STUDIES OF INDUSTRIAL WASTEWATER EFFLUENT TREATMENT IN WASTE STABILIZATION POND

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DEPARTMENT OF CHEMICAL ENGINEERING,

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DECLARATION

I declare that the work in this Thesis entitled "STUDIES OF INDUSTRIAL WASTEWATER EFFLUENT TREATMENT IN WASTE STABILIZATION POND" have been carried out by me in the Department of Chemical Engineering, Ahmadu Bello University, Zaria. The information derived from the literature has been dully acknowledged in the text and list of references provided. No part of this thesis was previously presented for another degree or diploma in this or any other institution.

Umar Musa (MSc./ENG/4760/2010-11) ____________________________________

Student Signature and Date

CERTIFICATION

This thesis entitled "STUDIES OF INDUSTRIAL WASTEWATER EFFLUENT TREATMENT IN WASTE STABILIZATION POND" by Umar MUSA meets the regulations governing the award of the degree of Chemical Engineering of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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Abstract

Large volumes of wastewater are generated in Nigeria from industrial activities which often cause water pollution when they are not properly treated before being discharged into receiving water bodies. The conventional wastewater treatment plants are expensive and associated with high running and maintenance cost. These plants are also associated with generation of large volumes of chemical sludge. In view of the global economic recession cheaper options are being considered for treatment of industrial waste water such as brewery wastewater effluents. In this work the suitability of waste stabilization pond (WSP)as a cheaper alternative in the treatment of industrial wastewater was investigated so as to obtain design data, empirical and kinetic parameters for the wastewater treatment in WSP.A pilot WSP was designed and constructed for the treatment of raw brewery wastewater effluent. The Brewery wastewater effluents were collected from Nigerian Breweries PLC, Kudendan light industrial layout, Kaduna.The parameters considered for the design include: temperature, influent flow rate, influent BOD, Net Evaporation which are 28 ^{o}C, 0.2 m^2/day, 1135.5 mg/L and 0.612 m^3, respectively. The pond capacity is 4.7m^3 (4700 L) and it was designed to reduce the BOD loading by 90% for a retention period of 21 days at an influent flow rate of 0.2m^3/day.The pilot WSP was operated on a continuous steady state flow at an average ambient temperature of 29 ^{O}C over the retention period.The parameters that were analyzed on the raw and treated wastewater include: pH, Temperature, Total suspended solids (TSS), Turbidity, Chlorides, Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Electrical conductivity (EC), Total dissolved solids (TDS) and Total Coliform. The mean values of these physicochemical parameters for the raw brewery wastewater for a period of 27 days were 3.76, 29.7 ^{o}C, 1048.9 mg/L, 6.09 NTU, 573.5 mg/L, 1128.8 mg/L, 2122.1 mg/L, 1011.8 µS/cm, 826.9 mg/L and 1 E-coli/100 mL respectively. At the retention period of 25 days, the values are 6.7, 27 ^{O}C, 199 mg/L, 2.0 NTU, 268 mg/L, 350 mg/L, 660 mg/L,287 µS/cm, 296 mg/L and 9 E-coli/100 ml respectively, after which negligible changes were recorded for the listed parameters at higher detention time. The BOD removal rate constant was 0.088 per day and the BOD-COD correlation was BOD = 0.531COD – 1.960.The BOD removal regression model was BOD = $0.0001t^5$- $0.0034t^4$- $0.1419t^3$+ $6.6096t^2$–102.09t 1114.5 and the pond performance efficiencies for the reduction/removal of TSS, Turbidity, Chlorides, BOD, COD, Conductivity and TDS are 81%, 67.2%, 53.2%, 69%, 68.9%, 71.6% and 64.2% respectively. The retention time was found to be 25 days as against 21 days calculated and this could be attributed to weather variation which influences the factors that enhance wastewater stabilization such as wind, temperature, and sunlight. The WSP was also found to be cost effective because of its low energy requirement for its operation and low maintenance. The pond performance was also found to be satisfactory and the kinetic parameter obtained can be utilized in the scale up design for industrial scale WSP.

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ACRONYMS

BOD = Biological Oxygen Demand

COD = Chemical Oxygen Demand

DO = Dissolved Oxygen

FEPA = Federal Environmental Protection Agency

NESREA = National Environmental Standards and Regulations Enforcement Agency

R = raw wastewater sample

S = Sample

T = Treated wastewater sample

TDS = Total Dissolved Solid

THOD = Theoretical Oxygen Demand

TOD = Total Oxygen Demand

TSS = Total Suspended Solid

WSP = Waste Stabilization Pond

CHAPTER ONE

INTRODUCTION

1.0 Background

Wastewater has historically been considered a nuisance to be discarded in the cheapest, least offensive possible way. This meant the use of on-site disposal systems such as the privy and direct discharge into our lakes and streams. It has been recognized over the last century that this approach has an undesirable effect on the environment (Davis andMasten, 2004). Wastewaters are generated from, domestic, agricultural and industrial activities and contain such contaminants as organic and inorganic matters, chemical compounds, heavy metals and pathogens and are discharged into the water bodies. This poses seriousenvironmental and public health hazards and has led to the variety of treatment techniques that characterize today's municipal treatment systems of wastewater and resultant residuals for minimization of environmental and public health hazards (Adekunle and Eniola, 2008).

