written concerning filter media deal with physical properties of size, shape, density and solubility, assuming that if these physical requirements are satisfied, the media will act as a successful filter. Other important criteria include porosity or permeability and durability.

2.3.1 Size

Grain size is specified by several methods which include microscope measurements, settling tests, photographical method, etc., but the use of sieves is the most practical both in the laboratory and on site (Ives, 1975).

There is no single size that is desirable for filtration. Grains that will do this have a ratio of sizes of less than 1:5, due to the geometry of the pore-sizes. Consequently, the coarsest of the size distribution of an upper layer should not exceed 5 times the finest of the size distribution of the adjacent lower layer.

2.3.2 Shape

The shape of filter material is described by its appearance given as spherical or near spherical, rounded or well-rounded and angular.

Before the advent of crushed anthracite it was believed that spherical or near spherical grains were desirable for filtration but the advent favours angular grains on the bases that it has more surface area per grain. However, angular grains pack to a more open porosity than spherical grains. So there were fewer angular grains per unit bed volume. Nevertheless, the advantage is attributed to the more tortuous flow paths created by the more angular grain.

A useful definition of shape (Ives, 1975) is the sphericity given by

$$\psi = \frac{dh}{ds} \qquad (2.1)$$

where, ds is the sieve size, being the mean of the opening of the passing and retaining sieves, and dh is the hydraulic diameter, being the size of a sphere or equal settling velocity to the grain (computed from fall velocity measurement).

Figure 2.1 is a plot of fall velocity at 20^0c against grain sieve size for some filter materials.

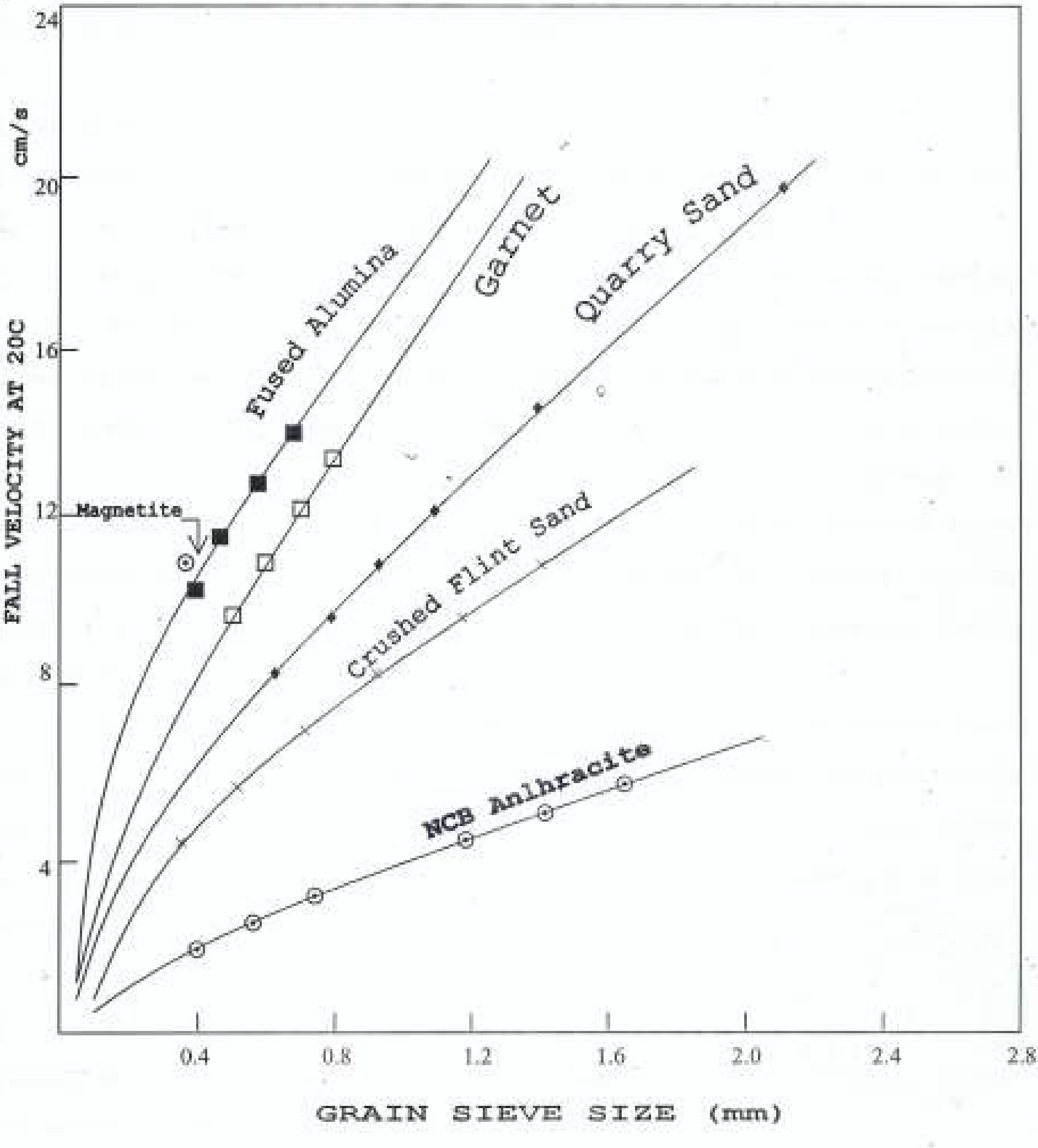

Fig 2.1 **Fall Velocity as a Function of Sand Particle Size, for Materials of Different Density in Water at 20^{0}c (Source: Ives 1975).**

2.3.3 Density

There is no unique density for a filter media which is optimal (Ives, 1975). Nevertheless, if the density is less than that of water or the liquid to be filtered, the media would float. The density of sand and gravel is the same the world over, 2650kg/m^3. This in effect enhances its usefulness in addition to its availability and inert properties.

2.3.4 Durability

The essence of durability in granular filter media is most important in rapid sand filter. This is as a result of the high velocity required for the backwashing.

The agitation to which filter grains are subjected during the washing processes requires that the grains should resist attrition. However, opinion differs on how this should be specified. But objectives are the same that the size of the grains should not be materially altered by fracture or attrition during a reasonable lifetime of the media.

A realistic specification is to limit the amount of fine material produced, and presumably washed away during an accelerated washing test which simulates several years operation. If no more than 1% by weight is lost per year, equivalent to 10mm depth of a 1m deep filter, the resistance to attrition during backwashing can be considered satisfactory (Ives, 1975).

Associated with durability is a requirement that the media should comprise whole grains and not cemented agglomerates. Although, such agglomerates may appear to be stable the cemented joints may constitute planes of weakness, or the cementing material may be more soluble than the grain material, with a consequent disintegration of the agglomerated grain.

2.3.5 Solubility

Grains that are likely to dissolve in the filtering liquid cannot be accepted even though this may be a long-term phenomenon.

Usually a specification is set which is more stringent than any situation which is likely to arise in practice. The American Water Works Association set a limit of solubility in 40% hydrochloric acid as 5% by weight (Ives, 1975). At the University

College London, 20% Hcl is used, and a limit of 2% loss of weight in 24hrs immersion (Ives, 1975) . Both are arbitrary, however, except that the stronger the acid, the more unrealistic is the specification. In some cases the soluble material is on or in the grains, but in other situations the soluble material is provided by grains of other material also present, but mechanically inseparable.

Another aspect of solubility concerns possible toxic or undesirable compounds leaching from the grains contaminating the water being filtered. This is said not to be a common problem, and the history of the granular material will usually indicate whether specific substances may be leached. The chemistry of the particular compound will also indicate what type of leaching test is suitable, and a specification for concentration limit in the leachate may be based on the International Standards for Drinking Water by the World Health Organisation (WHO, 1982).

2.3.6 Porosity and Permeability

By definition, porosity is the ratio of the pore volume to the total volume of the formation, given by:

$$] = \frac{Vv}{Vt} = 1 - \frac{Vs}{Vt} \qquad (2.2)$$

where Vv, Vs and Vt are the void, solid and total volume of the given soil sample respectively. The original porosity of a material is that which existed at the time the material was formed. Secondary porosity results from fractures and solution channel.

All soils are permeable materials, water being free to flow through the interconnected pore between the solid particles. The coefficient of permeability depends primarily on the average size of the pores which in turn is related to the distribution of particle sizes, particle shape and soil structure (Craig, 1987).

The permeability of a soil, expressed as the standard coefficient of permeability, is the rate of flow of water at 15.5^{0}C in litres/day through a cross section of 0.09m^2, under a head of 0.3m per 0.3m of water travel (Joseph and Salvato, 1982).

The coefficient of permeability or the hydraulic conductivity which is dependent on properties of the fluid and the medium can be expressed as

$$k = Cd^2 \frac{w}{\mu} = z \frac{w}{\mu} \quad (2.3)$$

where c is a factor involving the shape, packing, porosity, and other characteristics of the medium, w is the specific weight of the fluid, μ is its absolute viscosity and d is the average pore size of the medium, z is the intrinsic permeability of the media.

The intrinsic permeability is expressed in darcys, which has the dimension of area, while the hydraulic conductivity k has the dimensions of velocity. For sands, Hazen showed that the approximate value of k is given by (Craig, 1987).

$$k = 10^{-2} D^2_{10} \quad (2.4)$$

where D_{10} is the effective size in mm.

The variation of permeability with particle sizes is illustrated in table 2.3, while the porosity of various filtering materials is expressed in table 2.4.

Table 2.3: Approximate Particle Sizes and Permeability of Various Soils

Material	Particle Size (mm)	Approximate Permeability (gpd/ft²)	(m/day)
Clay	0.0001-0.005	10^{-5}-10^{-2}	10^{-7}-10^{-4}
Silt	0.005-0.05	10^{-2}-10	10^{-4}-0.4
Very fine sand	0.05-0.10	10-50	0.4-2
Fine sand	0.10-0.25	50-250	2-10
Medium sand	0.25-0.50	250-1000	10-40
Course sand	0.50-2.00	1000-15,000	40-600

(Source: Linsley, et al, 1972)

Table 2.4: Principal Characteristic of Granular Filtering Material

Filtering Material	Density g/cm^3	Porosity %	Grain Shape Coefficient
Quartz Sand	2.6-2.65	40-42	1.17
Crushed anthracite	1.6-1.7	45	1.5
Expanded Clay, Crushed	1.2-1.5	58-62	1.7-7-2.5
Expanded Clay Uncrushed	1.7-1.8	45	1.3
Burnt rock	2.4-2.5	52	2
Scoria	2.4-11.7	54-64	1.98-2.67
Shungisite, Crushed	1.5-1.8	56-58	1.7-2.0
Blast-furnace slabs	2.6	42-44	-
Slabs of Copper-nickel smelting	3.2	48	-
Expanded Polystyrene	0.1-0.2	41-42	1.02-1.1

(Source: Nikoladze, et al 1989)

2.4 Filter Classification

Filter troughs in which the process of filtration takes place are broadly classified as slow sand filter and rapid sand filter. The chief difference between them lies in the rate of filtration involved as the name 'slow' or 'rapid' would suggest (Duggal, 1993). Filters can also be classified based on the mode of media distribution and direction of flow. The flow could be upward flow, downward flow, biflow or radia flow. The commonly used in slow sand filter is the downward flow. In filter media, distribution can be described as ungraded, uniformly graded, or graded fine-to-coarse or coarse-to-fine. Slow sand filters are not backwashed and thus have randomly distributed (ungraded) media. Rapidly and slow sand filter are compared in sec 2.8.

2.5 Types of Filters

As published by authors such as Punmia (1979) and Purchas (1971), a summary of types of filters in operation include the followings:

a. Pressure filter

This is a gravity sand filter enclosed in an airtight cylindrical steel container. The sand bed is 45-90cm thick upon graded layers at the base of which are perforated collecting pipes for collecting filtered water. Pressure filters are used principally on relatively small public supplies, industrial plants and for swimming pools.

b. Diatomaceous Earth Filters

This is also called diatomite filters, which consist of a layer of Diatomaceous earth about 3mm thick layer supported on a filter element called septum. the filter element is made of synthetic fibre or porous ceramic material and is supported on a fine metal screen. Uses of this filter is generally limited to swimming pools and installations for small communities and military field unit. It has the advantages of lower first cost as compared to other conventional filters.

c. Dual Media Filters

This consists of sand layer topped with a bed on anthracite coal, each generally 30cm deep. Because of the different specific gravity of the two materials (coal: 1,4 and sand: 2.65), the coal of the proper size in relation to the sand remain on top of the sand during backwash. The filtration rate of dual media filter is about 12-15m/hr with the production of high quality water.

d. Mixed Media Filters

This is a three layer filter on three properly graded material. These materials are: Coal (sg: 1.4), sand (sg: 2.65) and garnet (sg: 4.2) in the proportion of 60,30 and 10 percent respectively. The particle size ranges from 1.00mm to 0.12mm from top to bottom of the filter bed. Materials are removed and sorted throughout the full depth of the bed in contrast to the same function in a sand bed which occurs only in the top few millimetres of sand. It is possible to commonly improve water quality having turbidity as low as 0.2 to 0.5 Jackson units against applied turbidity of about 20 units of the applied influent.

2.6. Theory of Filtration

As earlier mentioned, the process of filtration involves the passage of water or fluid to be filtered through a bed composed of granular materials with or without prior addition of chemicals. As water passes through the filter media suspended impurities are removed. The phenomenon of filtration may not be as simple, but it is summarised by Babbit et.al. (1967) as follows:

2.6.1 Mechanical Straining

This is responsible for removing such particles or suspended matter that are too large to pass through the interstices between the sand grains.

2.6.2 Sedimentation and Adsorption

These account for the removal of colloids, suspended and bacterial particles. The small untervening space between the sand grains act as minute sedimentation basins in which the suspended particles smaller than the voids in the filter-bed settle upon the sides of the sand grains. The particles adhere to the grains because of the physical attraction between the two particles of matter and because of the presence of the gelatinous coating so formed on the sand grains by the previously deposited bacteria and collided matter.

2.6.3 Biological Metabolism

This is the growth and life process of the living cells. The surface layer gets coated with a Z00glea film in which the bacteria activities are the highest. They feed on the organic impurities, converting them by a complex biochemical action into simple, harmless compounds, thus resulting in the purification of water.

2.6.4 Electrolytic Action

Dissolved and suspended matters in water carries charges which are of opposite polarity to the ionized particles of sand in filter bed. Hence, the charges neutralize each other thereby improve the effluent quality of the water treated.

2.7 Slow Sand Filters

Since this project focuses on the analysis based on the use of slow sand filters (SSF), it is imperative, to elaborate further on the SSF technique. Some properties of SSF are provided in table 2.5 It is important to add that slow sand filters are used mainly for surface water treatment. However, work by Muyibi, et al, (1989) shows that the use of an aeration-sedimentation - slow sand filtration technique was effective for the removal of iron content in borehole water in Bida, Niger State, Nigeria.

