DESIGN AND DEVELOPMENTOF GREYWATER TREATMENT UNIT FOR IRRIGATION PURPOSE

BY

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CERTIFICATION

This project report entitled " Design and development of greywater treatment unit for irrigation purpose" by Otuya Ifeanyi Austine, 96/5289EA meets the award of the degree of Bachelor of Engineering **(B.Eng)**, in Agricultural Engineering Department, School of Engineering and Engineering Technology, Federal University of Technology Minna. It is approved for its contribution to knowledge and literary presentation and in partial fulfillment for the award of the Bachelor degree.

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DEDICATION

This work is dedicated to thc glory of God Almighty and to the memory of my parents.

ACKNOWLEDGEMENT

I hereby acknowledge and appreciate God Almighty who, despite all the odds, gave me the grace to embark upon this work and finish it.

I also thank my supervisor Engr. Bashir Mohammed for giving me the motivation to carry out this work and for his constructive criticisms in the course of the work. This has been of immense benefit to me. I also thank Engr. (Dr.) D. Adgidzi, HOD Agric Engineering Department and all lecturers in the department.

I also thank my family for their encouragement and support. Mention must be made of my mother, Mrs. Otuya, Mrs. Olomah and my sister Miss. Aisha Adole. I must specifically mention my wonderful mentor, friend and brother, Mr. Alex Osula, Hadiza Adole, Dr. Otis. Thank you very much for all your encouragement, support and financial assistance.

ABSTRACT

The greywater treatment unit was evolved, designed and constructed with the intention of controlling the pathogenic and chemical load of greywater in the course of using it for irrigation. On evaluating the unit, it brought down the BOD level of the sample from within the campus from 100mg/l to 0.4mg/l. It also brought down the sodium level from 173mg/l to 0.036mg/l thereby reducing the SAR of the water. It reduced electrical conductivity, brought carbonates to zero level and reduced concentration of other metallic ions. It reduced the E.coli content of the sample from 143CFU/100ml to zero. This means it has brought down the pathogenic level of the sample. It also reduced total plate count from 349 to 18. It also brought down the pH level from 9.16 to 8.4, which is within acceptable standards of 6.5 to 8.5. However, the dissolved oxygen content was reduced to 0.70mg/l. This is very unusual as the dissolved oxygen content is supposed to increase as a result of the aeration process.

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CHAPTER ONE

INTRODUCTION

1.1 Background

The use of greywater (this is wastewater that contains about 70% bathwater and 30% wastewater from the kitchen and laundry) around the environs of FUT Minna, Niger State, Nigeria can no longer be ignored. Much greywater is released into the river flowing behind the school campus and this has become a major irrigation water source in the dry seasons. Thus, as this trend cannot be changed, it becomes necessary that a thorough analysis of this greywater samples be undertaken to determine its degree of usefulness and adverse effects it has on human health and the environment. This should also lead to the evolvement of a process by which if applied, the adverse effects of greywater use for irrigation will be brought to the barest minimum possible.

In many arid and semi-arid countries water is becoming an increasingly scare resource and planners are forced to consider any sources of water which might be used economically and effectively to promote further development. At the same time, with population expanding at a high rate, the need for increased food production is apparent. The potential for irrigation to raise both agricultural productivity and the living standards of the rural poor has long been recognized.

Irrigated agriculture occupies approximately 17 percent of the world's total arable land but the production from this land comprises about 34 percent of the world total. This potential is even more pronounced in arid areas, such as the Near East Region, where only 30 percent of the cultivated area is irrigated but it produces about 75 percent of the total agricultural production. In this same region, more than 50 percent of the food requirements are imported and the rate of increase in demand for food exceeds the rate of increase in agricultural production (Shaval HI et al. 1985).

Whenever good quality water is scarce, water of marginal quality will have to be considered for use in agriculture. Although there is no universal definition of marginal quality water, for all practical purposes it can be defined as water that possesses certain characteristics which have the potential to cause problems when it is used for an intended purpose. For example, brackish water is marginal quality water for agricultural use because of its high dissolved salt content, and municipal wastewater is marginal quality water because of the associated health hazards.

From the viewpoint of irrigation, use of 'marginal' quality water requires more complex management practices and more stringent monitoring procedures than when good quality water is used. This project deals with the agricultural use of greywater which is primarily domestic sewage water.

Expansion of urban populations and increased coverage of domestic water supply and sewerage gives rise to greater quantities of municipal greywater. With the emphasis on environmental health and pollution issues, there is an increasing awareness of the need to dispose of these greywaters safely and beneficially. Use of greywater in agriculture could be an important consideration when its disposal is being planned in arid and semi-arid regions. However, it should be realized that the quantity of greywater available in most countries will account for only a small fraction of the total irrigation water requirements. Nevertheless, greywater use will result in the conservation of higher quality water and its use for purposes other than irrigation. As the marginal cost of alternative supplies of good quality water will usually be higher in water-short areas, it makes good sense to incorporate agricultural reuse into water resources and land use planning.

Properly planned use of municipal greywater alleviates surface water pollution problems and not only conserves valuable water resources but also takes advantage of the nutrients contained in sewage to grow crops. The availability of this additional water near population centers will increase the choice of crops which farmers can grow. The nitrogen and phosphorus content of sewage might reduce or eliminate the requirements for commercial fertilizers. It is advantageous to consider effluent reuse at the same time as greywater collection, treatment and disposal are planned so that sewerage system design can be optimized in terms of effluent transport and treatment methods. The cost of transmission of effluent from inappropriately sited sewage treatment plants to distant agricultural land is usually prohibitive. Additionally, sewage treatment techniques for effluent discharge to surface waters may not always be appropriate for agricultural use of the effluent.

Many countries of the world have included greywater reuse as an important dimension in water resources planning. In the more arid areas of Australia and the USA, greywater is used in agriculture, releasing high quality water supplies for potable use. Some countries, for example, the kingdom of Jordan and the Kingdom of Saudi Arabia, have a national policy to reuse all treated greywater effluents and have already made considerable progress towards this end. In China, sewage use in agriculture had developed rapidly since 1958 and now over 1.33 million hectares are irrigated with sewage effluent. (FAO,1992)

In Northern Nigeria during the dry seasons, greywater effluent is used for agricultural reuse. Moreover, the water in this case is untreated and this poses a lot of hazards for the health of the final consumers of agricultural products. Thus, the purpose of this project is to evolve and design a simple greywater treatment unit which can be accessible to and affordable by local farmers, since most countries of sub-Saharan Africa and the third world cannot afford to treat all greywaters produced in their countries. Less than 1% of wastewater is treated in Nigeria (Aberuagba, Mohammed, 2001).

1.2 The aim and objectives of the project

The project aims at attaining the following aim and objectives:

1.2.1 Aim

To adopt the established physio-chemical and bacteriological design parameters for the treatment of greywater into a greywater treatment unit.

1.2.2 Objectives

(i) To appraise recommended treatment options and select most appropriate options under prevailing conditions.

(ii) To use selected options to draw up a design for a greywater treatment unit.

(iii) To construct a greywater treatment unit based on the design drawn up.

(iv) To carryout a performance evaluation of the greywater treatment unit.

(v) To compare test results of performance evaluation with WHO/FAO standards for irrigation water quality.

(vi) To determine efficiency of the greywater treatment unit.

(vii) To recommend possible modifications in order to enhance efficiency of the treatment unit.

1.3 Scope and limitation of the study

The scope of this work covers the design, construction and evaluation of a treatment unit for greywater only. This implies that it is not designed to carryout treatment process on solid sewage effluents. It is also limited basically to primary treatment levels and biological treatment processes.

1.4 Project justification

This project is of utmost importance to the society and environment because it seeks to:

(i) eliminate harmful effects of the use of greywater for irrigation processes.

(ii) stop the contamination of groundwater by untreated greywater.

(iii) stop the contamination of surfacewater by untreated greywater.

(iv) improve soil conditions by preventing the build up of chemical pollutants in soil (i.e. heavy metals).

(v) stop the creation of habitats for disease vectors.

(vi) stop eutrophication in canals and drainages conveying greywater.

CHAPTER TWO

LITERATURE REVIEW

2.1 Summary of results of pre-treated greywater analysis.

The pre-treatment analysis of the greywater (i.e. bath water and kitchen and laundry water) samples taken are the bacteriological, physical and chemical analysis. The tables below summarize the results obtained.

2.1.1 Bacteriological qualitative analysis.

Ascertaining the number of <u>Esherichia coli</u> in the greywater samples involved three tests. These are the presumptive, confirmed and the completed tests.

Table 2.1 below shows the results of the presumptive test carried out on the four greywater samples

Table 2.1: Results of the presumptive test carried out on four grex water samples

ater nple	Acid and gas											
	LB2x-10ml			LB1x-1ml			LB1x-0.1ml			*Reading*	*MPN*	*Range 95% Probability*
pe	1	2	3	4	5	6	7	8	9			
	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	3-3-3	1,100	150-4,800
	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	3-3-3	1,100	150-4,800
	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	3-3-3	1,100	150-4,800
	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	3-3-3	1,100	150-4,800

Table 2.2 also shows the results of the confirmed test while Table 2.3 shows the results of the completed test. Table 2.4 shows the results of the total viable plate count of the greywater samples.