Waste stabilization ponds (WSP) are one of the waste water treatment methods in which natural biological and physical processes are used to treat the wastewater to the required effluent standard. They are shallow, rectangular lakes in which domestic and/or industrial wastewater is retained for between 10 and 100 days, depending on the climate, to allow the removal of BOD, excreted pathogens and nutrients (Mara,1996). The ponds are usually arranged in series of anaerobic, facultative and maturation ponds to improve the efficiency of their performance (Kayombo*et al.*,2003).Anaerobic and facultative ponds are normally designed for BOD removal, while maturation ponds are designed to remove excreted pathogens (Mara*et al.*, 1992).

To prevent water pollution, public laws which required that municipalities and industries provide secondary treatment before disposing their wastewater were enacted by the environmental protection agency in nations such as the U.S. Environmental protection agency (EPA) and the National Environmental Standards and Regulations Enforcement Agency (NESREA) in Nigeria set up standards for waste water discharge (Bhatia, 2005).

WSP are considered as the most effective and appropriate method of wastewater treatment in warm climates where sufficient land is available and where the temperature is most favourable for their operation (Mara, 1992). WSP are not only restricted to countries with warm climates; they have also been used in regions with cold climates in Europe and the USA (Arthur, 1983). The US Environmental Protection Agency (1983) reports that about 7000 pond systems in USA are employed for treatment of a range of wastewaters, from domestic wastewater to complex industrial wastes. The effluent of WSP is relatively rich in nutrients (nitrogen and phosphorus) and represents an immediate resource for reuse in agriculture or aquaculture (Kayombo*et al.* 2003).The treatment, in opposition to conventional treatment processes such as activated sludge system takes days to weeks (Tchobanoglous and Angelakis, 2000), but WSPs provide a good option for a (semi-) centralized treatment in developing countries because of the low capital and particularly low Operation and Maintenance (O & M) costs. WSPs make use of the sun, wind, gravity, and biological activity (involving algae and bacteria) to achieve treatment (Agunwanba, 1992 a).

1.1 Problem Statement

Industrial activities generate large volumes of waste water which cause pollution of water bodies when they are not treated before discharge (Fakayode, 2005). Many conventional waste water treatment plants abound in the country but these are installed at huge costs, they are associated with high costs of operations, maintenance and energy. These plants are also associated with generation of large volumes of chemical sludges. In view of the global economic recession, cheaper options are being considered for treatment of industrial waste water such as brewery waste water. Waste water stabilization pond is one such potential cheap waste water treatment facility and is considered in this work.

1.2Aim and Objectives

The aim of this research is to study wastewater treatment process in wastewater stabilization pond.

The objective includes:

i. To study the physicochemical parameters of brewery wastewater in wastewater stabilization pond.
ii. To design and construct a pilotconcrete wastewater stabilization pond for treating wastewater from brewing industries.
iii. To treat brewery wastewater effluents using the constructed WSP
iv. To obtain empirical and kinetic parameters for brewery wastewater treatment in WSP.

1.3 Research Justification

Waste Stabilization Ponds (WSPs) are cost effective alternative wastewater treatment in developing countries such as Nigeria where there is availability of sunlight because of its low capital, operation and maintenance costs. They are also simple to construct and require no skilled expertise for their operations, very efficient and flexible in treating wastewater, and purely natural.

1.4 Scope of Work

The scope of this research covers sampling and analysis of brewery wastewater to obtain design data for wastewater stabilization pond (WSP), the design and construction of a pilot WSP, stabilization of brewery wastewater in the constructed WSP, analysis of the stabilized wastewater, to obtain empirical correlations of the wastewater physicochemical parameters and kinetic data for the WSP design and scale up for brewery wastewater effluents.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Wastewater Treatment

Physical, chemical and biological methods are used to remove contaminants from wastewater, in order to achieve different levels of contaminant removal, individual wastewater treatment procedure are combined into a variety of systems, classified as primary, secondary and tertiary wastewater treatment (Davis and Masten, 2004). More rigorous treatment of wastewater includes the removal of specific contaminants as well as the removal and control of nutrients. Natural systems are also used for the treatment of wastewater in land pond applications. Sludge resulting from wastewater treatment operations is treated by various methods in order to reduce its water and organic content and make it suitable for final disposal and reuse (Agunwanba, 2001a).

Wastewater can be defined as any water that has been adversely affected in quality by anthropogenic influence. It comprises liquid waste discharged by domestic residences, commercial properties, industry, and/or agriculture and can encompass a wide range of potential contaminants and concentrations (Arceivala, 1998). In the most common usage, it refers to the municipal wastewater that contains a broad spectrum of contaminants resulting from the mixing of wastewater from homes, businesses, industrial areas and often storm drains, especially in older sewer systems (Olajire, 2012).

The objectives of biological treatment of wastewater are to coagulate and remove the nonsettleable colloidal solids and to stabilize the organic matter. For domestic wastewater (i.e. sewage), the major objective is to reduce the organic content and, in many cases, the nutrients, such as nitrogen and phosphorus. For agricultural return wastewater, the objective is to remove the nutrients, specifically nitrogen and phosphorus that are capable of stimulating the growth of aquatic plants (Tchobanoglous and Angelakis, 2000).

For industrial wastewater, the objective is to remove or reduce the concentration of organic and inorganic compounds that are present in the wastewater. The inorganic compounds are often toxic to microorganisms; hence, a pretreatment may be required (Agunwanba, 1994).

2.2 Legal Framework for Wastewater Treatment

Prior to the dumping of toxic waste in Koko village, in Delta State, in 1987, Nigeria was ill-equipped to manage serious environmental crisis, as there were no institutional arrangements or mechanisms for environmental protection and enforcement of environmental laws and regulations in the country (Galadima*et al*, 2011).