Trouble-free operation of slow sand filters is only possible when the average turbidity of the raw water is less than 5 F.T.U., with peak values below 20 F.T.U. and occurring for periods of a few days only (Hofkes, 1981). When this is not the case the suspended load in the raw water must be reduced by a preflocculation, or rapid filtration.

The advantages of SSF for use in developing countries include the following:

i. It produces a clear water, free from suspend impurities
ii. it produces hygienically safe water
iii. It can be built with local materials, using local skill and labour
iv. Complex mechanical and electrical equipment can be avoided, and
v. Cost reduction is achievable in its operation since coagulation chemicals are not needed.

2.8 Comparison of Slow Sand Filter and Rapid Sand Filter

In slow sand filters, the action takes place principally at the surface of the sand bed, although it also continued for some distance below. The surface gets coated with a skin or layer formed due to the bacteria action (which is a biological process) of finely suspended matter, plankton and other organic matter present in raw water, with the algae, and bacteria in the present of conductive temperature. The layer is called schmulzdecke. The successful operation of a slow sand filter principally depends upon the existence of this layer. However, other bacteria zones are still present up to 30cm in depth below the schmulzdecke. Here the actions involved are to completely oxidize the organic matter, destroy most of the bacteria present and let only simple an objectionable inorganic salts to pass through the filter bed into the effluent (Duggal, 1993).

In the case of a rapid sand filter, there is no such scmutzdecke acting as a surface straining-mat. The straining action in this case proceeds throughout the depth of the filter sand rather than on the surface or to a small distance below this. Other actions involving complex biological and chemical changes as water passes through the sand-bed are similar to those of slow-sand filter. In rapid sand filter, it is necessary for waters to be coagulated before they are allowed to pass through the rapid sand filters. Other consideration for successful filtration are proper thickness of sand-bed and size of the sand grains. Table 2.5 present a comparison between the two types of filter.

2.9 Performance Objectives in Filtration

Influent characteristics: Among the most important influent characteristics which affect the successful performance of filters are:

i. Concentration of solids
ii. Particles size and their distribution
iii. Surface characteristics
iv. Floc or particle charge
v. Organic or inorganic nature of particles, and
vi. Properties of the fluid to be filtered.

2.10 Media Characteristics

The filter medium effectively controls the performance of a filter. The following competing and conflicting requirements control filter media design:

i. The finer the media the better the quality of effluent but the faster the headloss increases which rapidly reduces the run-length.
ii. The coarser the media, the higher the effluent quality degradation but the lower the build up of headloss.

Therefore, the grain size of the media is chosen such as to balance the conflicting requirements of effluent quality which improves with the finer size and solids storage and headloss requirements which improves with the coarser size (Cleasby and Baumann, 1967).

Table 2.5 The Comparison between Slow and Rapid Sand Filters

Items	Slow sand filter	Rapid sand filters
Rate of filtration	100-200 litres per hr per m^2	3000-6000 litres per hr per m^2
Loss of head	15cm initial - 100m final	30cm initial -3m final
Size of bed	Requires large area	requires small area
Coagulation	Not required	Essential
Filter media of sand	Effective size: 0.15-035mm Cu : 2 to 3 Depth: 105cm reduce to not less than 30cm by scrapping	Effective size: 0.35-06mm Cu : 1.2 to 1.7 Depth; 75cm, not reduced by washing
Based materials of gravel	Size: 3 to 65mm Depth: 30 to 75	Size: 3 to 40mm Depth: 60 to 90cm
Underdrainage system	Split tile laterals Discharging into the tile or concrete main drain or perforated pipe laterals	Perforated laterals mains or wheeler Leopard system for under drainage
Method of Cleaning	Scrapping the top layer of 15mm to 25mm	Agitation and backwashing with or without compressed air
Amount of Wash water	0.2 to 0.6% of water filtered	2 to 4% water filtered
Period of Cleaning	1 to 2 months	2 to 3 days
Penetration of Suspended matter	Superficial	Deep
Supplementary Treatment of water	Chlorination	Chlorination
Efficiency	Very efficient in the removal of bacteria but less efficient in the turbidity	Less efficient in removal in the removal of colour turbidity.
Economy	Relatively low contruction and operation costs	Relatively high contruction and operation costs
Flexibility	Not Flexible in meeting variations in demands	Quite flexible for reasonable fluctuation in demand
Skilled supervision	Not essential	Essential
Depreciation cost	Relatively low	Relatively high

(Source: Punmia, 1979)

2.11 Depth of Media

Hudson (1959) and some other researchers developed media showing that removal efficiency is directly related to the media depth. In fact, the design depth of a rapid gravity filters is a function of the grain size, terminal headless and terminal effluent quality.

2.12 Filter Bed Porosity

The porosity of the filter bed determines the headloss and solids removal characteristics of the filter media. It is defined as the ratio of the total volume of voids in the media and the total volume of the media. Studies have shown that media size and shape govern the size distribution of voids in porous media.

This is an important factor which affects the quality of the effluent from the filter. It has been established by (Cleasby and Baumann, 1967) that low filtration rates do not necessarily ensure good quality water and that with adequate chemical pretreatment and filter design, there is little difference in filtered water quality from filters operated at rates between 0.08 and $0.24m^3/m^2$ per min (2 and 6 gpm/ft^2). It follows therefore that, with poor pretreatment, poor quality of water can be obtained at rates lower than $0.03m^3/s/m^2$.

2.13 Terminal Headloss

This design variable is related to the filtration rate, the bed porosity, the depth, the influenced the behavior of headloss curves.

(Cleasby and Baumann, 1967) report that when filters are operated at constant rates, they usually show a nearly linear or straight line headloss versus time or filtration volume curves. According to them, this behaviour can be interpreted as indicating no strong surface removal of solids and so production per run to a given terminal headloss decreases as filtration rate is increased.

However, when water being filtered exhibits a strong surface removal of solids, which results from straining action of the finer media at the filter surface, the headloss curve is exponential when operated at a constant rate.

2.14 Size of Filter Bed

A slow sand filter bed area required may be calculated using the equation given by Van Dick and Oomen (1982) expressed as:

$$X = \frac{Q}{0.1a + b} \qquad (2.5)$$

where X = required filter bed area (m^2).

Q = design daily water demand (m^3/d).

a = number of daily production hours at normal operation (i.e filtration rate 0.1 m/h.

b = 0.5 if daily period of declining rate of filtration amount to 8 hours.

= 0.7 if daily period of declining rage filtration amount to 16 consecutive hours.

= 0 if no declining rate filtration is applied.

2.15 Length of Filter Run

Advance technology in filter units has shown that two criteria required for the termination of filter run are:

i. either the suspended solids broke through the filter bed before the head available was used up:

ii. or, the filter head available was used up before the solids broke through the full depth of the media.

In either case, the run will have to be terminated, due to the deterioration in effluent quality in the former and the inability to maintain the filtration rate in the latter.

2.16 Hydraulics of Filtration

The resistance of flow of liquids through a porous medium is analogous to flow through small pipe and to the resistance offered by a fluid to setting particle (Tebbutt, 1983).

The flow of water in filtration task is laminar and it obeys Darcys law given by the expression.

$$v = kh/l \quad (2.5)$$

where h is the headloss in bed of depth l with face velocity V. K is the co-efficient of permeability.

Further dimensional analysis to develop the equation gives

$$h/l = 1 = 1.067\ C_D\ v^2/gd\Psi\ .\ 1/f^4 \quad (2.6)$$

where f is the best porosity, Ψ is the particle shape factor and C_D is the Newton's drag coefficient expressed as 24/R + 3/R + 0.34

In most conditions of water filtration, the value of k in 2.5 assumes a magnitude close to 5 under most conditions of water filtration (Jegede, 1988).

In the same view, Blake - Kozeny (Fair et al, 1971) developed a similar equation which described the resistance of a clean bed of particulate materia, such as sand, given thus.

$$H_L = \frac{5\mu v}{\varrho_w g}\ \frac{(1-e)^2}{e^3}\ \left(\frac{6}{\Psi d}\right)^2 L \quad (2.7)$$

where

H_L	=	Headloss through the filter media (cm),
μ	=	Absolute viscosity of the fluid (poise),
ϱ_w	=	Mass density of the fluid (g/cm^3)
v	=	Approach velocity at the top of the bed (cm/sec)
g	=	Gravity acceleration (cm/sec^2)
e	=	Porosity of bed
l	=	Depth of the be (cm)
d	=	Characteristic diameter of bed particle

In general, non-uniform filter media particles and the selection of diameter which characterizes the filter-media grains require some thought (Cleasby et al, 1967) chose the

10 percentile (i.e D_{10}) as the hydraulic effective size, because he had observed that the hydraulic resistance of unstratified sand bed was relatively unaffected by size variation (up to D_{60}/D_{10} of about 5) as long as D_{10} remained unchanged (Fair et al 1971).

It has been suggested on other hand, that, for particle of mixed sized (i.e non uniform media) an average particle diameter, d, can be defined as:

$$\frac{1}{d} = \sum_{i=1}^{n} \frac{(x_i)}{(d_i)} \qquad (2.8)$$

where

x_i = Weight fraction of particles in the i-th sieve,

d_i = The mean of sieve openings of the i-th and the (i + 1) - the sieves (Ogedengbe, 1985)

Hence equation 2.7 becomes

$$H_L = \frac{5\mu V}{\rho_o g} \frac{(1 - e)^2}{e^3} \left[\frac{6}{\psi} \sum_{i=1}^{n} \frac{(x_i)}{(d_i)} \right]^2 L \qquad (2.9)$$

Equation (2.9) then represents head loss for a non-uniform media, that is, particle of mixed sizes.

Table 2.6: Typical value of particle shape factor

Material	ψ
Mica flakes	0.28
Crushed glass	0.65
Angular sand	0.73
Worn sand	0.89
Spherical sand	1.00

(Source: Tebbutt, 1983)

Equation 2.9 gives the head loss with a clean bed, but when used to remove suspended matters the porosity of the bed is continually changing due to the collection of particles in the voids. It is generally assumed that the rate of removal of particles is proportional to their concentration given as

$$\frac{\partial c}{\partial L} = -\lambda c \qquad (2.10)$$

where

c = Concentration of suspended solids,

L = Depth from inlet surface

λ = Constant characteristic of the bed

The partial differential equation 2.10 which shows the variation of concentration with time and position in the bed can be integrated to give

$$\frac{C}{C_o} = e^{-\lambda L} \qquad (2.11)$$

where C_o = Solid concentration at inlet surface (L=0).

Ives and Gregory (1966) showed that if the retained solids the total head loss can be expressed as a linear function which for uni-size media is

$$H = h + \frac{K_v C_o T}{(i-e)} \qquad (2.12)$$

where

h = head loss from the Blake - Kozeny equation

t = time of operation

k_v = constant

Equation 2.12 is similar for a graded media with the replacement of k by another constant depending on the size grading and the variation of k with particle size.

It should be noted that suspended matter in porous media bed is not removed simply by a straining action. Removal depends upon transport mechanisms such as gravity, interception, diffusion, sedimentation and hydrodynamic processes. Once transported into the pores of a bed the suspended matter is held in place by attachment mechanisms due to physico-chemical intermolecular forces similar to those which operate in coagulation. This is why a porous media is able to remove particles considerably smaller than the voids in the bed.

2.17 Water Demand and Water Quality

A very important parameter in the design of water supply system is the determination of the total quantity of water that would be required by the community after the completion of the water work. Two factors are involved:

a. the probable population estimated at the end of the design period, and

b. the rate of water supply per capita per day.

The design period is the period into the future for which the estimate is to be made (Duggal, 1993). The design period should neither be too long so that servibility is not impede nor too short because this would not justify the initial capital investment. In practice, for most civil engineering work, a period varying from 20 to 30 years is usually considered for design purposes. For the purpose of estimating water demand by a community, it is a usual practice to calculate the consumption per person referred to as per capital consumption in litres.

Per capita consumption of water is affected by many factors which can be summarised as follows:

i. Climate: The hotter a place is, the more water would be demanded for bathing, lawn and street sprinkling viz versa.

ii. Class of consumer: Higher economic status implies better standard of living which subsequently would increase quest for water supply.

iii. Industries and Commerce: Consumption is usually higher when water supply has to cater for large industrial and commercial uses.

iv. System of supply: When water is supplied for certain fixed hours of the day because of one reason or the other, consumption may be reduced. As if water is supplied by stand pipe of house connection this would also affect amount of water consumed.

v. Extent of metering system: If water supply is effectively metered and subsequent charges of consumption, consumption may be reduced.

Water that may be considered absolutely pure is not found in nature. Even rain water, expectedly distilled, collects impurities such as dust, gases, bacteria e.t.c. during its passage through the atmosphere (Duggal, 1993).

Impurities in water may be classified broadly as follows:

a. Physical impurities
b. Chemical impurities, and
c. Bacteriological impurities.

The physical impurities give taste, odour, colour and turbidity. Physical impurities do not have a direct relationship with health but produce many indirect consequences. It is often observed that a safe water supply that has a taste and odour is likely to be passed up by people for unsafe water. A turbid water may protect pathogens from the effect of chlorination in water treatment and it may contain mineral matters that irritate stomach lining.

The chemical impurities may be either organic or inorganic, as shown in table 2.7, which describes the nature, cause and effect of chemical impurities.

The bacteriological impurities are determined by coliform count. Pathogen, which is a disease-causing organism, is generally inherent in the coliform group of bacteria of which the Escherichia Coli (E.Coli) is important.

The E.Coli themselves are not harmful but their presence serves as an indicator to the possible existence in water of the pathogenic type of bacteria such as the typhoid bacillus. It is necessary, therefore, to test for the presence of otherwise of E.coil.

It should be noted that series of research has evolved in water treatment to standardised requirement for water use. Example of this is shown in table 2.8 which gives some example of World Health Organisation guideline for drinking water.

Table 2.7 Chemical Impurities in Water, Their Causes and Effects

IMPURITIES	CAUSES	EFFECTS
A. Inorganic or Mineral		
a. Suspended	Particles of silt and clay	Turbidity
b. Dissolved	Carbonates and bicarbonates of Calcium(Ca) & Magnesium(Mg)	Hardness and alkalinity
	Sulphates and chlorides of Calcium and Magnesium	Hardness and Corrosion of Boilers
	Carbonates and bicarbonates of Sodium (Na)	Alkalinity and Softness
	Nitrates	Excess over 45 mg/l causes methemoglobinemia or "blue babies"
	Chlorides of Na	Brackish taste
	Fluorides of Na	Excess over 1.5mg/l causes teeth to be stained
	Iron Oxide	Taste, colour and hardness
	Maganese (Mn)	Taste and brown colour
B. Organic		
i. Suspended		
a. Vegetable	Decayed leaves, algae, fungi etc.	Acidity, taste and change of colour, water suspicious.
b. Animal	Dead animals, hair, insects etc.	Bacteria, water contaminated and dangerous for health
ii. Dissolved		
a. Vegetable	Large quantities of albuminoid nitrogen with a little free ammonia and chlorides	Bacteria, water suspicious
b. Animal	Large quantities of albuminoid nitrogen with large quantities of free ammonia and chlorides	Disease-producing bacteria pollution due to sewage, water dangerous.