Table 2.2: Results of the confirmed test carried out on the four grey water samples

Water Sample	Coliforms		Potability
	EMB agar plate	Macconkey agar plate	
A	Pinkish mucoid and metallic sheen colonies	Pinkish colonies and Whitish colonies	Non - potable
B	Pinkish mucoid and metallic sheen colonies	Pinkish and red colonies	Non - potable
C	Metallic sheen colonies	Red colonies and whitish colonies	Non - potable
D	Mixed pinkish/mucoid metallic sheen colonies	Pinkish colonies and Pale Pink colonies	Non - potable

Table 2.3: Results of the completed test on the four grey water samples

Water source	Lactose broth A/G (+) or (-)	Gram's stain Reaction Morphology	Potability	
			Potable	Non-potable
A	A/G	Gram –ve rods short and +ve cocci in shape	___	✓
B	A/G	Gram +ve and –ve short rods	___	✓
C	A/G	Gram –ve short rods and long rods with +ve cocci	___	✓
D	A/G	Gram –ve short rods and +ve cocci	___	✓

Table 2.4: Results on the total viable plate count carried out on the four grey water samples

Sample Source	Colonies (CFU) E.coli	Indicator Organism	Total Count
A	163	186	349
B	107	203	310
C	242	170	412
D	115	243	358

Note:
A: Grey water sample from girls' hostel
B: Grey water sample from boys' hostel
C: Grey water sample from Tudun/ Fulani
D: Bathwater
+ve: Positive
-ve: Negative
A: Acid production
G: Gas production

The presumptive test (Table 2.1) shows the presence of coliforms in the water samples along with their probable amounts in the samples. Although coliforms are present one is not sure if Esherichia coli, which is the indicator coliform is present. The confirmed test (Table 2.2) confirms the presence of E.coli in the water samples. Only E.coli would produce the above observations in a water sample.

The completed test (Table 2.3) confirms absolutely the presence of E.coli in the samples. The total viable plate count (Table 2.4) shows the total number of coliforms in the water samples.

Therefore, since E.coli is present in the water samples in probable quantities as shown in Table 2.1 and 2.4, these shows that the water samples contain pathogenic microorganisms. Thus, it becomes necessary that the proposed greywater treatment unit should be capable of eliminating all E.coli in the samples before the samples can be used for irrigation.

2.1.2 Implications of the results

From the results of the bacteriological analysis, it can be seen that The number of E.coli present is about 1,100. This means that the greywater definitely contain lots of pathogenic organisms. Using this greywater in its raw state to irrigate crops especially vegetables and crops that are eaten uncooked becomes very risky.

This is because the crops may surely be contaminated with these pathogens. When these crops are eaten, they could infect man and animals with disease. Thus, it is necessary that the intended greywater treatment unit should be designed in such a way that it will reduce the bacteriological load of the greywater.

2.1.3 Chemical qualitative analysis

The table below gives a summary of the physio-chemical analysis of the four greywater samples.

Table 2.5: Results of the physio-chemical analysis of the four grey water samples

S/NO	PHYSIO-CHEMICAL ANALYSIS	SAMPLE "A"	SAMPLE "B"	SAMPLE "C"	SAMPLE "D"
1.	Temperature (^{o}C)	28	22	24	28
2.	PH	9.16	8.70	8.24	8.65
3.	Electrical conductivity uS/cm	598	206	311	219
4.	Total dissolved solid (mg/l)	89.3	126.3	61.10	54.05
5.	Total hardness	45	63	41	56

	($mgCaCO_3/l$)				
6.	Dissolved oxygen (mg/l)	1.29	0.96	0.85	1.00
7.	Chloride Cl^- (mg/l)	165.0	13.65	10.50	12.25
8.	Sulphate SO_4^{2} (mg/l)	212.5	60.6	58.7	62.3
9.	Calcium Ca^{2+} (mg/l)	50	48	41	34
10.	Iron Fe^{2+} (mg/l)	0.63	0.69	0.72	0.86
11.	Magnesium Mg^{2+} (mg/l)	0.30	0.25	0.41	0.36
12.	Phosphate PO_4^+ (mg/l)	5.27	5.61	6.02	5.31
13.	Nitrate NO_3 (mg/l)	0.65	0.64	0.65	0.52
14.	Sodium Na^+ (mg/l)	173	165	23	89
15.	Potassium K^+ (mg/l)	72	62	37	77
16.	Bicarbonate HCO_3 (mg/l)	143.6	87.6	107.6	99.6
17.	Biological oxygen demand (mg/l)	100.0	106.0	104.0	103.0
18.	Chemical oxygen demand (mg/l)	165	12.0	8.0	10.0

2.1.4 Implications of the results

The most important parameter in these test is the BOD. As can be seen, the BOD level is 100mg/l in sample A while they are higher in other samples. This means that the greywater samples are highly contaminated pathogenically; therefore the greywater treatment unit should embrace methods of bringing this level to a reasonable minimum. The electrical conductivity of sample A is much higher than that of B, C and D. This implies that the salt concentration of sample A is very high. To buttress this fact, it can been seen that the chloride concentration and the COD of sample is far higher than those of the other samples. The pH of samples A, B and C is too high. This shows that the greywater samples contain too many salts. The sodium concentration is too high in all samples. This will cause much harm to the plants and soil, as the SAR will become too high.

2.2 Treatment types for sewage/greywater

There are various treatment types for the treatment of sewage/greywater. The degree of risk of infection from the sewage-borne pathogens depends on many factors, including the efficiency of greywater treatment processes in removing or inactivating the pathogens and the survival of the pathogens in the greywater effluent in the soil and on the crops.

2.2.1 Primary Treatment

This comprises preliminary treatment, for example by screening and grit removal, to remove large particles and abrasive materials and sedimentation to remove settleable solids, organic and inorganic. Primary treatment removes about one-third of the oxygen demanding organic materials, provides some partial removal of bacteria and viruses (which are attached to precipitated solids) and precipitates a significant proportion of the non-soluble species of heavy metals and toxic organics.

2.2.2 Secondary Treatment

This step is the biological oxidation of organic matter in which a large mass of microorganisms is contacted with the sewage/greywater in an aerobic environment. The microbes consume the soluble and colloidal organics producing more microbes, which are removed in final sedimentation, and carbon dioxide, which escapes to the atmosphere. There are several processes available for this stage, varying in the way in which contact is achieved. Many studies have indicated that the removal of pathogens is time dependent and therefore the effectiveness of the secondary treatment process in the removal of pathogens is proportional to the detention time within the system. This varies from the trickling filter and activated sludge processes, which normally have detention times measured in hours rather than days, with a pathogen removal efficiency of less than 90% to oxidation ponds and lagoon systems with detention times of weeks and removals in excess of 97%. However, because of the large numbers of pathogenic organisms involved, even 99.99% removal is

sometimes inadequate to achieve the standards for reuse. The removal of heavy metals and other toxic organics is very variable and so far no satisfactory figure could be placed on their removal.

2.2.3 Tertiary Treatment

Advanced treatment processes can be applied to greywater to meet the most stringent requirement for reuse. Principal processes include chemical treatment, coagulation, flocculation and filtration, activated carbon absorption, reverse – osmosis, electrodialysis, micro-screening, ion exchange and disinfection, by chlorination or ozonation.

2.3 Operations involved in treatment

The methods used for greywater treatment can be classified as physical unit operations and chemical and biological unit processes. Physical unit operations are used to describe those methods in which change is brought about by the application of physical forces such as gravity settling. In chemical and biological unit processes, change is brought about by means of chemical and biological reactions.

2.3.1 Contaminants of concern in greywater

The important contaminants in greywater and the reasons for concern are summarized in Table 2.5.Of the contaminants listed in Table 2.5, suspended solids, biodegradable organics and pathogenic organisms are of major importance, and the greywater treatment unit is designed to accomplish their removal. Although the other contaminants are also of concern, the need for their removal is considered as very paramount.

2.3.2 Levels of Treatment

Treatment levels are often identified as primary, secondary, or advanced (also known as tertiary). Primary treatment involves separating a portion of the suspended solids from the greywater. This separation is usually accomplished by screening and sedimentation. The effluent from primary treatment will ordinarily contain considerable organic material and will have a relatively high BOD. Secondary treatment involves the further treatment of the effluent from primary treatment. The removal of the organic matter and the

Table 2.5: Important contaminants in greywater and the unit operations, processes, and treatment systems used for their removal.

Contaminants	Reason for importance	Unit operation, unit process or treatment system
Suspended solids	Suspended solids can lead to development of sludge deposits and anaerobic conditions when untreated	Sedimentation, screening and communition, filtration variations, flotation. Chemical polymer

	when untreated greywater is discharged in the aquatic environment.	Chemical polymer addition,, coagulation/sedimentation, land treatment systems.
Biodegradable organics	Composed primarily of proteins, carbohydrates. Biodegradable organics are measured most commonly in terms of BOD (biochemical oxygen demand) and COD (chemical oxygen demand). It discharged untreated to the environment; their biological stabilization can lead to the depletion of natural oxygen resources and to the development of septic conditions.	Activated sludge variations, fixed-film trickling fillers, fixed-film rotating biological contractors, lagoon variations, intermittent sand filtration, land-treatment systems, physical-chemical systems.
Pathogens	Communicable diseases can be transmitted by the pathogenic organisms in greywater.	Chlorination, hypochlorination, ozonation, ultra violet light, land treatment system, sand filtration.
Nutrients	Both nitrogen and	Nitrogen removal:

	phosphorus are essential nutrients for growth, along with carbon. When discharged to the aquatic environment, these nutrients can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land as a result of irrigation they can also lead to the pollution of groundwater.	suspended-growth nitrifications and denitrification variations, fixed film nitrification and denitrification variations, iron exchange, breakpoint chlorination Land-treatment systems, phosphorus removal :Biological-chemical phosphorous removal, metal salt addition/sedimentation, land treatment systems.
Refractory organic and Organic priority pollutant	These organics tend to resist conventional methods of wastewater treatments. Many of the priority pollutants pose health risks. Typical examples include surfactants, phenols and agricultural pesticides.	Carbon absorption, tertiary ozonation, land-treatment system.
Dissolved inorganic salts	Inorganic constituents such as calcium, sodium, and sulphate are added to the original domestic water supply	Ion exchange, reverse osmosis, electrodialysis.

	as a result of water use and may have to be removed if the greywater is to be reused.	