Following the Koko toxic waste episode, the Federal Government promulgated the Harmful Waste Decree 42 of 1988, which facilitated the establishment of the then Federal Environmental Protection Agency (FEPA) through Decree 58 of 1988. In the wisdom of Government, FEPA and other relevant Departments in other Ministries were merged to form the Federal Ministry of Environment in 1999, but without an appropriate enabling law on enforcement issues. This situation however created a vacuum in the effective enforcement of environmental laws, standards and regulations in the country. To address this situation, the National Environmental Standards and Regulations Enforcement Agency (NESREA) wereestablished as an agency of the Federal Ministry of Environment, Housing and Urban Development. The NESREA Act was accented to by Mr. President on 30th July, 2007. By the NESREA Act, the FEPA Act Cap F 10 LFN 2004 has been repealed (NESREA, 2008).

NESREA is charged with the responsibility of enforcing all environmental laws, guidelines, policies, standards and regulations in Nigeria. It also has the responsibility to enforce compliance with provisions of international agreements, protocols, conventions and treaties on the environment. The vision of the Agency is to ensure a cleaner and healthier environment for all Nigerians, while the mission is to inspire personal and collective responsibility in building an environmentally conscious society for the achievement of sustainable development in Nigeria (NESREA, 2008).

Prior to the establishment of FEPA in Nigeria, most municipal wastewater generated from domestic sources, the industrial wastewater and agricultural runoff water lines are discharged into the water bodies without any treatment and that has been responsible for the pollution of the water bodies which are the major source of drinking water both in the rural and the urban settlements and thereby causing several illnesses and diseases such as cholera, typhoid fever, diarrhea and several other water borne diseases. Increasing amounts of industrial wastewaters that have been and continue to be discharged to municipal collection systems have also amounts to heavy metal and synthesized organic compounds contaminants into the water bodies. Many of these compounds are not found in the wastewater from most municipalities and communities (Adeniyi, 2002).

As technological changes take place in manufacturing, changes also occur in the compounds discharged and the resulting wastewater characteristics. Numerous compounds generated from industrial processes are difficult and costly to treat by conventional wastewater treatment processes. Therefore, effective industrial pretreatment becomes an essential part of an overall water quality management program. Enforcement of an industrial pretreatment program is a daunting task, and some of the regulated pollutants still escape to the municipal wastewater collection system and must be treated in the future with the objective of pollution prevention. Every effort should be made by industrial dischargers to assess the environment impacts of any new compounds that may enter the wastewater stream before being approved for use (AWWA, 1998).

2.4 Wastewater Treatment Methods

Methods of treatment in which the application of physical forces predominate are known as unit operations. Methods of treatment in which the removal of contaminants is brought about by chemical or biological reactions are known as unit processes. At the present time, unit operations and processes are grouped together to provide various levels of treatment known as preliminary, primary, advanced primary, secondary (without or with nutrient removal) and advanced (or tertiary) treatment. These operationsand processes are tabulated in Table 2.1. In preliminary treatment, gross solids such as large objects, rags and grit are removed that may damage equipment. In primary treatment, a physical operation, usually sedimentation is used to remove the floating and settleable materials found in wastewater (Marai, 1974). For advanced primary treatment, chemicals are added to enhance the removal of suspended solids and, to a lesser extent, dissolved solids. In secondary treatment, biological and chemical processes are used to remove most of the organic matter. In advanced treatment, additional combinations of unit operations and processes are used to remove residual suspended solids and other constituents that are not reduced significantly by conventional secondary treatment (Adekunle and Eniola, 2008).

About 20 years ago, biological nutrient removal (BNR) for the removal of nitrogen and phosphorus was viewed as an innovative process for advanced wastewater treatment.Because of the extensive research into the mechanisms of BNR, the advantages of its use, and the number of BNR systems that have been placed into operation, nutrient removal, for all practical purposes, has become a part of conventional wastewater treatment (Metcalf and Eddy 2003) When compared to chemical treatment methods, BNR uses less chemical, reduces the production of waste solids, and has lower energy consumption. Because of the importance of BNR in wastewater treatment, BNR is integrated into the discussion of theory, application, and design of biological treatment systems.Land treatment processes, commonly termed "natural systems" combine physical, chemical, and biological treatment mechanisms and produce water with quality similar to or better than that from advanced wastewater treatment. Natural systems are used mainly with small treatment systems (Abbas, 2006).

Table 2.1: Wastewater Treatment Stages

Preliminary	Removal of wastewater constituents such as rags, sticks, floatables, grit, and grease that may cause maintenance or operational problems with the treatment operations, processes, and ancillary systems.
Primary	Removal of a portion of the suspended solids and organic matter from the wastewater
Advanced primary	Enhanced removal of suspended solids and organic matter from the wastewater. Typically accomplished by chemical addition or filtration
Secondary	Removal of biodegradable organic matter (in solution or suspension) and suspended solids. Disinfection is also typically included in the definition of conventional secondary treatment.
Secondary with nutrient removal	Removal of biodegradable organics, suspended solids, and nutrients (nitrogen, phosphorus, or both nitrogen and phosphorus)
Tertiary	Removal of residual suspended solids (after secondary treatment), usually by granular medium filtration or micro screens. Disinfection is also typically a part of tertiary treatment. Nutrient removal is often included in this definition.
Advanced	Removal of dissolved and suspended materials remaining after normal biological treatment when required for various water reuse applications

Source: (Agunwamba, 2001 a)

2.5 Types of Wastewater

a. Domestic (also called sanitary) wastewater discharged from residence and from commercial institutional and similar facilities

b. Industrial wastewater: wastewater in which industrial waste predominate.

c. Agricultural wastewater: Wastewater containing agrochemicals and chemical fertilizers (Agunwanba, 2001a).