(Source: Duggal, 1993)

[illegible] Guidelines for Drinking Water Quality, WHO Geneval (1982)

CHARACTERISTICS	PERMISSIBLE LEVEL
Arsenic	0.05 mg/1
Cadmium	0.005 mg/1
Chromium	0.05 mg/1
Cyanide	0.01 mg/1
Fluoride	1.5 mg/1
Lead	0.05 mg/1
Mercury	0.001 mg/1
Nickel	0.1 mg/1
Nitrate and Nitrite nitrogen	10 mg/1
Nitrate nitrogen	No guideline value set
Selenium	0.01 mg/1
Chlorine	250 mg/1
Sulphate	400 mg/1
Hardness as $CaCo_3$	500 mg/1
Total dissolved solids	1000 mg/1
Aluminium	0.2 mg/1
copper	1.0 mg/1
Iron	0.3 mg/1
Manganese	0.1 mg/1
Sodium	200 mg/1
Zinc	5 mg/l
Chlorophenols	0.1 µg/1
Chloroform	30 µg/1
DDT	1.0 µg/1
Heptachlor	30 µg/1
Lindane	3.0 µg/1
Monochlorobenzene	3.0 µg/1
1.4 dichlorobenzene	0.1 µg/1
2.4.D	100 µg/1
Gross alpha activity	0.1 Bq/1
Gross beta activity	1.0 Bq/1
Colour beta activity	15 TCU
Turbidity	5 NTU
Taste	not objectionable to 90% of Consumers
PH	6.5 to 8.5
Califorms	absent in 100ml.

(Source: Tebbutt, 1983)

CHAPTER THREE

MATERIALS AND METHODS

As this research work focused on the use of local sand as filter media in slow sand filtration technique, the methods employed involved the laboratory analysis of sand samples coupled with a design of a model filter to treat raw water of varying degree of impurities in order to test the efficiency of the analysed sand sample.

3.1 Materials

3.1.1 General Layout

The experiment was set up in the Mineral Processing Laboratory of the Federal University of Technology, Akure. The location was selected because of the existing overhead tank situated outside the laboratory which could be used as a storage tank for the raw water.

A schematic diagram of the experimental set up is presented in fig. 3.1. The rectangular, 2000 litre overhead tank was constructed using a galvanised metal sheet and was mounted on a sandcrete block support of 2.5m height above the ground level. This height allows raw water from the tank to flow under gravity into the filter box. Other features of the experimental set up is the glass u-shaped water manometer, used for the measurement of headlosses.

Figure 3.2 is a section through the filter box, showing the placement of the filter sand, gravel and the filtrate collection reservoir.

3.1.2. Sand and Gravel

Three sand stocks were eventually considered for use in the experiments, they are: common sand, river sand and white coastal sand.

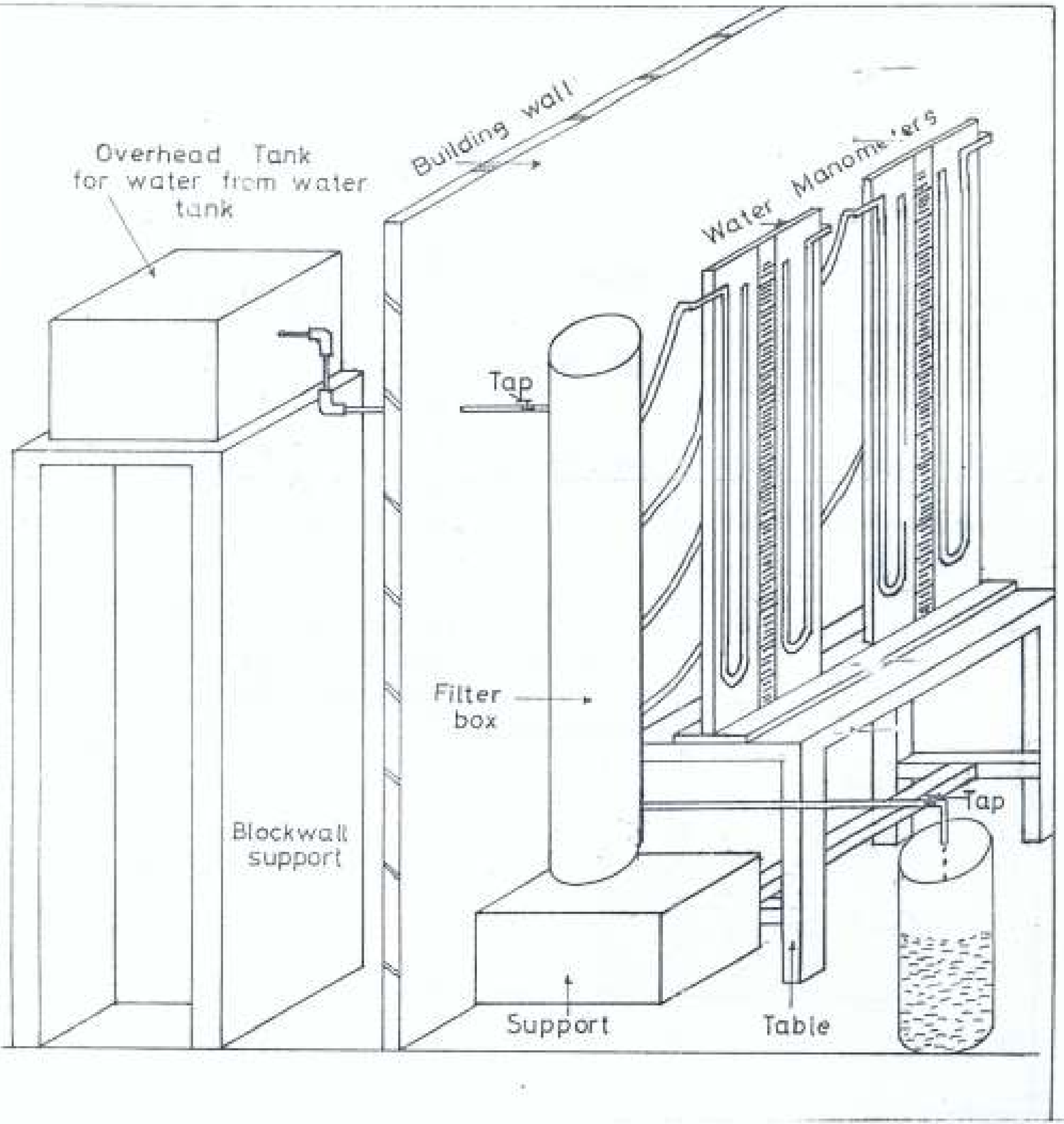

Fig. 3.1: Experimental set up for the slow-sand filtration

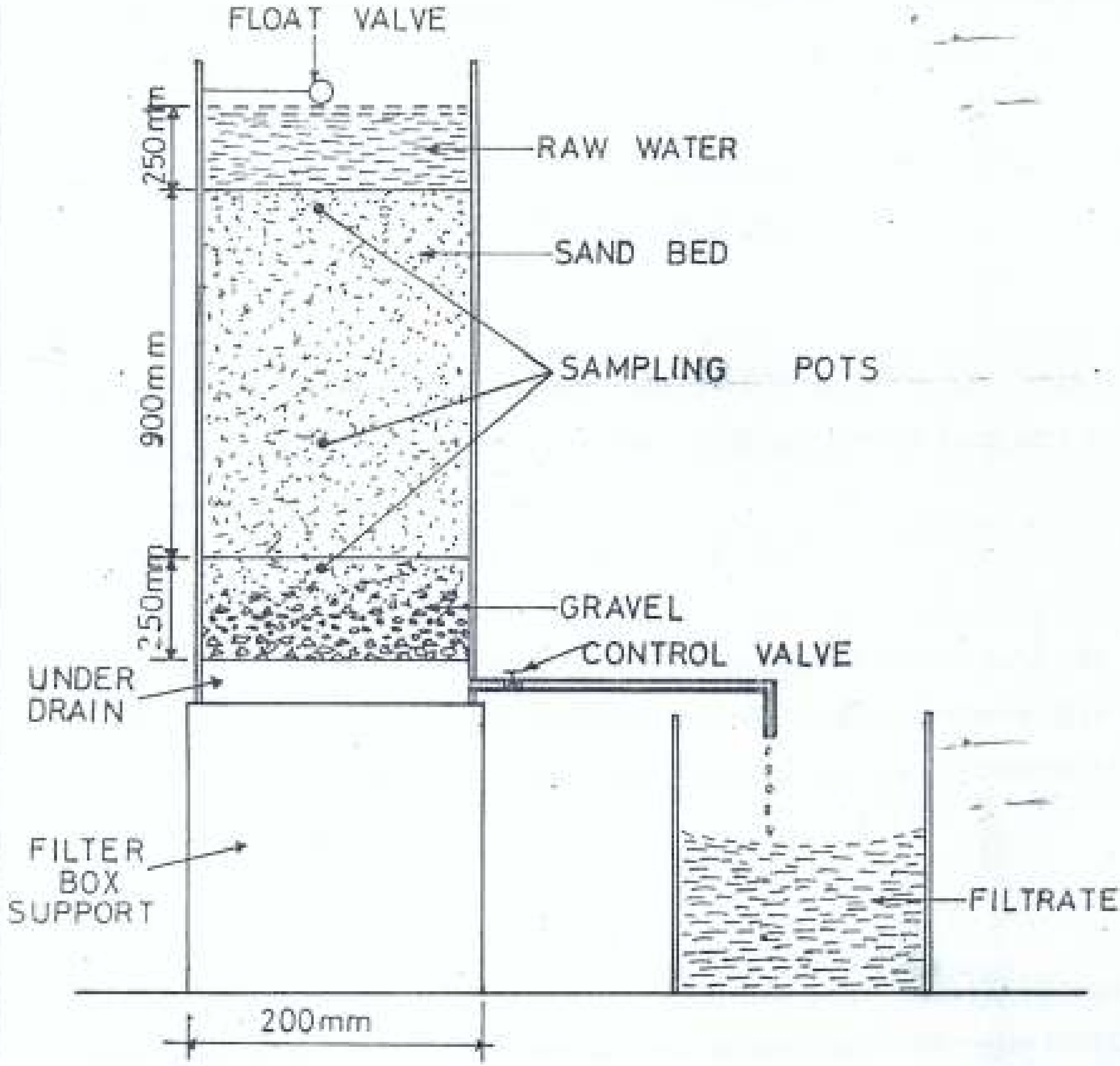

Fig. 3.2: Section through the Filter Box

Common sand and river sand have been established to be good filter materials (Ogedengbe, 1982) for rapid sand filtration systems. However, the common sand and river sand were re-considered because they were obtained from a different geographical location from those considered by earlier researchers. The white coastal sand as third sand stock is an additional source locally available.

The only source of gravel used in this project is the type that is usually sieved out of a gravely soil, it is commonly revered to as bush gravel..

3.1.3 Sieves

A set of British Standard Sieves apertures 0.063, 0.075, 0.150, 0.300, 0.425, 0.850, 1.18 and 2.00mm was used. This was justified by the fact that the grain sizes for slow sand filter sand lies within this range.

3.1.4 Pipes and Appurtenances

A PVC pipe of 19mm internal diameter was used to connect the overhead tank to the filter box unit along side with appurtenances such as elbows, nipples, unions, float valve, tap and gate valves. To prevent leakage, yarns were used as sleeves to connect the pipes and the appurtenances.

3.1.5 Measuring Cylinder and Stop Clock

A 1000ml glass measuring cylinder was used along with a stop clock for measuring the volume of water collected over a specified time lag in order to determine the flowrate value.

3.1.6 Mechanical Sieve Shaker

This was used to apply the mechanical vibration needed in grading the sand in accordance with the set of sieves used.

3.1.7 Raw Water

The raw water that was used for the experiment was obtained from River Ala in Akure.

This is typical of the river water used by some communities in the rural environment as sources of water supply. The clean water used in washing the sandstocks was obtained from a borehole in the premises of Ondo State Water and Sanitation Office in Akure.

3.1.8 Other Materials

These include 150cl "eva" plastic container for collecting both the raw water and filtered water for laboratory analysis, nylon spread for drying the sand, plastic basin for washing sand and gravel, an adopted filter box made up of 200mm internal diameter PVC pipe and a collection reservoir made up of a plastic container of about 120 litres in capacity.

3.2 Methods

3.2.1 Sample Collection

Four sand samples were initially collected from the following places in Ondo State.

i. Igbokoda, a location in the riverine area in the State with abundant white coastal sand being commercially exploited for sheet glass manufacturing. This sand is referred to in this project as Igbokoda sand.

ii. River Ala, a major river in Akure, Ondo State, with a sizeable urban catchment. It is termed river sand.

iii. Ayede Ogbese, a location in Akure North Local Government with a typical sand quarry usually located in swampy areas which are commonly used for construction work. It is being referred to in this project as common sand or construction sand.

iv. Aba Jegele, a village in Akure North Local Government Area of Ondo State, with a privately owner stone quarry. The sand sample was labelled as quarry sand.

However, preliminary investigations into the quarry sand sample showed that it would not be worthwhile to consider it for filter sand for now, because, sieve analysis showed that only a small proportion of the stock could be usable sand. Unlike river sand, which has a relatively constant property, irrespective of the source, quarry sand has varying composition depending on the geological formation and mineral composition of the parent rock. Also, quarry sand is likely to produce leachate while in use as a filter, which is not desirable.

Raw water whose quality was to be determined to indicate the efficiency of the proposed sands was collected from River Ala, with the aid of a tractor-propelled water tank.

The usual construction gravel for the filter bed was obtained from a construction site at Igbara-Oke also in Ondo State.

3.2.2 Sample Preparation

A representative sample of each sand and gravel was washed thoroughly using borehole water from the premises of Ondo State Water and Sanitation Officer to remove the soluble components as well as silt and clay which would have a negative effect on sand filters.

The washed samples were sun-dried by spreading them on a nylon. Because of the possibility of contamination, research works have not encouraged sun-drying to be the best method of drying filter sand. However, it is still the cheapest method in rural communities. Contamination resulting from drying can be curtailed, if the processes are properly supervised.

3.2.3 Grain Size Analysis

To determine the grains composition of the sand samples, a set of BS sieves (number ranging from 10 to 230) was used.