Table 2.6: Applications of physical unit operations in greywater treatment

Operation:	Application
Screening:	Removal of coarse and settleable solids by interception (surface straining).
Communition:	Grinding of coarse solids to a more-or-less uniforms size.
Flow equalization:	Equalization of flow and mass loadings of BOD and suspended solids.
Mixing:	Mixing of chemicals and gases with greywater, and maintaining solids in suspension
Flocculation:	Promotes aggregation of small particles into larger particles to enhance their removal through gravity sedimentation.
Gas transfer:	Addition and removal of gases; gas stripping
Filtration:	Removal of fine residual suspended solids remaining after biological or chemical treatment.

Residual suspended material is generally accomplished by biological processes. The effluent from the secondary treatment usually has little BOD_5 and may contain several milligrams per liter of dissolved oxygen. Advanced treatment is used for the removal of dissolved and suspended materials remaining after normal biological treatment when required for reuse purposes like drinking or for the control of eutrophication in receiving waters. Only primary and secondary treatments are considered in this work.

2.3.3 Physical Treatment Methods

Physical treatment methods, as reported in Table 2.6, include flow metering, screening, communition, grit removal, sedimentation and filtration. Except for filtration, each of these unit operations are incorporated in most modern treatment plants. Although metering is not in a strict sense, a physical treatment method, it is a critical factor in the control and monitoring of wastewater treatment plants regardless of size.

2.3.4 Screening

In most modern wastewater treatment plants, coarse screens or bar racks with 50mm openings or larger are used to remove large floating objects from wastewaters. They are installed ahead of pumps to prevent clogging. The materials removed usually consist of wood, rags, and paper that would not putrefy and may be disposed of by incineration, burial or dumping. Medium screens have openings ranging from about 12 to 40mm. Coarse and medium screens should be large enough to maintain a velocity of flow through their openings under 1m/sec. This limits the headloss through the screens and reduces the opportunity for screenings to be pushed through openings. Fine screens with openings 1.6 to 3mm are often used to pretreat industrial wastewater or relieve the load on sedimentation basins at municipal plants where heavy industrial waste are present. They will remove as much as 20% of the suspended solids in wastewaters. A coarse screen or shredder to remove the large particles should ordinarily precede a fine screen.

2.3.5 **Sedimentation**

Plain sedimentation is the quiescent settling or storage of waters such as would take place in a reservoir, lake, or basin, without the aid of chemicals. This natural treatment results in the settling out of suspended solids; reduction of hardness, ammonia, lead, cadmium and other heavy metals; breakdown of organic chemicals and faecal coliform; removal of color (due to the action of sunlight); and die-off of pathogenic micro-organisms principally because of the unfavorable temperature, lack of suitable food and sterilizing effect of sunlight. Certain microscopic-organisms, such as protozoa, consume bacteria, thereby aiding in purification of the water. Also, the material to be removed is high in organic content (50 percent to 75 percent) and has a specific gravity of 1.2 or less. The settling velocity of these organic particles is commonly as low as 1.25m/h. A sloping bottom facilitates the removal of the sludge. To get satisfactory performance from a sedimentation tank, the inlet must be designed to cause a uniform velocity distribution in the tank. This may be accomplished by placing baffles just downstream from the inlet. Because large amounts of scum usually accumulate on the surface of sedimentation tanks, scum-removal facilities must be provided. A properly designed sedimentation basin will remove 50 to 60 percent of the suspended solids in untreated wastewater.

2.3.5 **Aeration**

Aeration is a natural or mechanical process of increasing the contact between water and pure oxygen or air. It is used in the treatment of raw water (meant for human consumption) for the purpose of releasing entrained gases, adding oxygen, reducing iron and manganese content, odour and generally improving the chemical and physical characteristics of the water. It is also used in the biological treatment of greywater for the purpose of reducing the BOD of the organic matter content in the water. This is done by converting organic matter to cell tissues. These cell tissues are then subsequently removed. The conversion is done using oxygen.

The microorganisms responsible for the conversion can be maintained in suspension or attached to a fixed or moving medium. Such biological treatment processes are known as aerobic suspended growth or attached growth processes. The activated sludge process is the best-known example.

In the activated sludge process, untreated or settled wastewater is mixed with 20 to 50 percent of its own volume of return activated sludge. The mixture enters an aeration tank where the organisms and greywater are mixed together with a large quantity of air. Under these conditions, the organisms oxidize a portion of the waste organic matter to carbon dioxide and water and synthesize the other portion into new microbial cells. The mixture then enters a settling tank where the flocculants microorganisms settle and are removed from the effluent stream. The settled microorganisms or activated sludge are then recycled to the head end of the aeration tank to be mixed again with wastewater. This process is illustrated in figure 2.2.

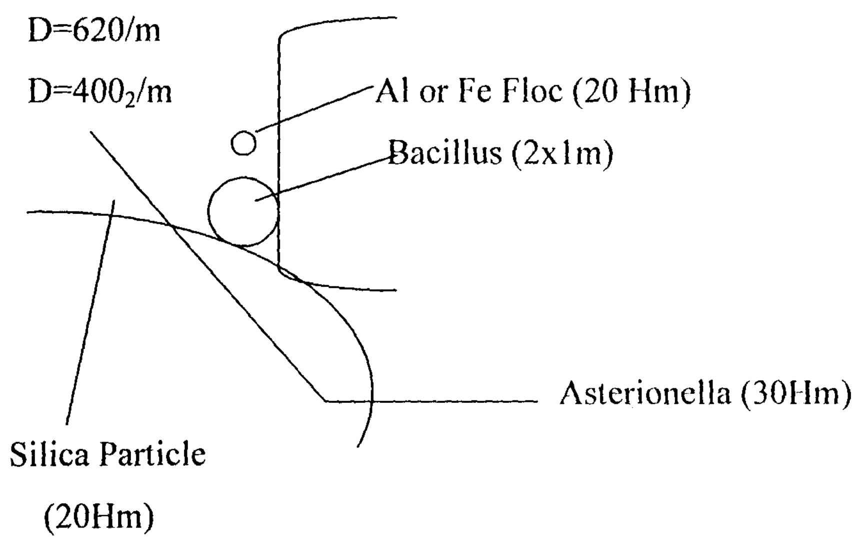
In the proposed greywater treatment plant, air will be supplied to the greywater. This will instigate the growth of bacteria. These bacteria will act as the breakdown mechanism of all organic matter in the water and reduce the chemical constituents like iron, manganese etc.

2.3.6 **Filtration**

Filtration is the purification process whereby water to be treated is passed through a porous medium. During this passage, water quality improves by the removal of suspended and dissolved solids contents, the removal of floating and colloidal matter removal of bacteria and other pathogenic microorganisms and changes in its chemical constituents. The overall removal of impurities which is associated with the process of filtration is mostly brought about by the following combination of phenomena:

i. **Mechanical Straining:** This is the process involving the removal of particles of suspended matter that are too large to pass through the interstices. As such, it takes place at the top surface of the filterbed and is generally independent at the filtration rate. This is illustrated in the figure 2.3 below.

Figure 2.3: LIMITATIONS OF MECHANICAL STRAINING



D = grain diameter

d = diameter of enclosed circle

If floc formation occurs in the sand bed, the flocs will be retained with this process. During filtering (or filter run) mechanical straining becomes more effective due to depositions which reduce poor sizes until clogging hinders filtration.

ii. **Sedimentation:** This process removes particulate suspended matter of finer sizes than the pore openings by precipitation upon the surface of the sand grains. With a porosity p, one m^3 of spherical filter grains having a specific diameter has a cross surface area $A = \underline{6} (1\text{-}p)\ m^2$. However, only the fraction of this surface area which faces up will be available for sedimentation.

iii. **Adsorption:** This is the most important purifying process in rapid sand filter (RSF). It removes finely divided suspended matter as well as colloidal and molecular dissolved impurities. The forces of adsorption exert their influence over extreme short distances.

iv. **Chemical Activities:** This is the process by which dissolved impurities are either broken down into simpler, less harmful substances or converted into insoluble compounds which can be removed by any of the three previous processes thereafter.

v. **Biological Activities:** These are most predominant in slow sand filters (SSF) which form the living quarters for organisms at the top of the filter bed usually called schmutzkdecke. The biochemical activities of microorganisms living here result into high improvements in bacteriological quality of water being filtered. Due to the high filter bed porosity, RST brings about very negligible improvements of bacteriological quality of filtered water. These processes also breakdown organic matter to such harmless compounds as water, CO_2, NO_3, PO_4 by mineralization which are discharged with the filtrate.