2.6 Physicochemical characteristics of wastewater

Below are some of the physicochemical properties of wastewater:

2.6.1 pH (Hydrogen ion concentration)

The hydrogen ion concentration (pH) is an important wastewater quality parameter. It is the logarithm to base 10 of the reciprocal of hydrogen ion concentration (the hydrogen concentration is measured in moles per liter). By definition pH is the negative logarithm of the hydrogen ion concentration of a solution and it is thus a measure of whether the liquid is acid or alkaline. The pH scale (derived from the ionization constant of water) ranges from 0 (very acid) to 14 (very alkaline). The range of natural pH in fresh waters extends from around 4.5, for acid, peaty upland waters, to over 10.0 in waters where there is intense photosynthetic activity by algae. However, the most frequently encountered range is 6.5-8.0.

In waters with low dissolved solids, which consequently have a low buffering capacity (i.e. low internal resistance to pH change), changes in pH induced by external causes may be quite dramatic. Extremes of pH can affect the palatability of water but the corrosive effect on distribution systems is a more urgent problem. The effect of pH on fish is also an important consideration and values which depart increasingly from the normally found levels will have a more and more marked effect on fish, leading ultimately to mortality. The range of pH suitable for fisheries is considered to be 5.0-9.0, though 6.5-8.5 is preferable. Wastewater with an adverse pH value is difficult to treat by biological means, and if the pH is not adjusted before discharge, the wastewater effluent can alter the pH of the water receiving body(EPA 2001;Olaniyi*et al*, 2012).

2.6.2 Temperature

Temperature is an expression of thermal state of an object indicating degree of cold or heat. Temperature of wastewater is an important parameter because of its effect on the aquatic life. Thermal pollution would, of course, alter the position, possibly very significantly. The effect of temperature, and especially changes in temperature, on living organisms can be critical and the subject is a very wide and complex one. For biochemical reactions, as in the uptake of oxygen by bacteria, a rise of $10^{O}C$ in temperature leads to an approximate doubling of the rate of reaction. Conversely, such reactions are retarded by cooling, hence the recommendation often made that waters be cooled to $4^{o}C$ in the interval between sampling and analysis. Another most important factor is that some key constituents of a water either change their form (as in the ionization of ammonia) or alter their concentration (as with dissolved oxygen) when temperature changes. In fact, the primary interest in the temperature of surface waters is due to the inverse relationship between it and oxygen solubility. However, elevated temperatures and, more importantly, steep temperature gradients can have directly harmful effects on fish. It is for the latter reason that changes in temperature are subject to limits (EPA, 2001)

2.6.3 Colour

Effluent wastewater discharged into a receiving water body has a pronounced colour. The color is due to organic dyes, though, there are some other colour substances of mineral origin like iron and chromium. Rivers associated with wastewater effluents have colour like dark green, red and purples which helps to indicate good and bad water in the river (Bhatia, 2005).

Objections to high colour are generally on aesthetic grounds rather than on the basis of a health hazard. Consumers are reluctant to drink water, however safe, which has a yellowish-brown colour not unlike that of urine, and because of this revulsion any marked colour is very undesirable. So strong may be the objection to colour in water that occasional cases have been noted of people turning from coloured but otherwise safe waters to alternative supplies without coloration, and of a much lower bacteriological quality. However, the 1998 EU Drinking Water Directive, in contrast to its 1980 predecessor, does not set a quantitative standard for colour, effectively leaving the matter to the reactions of consumers. Nonetheless, it must be noted that the presence of colour on a persistent basis (i.e. with short-term seasonal peak values discounted) in a water which is then disinfected by chlorination is highly undesirable. This is because of the readiness with which the colour-causing substances reacted with the added chlorine giving rise to the presence of trihalomethanes (THM; q.v.). The latter compounds are a potential hazard to public health (EPA, 2001).

2.6.4 Biochemical oxygen demand (BOD)

Biochemical oxygen demand is a measure of the oxygen required to break down organic matter by micro-organisms for a period of 5 days at 20^oC.

Biochemical oxygen demand is one of the most important parameters of wastewaters and sewage. It is described by simple first order kinetics. The reaction rate constant, K values at 20^oC are usually from 0.10 - 0.20 per day. For highly polluted waters it can be as high as 0.25 day. The average value of K is 0.17 in southern and central Africa and 0.16 in Nigeria (Agunwamba, 2001a). For effluent from biological treatment, K is 0.05 - 0.1 per day. The typical values for different wastes are given in Table 2.2.

Because of the potential danger to the oxygen levels in receiving waters from waste discharges considerable emphasis is placed in the laboratory on the estimation of the oxygen demand of wastes: i.e. the amount of oxygen which will be required in their breakdown. This is done chemically and biologically, by a variety of tests which are also employed to assess the actual effects of waste discharges on receiving water. As in most cases the oxygen demand of a waste on the DO level of a receiving water results from biological action, it follows that the most important analytical method should also depend on a biological process, to measure the biochemical oxygen demand or BOD. The principle of this test, which was devised some 85 years ago, is straightforward. The (five-day) BOD of water is the amount of dissolved oxygen taken up by bacteria in degrading oxidizable matter in the sample, measured after 5 days incubation in the dark at 20 ^{O}C. The BOD is simply the amount by which the DO level has dropped during the incubation period. This technique is the basis of BOD analyses for all types of sample even though considerable extensions of procedure are necessary in dealing with wastewaters and polluted surface waters (EPA, 2001).