A small quantity of each sand sample was washed and oven dried. Two hundred grams of the oven sample was placed on the arranged set of sieves; it was mechanically vibrated for 10 minutes using a sieve shaker. The amount of sand retained on each sieve was weighed and recorded. (See plate 1 showing the sieving process).

The percentage passing, percentage retained and cummulative percentage retained were calculated to plot the particle size distribution curves (Fig. 4.1). The effective size D_{10} was determined from the graph. The uniformity coefficient Cu was also determined by computing the ratio of D_{60} to D_{10}.

Plate 1: Sieving of the Sand Samples

The gravel was sieved to sizes 9.50mm and 26.5mm being the acceptable range of filter gravel support in sand filters by (Ives, 1975).

The bulk of the sand used for the filter box was prepared with the sand grains passing sieve 0.850mm but retained on 0.150mm. This was acceptable due to the fact that the ratio of the grain sizes within this range was less than 1:5 (Ives, 1975).

3.2.4 Grains Shape

The grain shape for each sand sample under consideration for this project was determined using a photomicrograph technique which involves two stages: the preparation of the grain slides and the preparation of the Photomicrographs.

a. Preparation of the Grain Slides

The grain slide was prepared by putting a labelled piece of glass slide with a glass cover slip on a hot plate. The hot plate was switched on and canada balsam was spread on the glass slide and the slip. When the canada balsam melted, the grains were evenly spread on the balsam on the glass slide. A cover slip was used to cover the grains, which was pressed to exclude bubles. The slide was put on the bench to cool, after which it was washed with methylated spirit, detergent and rinsed in water. It was then dried and labelled.

b. Preparation of the Photomicrographs

The photomicrograph unit was set up and switched on, each slide was placed on the stage of the polarising microscope. The light control was turned up to produce a bright illumination. A panchromatic black and white film with speed 100 ASA was located into the camera attached to the polarising microscope. A portion of the slide containing the grains was selected and an objective for a suitable magnification was used. The lens of the camera was adjusted to produce a sharp image and the image recorded on the film was taken. After all the slides had been photographed, the film was removed into its pack, developed and the photomicrographs printed and labelled.

3.2.5 Solubility Test

The equipment and materials required for the purpose of this test include the following:

Electronic weighing Balance, Beaker, 40 percent hydrochloric acid (Hcl), filter paper, was bottle, crucible, funnel and electric oven.

The crucible was cleaned, dried and weighed. Then, twenty grams of sample (sand) was added into the crucible, weighed and recorded as M_2. Fourty percent Hcl was poured into the sample in the crucible till it was completely covered and left for 24 hours.

Then, the acid was filtered off using filter paper-cum-funnel. It was properly rinsed with distilled water and then oven-dried for 8 hours, reweighed and recorded as M_1. The difference between the original weight, M_2 and the new weight, M_1, is the solubility. The result usually expressed in percentage gives the solubility of the sample as:

$$Sd = \frac{M_2 - M_1}{M_2} \times 100 \qquad (3.1)$$

3.2.6 Specific Gravity Test

Specific gravity test involves the use of the following equipment and materials: Pycnometer bottle (density bottle), oven, wash bottle, glass rod, weighning balance distilled water and desiccator.

The complete density bottle with stopper was cleaned and dried at 100^0c, cooled in the desiccator, weighed and recorded as M_1. A prepared sand sample, also cooled in desicator, was transferred from the desicator into the bottle. The bottle with its contents together with the stopper was weighed and recorded as M_2.

Sufficient air-free distilled water was added so that the sand in the bottle was just covered, the bottle along with its content was then shaken gently to eliminate air traped in the sand sample and finally filled to the top cone of the bottle with distilled water, and then weighed as M_3.

The bottle was then emptied cleaned and filled completely with air-free distill water and weighed as M_4. The specific gravity of sand sample, G_S, was calculated using expression:

$$Gs = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \qquad (3.2)$$

3.2.7 Design of Filters

The design of an effective filter hinges on good determination of the filter media parameters, that is, the physical properties such as grain size analysis, density, solubility, porosity and shape.

The filter box adopted in this project was constructed using a cylindrical PVC pipe, 200mm internal diameter, cut into a length of 1.4m, to provide a sufficient depth for the filter materials. The bottom side of the box was sealed to be able to retain the filter filling and water. Other important features of the box include the following: Float valve, to maintain constant head of water above the sand level; the installation of the float valve was made possible by reducing the length of its arm. The under-drain pipe, which was constructed of a 30mm internal diameter PVC pipe, with perforated holes of about 5mm diameter along its length and at 10mm centre to centre; the effluent tap, to control the flowrate; and the headloss port, linked to the water manometers by rubber tubes required to measure the headlosses.

3.2.8 Underdrain System

The underdrain system was provided to support and retain filtering media and to collect filtrate. However, in rapid filters, such would serve to distribute washwater. The three general types of underdrain are:

a. Pipe lateral and gravel,

b. Block with or without gravel, and

c. False bottom with or without gravel.

For this project, the pipe lateral and gravel were used. The design principles given by Fair et al (1968), state that the total area of orifices should be 0.5% of the area of bed served and that the cross-sectional area of lateral on the pipe should be between two and four times total area of orifices served. This implies that the total area of orifices is given by:

$$A = \frac{0.005\pi D^2}{4} \quad (3.2)$$

Where D is the diameter of the bed served. Given D as 200mm, total area of the orifices and diameter were calculated to be 158mm^2 from the second condition, the cross-sectional area of lateral being four times total area of orifices served, was estimated to be 632mm^2.

The cross-sectional area or lateral was therefore 30mm, the total number or orifices, N is given by:

$$N = \frac{\text{total area of orifices}}{\text{area or an orifice}}$$

$$N = \frac{158}{19.6} \approx 8$$

3.2.9 Filter Packing

Clean water was fed into the filter box to about three quarters of its height. The essence of this water was to remove air bubbles when placing the filter materials.

Three layers of gravel sizes 9.50mm, 19.0mm and 26.5mm were first poured into the filter box with its water content, starting with the largest size to the smallest size making up to 250mm of the entire filter box depth of 1.4m.

The sieved sand (with grain size range of 0.150mm to 0.850mm) was poured into the filter box, to form an unstratified layer up to 1.150 in depth. This non-stratification was justified because slow sand filters requires no backwashing.

However, the filter box was rocked gently as the materials were being placed, to eliminate air bubbles. The top 250mm of the box was left for constant water level above the sand bed.

The prepared sand and gravel samples as packed into the designed filter box constituting a downward flow slow sand filter system are illustrated in figures 3.1 and 3.2.

3.2.10 Experimental Procedure

Through the headloss ports fixed to the filter box in the construction, rubber tubes were used to connect the port with the water manometer for headloss measurement.

The filter was charged by running clean water continuosly through the filter for about two hours, this is to further expel trapped air in the filter unit. This was done by keeping both the influent and effluent valves opened. Subsequently, a three-day maturation was achieved by keeping the effluent tap partially open to allow water droplets, which in essence enhanced air circulation in the system, while the influent tap was kept fully open to provide a constant level supernatant water above the sand bed (Plate 2).

Raw water to be used as influent water was drawn from River Ala in Akure town with the use of water tanker that discharged the raw water into the overhead tank through a hose-pipe. The raw water replaced the clean water with which the filter unit was charged by gradually opening the effluent tap, while the influent tap was kept fully open. The gradual opening of the effluent tap was necessary so that the surface of the sand bed was not disturbed by sudden flow into the system.

The effluent tap was kept at a level where available head could be read in the water manometer. This was maintained until a two-hour flow was attained. The headloss was read from the manometer as the difference between the average water levels at the top and bottom headloss ports. At this point, the influent water sample was collected for quality analysis.

After determining the flow rate as described in the following section, the filtration system was allowed to run for an average of six hours, considered as a one-day run. For each, the headloss was measured and recorded, the flow rate was determined and effluent water sample collected for quality analysis. This procedure was repeated for five days on each sand sample ensuring that there was air circulation in the filter unit at the termination of each day's run.

Plate 2: Experimental Set-up for the Slow Sand Filtration System

3.2.11 Flowrate Measurement

In the absence of a flow meter to measure the flowrate of the model filter a simple volummetric system was adopted.. A 1000ml measuring cylinder was used to collect a quality of flow within a specified period of time while the effluent tap was kept open (Plate 3).

At least two measurements of the flowrate were taken for each flow to obtain an average reliable value. The flowrate per unit area gave an indication of residence of raw water within the filter bed.

3.2.12 Determination of Water Quality Parameters

To determine the efficiency of the sand samples in the filtration process, the influent and effluent water qualities such as the Total hardness, Total dissolved solid, Total suspended solids, Turbidity, Total bacteria count and so on were determined in accordance with standard test in the laboratory. The results are as presented in tables 4.6 - 4.10. The colorimeter employed by the Owena-FUTA Laboratory to measure the turbidity gave low values of results, which needed to be verified by alternate method of direct reading from turbidimeter at Ondo State Water Corporation, Akure. Appropriate correlation adjustments were necessary to obtain values considered reasonable, as reported in Tables 4.3 and 4.6 - 4.10.

Plate 3: Flowrate Measurement

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Grain Size

Table 4.1 showed the grading of the sand sample from the sources under consideration after clay and silt have been removed by washing. It can be observed from the table, that the bulk of the particles falls within sieve number 40 and 100, that is passing sieve size 0.850mm but retained on 0.150mm sieve. The table shows that Igbokoda sand gave the highest yield of 95.84% followed by the construction sand, 79.15% and River sand 59.92% within passing 0.850mm but retained on 0.150mm size range.

The particle distribution curves, from the sieve analysis, (Fig. 4.1) gave the effective size (effective size (D_{10}) of 0.174mm, 0.25mm and 0.12mm for Igbokoda sand, River sand and construction sand respectively. The corresponding value for the uniformity coefficient (Cu) were 2.41, 3.0 and 2.92.

Figure 4.1 further indicates that the three sand stocks were not well graded, as the uniformity coefficient of each was less than 5. A large proportion of the sand stock fell within 0.2mm and 0.6mm particle size range. But in the preparation of samples from each stock, the 0.150mm - 0.850mm particle size range was used, thus containing both fine and medium size in different proportions.

4.2 Grain Shape

The grain shape was determined using a photomicrograph technique. Plate 4, 5 and 6 show the results of the grain shape. A visual observation of the plates indicate that the grains are generally rounded rounded in shape, with a closer similarity between Igbokoda sand and River sand. However, one would have expected that the similarity should be between Igbokoda and construction sand because of their mode of formation and deposit, but the roundedness of the river sand could be justified because of its involvement in sediment transportation in the river bed which causes rubbing of the grain against one another thereby bring about its roundness.

The results of other physical properties of the samples under consideration can be seen in table 4.2. Unlike the construction sand that had a different odour when moist and dry, the other two sources had no marked difference in the odour when either moist or dry. However, the reverse was the case when considering the colours. A change in colours of the samples could be noticed when either the sample was dry or moist.

The solubility of the samples in 40% Hcl can be said to be negligible, which is an indication that the sand samples are whole grains and that they neither contained fossil or organic compound (see table 4.2).

4.3 Filter Performance

When raw water was passed through the prepared filter sands, that is, those passing sieve 0.850mm but retained on 0.150mm sieve, packed in the designed filter box previously discussed and monitored for five days, the general results can be seen in table 4.6 to 4.10.

4.3.1 Colour and Odour

Throughout the monitoring period of five days, it can be observed (see table 4.2), that the filter medium had no effect on the colour of the filtered water, confirming that sand filters do not remove colours in water treatment. Similarly, the effect of odour removal by sand filters could not be readily ascertained in the course of this experiment. However, since slow sand filtration involves to some extent a complex adsorption technique, it is not unlikely that a small reduction in the colours threshold of the treated water occurs.

4.3.2 Turbidity Removal

Table 4.3 is the summary of the filtration time, filtration rate and effluent turbidity for the three sands samples. In consonance with the fact that the average turbidity of less than 5 F.T.U. is required for a trouble free operation of slow sand filters (Hofkes, 1981), the maximum influent water turbidity in this study was 7 N.T.U. (Table 4.6). The graphical illustration of the turbidity removal can be seen in figure 4.2.

Table 4.1 Result of Sieve Analysis on the Sand Samples

Sieve No (U.S)	Sieve Aperture (mm)	Igbokoda Sand			River Sand			Construction Sand		
		Wt of Sand retained (g)	% Cummulative % retained	Passing	Wt of Sand retained	% Cummulative % retained (g)	Passing	Wt of Sand retained	% Cummulative % retained (g)	Passing
10	2.00	0.10	0.05	99.95	7.00	3.53	96.47	0.90	0.45	99.55
14	1.18	1.40	0.70	99.25	31.40	15.85	80.62	6.20	3.13	96.42
20	0.85	3.80	1.91	97.34	29.00	14.64	65.98	7.40	3.74	92.68
40	0.425	56.70	28.48	68.86	67.00	33.82	32.16	50.40	25.44	67.24
52	0.30	52.70	26.22	42.64	37.70	19.03	13.13	29.10	14.69	52.52
100	0.15	81.90	41.14	1.50	14.00	7.07	6.06	77.30	39.02	13.53
200	0.075	2.00	1.00	0.50	11.90	6.01	0.05	17.80	8.99	4.54
230	0.063	1.00	0.50	0.00	0.10	0.05	0.00	8.30	4.19	0.35
	Pan	0.00	0.00		0.00	0.00		0.70	0.35	0.00
		199.10	100.00		198.10	100.00		198.10	100.00	
		$C_u = \frac{D_{60}}{D_{10}} = \frac{0.42}{0.174} = 2.41$			$C_u = \frac{D_{60}}{D_{10}} = \frac{0.75}{0.25} = 3.0$			$C_u = \frac{D_{60}}{D_{10}} = \frac{0.35}{0.12} = 2.92$		
Used Sand	(0.15-0.425) (mm)	95.84%			59.92%			79.15%		

% Passing = 100-Σ% retained, D_{60} and D_{10} as obtained from the grain size analysis curves.