2.3.7 **Slow Sand Filter**

A slow sand filter consists of a watertight basin, usually covered, built of concrete and equipped with a rate controller and loss of head gauge. The following activities take place in the slow sand filter.

i. Biological processes occur mostly at the top layer of the filter bed which is called "schmutzkdecke".

$$\text{Organic matter} + O_2 \text{ ------ mineralization ----- } CO_2 + H_2O + \text{inorganic}$$
$$\Downarrow$$
$$(\text{like } NO_3\text{-}, SO_4^{2}\text{-}, PO_4\text{-})$$

For this layer to function properly:

O_2 concentration >4mg/l

Thus aeration before SSF is necessary inorder to ensure better function since dissolved oxygen levels will be low in greywater.

i. Removal of bacteria by straining, sedimentation, adsorption and dying away due to lack of food of animal origin takes place in the SSF bed.

ii. The better the formation of fauna (animal origin matter) and flora (plant origin) in the schmutzkdecke, the higher the removal of E. coli, pathogens, and other intestinal bacteria.

iii. Algae can grow in the supernatant (especially if greywater is highly organically polluted. Excess algae results in clogging of the SSF, therefore no schmutzkdecke formation as a result of frequent cleaning of the bed. To prevent alga growth, the filter should be covered inorder to prevent light.

2.4 Recent Works on Sewage Treatment

Sewage treatment researches and development have recently been carried out in some other places. In Ahmadu Bello University, Zaria, an aerated lagoon that can reduce over 99% BOD level has been developed. In Ibadan, the Nigeria Breweries established an activated sludge process and oxidation ponds to treat wastewater.

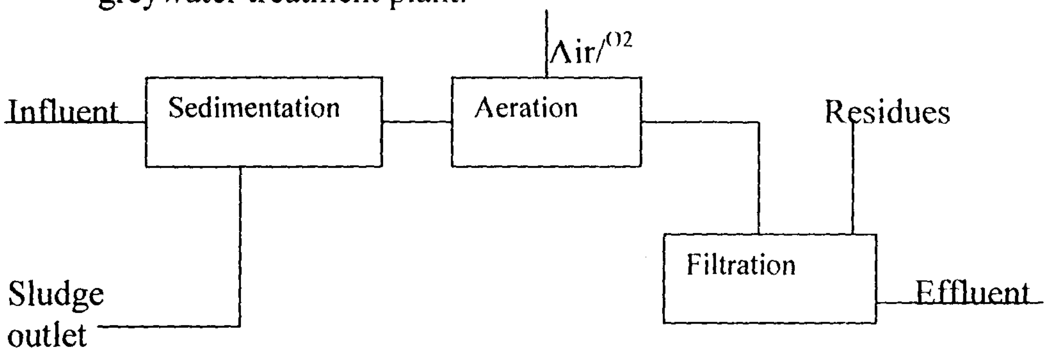
CHAPTER THREE

DESIGN CONSIDERATIONS, CONSTRUCTION METHODOLOGY AND PERFORMANCE EVALUATION.

3.1 Design of treatment unit.

The figure below represents the flow diagram for the operation processes of the greywater treatment unit. It shows basically the processes of sedimentation, aeration and filtration.

FIGURE 3.1 Flow diagram for the operation processes of the greywater treatment plant.



After the flow diagram has been developed, the next step in design involved selection of design criteria and sizing the treatment units. Design criteria were mainly selected on the basis of theory the results of bench tests and preliminary studies like determining settling velocities, permeabilities of different grades of sands, gravels etc and the past experience of the designer.

3.2 Design of sedimentation tank.

In designing the sedimentation tank, the following design criteria were followed:

i. Given Q and the settling distribution curve , $A = \frac{Q}{So}$,

So was chosen according to the effluent water quality required which is established by laboratory tests on greywater.

ii. Inorder to ensure minimal or no reduction in basin settling efficiency and to simulate quiescent conditions, the sedimentation tank required that Reynold's number and Froude's number were kept in such a way that:

$$\mathrm{Re} = \frac{Vo * R}{v} < 2000 \quad \text{and} \quad Fr = \frac{Vo^2}{gR} > 10^{-5} \text{ (Flow stability)}$$

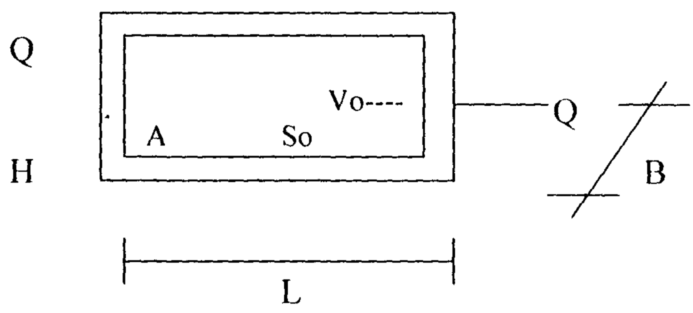
This is also to take care of basin instability and short-circuiting.

iii. Scour was prevented from occurring by making sure that Vo < Vs

iv. The shape of the settling zone was designed in such a way that it met hydrodynamic requirements on the one hand and economic considerations on the other hand.

Please note that:

A	=	Plan area of the tank
Q	=	Discharge rate of the tank
So	=	Overflow rate or surface load of the tank
Re	=	Reynold's Number
Fr	=	Froude's number
Vo	=	Horizontal flow velocity (m/s)
R	=	Hydraulic radius
v	=	Flow viscosity
Vs	=	Bottom Scour velocity



$$Vo = \frac{Q}{B \times H} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where B = Breadth of Tank

H = Height of Tank

L = Length of Tank

Applying proportionality,

$$\frac{So}{Vo} = \frac{H}{L} \therefore \Rightarrow So = Vo.\frac{H}{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Substituting (2) into (1),

$$So = \frac{Q \times H}{L \times B \times H} = \frac{Q}{B \times L} = \frac{Q}{A}$$

Assume tank can sediment 100l/day of greywater, assume 1.2mx0.2m tank,

therefore Q = 100l/day = $0.1m^3$ = 1.16×10^{-6} m^3/sec

therefore $So = \frac{Q}{A} = \frac{1.16 \times 10^{-6}}{(1.2 \times 0.2)} m/s = 4.8 \times 10^{-6} m/s$

therefore So = $4.8x10^{-6}$ m/s

Tank Design:

Assume Q = $1.16 \times 10^{-6} m^3$/sec

So = 4.8×10^{-6}m/sec

$So = \frac{Q}{A}$ therefore $A(\text{reqd.}) = \frac{Q}{A} = \frac{1.16\times10^{-6}}{4.8\times10^{-6}} = 0.242\,\text{m}^2$

Assume coldest temp of greywater T = 26°C, V = 0.9 x 10^{-6} m^2/sec

β = 0.05 & ^ = 0.03, P_s = 2500kg/m^3

Note that β = grain friction factor

^ = hydraulic friction factor

P_s = mass density of particles

1st trial:

L = 0.6m, B=0.4m, H=0.4m; volume = 0.096 m^3

(a) $Td = \frac{V}{Q} = \frac{0.096\times24}{0.1} = 23.04 hours \approx 23 hours$

Where Td = Detention time

(b) $\text{Re} = \frac{Vo\times R}{v}$ where $Vo = \frac{Q}{B\times H} = \frac{1.16\times10^{-6}}{0.4\times0.5} = 7.25\times10^{-6}\,m/s$

$$R = \frac{0.4\times2}{2+(0.4\times2)} = \frac{0.8}{2.8} = 0.29 \approx 0.3$$

Note that P = wetted perimeter

$$\therefore \text{Re} = \frac{Vo\times R}{v} = \frac{7.25\times10^{-6}}{0.9\times10^{-6}}\times0.3 = 2.42 < 2000$$

Re = 2.42<2000 ....good (laminar flow)

(c) $Fr = \frac{Vo^2}{gR} = \frac{7.25^2\times10^{-12}}{9.81\times0.3} = 1.8\times10^{-5} \geq 10^{-5}$ (Nearly stable flow condition)

(d) $Vs = \frac{8B}{\wedge}\times\frac{Ps-Pw}{Pw}\times g\times\frac{V}{A}$

(e) $= \frac{8\text{x}0.05}{0.03}$ x 1.5 x 9.81 x 0.4 x 10^{-6}

$= \quad 8.6\text{x}10^{-3} > Vo$

$Vs = 8.6\text{x}10^{-3}$ m/s

$\therefore$ Vs > Vo, since Vo = 7.25 x 10^{-6}m/s (ok)

(f) Height of settling zone, $H = \frac{1}{12} \times L^{0.8}$

$= \frac{1}{12} \times 0.6^{0.8} = 0.055m$

A depth of 0.055m was added to the height to act as sludge storage depth.

$\therefore$ LxBxH = 0.6m x 0.4m x 0.455m

3.1.2 Design of Aeration Tank

The aeration tank is a kind of aerated lagoon. Air is supplied to the system using an oxygen pump.

The rate of oxidation of greywater in the aeration tank is found to be well approximated by a first order equation.

$$Le = \frac{Li}{1 + k_1 t^*} \qquad \ldots\ldots\ldots\ldots (1)$$

Le is the BOD_5 of the effluent which is due to two separate fractions:

a. the small amount of the influent waste not oxidized in the tank

b. the bacterial cells synthesized during oxidation. These fractions are generally referred to as the "soluble" and "insoluble" BOD respectively.

It is convenient (and infact conceptionally more correct) to apply first order kinetic only to the removal of the soluble fraction:

$$Fe = \frac{Li}{1 + kt*}$$

where Fe = soluble BOD_5 in the effluent (i.e. fraction of the influent BOD_5 which escapes oxidation), mg/c

K'= first order rate constant for soluble BOD_5 removal, h^{-1}

It should be assumed that all the influent BOD_5 is assumed to be soluble (i.e. Fi = Li).