Table 2.2: Typical values of BOD_5 degradation coefficient

Wastes	K at 20 ^{o}C (per day)
1. Untreated sewage	0.15 – 0.28
2. High rate filters and anaerobic contact basins	0.12 – 0.22
3. High degree of bio-treated effluent	0.06 – 0.10
4. Low pollution	0.04 – 0.08

Source: (Agunwamba, 2001 a)

2.6.5 Chemical oxygen demand (COD)

The chemical oxygen demand of wastewater is a measure of the oxygen equivalent of the organic matter susceptible to oxidation by a strong chemical oxidation. Standard Dichromate is used in oxidation and it takes 3 hours. The text may be performed with potassium permanganate added with sulfuric acid (Agunwamba, 2001a).

It has been mentioned that the COD test is applicable to heavily polluted waters and to wastewaters. This is because the sensitivity of the normal test procedure is not adequate for waters with an oxygen demand of only a few mg/l O_2. There is a "low level" test but this is best applied to waters with an oxygen demand in the vicinity of 25 mg/l O_2 which is rather larger than one would hope to find in clean waters. It may be noted that the original (U.S.) standard method for COD used quite large volumes of sample and reagents. As the latter contain toxic and/or expensive additives (mercury and silver salts are used in relatively large amounts to suppress interference and catalyse the oxidation, respectively), and as the reaction mixture comprises 50 per cent sulphuric acid, it is highly desirable on grounds of both safety and economy that quantities should be scaled down. The use of "miniature" digestion apparatus is therefore recommended strongly (EPA, 2001).

2.6.6 Total suspended solids (TSS)

Matter which is suspended in quiescent water consists of finely divided light solids which may never settle or do so only very slowly. Indeed, the net effect may be one of apparent turbidity without any discernible solids. In flowing water, on the other hand, the solids which are kept in suspension by the turbulence may be settleable if the water is let stand. While the latter would be determinable as "Solids, Settleable," and the former could possibly be assessed as "Turbidity," there will be those solids of intermediate grading which also require estimation. To determine as much as possible of the solids present (not in solution), the determination of "suspended" solids is carried out (EPA, 2001).

The significance of suspended solids in water is great, on a number of grounds. The solids may in fact consist of algal growths and hence be indicative of severely eutrophic conditions; they may indicate the discharge of washings from sandpits, quarries or mines; they will reduce light penetration in surface waters and interfere with aquatic plant life; they will seriously damage fishery waters and may affect fish life; they may form deposits on the bed of rivers and lakes which will in turn give rise to septic and offensive conditions; and they may indicate the presence of unsatisfactory sewage effluent discharges (EPA, 2001).

2.6.7 Total dissolved solids (TDS)

The total dissolved solids (TDS), includes ionized and non-ionized matter but only the former is reflected in the conductivity. Where TDS are high the water may be "saline" and the applicable parameter "Salinity"(EPA, 2001).

2.6.8 Turbidity

Turbidity in water arises from the presence of very finely divided solids (which are not filterable by routine methods). The existence of turbidity in water will affect its acceptability to consumers and it will also affect markedly its utility in certain industries. The particles forming the turbidity may also interfere with the treatability of waters and in the case of the disinfection process the consequences could be grave. As turbidity can be caused by sewage matter in water there is a risk that pathogenic organisms could be shielded by the turbidity particles and hence escape the action of the disinfectant.

There is a relative multiplicity of units for turbidity in water, a fact which has caused a marked degree of confusion at times. However, the position is rather simpler than at first appears, as FTU (formazin), JTU (Jackson) and NTU (nephelometric) are virtually equivalent and are used interchangeably. Silica units differ. The 1980 Drinking Water Directive showed the following "parallel" MAC values for turbidity (from which the relationship may be inferred): Jackson units [JTU/FTU/NTU] - MAC 4; Silica units - MAC 10 mg/l SiO_2. It will be noted below that Drinking Water Directive [98/83/EC] adverts to nephelometric units [NTU] (EPA, 2001).

2.6.9 Electrical conductivity (EC)

The electrical conductivity of water is an expression of its ability to conduct an electric current. As this property is related to the ionic content of the sample which is in turn a function of the dissolved (ionizable) solids concentration, the relevance of easily performed conductivity measurements is apparent. In itself conductivity is a property of little interest to a water analyst but it is an invaluable indicator of the range into which hardness and alkalinity values are likely to fall, and also of the order of the dissolved solids content of the water. While a certain proportion of the dissolved solids (for example, those which are of vegetable origin) will not be ionized (and hence will not be reflected in the conductivity figures) for many surface waters the following *approximation* will apply: Conductivity (μS/cm) x 2/3 = Total Dissolved Solids (mg/l). It is important to note that there is an interrelationship between conductivity and temperature, the former increasing with temperature at a rate of some 2 per cent per degree C rise (EPA, 2001).