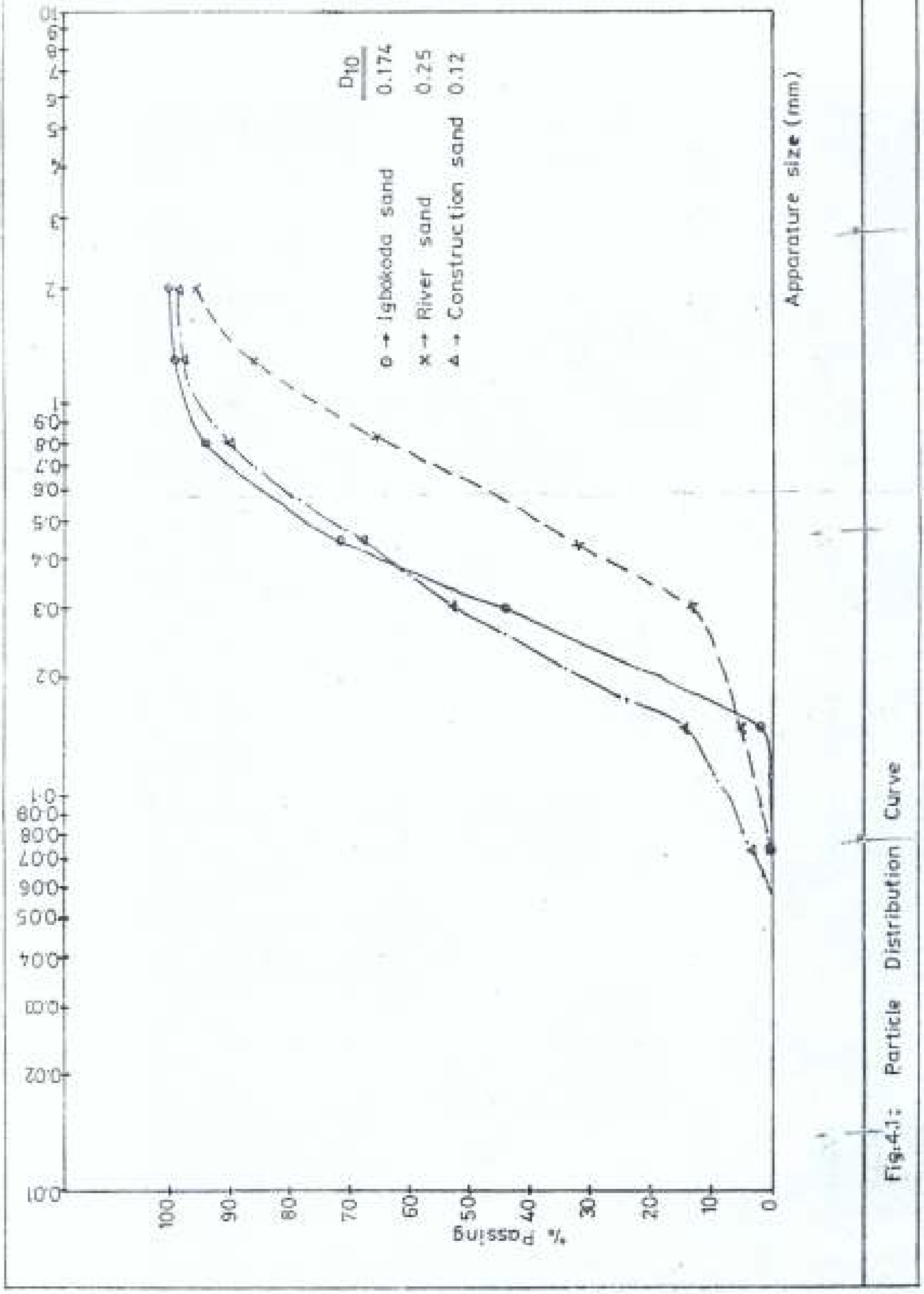

Fig. 4.1: Particle Distribution Curve

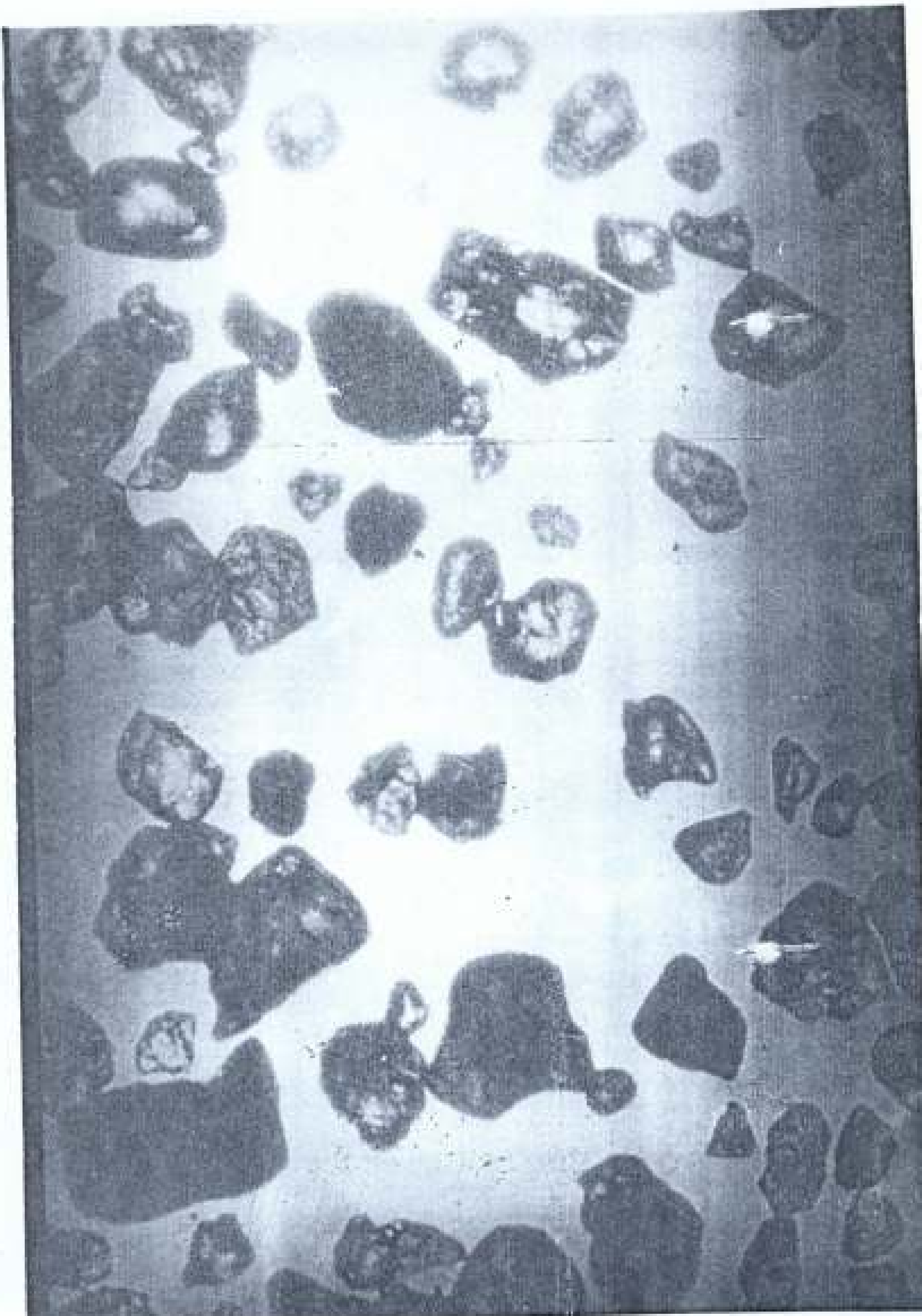

Plate 4: A Photomicrograph of Igbokoda Sand

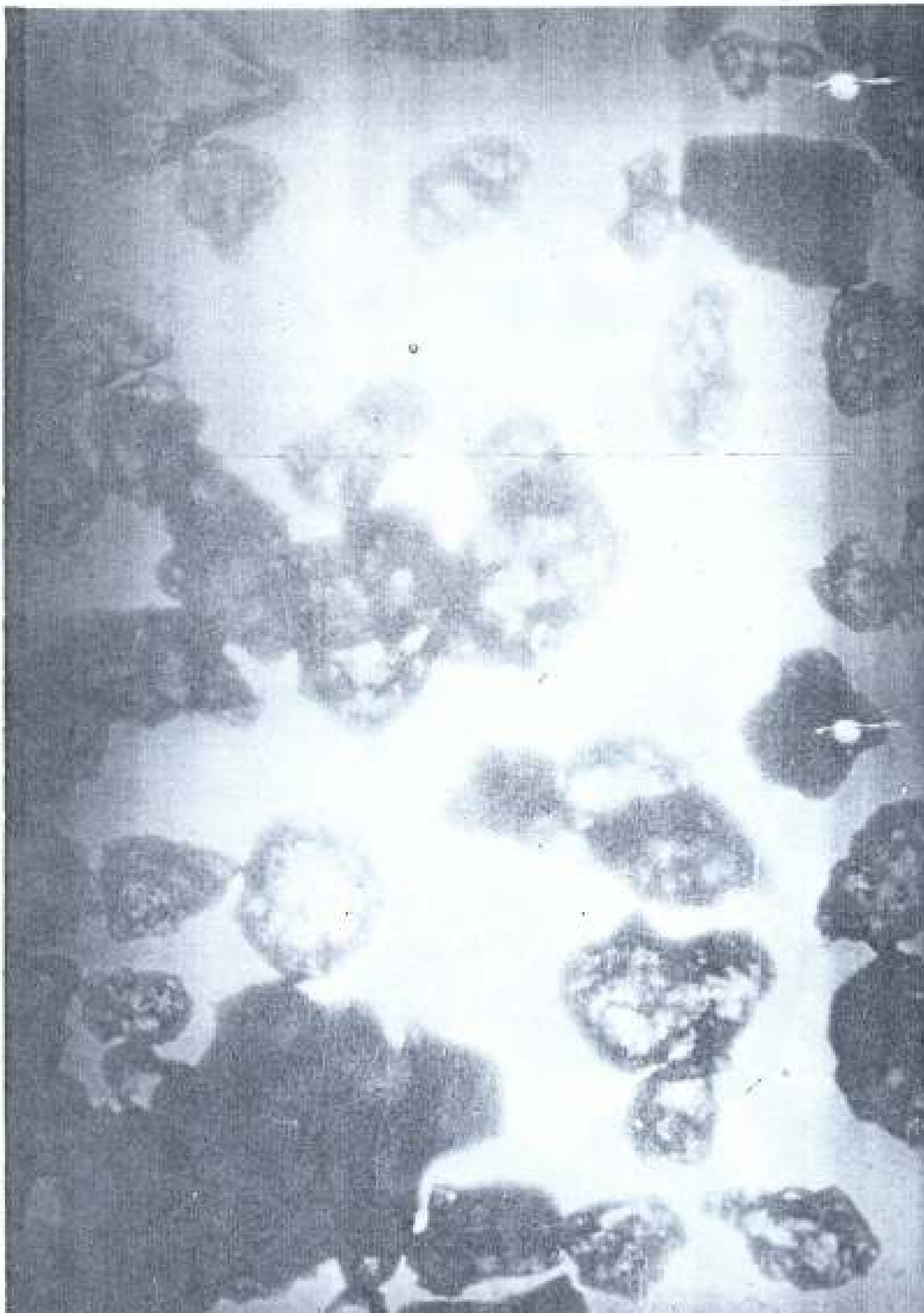

Plate 5: A Photomicrograph of River Ala Sand

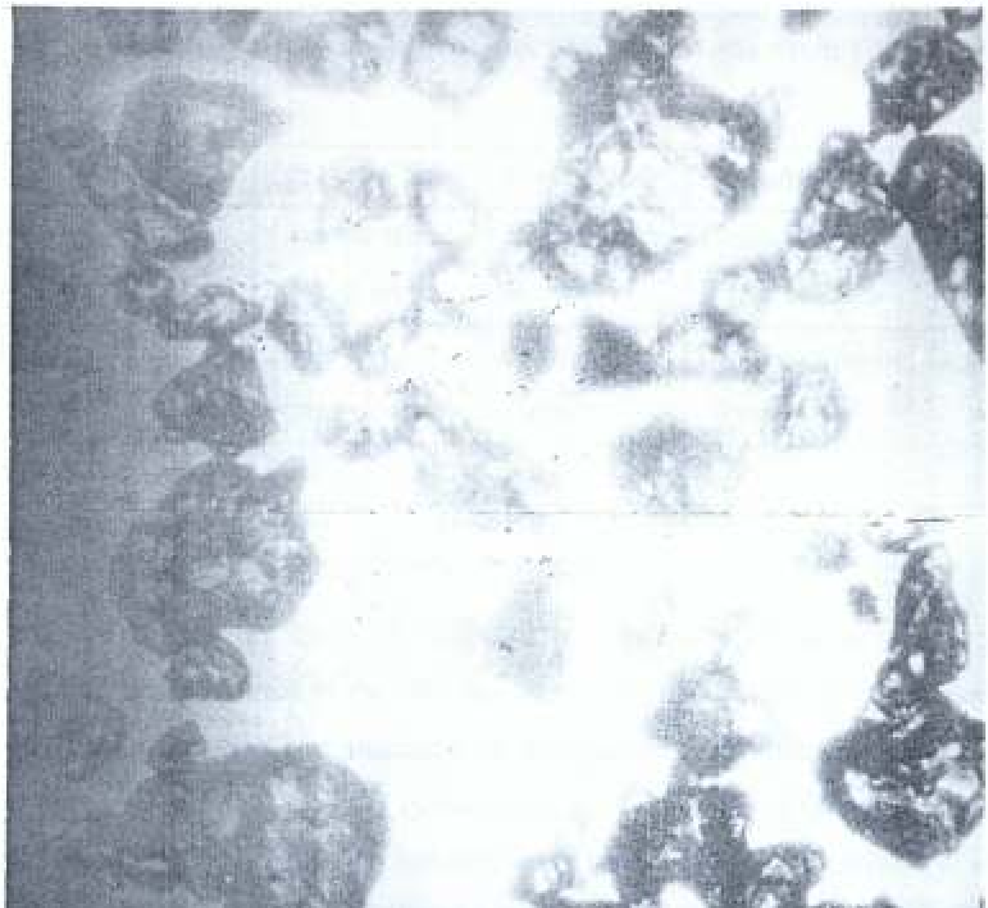

Plate 6: A Photomicrograph of Construction Sand

Table 4.2 Summary of Physical Properties of Filters Media From Different Sources

	Igbokoda Sand	River Sand	Construction Sand
Colour Moist Dry	Greyish white broken white	Light brown Brown	Greyish brown Redish brown
Odour Moist Dry	None None	None None	of Decomposing Organism None
Specific gravity	2.67	2.67	2.65
solubility in 40%Hcl	0.5%	1%	0%

Within the first six hours of filtration, it was observed that there was a sharp decline in the turbidity level of the effluent water when filter through the construction sand and Igbokoda sand. The similarity is the shape of the effluent turbidity curve between the Igbokoda sand and the construction sand could be attributed to their grain size composition. The fact the Igbokoda sand has an improved turbidity removal capability over the construction sand was a reflection of the percentage composition of grains sizes retained on sieve 0.150mm sieve. However, the river sand that seems coarser shows less turbidity removal even at a low filtration rate. Quantitatively, the average turbidity removal within the studied periods are 73.1% for Igbokoda sand, 55.1% for construction sand and 31.9% for river sand.