The design value for K is taken to be $5h^{-1}$ at 20°C, it's value at other temperatures can be estimated from the equation:

$$KT = 5(1.035)^{t-20} \text{.....................................} (2)$$

The quantity of bacteria synthesized in the aeration tank is related to the quantity of soluble BOD_5 oxidized.

$$\frac{dX}{dt} = \frac{XdF}{dt} \text{.................................} (3)$$

where X= cell concentration in tank, mg/l

Y = yield coefficient (declined by this equation as the weight of cells formed per unit weight at soluble BODs consumed).

Note that Y is typically 0.6 – 0.7. On a finite time basis, say one retention time, equation 3.3 can be rewritten for the whole tank as:

$$\frac{XV}{t*} = \frac{Y(Li - Fe)V}{t*} \text{....................................} (4)$$

where V = aeration tank volume, m^3.

The rate of cell synthesis must be balanced by the sum of the rates which cells leave the aeration tank in the effluent and at which they die in the aeration tank. The rate at which the cells leave the tank is QX where Q is the flow through the aeration tank. The rate at which some of the cells in the tank die is proportional to the quantity of cells present; it is usually given as bxv where b is the rate of autolysis in h^{-1} (typically b= $0.07h^{-1}$ at 20°C). Thus:

$$\frac{Y(Li - Fe)V}{t^*} = bxv + QX \text{ ....(5)}$$

(rate of synthesis = (rate of autolysis)+(rate of loss in effluent)

Rearranging and writing V/Q as t*

$$X = \frac{Y(Li - Fe)}{1 + bt^*} \text{ ....(6)}$$

This quantity of cells x can be converted to an equivalent ultimate BOD by considering the chemical equation for their complete oxidation:

CsH_7NO_2 + $5O_2$ -------- $5CO_2 + 2H_2O + NH_3$

(Cells)

113 5x32

Thus 1g of cells has an ultimate BOD of (5x32/113) = 1.42g.

Since BOD_5/BOD_u = 2,1g of cells has a BOD_5 of 0.95g. Thus the effluent BOD_5 Le is given by:

Le = Fe + 0.95X -------------------- 7

Oxygen requirement.

The quantity of oxygen required for bio-oxidation is the amount of total (i.e. soluble + insoluble) ultimate BOD removed.

RO_2 = 1.5(Li – Le)Q ------------------ 8

Substituting equation 7:

RO_2 = 1.5(Li – Fe)Q - 1.42Q

Design

Lets take t* = 3h, k = $5h^{-1}$, b = $0.07h^{-1}$ and y = 0.65

Therefore from equations 1, 5 and 7

$$Fe = \frac{Li}{1 + bt^*} = \frac{100}{1 + (5 \times 3)} = 6.25$$

$$X = \frac{Y(Li - Fe)}{1 + bt^*} = \frac{0.65(100 - 6.25)}{1 + (0.07 \times 3)} = \frac{60.9375}{1.21} = 50.4$$

$$Le = Fe + 0.95X = 6.25 + (0.95 \times 50.4) = 54.13 g/l = 0.54 mg/l$$

Tank size: The depth of tank is assumed to be 0.54m

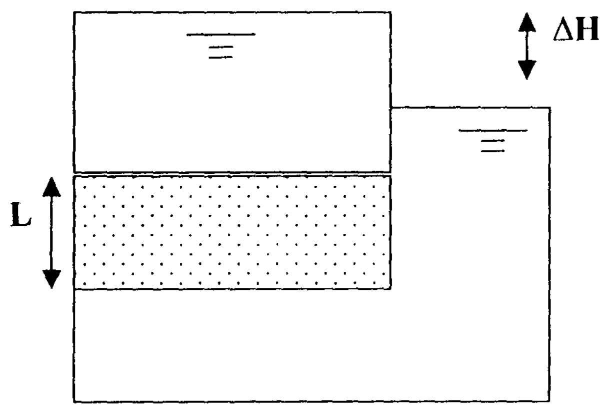
The tank mid-depth area is given by the equation

$$A = \frac{Qt^*}{D} = \frac{0.5 \times 3}{0.54} = 2.8 m^2$$

Estimate the quantity of oxygen required from equation 8:

$$RO_2 = 1.5(Li - Le)Q = 1.5(100 - 0.54)0.5 = 75 kg\ O_2/h$$

3.1.3 Design of filtration tank



From Darcy's law,

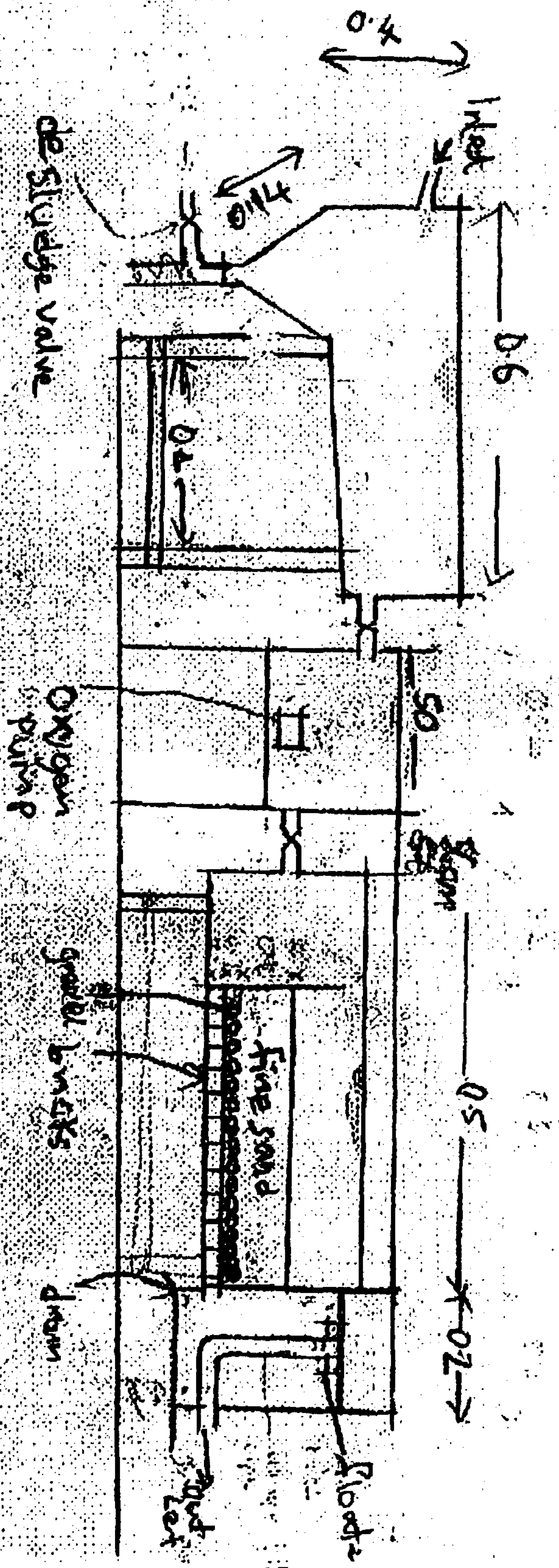
$$V = \frac{Q}{A} = K\frac{\Delta H}{L}$$

Where K = permeability of filter material

$\frac{\Delta H}{L}$ = hydraulic gradient

To design the filtration tank, we must know the hydraulic gradient ΔH of

Figure 3·1: A CROSS SECTION DIAGRAM OF THE GREYWATER TREATMENT UNIT



B: All dimensions are in metres.

3.6 Greywater treatment unit costing

The table below describes the material costing of the greywater treatment unit.

TABLE 3 Material costing of treatment unit

S/NO	ITEM DESCRIPTION	MATERIAL	QUANTITY	UNIT COST (N)	TOTAL COST (N)
1	Sedimentation tank	Graded Steel	$1^{1}/2$	1,200.00	1,800.00
2	Filtration tank	Graded Steel	$1^{1}/2$	1,200.00	1,800.00
3	Aeration tank	Plastic material	1	800.00	800.00
4	Oxygen pump	Electronic device	1	4,500.00	6,500.00
5		Bodyfiller hardener	1	600.00	600.00
6	Water valves	Steel taps	4	300.00	1,200.00
7	Underdrains	Concrete bricks	10	20.00	200.00
8	Tank stand	Metal rods	4	450.00	1,800.00
9	Body paint	Black paint	1	1,500.00	1,500.00
-	-	-	-	-	**17,400.00**

Material cost = N17,400.00

Labour cost = 20% of total material cost taken to be labour cost of treatment unit.

Labour cost $= 17{,}400 \times \frac{20}{100} =$ N3,480.00

Overhead cost of treatment unit = 10% of total material cost.

$17400 \times \frac{10}{100} =$ ₦1,740.00

Cost of fabrication of the greywater treatment unit material cost + labour cost + overhead cost = ₦17,400.00 + ₦3,480.00 + ₦1,740.00 = ₦22,620.00

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Processes involved in performance evaluation

The following processes took place in the course of carrying out the performance evaluation. In the sedimentation tank, a large volume of suspended and dissolved solids settled down under gravity to the bottom of the tank and settled in the sludge chamber as sludge. Here, the desludging valve was opened and the sludge was drained out. This natural treatment resulted in the settling out of the suspended solids, reduction of hardness, ammonia, heavy metals if any; breakdown of organic chemicals and some faecal coliform; removal of some colour (due to the action of sunlight); and die-off of some pathogenic microorganisms principally because of unfavourable temperature, lack of suitable food, and sterilizing effect of sunlight.