2.6.10 Chloride

Chloride exists in all natural waters, the concentrations varying very widely and reaching a maximum in sea water (up to 35,000 mg/l Cl). In fresh waters the sources include soil and rock formations, sea spray and waste discharges. Sewage contains large amounts of chloride, as do some industrial effluents. Chloride does not pose a health hazard to humans and the principal consideration is in relation to palatability. At levels above 250 mg/l Cl water will begin to taste salty and will become increasingly objectionable as the concentration rises further. However, external circumstances govern acceptability and in some arid areas waters containing up to 2,000 mg/l Cl are consumed, though not by people unfamiliar with such concentrations. High chloride levels may similarly render freshwater unsuitable for agricultural irrigation. Because sewage is such a rich source of chloride, a high result may indicate pollution of water by a sewage effluent. Natural levels in rivers and other fresh waters are usually in the range 15-35 mg/l Cl, which is much below drinking water standards. What is normally important to note in a series of results from a river, for example, is not the absolute level, but rather the relative levels from one sampling point to another. In coastal areas, however, elevated chloride values may be due to sea spray, or sea water infiltration, and not necessarily to discharges. Normal raw water treatment processes do not remove chloride (EPA, 2001).

2.6.11 Total coliform

Coliform bacteria consist of several genera belonging to Family *Enterobacteriaceae.* Fecal coliform which belongs to this group is found mostly in feces and intestinal tracts of humans and other warm blooded animals. It is not pathogenic per se, however, it is a good indicator of the presence of pathogenic bacteria. High levels of fecal coliform in the water may cause typhoid fever, hepatitis, gastroenteritis, dysentery and eat infection.

The risk to consumers of infection from drinking polluted waters will vary very widely from instance to instance because the numbers of pathogenic organisms (i.e. the actual disease-causing organisms) in contaminated waters will show great variations. The number of pathogens in sewage contaminated water is a function of the number of persons (so- called "carriers") who excrete such organisms. As the latter is an unknown quantity, and as the positive identification of specific bacteria may be a very difficult task (and not one suited to the routine bacteriological screening of a water on public health grounds) an indirect approach is universally adopted.

To ensure a high factor of safety, the practice has been to monitor *indicator organisms* which, by definition, should be

(i) easily detected and identified,

(ii) of the same origin as the pathogens (i.e. from the human or animal intestine),

(iii) present in far greater numbers than the pathogens, and

(iv) Present whenever the pathogens are likely to be present.

In addition, they should show the same or better survival characteristics than the pathogens and, of course, *they must not be inthemselves pathogenic.* To date the universal indicator organisms have been the coliforms, specifically *Escherichia coli*.These bacteria are of definite faecal origin (human and animal) and they are excreted in vast numbers. Their presence in a water supply is proof that faecal contamination has occurred and it is therefore a definite indication of the risk that pathogens may be present. The absence of these faecal coliforms indicates strongly the probability that pathogens are absent.

Because not all coliform organisms (or organisms which show the same test behaviour as coliforms) are of faecal origin, some types being able to grow in soil, a second analysis is carried out for the presence of total coliforms, giving an indication of the general level of microbiological contamination of a water. Each microbiological test procedure is designed around some distinctive, characteristic property of the group of organisms under study. In the case of the coliforms this is the ability to grow aerobically on an agar/bile-salt medium and to ferment lactose; producing acid and gas, within 48 hours at 37^{o}C.*E. coli* are distinguished by further individual properties.

As indicated above, two distinct analytical procedures are used routinely. The first is a multiple tube technique in which several replicates of each of three different dilutions of sample are incubated in test-tubes containing the appropriate medium. After incubation the number of positive results is noted, i.e. the number of tubes at each dilution in which the production of gas etc. is observed, and the result - the Most Probable Number of organisms in 100 ml of sample, commonly known as the MPN - is obtained from probability tables. It is presumed that each "positive" indication is due to the presence of coliforms and the test is known as the "presumptive coliform test." [Confirmatory tests may then be carried out as required.] Concurrent Most Probable Number determinations are made for faecal and total coliforms (at different incubationtemperatures) and the results reported separately (EPA, 2001).

2.7 Sewage strength

The strength of sewage is determined from the amount of organic and other oxidizable matter it contains. It is influenced by:

1. the type of sewage system;
2. infiltration water
3. daily water consumption
4. food and other habitats of the population; and
5. nature and quality of trade waste

The strength of sewage may be classified based on the amount of BOD_5 and COD as shown in Table 2.3 (Agunwanba, 2001a).

Table 2.3: Strength of sewage

Strength	BOD_5(mg/L)	COD (mg/L)
Weak	<200	400
Medium	350	700
Strong	500	1000
Very strong	>700	>1500

Source: (Agunwamba, 2001 a)

2.8 Wastewater Treatment Standards

NESREA has responsibility for the protection and development of the environment, biodiversity conservation and sustainable development of Nigeria's natural resources in general and environmental technology including coordination, and liaison with, relevant stakeholders within and outside Nigeria on matters of enforcement of environmental standards, regulations, rules, laws, policies and guidelines.

Some functions of the Agency, amongst others include to:

i. Enforce compliance with laws, guidelines, policies and standards on environmental matters;

ii. Coordinate and liaise with, stakeholders, within and outside Nigeria on matters of environmental standards, regulations and enforcement;

iii. Enforce compliance with the provisions of international agreements, protocols, conventions and treaties on the environment including climate change, biodiversity conservation, desertification, forestry, oil and gas, chemicals, hazardous wastes, ozone depletion, marine and wild life, pollution, sanitation and such other environmental agreements as may from time to time come into force;

iv. Enforce compliance with policies, standards, legislation and guidelines on water quality, Environmental Health and Sanitation, including pollution abatement;

v. Enforce compliance with guidelines, and legislation on sustainable management of the ecosystem, biodiversity conservation and the development of Nigeria's natural resources;

vi. Enforce compliance with any legislation on sound chemical management, safe use of pesticides and disposal of spent packages thereof;

vii. Enforce through compliance monitoring, the environmental regulations and standards on noise, air, land, seas, oceans and other water bodies other than in the oil and gas sector;

viii. Conduct environmental audit and establish data bank on regulatory and enforcement mechanisms of environmental standards other than in the oil and gas sector;

ix. Create public awareness and provide environmental education on sustainable environmental management, promote private sector compliance with environmental regulations other than in the oil and gas sector and publish general scientific or other data resulting from the performance of its functions (NESREA, 2008).