4.3.3 Filtration Rate

Table 4.4 shows the results of filtration time, headloss and filtration rate for the three samples. From the table, the mean value of filtration rate computed shows that more filtrate would be produced by the river sand within the five days duration of filtration followed by the construction sand when a unit headloss was considered. This can be attributed to the composition of the sand grains, the Igbokoda sand is finer thus effecting a slower filtration rate and generating more headloss. Figure 4.2 is a graphical illustration of the filtration rate and the filtration time. The shapes of Igbokoda sand and construction sand look somehow similar which further be attributed to the composition of the grain sizes in the filter bed. The curve for the river sand is an indication that the bed was more porous. Since media shape and size govern media voids which invariably affect the filtration rate and other effluent water qualities, the shape exhibited by the filtration rate and time curve and other effluent qualities results reflected in this thesis can be said to be justified.

4.3.4 Reduction in Total Hardness, Total Dissolved Solid and Conductivity

The overall results shown in tables 4.6 to 4.10 indicated that all the three sand samples reduced the total hardness available in the raw water to a different magnitude with an average percentage in reduction of 30.45%, 18.18% and 16.82% for Igbokoda sand, River sand and Construction sand respectively. The influent water hardness for this project can be regarded as slightly hard if we have to go by the account given by (Duggal 1993) which expenses scale of hardness from consumer point of view as follows:
0 - 50mg/l as soft, 50 - 100mg/l as moderatelty soft, 100 - 150mg/l as slightly hard, 150 - 200mg/l as moderately hard and over 250mg/l as hard.

Dissolved salts of magnesium and calcium are known causes of total hardness in water, similarly, dissolved salts enhance conductivity. It can be deduced from the experimental results that the reduction in total hardness also causes reduction in total dissolved solid and conductivity.

From the results, it can be seen that the Igbokoda sand showed that the conductivity of the effluent water can not be reduced beyond 140μmhos, for the five days monitoring, while the River sand and construction sand have their unit at 150μmhos and 230μmhos respectively. It was also observed that the lower the percentage of total hardness removal, the more the conductivity.

The reason for the reduction in the total hardness, total dissolved solid and conductivity is justified by the explanation given by Hofken (1981). He showed that clean quartz sand has negative charge and is therefore unable to absorb negatively charged particles, such as bacteria, colloidal matter of organic origin, anions of nitrate and so on. Thus, during the ripening period of slow sand filters, only positive charged particles are absorbed. However, it was noted in the same researchers work that the process could not continue unabated, at a stage when oversaturation occurs, the overall charges of the filters bed grains coatings reversed and become positive after which negatively charged particles would be attracted and retained.

Table 4.3 Filtration Time, Effluent Tubidity and Filtration Rate for All the Sand Stock Sources

Filtration Time (hours)	Igbokoda Sand		River Sand		Construction Sand	
	Filtration Rate (l/s)	Effluent Turbidity	Filtration Rate l/s)	Effluent Turbidity (NTU)	Filtration Time (/sec)	Effluent Turbidity (NTU)
6	11.0×10^{-3}	2.1	17.0×10^{-3}	2.0	18.5×10^{-3}	1.4
12	8.0×10^{-3}	2.3	15.8×10^{-3}	2.1	13.5×10^{-3}	1.4
18	8.0×10^{-3}	1.4	13.8×10^{-3}	2.4	7.5×10^{-3}	2.1
24	7.5×10^{-3}	1.4	10.5×10^{-3}	2.0	6.0×10^{-3}	2.1
30	7.5×10^{-3}	1.5	7.3×10^{-3}	2.1	5.5×10^{-3}	2.1

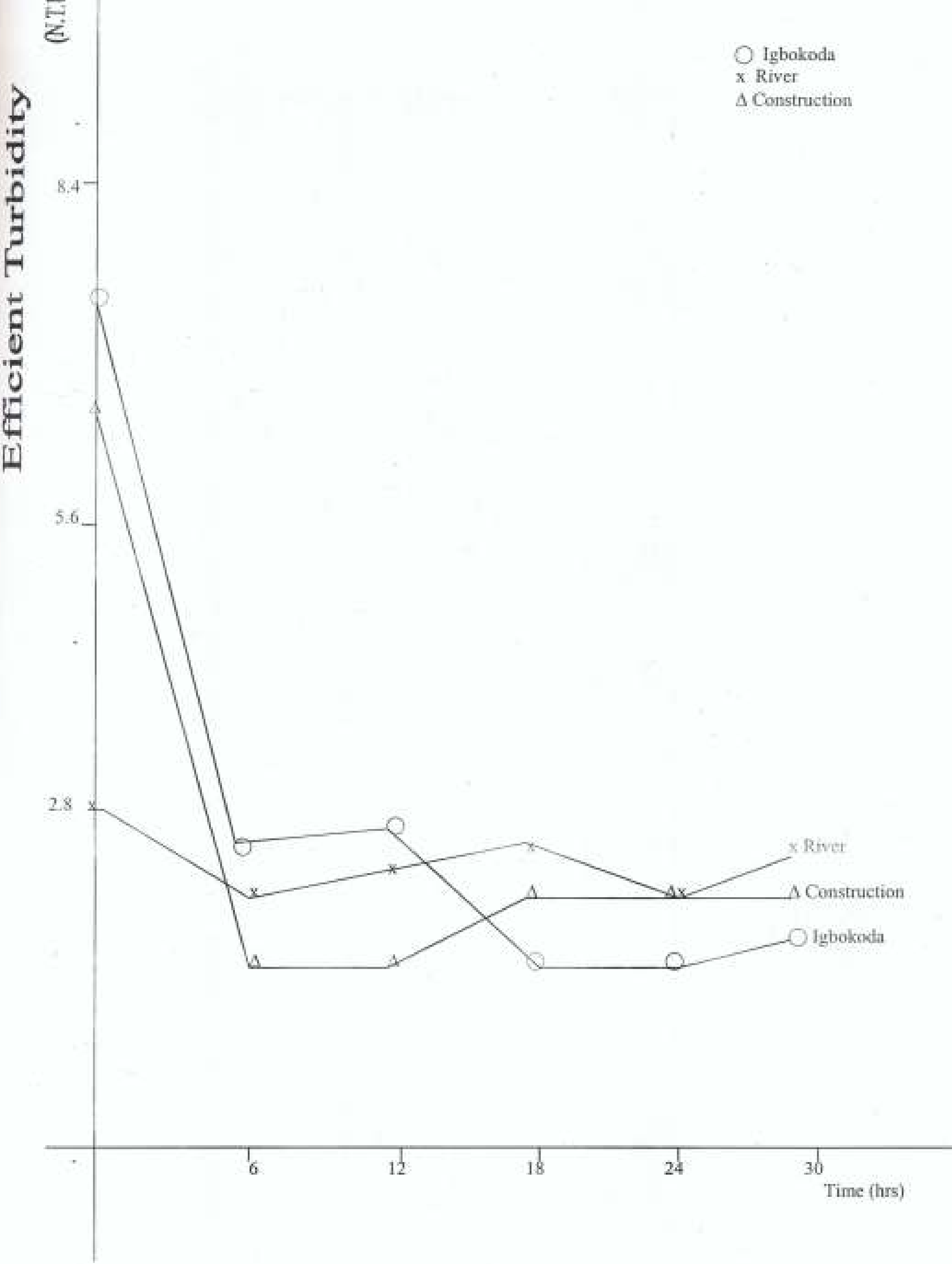

Figure 4.2. Variation of effluent turbidity with time

Table 4.4 The Relationship Between Filtration Time, Headloss and Filtration Rate for All the Sandstock Sources

Duration of filtration(hours)	Igbokoda Sand		River Sand		Construction Sand	
	Headloss(cm)	Filtration Rate(L/sec)	Headloss(cm)	Filtration Rate(L/sec)	Headloss(cm)	Filtration(L/sec)
6	46.80	11.0×10^{-3}	32.40	17.0×10^{-3}	30.70	18.5×10^{-3}
12	40.70	8.0×10^{-3}	40.55	15.8×10^{-3}	37.05	13.5×10^{-3}
18	44.20	8.0×10^{-3}	44.85	13.8×10^{-3}	39.30	7.5×10^{-3}
24	43.66	7.5×10^{-3}	44.80	10.5×10^{-3}	43.10	6.0×10^{-3}
30	43.35	7.5×10^{-3}	43.20	7.3×10^{-3}	46.10	5.5×10^{-3}
Mean Value	43.71	8.40	41.16	12.88	39.25	10.20

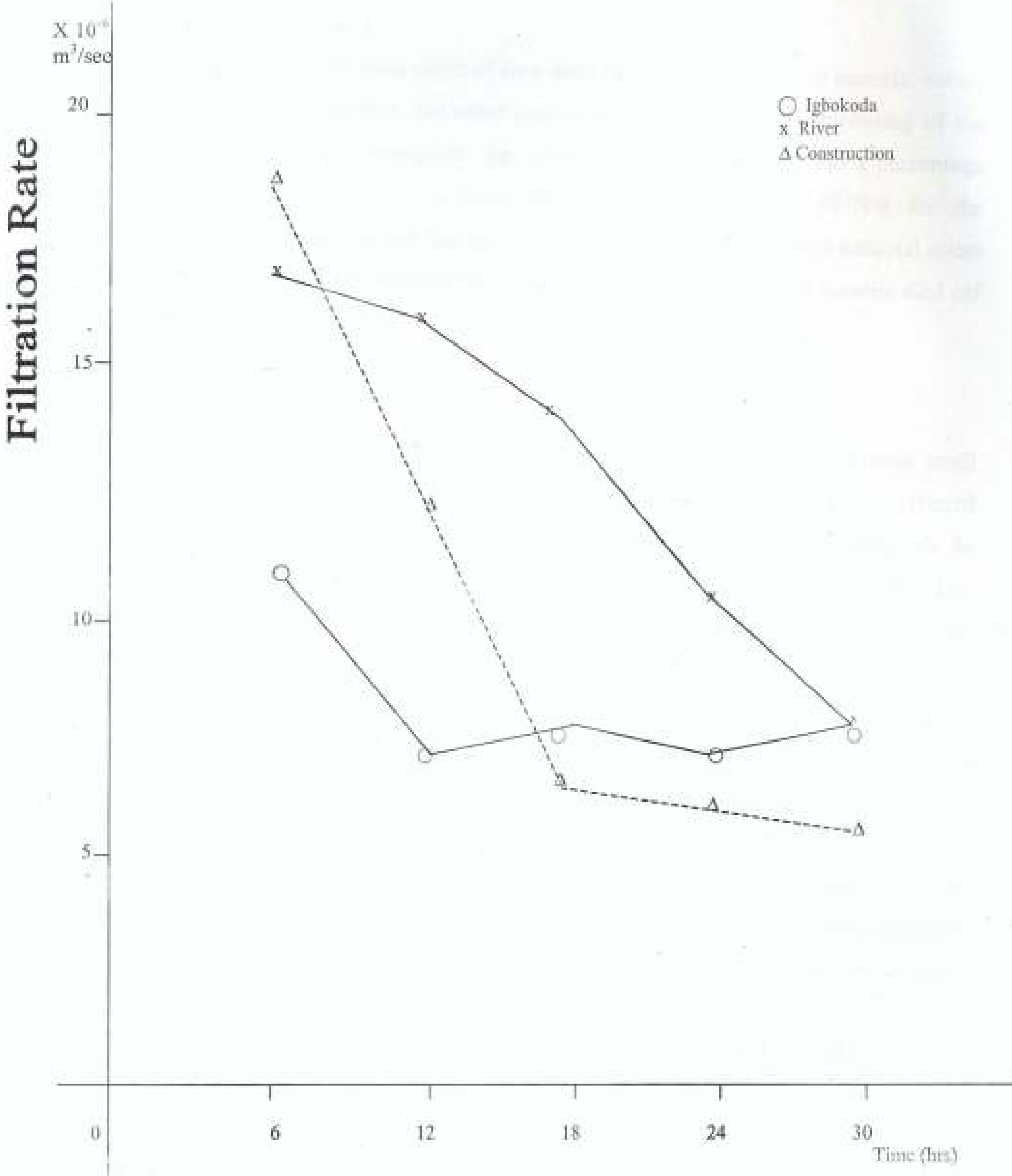

Figure 4.3. Variation filtration rate with time of filtration

4.3.5 Total Bacteria Count

The most important purification effect of slow sand filters is the removal of bacteria, which is achieved through adsorption and other processes. For the five days monitoring of the model filter used for this experiment, the influent total bacterial count had a percentage removal of 99.99% for Igbokoda sand, 99.98 for River sand and 99.79% for the construction sand. It can be stated that the three sources of sands reduce total bacterial count effectively. However, it was observed in Tables 4.6 - 4.7 that most of the bacteria died off before the last monitoring day.

4.3.6 Headloss

The resistance to flow of liquid through porous media is analogous to flow through small pipes and to the resistance offered by a fluid to settling particles. This resistance is referred to as headloss. Research work had developed equations whereby the headloss can be calculated while values have been computed for minor losses in reputable text books. Two methods were adopted for obtaining headlosses in this thesis, they are, direct measurement using a water manometers any by equation credited to Blake-Kozeny.

The result of direct measurement is as presented in table 4.4 while table 4.5 gives the results of the computed values. It can be deduced from table 4.5 that the smaller the value of sand grain diameter (d) the higher the headloss. Although one would have expected a close magin between the measured value and the calculated value, the variation could be attributed to the fact that so many assumptions were made in the calculated values as a result of limited laboratory equipment to determine their exact values. Also, when measured values were taken, the filter bed could not be considered clean because it has been charged for three days which would have affected the pores of the filter bed.

Figure 4.3 present the variation of headloss with filtration time. It can be observed that the curves for the sandstocks were similar to a large extent. The curvilinear shape shown after the 6 hours of filtration is an indication of strong surface removal characteristics which justified the findings by Cleasby (1968).