In the aeration tank the actual treatment took place. Oxygen was supplied to the system using the oxygen pump in order to energize the bacteria in the greywater. The reason for supplying this oxygen is to empower the bacteria in the system to accelerate the decomposition of all harmful materials in the water into harmless substances. Oxygen was supplied at $75O_2$kg/hr for 3 hours. At the end of three hours, the colour of the water was clearer. This confirms that treatment had actually taken place. In the filtration chamber, there was a gradual growth of a biofilm layer called the schmutzkedze on the fine sand layer. This layer contains both micro-fauna and flora. This is the main filtering medium of the system. The schmutzkedze traps all the impurities in the water sample. It also kills off all the bacterial and pathogenic organisms in the sample. This includes also the E.coli which is the indicator for pathogens. The filtrate passes through the fine sand layer, through the gravel layer to the underdrains. This now moves into the outlet chamber where it rises until it gets into the telescopic pipe. With time, the schmutkedze increases and this reduces the efficiency of filtration. Therefore the schmutkedze layer is scraped off and replaced with new sand. The scraped schmutkedze layer is contained the residues as well as the flora and fauna.

4.2 Result of performance evaluation

After the collection of the treated water sample, it was taken to the water laboratory for analysis

4.2.1 Result of influent and effluent greywater

The table below gives us the end result of the performance evaluation of the greywater treatment unit. This includes the result of influent and effluent greywater.

Table 4.1 Results of influent and effluent greywater

S/NO	PARAMETER	INFLUENT RESULT	EFFLUENT RESULT
	PYSIO-CHEMICAL		
1	Bicarbonate (HCO_3)mg/l	143.6	0.00
2	Phosphate (PO_4)mg/l	5.27	3.49
3	Chloride (Cl) mg/l	165.0	0.30
4	Total hardness mg/l	45	0.25
5	Total Dissolved solids mg/l	89.3	84.7
6	Biological oxygen demand (BOD mg/l	100.0	0.40
7	Nitrate (NO^-_3) mg/l	0.65	0.22

8	Chemical Oxygen Demand (COD) mg/l	165.0	0.00
9	PH	9.16	8.4
10	Electrical conductivity ($\mu S/cm$)	598	169.3
11	Calcium (Ca)mg/l	50	0.51
12	Sodium (Na) mg/l	173	0.036
13	Potassium (K) mg/l	72	3.63
14	Magnesium (Mg) mg/l	0.30	0.24
15	Dissolved oxygen (DO) mg/l	1.29	0.70
16	Sulphate (SO^{2-}_4) mg/l	212.5	28.0
17	Iron (Fe) mg/l	0.63	0.27
18	Temperature (^oC)	28	30.8
	BACTERIOLOGICAL		
1	Fecal coliform (CFU/100ml)	186	14
2	E.coli (CFU/100ml)	163	0.0
3	Total Plate count (CFU/100ml)	349	18
4	Salmonella/Shigella (CFU/100ml)	0.0	0.0

4.3 Comparison of treated greywater results with FAO/WHO standards for irrigation water quality.

The table below compares the result gotten from the treated greywater analysis with the FAO/WHO standards for irrigation water quality.

S/NO	PARAMETERS EVALUATED	EFFLUENT RESULT	WHO/FAO STANDARD
	PHYSIO-CHEMICAL		
1	Bicarbonate (HCO_3)	0.0	1.88

	mg/l		
2	Phosphate (PO_4) mg/l	3.49	5.0
3	Chloride (CL) mg/l	0.30	100 - 700
4	Total hardness mg/l	0.25	
5	TDS mg/l	84.7	≤ 1000
6	BOD mg/l	0.40	2.0
7	Nitrate (NO_3) mg/l	0.22	
8	COD mg/l	0.00	
9	pH	8.4	6.5 – 8.5
10	EC μS/m	168.2	< 260
11	Calcium (Ca) mg/l	0.51	1.41
12	Sodium (Na) mg/l	0.036	0.89
13	Potassium (K) mg/l	3.63	
14	Magnesium(Mg) mg/l	0.24	0.44
15	Dissolved oxygen (DO) mg/l	0.70	2.0 – 7.5
16	Sulphate (SO_4)mg/l	28.0	500
17	Iron (Fe)mg/l	0.27	5.0
18	Temperature (^oC)	30.3	
	BACTERIOLOGICAL		
1	Fecal coliform (CFU/100ml)	18	≤ 100
2	E.coli (CFU/100ml)	0.0	
3	Total plate count (CFU/100ml)	18	
4	Salmonella/shigella (CFU/100ml)	0.0	0.0

4.4 Discussion of results.

Table 4.1 shows the influent and effluent results of the parameters evaluated. The influent bicarbonate concentration was 143. 6mg/l. After the performance evaluation, the concentration was reduced to zero.

The phosphate concentration in the influent greywater was 5.27mg/l. it was reduced to 3.49 mg /l concentration in the effluent greywater.

The chloride concentration in the effluent greywater was very high. It was 165 mg /l. However, it was reduced to 0.30 mg /l after performance education had taken place. The influent BOD level was 100 mg / l. It was reduced to 0.40mg /l.

The influent COD was very high. It was 165 mg /l. It was reduced to 0.0mg /l. The pH of influent greywater was 9.16. Its effluent pH was 8.24.The electrical conductivity was high. It was 598 μS / cm. However, it was reduced to 169.2 μS / cm .The influent DO was 1.29 mg /l. However, instead of increasing, it was reduced to 0.70mg.

The dissolved oxygen in the effluent was 0.07mg/l . The influent sulphate conc was 212.5mg /l. It was reduced to 28.0mg /l. The greywater treatment unit was also very effective in reducing the bacteriological characteristics of the influent greywater sample. The influent fecal coliform was 186 CFU /100ml and this was brought down to 14CFU /100 ml in the effluent greywater.

The E.coli , which is directly the indicator for the pathogenic quality of the influent greywater sample , was 163 CFU/100 ml . It was reduced to zero in the effluent.

The total plate count was 349 CFU /100 ml in the influent greywater sample. However, it was reduced to 18 CFU /Ml. Table 4.2 shows the comparison between the effluent greywater parameters concentration against WHO / FAO standards for irrigation water quality.

The BOD level in the effluent was 0.04 mg/ l. This shows that it is acceptable because the required WHO / FAO standard says it should not exceed 2.0 mg /l . The pH effluent was 8.4. This falls between the WHO / FAO standards of 65-8.5. The dissolved oxygen in the effluent was 0.07 mg /l. This did not meet up with the WHO/FAO standards of 2.0 mg/l – 7.5 mg/l for all types of soils. The effluent EC was 168.2μS /cm.. This is less the maximum perishable level of 26μS / cm . The effluent sulphate was 28.0 mg /l. This falls under the maximum perishable standard of 50mg /l.

The effluent fecal coliform was 14CFU/100ml. This falls below the required the required maximum perishable level at 100 CFU / 100ml.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions.

The greywater treatment unit was very effective in controlling the following parameters. The bicarbonate concentration in influent greywater was 143.6 mg /l. It brought it down to zero far below the required WHO /FAO standards of 1.88.

The phosphate parameter was reduced from 5.27 mg/l to 3.49mg /l. The end result fell below the required standard of 5.0mg /l . The chloride was very high: it was 165mg/l. This is probably due to the high rate of using bleaching soaps and creams by the female students. Though the WHO / FAO standard for chloride is 100 –700 mg /l, the chloride parameter was reduced to 0.30mg /l. The effluent chloride concentration is very low compared to the required standard.

The BOD concentration in effluent was 100 mg/l. This was reduced to 0.4 mg /l far below the 2.0 mg /l point set by the WHO / FAO standards for irrigation water quality .

The dissolved oxygen in influent was 1.29 mg /l. This was reduced to 0.70 mg /l. However, this is not suppose to be so as a result of the aeration process, the dissolved content was supposed to increase. This implies that the detention time for aeration is not enough is not enough For this to occur. Thus the dissolved oxygen content did not met up wit the required WHO / FAO standards for 2.0 to 7.5 mg /l.

The fecal coliform of effluent was 186 CFU / ml. It was reduced to 14 CFU/ml . This falls under the maximum permissible concentration of 100 CFU/ ml of the WHO / FAO standards.

The E.coli of influent was 163 CFU/ml. This was brought down to zero. This implies that the pathogens in the greywater samples where completely eliminated.

5.2 Recommendations

I will like to recommend that in order to ensure very accurate results from the use of the greywater treatment unit, the fine sand component of the filter chamber of the filtration tank should be very clean. Also, the metal part of the treatment unit should be well painted to avoid contamination of the greywater sample by iron as a result of rust.