Several regulations and guidelines are given by Federal Ministry of Environment and NESREA to regulate the activities of the industries and the municipalities in wastewater and sewage discharge into the water bodies. Table 2.4 shows the limitation guidelines for industrial wastewater discharge into water bodies by Federal Ministry of Environment of Nigeria (NESREA, 2008).

Table2.4: Interim effluent limitation guidelines in Nigeria for all categories of industries.

Parameter	Limit for discharge into surface water	Limit for Land application
Temperature	< 40°C within 15m out outfall	< 40°C
Colour (lovibond unit)	7	-
pH	6.9	6.9
BOD_5 at 20°C	30	500
Total suspended solids	30	-
Turbidity(NTU)	< 1	-
Total dissolved solids	2000	2000
Chloride (as Cl^-)	600	600
Sulphate (as SO_4^{-2})	500	1000
Sulphide (as S^2)	0.2	-
Cynide (as CN^-)	0.1	-
Detergents	15	15
Oil and Grease	10	30
Nitrates (as NO^{-3})	20	-
Phosphate (as PO_4^{-4})	5	10
Arsenic	0.1	-
Barium	5	5
Tin	10	-
Iron	20	-
Manganese	5	-
Phenol	0.2	-
Chlorine (free)	1.0	
Cadmium	< 1	-
Chromium	< 1	-
Copper	< 1	-
Lead	< 1	-
Mercury	0.05	-
Nickel	< 1	-
Selenium	< 1	-
Silver	< 1	-
Zinc	< 1	-
Total metals	3	-
Calcium	200	-
Magnesium	200	-
Boron	5	5

Source: (NESREA, 1992). All in mg/L unless otherwise stated.

2.9 General description of Waste Stabilization Ponds (WSP)

Waste Stabilization Ponds (WSP)arelarge, shallow basins enclosed by earthen embankments in which wastewater is biologically treated by natural processes involving pond algae and bacteria. WSP comprise a single series of anaerobic, facultative and maturation ponds or several of such series in parallel. A long hydraulic retention time is necessary because of the slow rate at which the organic waste is oxidized. Typical hydraulic retention times range from 10 days to 100 days depending on the temperature of a particular region (person *et al.*, 1987).

WSP are considered as the most effective and appropriate method of wastewater treatment in warm climates where sufficient land is available and where the temperature is most favorable for their operation (Arthur, 1983). WSP are not only restricted to countries with warm climates; they have also been used in regions with cold climates in Europe and the USA (Kayombo*et al*, 2003). The US Environmental Protection Agency (2010) reports that about 7000 pond systems in USA are employed for treatment of a range of wastewaters, from domestic wastewater to complex industrial wastes.

Anaerobic, facultative and maturation ponds are the three major types of pond in a WSP system. These ponds are normally arranged in series to achieve effective treatment of raw wastewater. Anaerobic and facultative ponds are employed for BOD removal, while maturation ponds remove excreted pathogens(Kayombo*et al,* 2003). A constructed facultative pond for sewage stabilization is shown in Figure 2.1.

A series of anaerobic and facultative ponds can treat wastewater to a sufficient degree to allow it to be used in a restricted way for irrigating crops. It has been argued that such pond systems remove nematode eggs significantly by sedimentation (WHO, 2000). Maturation ponds are normally used if the treated wastewater is to be used for unrestricted crop irrigation complying with WHO guidelines of less than 1000 faecal coliforms (FC) per 100 ml (WHO, 2000). Maturation ponds have also been used when stronger wastewaters with high concentrations of nutrients (nitrogen, phosphorus) are to be treated prior to surface discharge(Mara, 1992). A typical maturation pond is shown in Figure 2.2.

Figure 2.1: Constructed facultative pond for sewage treatment

Bacterial effluent limits may also be included in the NPDES permit. For example, municipal wastewater treatment plants in Michigan must comply with limits of 200 Fecal Coliform bacteria (FC) per 100mL of water as a monthly average and 400 FC per 100mL of water as a 30 day average and 300 *E. coli* per 100mL at any time. Partial-body contact recreation is permitted for water with less than 1000 *E. coli* per 100mL of water.

For thermal discharges such as cooling water, temperature limits may be included in the permit. Michigan rules state that the Great Lakes and connecting waters and inland lakes shall not receive a heat load that increases the temperature of the receiving water more than 1.7^{O}C above the existing natural water temperature after mixing. For rivers, streams, and impoundments, the temperature limits are 1 ^{o}C for cold-water fisheries and 2.8^{o}C for warm water fisheries.

Figure 2.2: A maturation pond for municipal wastewater treatment

2.10 Biological Treatment of Wastewater

The basic ingredients needed for conventional aerobic secondary biologic treatment are the availability of many microorganisms, good contact between these organisms and the organic material, the availability of oxygen, the maintenance of other favorable environmental conditions (e.g. favorable temperature and sufficient time for the organisms to work). A variety of approaches have been used in the past to meet these basic needs. The most common approaches for municipalities are the trickling filter process and the activated sludge process. Lagoons are employed when wastewater flows are not large and land space is available (Kayombo*et al*, 2003).