Table 4.5 Headloss Computations of a Clean Sand Bed for the Three Sources of Sand Under Consideration

VARIABLE	IGBOKODA SAND	RIVER SAND	CONSTRUCTION SAND
Water temperature 0C	24^0	24^0	24^0
Viscosity, n (Poise)	0.00894	0.00916	0.00916
Density, ℓ (kg/m^3)	999.1	996.82	996.82
Average grain diameter d (mm)			
a. From equation (2.8)	0.168	0.291	0.140
b. With d = D_{10}	0.174	0.250	0.120
Porosity (e) taken from Table 4.2	0.42	0.42	0.42
Depth of filter bed, L (mm)	1150	1150	1150
Particule spericity Ʉ	0.86	0.86	0.86
Face velocity, V from equation (2.5)	4.3	4.3	4.3
Headloss, H_1 (cm) from equation (2.9)	176.44	60.25	260.32
H_1 assuming d = D_{10}	164.48	81.63	354.33

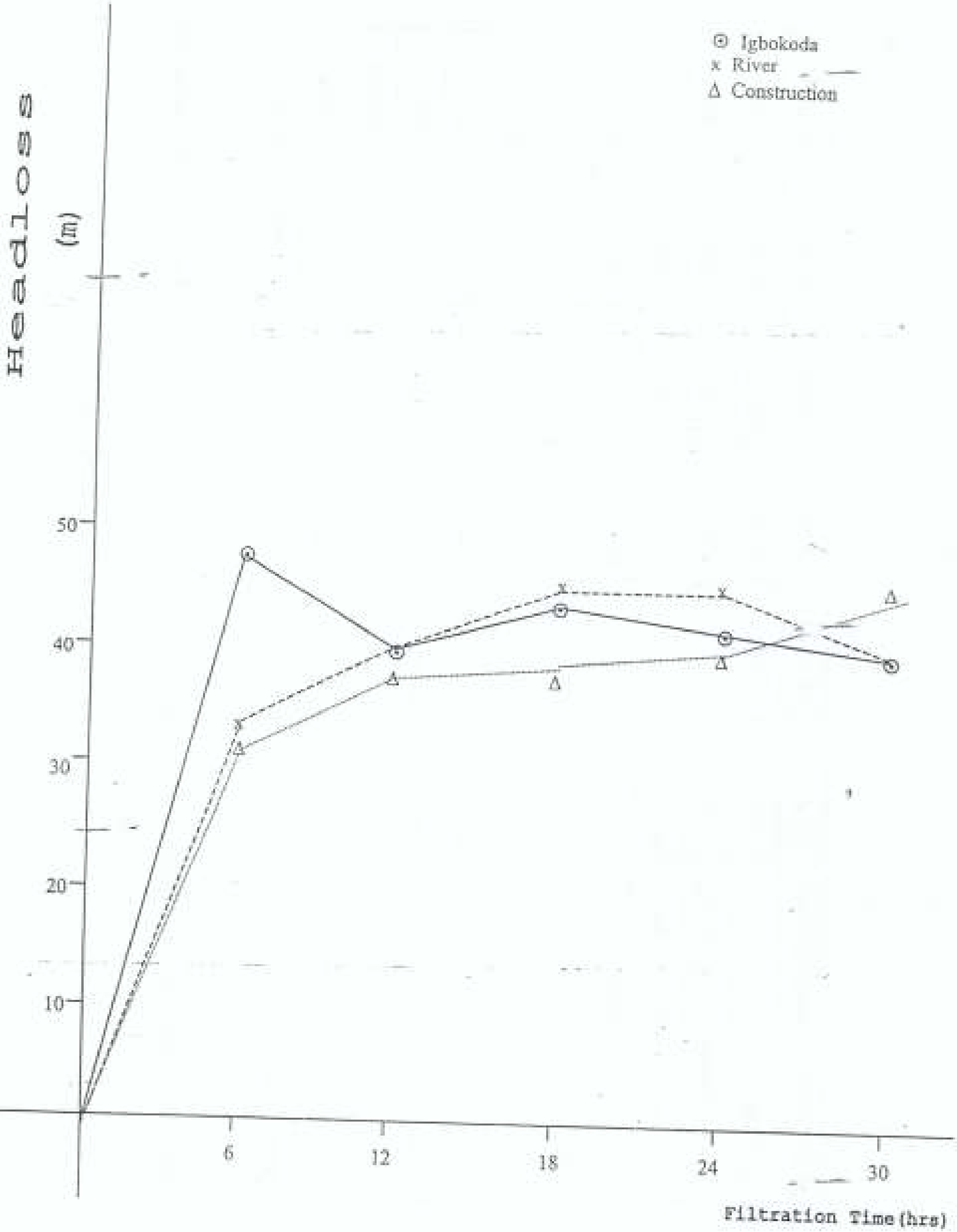

Figure 4.4 Variation of Headloss with Filtration time

TABLE OF THE EXPERIMENTAL DATA

Table 4.6: Influent and Effluent Water Quality Using Different Sources of Filter Media (First Day Monitoring)

Quality Parameter	Igbokoda Sand		River Sand		Construction Sand	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Colour	Greenish	Greenish	Greenish	Greenish	Greenish	Greenish
Odour	None	None	None	None	None	None
PH	6.5	6.5	7.1	7.0	6.7	7.5
Conductivity (μohm)	150	140	250	150	300	260
Turbidity (N.T.U)	7.0	2.1	3.0	2.0	6.3	1.4
Total Hardness (ppm)	112.10	80.07	84	64	152	88
Total Dissolved Solid (ppm)	0.17	0.022	0.036	0.031	0.036	0.032
Total Suspended Solid (ppm)	0.12	0.10	0.32	0.04	0.096	0.084
Chloride	57.38	57.38	40.30	40.30	23.08	23.08
Total Bacteria Count (per ml)	37.43	16.52	51.50	34.50	63.20	39.20

Table 4.7: Influent and Effluent Water Quality Using Different Sources of Filter Media (Second Day Monitoring)

Quality Parameter	Igbokoda Sand		River Sand		Construction Sand	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Colour	Greenish	Greenish	Greenish	Greenish	Greenish	Greenish
Odour	None	None	None	None	None	None
PH	6.5	6.4	7.4	7.7	7.9	8.2
Conductivity (μohm)	140	140	150	148	250	250
Turbidity (N.T.U)	6.7	2:3	2.8	2.1	4.9	1.4
Total Hardness (ppm)	108.09	75.07	68	56	112	124.1
Total Dissolved Solid (ppm)	0.10	0.10	0.02	0.02	0.04	0.02
Total Suspended Solid (ppm)	0.17	0.021	0.34	0.028	0.07	0.038
Chloride	57.38	57.38	40.30	40.30	23.08	23.08
Total Bacteria Count (per ml)	14.61	9.26	0.37	0.19	0.169	0.041

Table 4.8: Influent and Effluent Water Quality Using Different Sources of Filter Media (Third Day Monitoring)

Quality Parameter	Igbokoda Sand		River Sand		Construction Sand	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Colour	Greenish	Greenish	Greenish	Greenish	Greenish	Greenish
Odour	None	None	None	None	None	None
PH	6.7	7.4	7.4	7.7	7.8	7.7
Conductivity (μohm)	140	140	150	148	280	240
Turbidity (N.T.U.)	6.3	1.4	3.5	2.5	2.8	2.1
Total Hardness (ppm)	102.09	70.09	60.05	56.05	112	106
Total Dissolved Solid (ppm)	0.02	0.018	0.04	0.03	3.06	0.18
Total Suspended Solid (ppm)	0.08	0.01	0.20	0.19	8.4	2.6
Chloride	57.38	57.38	40.30	40.30	23.8	23.8
Total Bacteria Count (per ml)	9.16	7.81	0.28	0.11	0.109	0.05

Table 4.9: Influent and Effluent Water Quality Using Different Sources of Filter Media (Fourth Day Monitoring)

Quality Parameter	Igbokoda Sand		River Sand		Construction Sand	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Colour	Greenish	Greenish	Greenish	Greenish	Greenish	Greenish
Odour	None	None	None	None	None	None
PH	7.1	7.3	7.4	7.4	7.8	7.7
Conductivity (μohm)	140	140	150	150	260	240
Turbidity (N.T.U)	6.3	1.4	2.1	2.0	3.5	2.1
Total Hardness (ppm)	100.08	68.20	72.05	56.05	108	92.1
Total Dissolved Solid (ppm)	0.04	0.04	0.03	0.026	0.36	0.12
Total Suspended Solid (ppm)	0.05	0.04	0.04	0.026	0.60	0.20
Chloride	57.38	57.38	40.30	40.30	23.08	23.08
Total Bacteria Count (per ml)	0.86	0.025	0.065	0.015	0.072	0.020

Table 4.10: Influent and Effluent Water Quality Using Different Sources of Filter Media (Fifth Day Monitoring)

Quality Parameter	Igbokoda Sand		River Sand		Construction Sand	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Colour	Greenish	Greenish	Greenish	Greenish	Greenish	Greenish
Odour	None	None	None	None	None	None
PH	6.3	7.1	7.1	7.1	7.9	7.7
Conductivity (μohm)	140	140	150	150	230	230
Turbidity (N.T.U)	6.4	1.5	5.6	2.5	2.4	2.1
Total Hardness (ppm)	106.4	74.3	72.06	64.05	32	32
Total Dissolved Solid (ppm)	0.05	0.04	0.04	0.017	0.28	0.036
Total Suspended Solid (ppm)	0.05	0.04	0.08	0.06	0.426	0.30
Chloride	57.38	57.38	40.30	40.30	23.08	23.08
Total Bacteria Count (per ml)	0.011	0.00	0.010	0.00	0.13	0.00

CHAPTER FIVE

DESIGN OF SLOW SAND FILTER FOR A TYPICAL RURAL COMMUNITY

5.1 Background

For the purpose of applying some of the information obtained from the laboratory experiments, a typical rural farming community with a population of about 3,000 in 1991 along River Aigo in Ile-Oluji/Okeigbo local government area of Ondo State was selected.

The water quality analysis for the river was obtained from the Ondo State Water Corporation (Table 5.1). The river was considered suitable for the potable water supply for such a community by a slow-sand filtration system.

In conducting the experiments for the project, it was discovered that adequate storage time preceding filtration would enhance the reduction of the bacteria in the raw water, and the settlement of the settleable solids. Hence an adequate sedimentation basin must be provided along with the slow sand filters for the community.

Figure 5.1 is a sketch of process arrangement for a typical slow sand filtration system, suitable for rural community. The process entails an intake of water from the flowing river by gravity into a designed settling basin. A preliminary settling of settleable solids take place in this basin within a chosen detention time of 8 hours. The raw water from the settling basin is then fed into the filter units under gravity through a pipes for the main purification processes.

The filtrate from the filter units discharge into the clear reservoir to be disinfected by chlorination, prior to distribution through the service pipe network to the consumers.

The quantity of the clean sand sample from any of the sand stocks, required for the filter bed can be estimated since the percentage of usable sand had been determined by particle distribution analysis.

Table 5.1 Summary of the results of Water Quality Monitoring for River Aigo

Constitutent	Water Quality Parameters	
	January 1997	August 1997
Appearance	Clear	Brownish
pH	7.2	7.4
Turbidity	15.00	28.00
Temperature (^{o}c)	25.90	29.60
Total Dissolved Solid (g/cl)	0.03	0.04
Total Hardness (mg/l)	15.00	84.00
Calcium (mg/l)	8.00	33.60
Magnesium (mg/l)	5.00	50.00
Iron (mg/l)	1.05	1.20
Chloride (mg/l)	5.00	80.00
Copper	0.13	-
Phosphate	0.20	1.20
Chromium	0.20	-
Maganese (mg/l)	0.10	-
Sulphate (mg/l)	9.00	-
Nitrate	0.004	-
Ammonia (mg/l)	-	-
Total coliform count/100ml of sample	12.00	14.00
Flow rate (m/s)	0.11	0.25

(Data obtained from Ondo State Water Corporation, 1997)

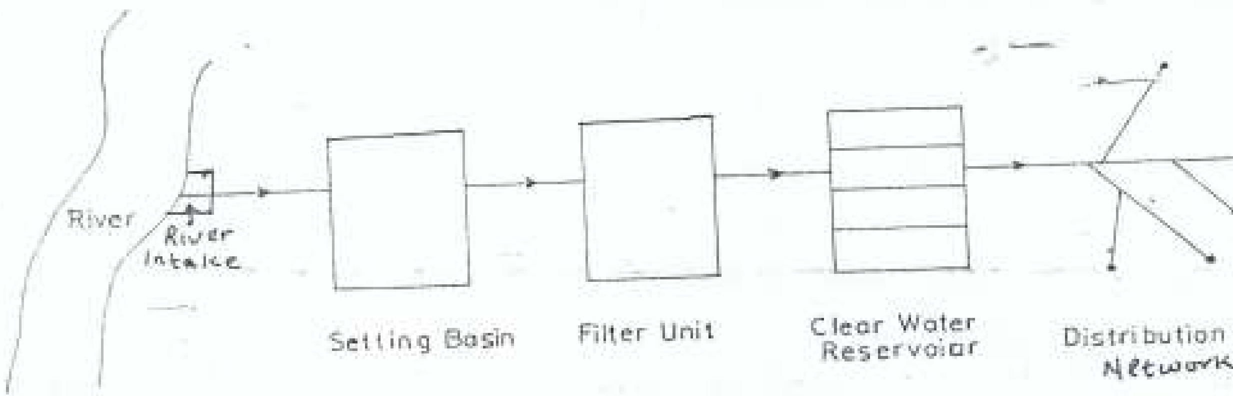

Fig. 5.1 Flowchart for a Simple Water Treatment by Slow Sand Filtration Technique.

5.2 Design Considerations

The number of filter units required for communities is a function of its population and the capacity of the sources of raw water. Table 5.2 gives the general guideline for determining the number of slow sand filter units required for different communities.

Table 5.2 General guideline for determining the number of slow sand filters required for different sized communities

Population	Total Number of Units	Reserved Capacity
2,000	2	100%
2,000 to 10,000	3	50%
10,000 to 60,000	4	33%
60,000 to 100,000	5	25%

(Source: Schulz and Okun, 1984)

Other considerations include the following:

i. The filtration rate of filter, to be kept at 0.10m/hr

ii. Mode of filter operation, that is whether the system would include a declining rate of filtration in the night. A declining rate of filtration is when no rate controllers are used and the filter inlet is placed below the minimum water level, filtration wil take place at a declining rate.

iii. The effective size of the filter medium which should be less than 0.35mm.

iv. Turbidity of the raw water, which should be less than 50 NTU where the filtration is not preceded by roughing filtration for a trouble free filter.

Table 5.3 is a summary of general design criteria for slow sand filters.

Table 5.3 General Design Criteria for Slow Sand Filters

Parameter	Range	Preferred value
Filtration velocity (m/s)	0.1 to 0.2	0.1
Depth of filter bed (m)	1 to 1.4	1.0
Area per filter bed (m^2)	10 to 100	-
Height of supernatant water (m)	1 to 1.5	1.0
Depth of system of underdrain (m)	0.3 to 0.5	0.4
Specification for filter bed sand particles	°Cu=1.5 to 3.0 Effective size Minimum of 2	
Number of filters	Minimum of 2	

(Source: Schulz and Okun, 1984)

5.3 Population Projection

A population density of 3,000 as given by 1991 census for the community can be projected to the end of the design period of 15 years, using

$$p_p = p_o (1 + r/100)^n \qquad (5.1)$$

where:

p_p	=	Projected Population
p_o	=	Present Population
r	=	Growth rate per annum
n	=	Projected year

The projected population, is 5,508. A population of 6,000 is used for the design.