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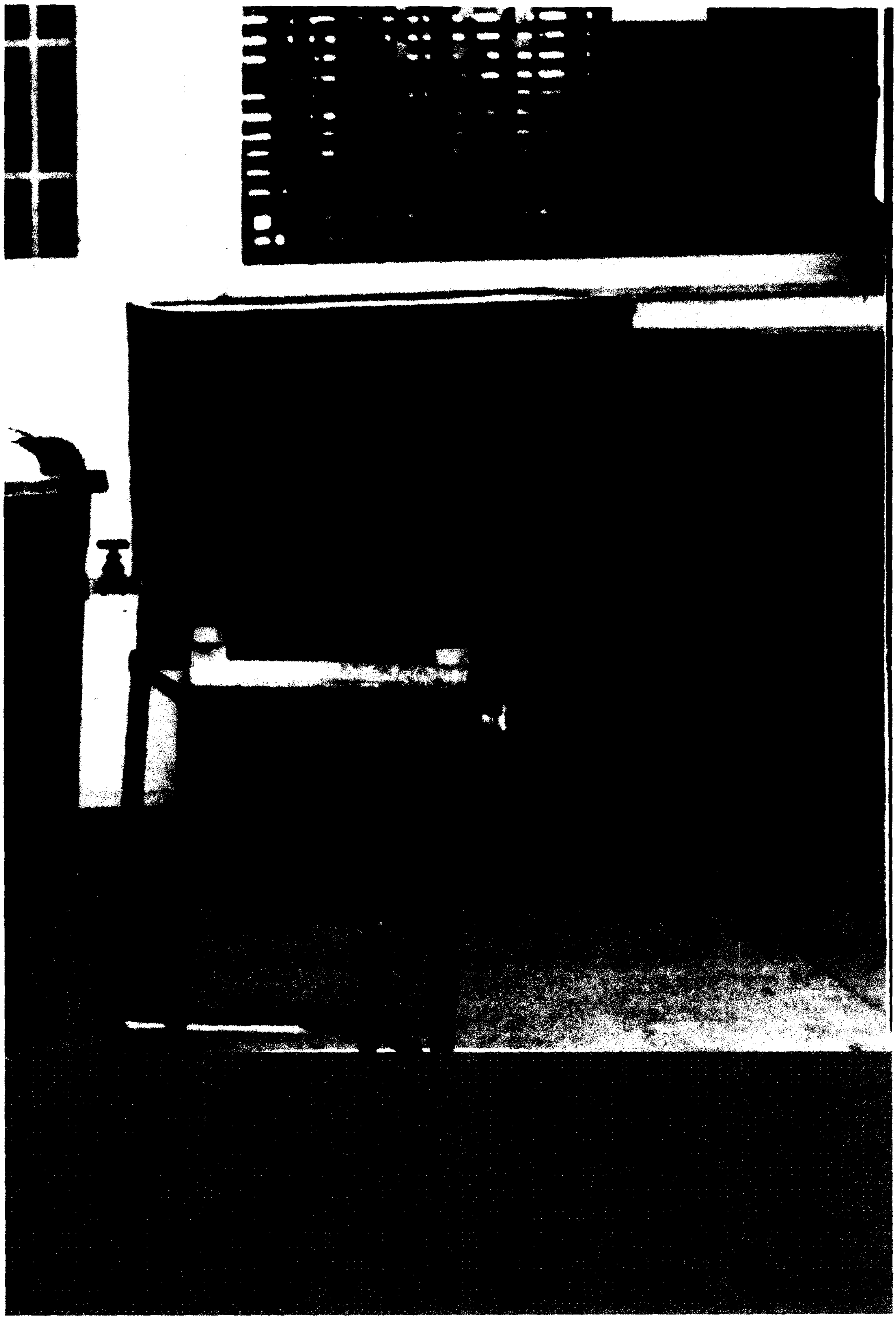
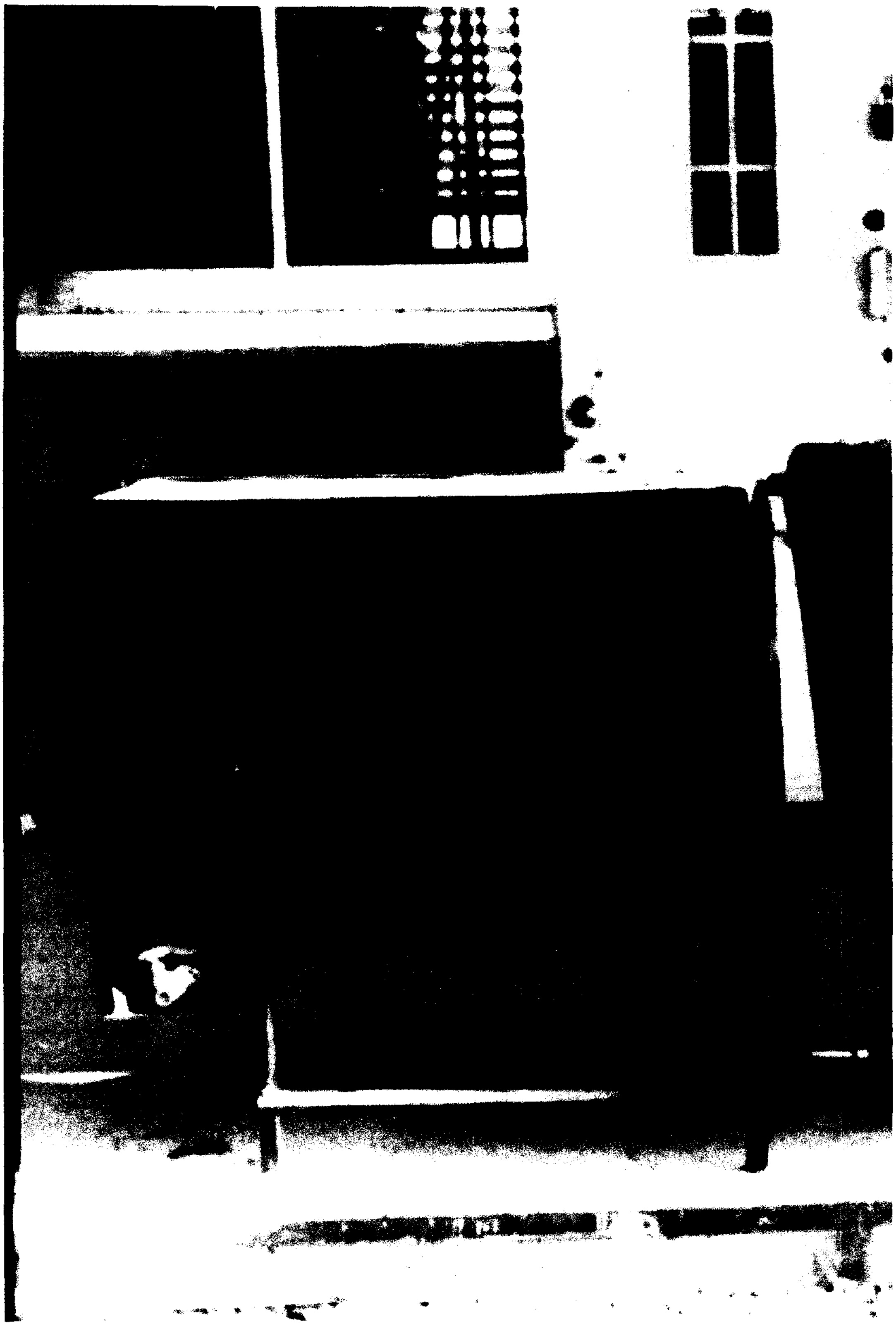
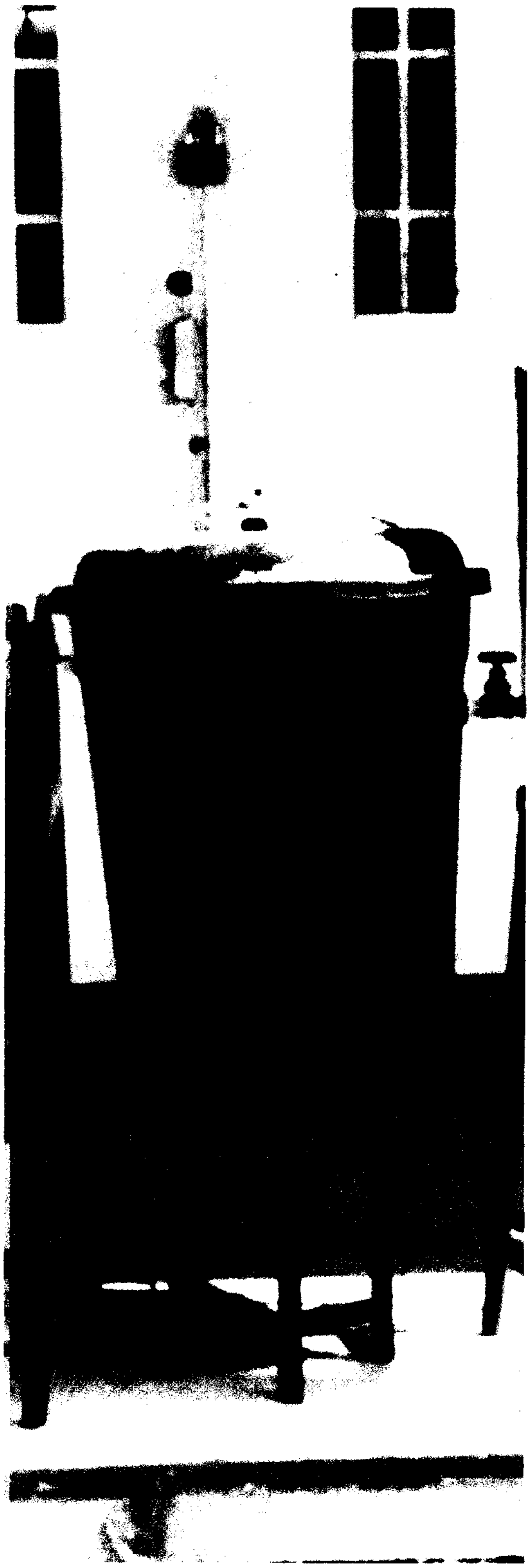
APPENDIX I: THE GREYWATER TREATMENT UNIT