5.4 Water Demand Projection

The water demand projection is a function of projected population, and expected per capit consumption with allowances for waste, industrial and commercial requirements.

It is assumed that a 30% and 70% of the population will be served by hous connection and stand pipe respectively, and the expected daily consumption per person i 80 litres per day for house connection and 30 litres per day for stand pipe. Thus, per capita consumption for house-hold using stand pipe is 126 m^3/day while the per capita consumptio using house connection is 270 m^3/day.

Giving a total of 270 m^3/day for the community. With 10% allowed for wastage, th total gross demand is 304m^3/day approximated to 350m^3/day for this design.

5.5 Design of Sedimentation Basin

A sedimentation basin unit is required in the slow sand filtration to improve the quality o water going into the filter bed by the settlement of the collodial particles in the raw water Table 5.4 gives a summary of the design criteria for a rectangular sedimentation basin Although the figures mentioned are not universally applicable they may serve as a goo guide for specific designs.

Table 5.4: Design Criteria for Rectangular Sedimentation Basins

PARAMETER	SYMBOL	RANGE OF VALUES
Detention time	V/Q	4-12 hours
Surface loading	Q/A	2m/day - 10m/day
Depth of the basin	H	1.5 - 2.5m
Weir overflow rate (outlet)	Q/R	3-10m^2/hr
Length/width ratio	L/W	4:1 up to 6:1
Length/depth ratio	L/H	25:1 up to 35:1 or 5:1 up to 20:1 for small basins

(Source: IRC Publication, 1982)

The various parameters are defined by:

H = depth (in metres)

L = length (metres)

W = width (metres)

V = volume of the basin $(m)^3$

Q = raw water feed flow (m^3/hour)

A = bottom area of the basin (m^2)

R = total length of overflow of the outlet weir (m)

5.5.1 Calculation

Assuming a one shift operation of 8 hours with no declining rate of filtration at night, the rate of intake is:

$$Q = \frac{350m^3}{8hrs} = 43.75m^3/hr$$

Detention time, t, =V/Q is also taken to 8 hours, that is, the volume V treated daily is $350m^3$ being the total capacity of the sedimentation basin.

Assuming a depth of 1.8m for the basin, the surface area is $194.44m^2$. The dimensions of the basin are width, W = 6.24 m, and length, L = 31.20m.

Therefore, a suitable sedimentation tank of 31.20m x 6.24m x 1.8m would be required.

5.6 Filter Box Design

The following parameters determine the minimum depth of filter box.

a.	Free board above supernatant water level	0.20m
b.	Supernatant water	1.00m
c.	Filter medium	1. 00m
d.	Layer of gravel support	0.30m
e.	Brick filter bottom	0.20m
		2.70m

5.6.1 System Design

Given	i.	Population	=	6000
	ii.	Water demand	=	$350m^3$/day
	iii.	Filtration rate	=	0.10m/hr
	iv.	Single shift of 8hrs daily operation with 16hrs declining rate of filtration.		

Applying equation 2.5, Area of filter X $= \dfrac{350m^3/d}{0.1m/h \times 8 \times 0.7} = 233.33m^2$

From table 5.1, the number of filter required is 3 units

$\therefore$ Area of each filter $= \dfrac{233.33}{3} = 77.78m^2$

Assume a filter depth of 3m, volume of each filter unit = 77.78 x 3 = $233.34m^3$. For a circular bed, diameter D = 9.95m

It is necessary however, to provide a spare unit in the case of emergency breakdown, or need for repair or maintenance of the any of the other. Hence 4 Nos filter units are recommended to be built. The standard layout, inlet structure and weir chamber are illustrated in figures 5.2, 5.3 and 5.4 respectively.

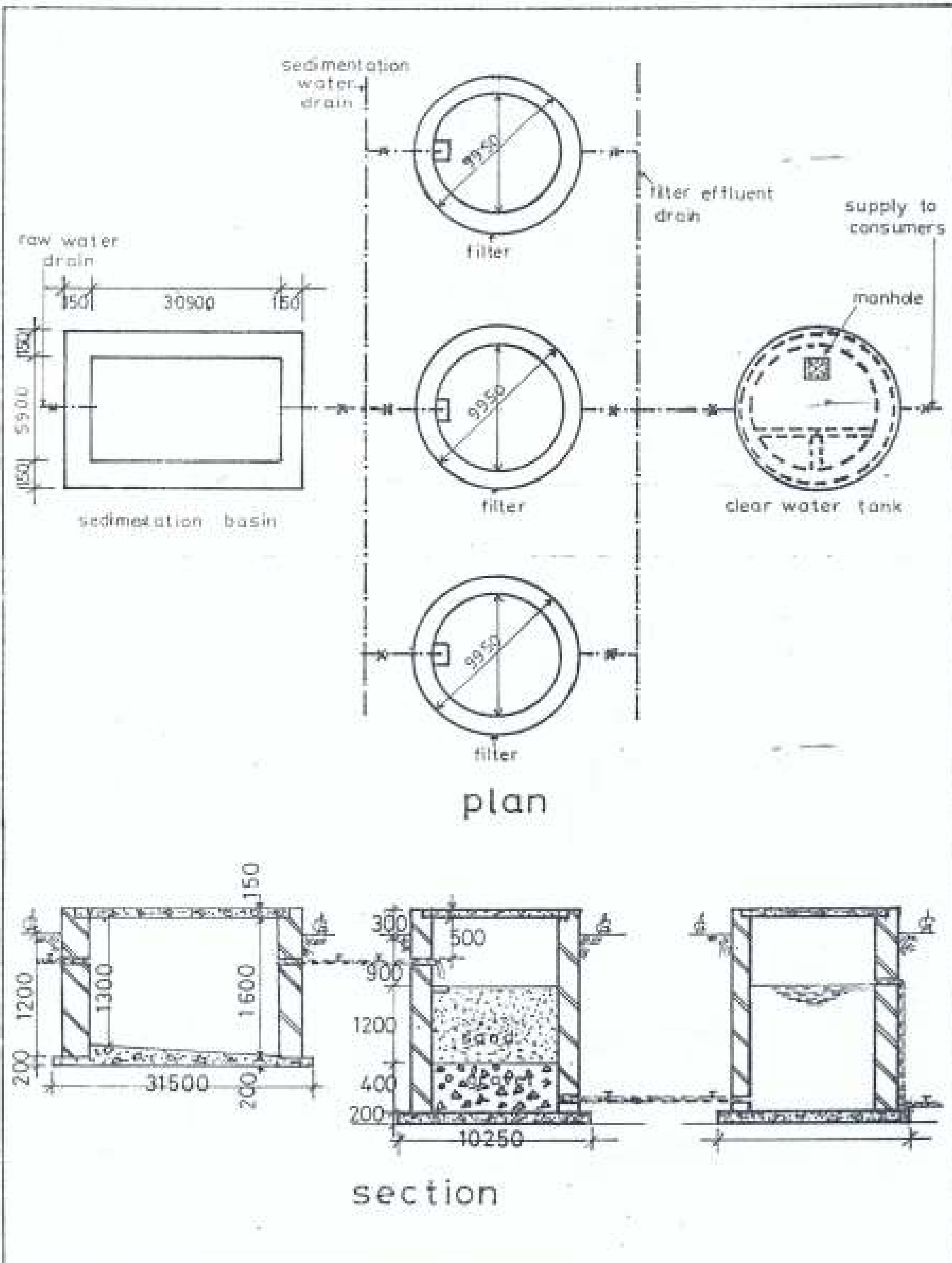

Fig. 5.2: Slow Sand Filtration.

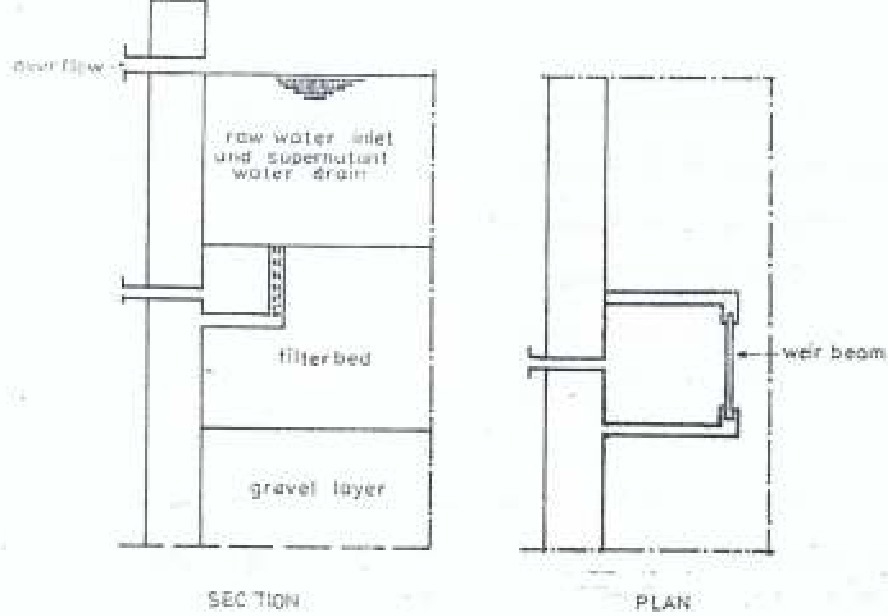

Fig. 5.3: Inlet Stucture

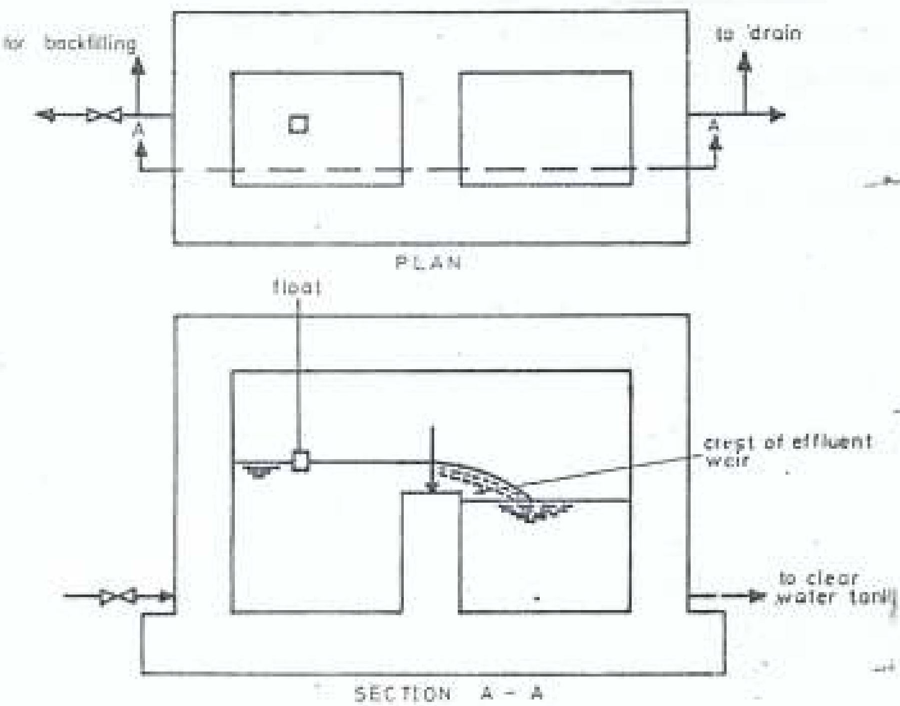

Fig. 5.4: Standard Weir Chamber

5.7 Use of Experiment Results

The most useful information from the experiment work for the construction of a filtration system for a community is the determination of the relative volumes of sand from the respective stocks (Igbokoda, Construction and River) that can be used in the filter bed. The filter box as designed has a filter sand capacity of $77.76m^3$. Thus, from the percentage composition of useful sand in each washed sand stock analysed, a total of $81.14m^3$ of Igbokoda sand or $98.24m^3$ of construction sand or $129.77m^3$ of River sand would have to be hauled to prepare the required $77.76m^3$ filter sand.

It should be noted that filtration rate of 0.10m/hr (100 litres/h/m^2) has been used in both experiment and the typical designed filter, a rate applicable to all the three stocks of sand.

For economic reasons, it would be better to adopt the night time declining rate of filtration. This in effect would reduce the volume of sand stock required for the bed, since the act of declining rate has considerably reduced the filter diameter from 13.63m to 9.95m.

In using any of these materials, it is necessary to:

i. Wash the sand thoroughly to eliminate silt and clay particles;

ii. Test its dissolubility in HCl to ensure that there is no fossil material; and

iii. Perform the particle analyses to determine useful sand grains and thus the proportion of the sand stock to be used.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The physical properties of the sand stocks indicated that they are good filter media for slow sand filtration systems. The specific gravity fell within the range of 2.65 to 2.67, and solubility in 40% HCl soaked for 24 hours was negligible. Effective size and uniformity coefficients were within the recommended value of 0.15mm to 0.35mm and 2 to 3 respectively, as recommended by several authors. The three sources of sands samples could not produce any noticeable change as per colour and odour, implying that an alternative method should be sought for colour and odour removal.

The percentage yield of the useful sand, that is, those that passed sieve size 0.850mm but retained on 0.150mm yielded approximately 96% of Igbokoda sand, 76% of construction sand and 60% of River sand. In effect, if the abundant Igbokoda sand is exploited on commercial basis, for slow sand filter medium, only about 4% of a well washed Igbokoda sand stock would be wasted.

The result of the sieve analysis on the sand stock samples could serve as a guide to direct the local contractors to a source from where a maximum yield of a specific grain size could be obtained. From the results obtained using each of the sand samples as filter medium separately, the Igbokoda sand ranked the best followed by the construction sand in turbidity removal as well as reduction in total hardness. This could be as a result of the fact that Igbokoda sand has a greater proportion of fine sand coupled with the fact that it appeared more rounded in structure.

If the samples from the three sources under consideration in this research work is well washed, no leachate would be experienced in the filtrate.

To prevent leachate of pollutant, the materials has to be washed thoroughly and dried under high hygienic condition.

6.2 Recommendations

To confirm that grain structure is responsible for conductivity reduction, it would be desirable to determine the exact shape factor and how it affects adsorption.

Although, this might not be a problem in the rural environment where cheap labour could be obtained, too much energy is required for washing and drying the sand stocks. Efforts should be geared towards the mechanisation of the washing and drying that would not alter the grain sizes and shapes.

Since sufficient storage time would improve the quality of the raw water, the proper pre-filtration storage should always be provided for slow-sand filtration system for a small community.

From the observation that the larger the effective size of the sand the less the headloss, it is recommended that in designing slow sand filters, effective size of grains selected should be close to the maximum allowable.

As this study has not optimized the sand stocks, mixing of these samples should be studied for optimization. Hence, the percentage composition of each grain size to produce the best filtrate in each sample could be determined.

Further work is required to determine that relationship of headloss to the percentage composition of the grain sizes used.

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