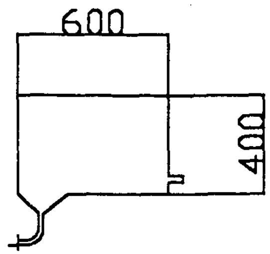
APPENDIX II: THE SEDIMENTATION TANK



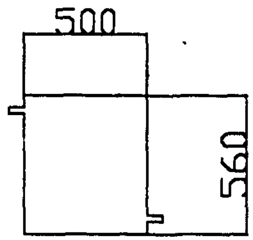
APPENDIX III: THE FILTRATION TANK



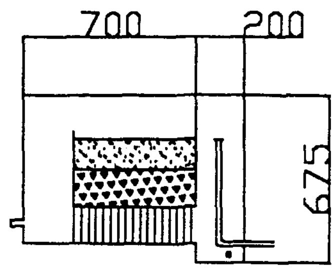
APPENDIX IV: THE AERATION TANK



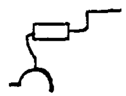
SEDIMENTATION TANK



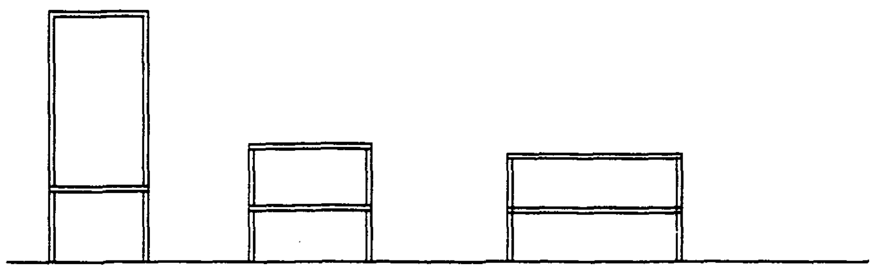
AERATION TANK



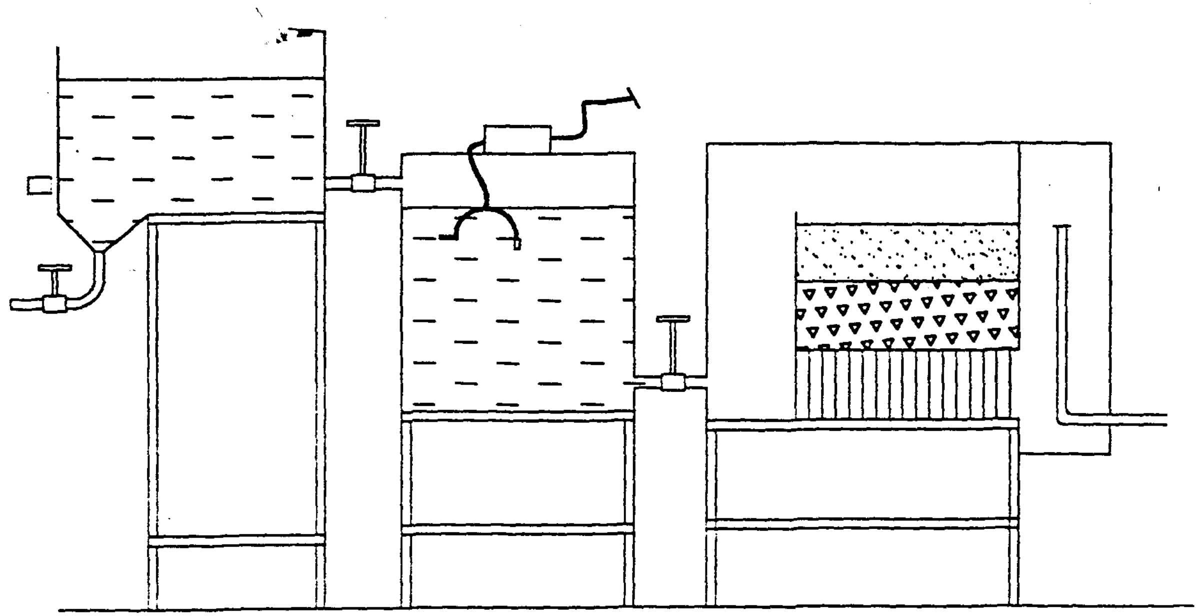
FILTRATION TANK



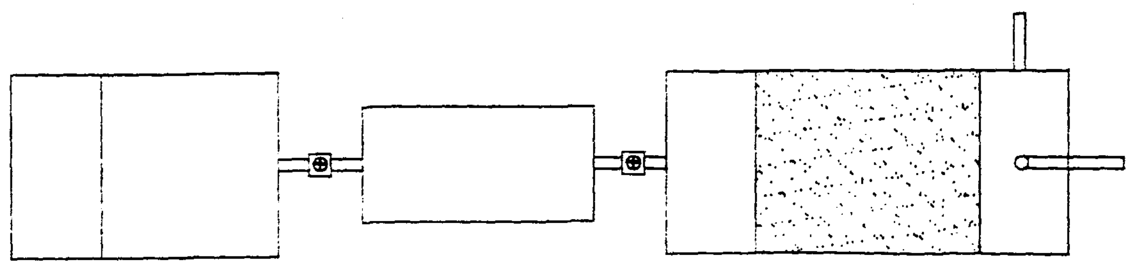
OXIDATION PUMP



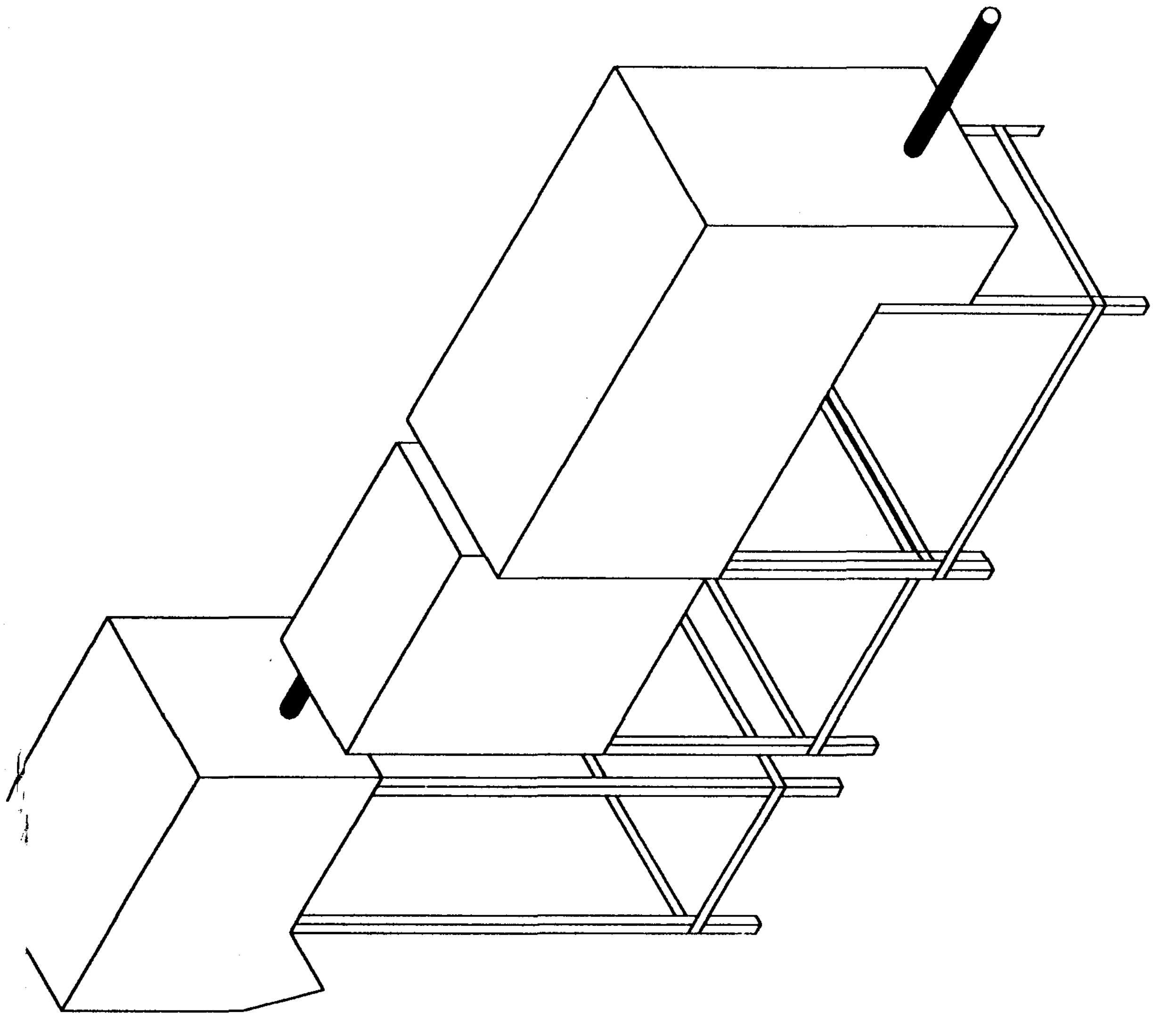
STANDS ASSEMBLING PART



X-X OF TREATMENT UNIT



PLAN VIEW



Isometric view