2.10.1 Role of Microorganisms

The stabilization of organic matter is accomplished biologically using a variety of microorganisms, which convert the colloidal and dissolved carbonaceous organic matter into various gases and into protoplasm. Because protoplasm has a specific gravity slightly greater than that of water, it can be removed from the treated liquid by gravity setting.

It is important to note that unless the protoplasm produced from the organic matter is removed from the solution, complete treatment will not be accomplished because the protoplasm, which itself is organic, will be measured as BOD in the effluent. If the protoplasm is not removed, the only treatment that will be achieved is that associated with the bacterial conversion of a portion of the organic matter originally present to various gaseous end products (Tchobanoglous and Angelakis, 2000).

2.10.2 The Microbial Ecosystem

In the discussion of the behavior of bacterial cultures that follows, the inherent assumption is that all the requirements for growth are initially present. In wastewater treatment, as in nature, pure cultures of microorganisms do not exist. Rather a mixture of species competes and survives within the limits set by the environment.

2.10.3 Population Dynamics

Population dynamics is the term used to describe the time varying success of the various species in competition. It is expressed quantitatively in terms of relative mass of microorganisms.

The prime factor governing the dynamics of the various microbial populations is the competition for food. The second most important factor is the predator-prey relationship (Egwuonwu*et al*, 2014)

The relative success of a pair of species competing for the same substrate is a function of the ability of the species to metabolize the substrate. The more successful species will be the one that metabolizes the substrate more completely. In so doing, it will obtain more energy for synthesis and consequently will achieve a greater mass.

2.10.4 Biological Oxidation of Organic Matter

The presence of organic matter is a major problem associated with wastewater. This is usually solved by conversion to inert and stable compounds with the help of microorganisms, either in the presence of oxygen (aerobic oxidation) or absence of it (anaerobic oxidation).

The organic matter is composed essentially of carbohydrates (e.g. glucose), nitrogenous compounds such as proteins and lipids or fats containing carbon, hydrogen and a little oxygen.

In order to effectively oxidize the waste, it is essential that certain compounds be available to support bacterial growth. When bacterial growth is hindered there will be inadequate concentration of microorganisms for biological waste degradation or treatment. The requirements include:-

i. Carbon, nitrogen and phosphorus.
ii. Energy sources which are required by microbes for metabolic activities.
iii. Inorganic ions such as calcium, magnesium, iron, manganese and so on; and
iv. vitamin

If any of these is lacking in a particular wastewater, it will be necessary to add it before biological treatment can be effective.

Essentially, the equations for waste degradation are:

Organic waste + $O_2 \rightarrow$ bacteria treated waste + New bacteria (2.1)

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ (2.2)

Six molecules of oxygen combine with a molecule of glucose for complete conversion to water and carbon dioxide. Oxygen is not only required for decomposition of carbonaceous matter as presented above but also during the nitrification of nitrogenous compounds; that is, during the conversion of nitrogenous compounds in the waste into nitrite and then nitrate. The equations of nitrification are expressed below:

$$2NH_3 + 3O_2 \xrightarrow{\text{Nitrifying bacteria}} 2NO_2 + 2H^+ + 2H_2O \qquad (2.3)$$

$$2NO_2 + O_2 + 2H^+ \xrightarrow{\text{Nitrifying bacteria}} 2NO_3 + 2H^+ \qquad (2.4)$$

The theoretical ultimate oxygen demand (UOD) for both stabilization of carbonaceous matter and nitrification may be determined from the relationship:

UOD = 2.67 Organic Carbon (mg/l) + 4.57(Org. N+Amm.N) mg/l + 1.14NO_2N mg/l (Agunwamba, 2001a).

2.10.5 Aeration

The available dissolved oxygen in water or wastewater plays a significant role in the type and rate of biological oxidation in treatment plants. As mentioned previously the microbes especially aerobic bacteria, require oxygen for synthesis during which they degrade the organic matter in the wastewater. Hence, for aerobic treatment systems, the amount of dissolved oxygen is important. The amount of dissolved oxygen required for complete oxidation may not be adequate. If wastewater is left on its own some oxygen may be absorbed by the wastewater from the atmosphere but the rate of transfer as well as the amount is too small to encourage rapid degradation. Left in that form, the reaction tanks will be very large and the waste will take much time to be degraded (Khan and Ahmed, 1992). Hence, in aerobic treatment systems there may be the need to introduce enough air artificially. This process is called aeration.

Generally, the objectives of aeration are to:-

i. Oxidize iron and manganese in water
ii. Maintain a certain level of oxygen suitable for treatment and disposal;

iii. Remove H_2S to eliminate taste and odour; and

iv. Remove volatile oils and similar odour and taste producing substances released by algae and other microorganisms.

Since the solubility of oxygen in water is low, it is increased by stirring or agitating the liquid.

Model: The rate of transfer of oxygen from air into a liquid (wastewater) is described by the equation

$$\frac{dc}{dt} = K_a(C_s - C) \quad (2.5)$$

Where C_s is the saturation concentration of oxygen; C is the concentration of oxygen in wastewater; and $K_a$is the overall mass transfer coefficient. The above equation can be expressed as:

$$\frac{dc}{dt} + K_a C = K_a C_s \qquad (2.6)$$

The equation is an ordinary first order linear differential equation and can be solved by method of integrating factor.

2.10.6 Determination of K_a

Experimentally, the data for determination of K_a is generated by first of all adding sodium sulfite for removal of all dissolved oxygen. That is,

Na_2SO_3 + ½ $O_2COCl_2 \rightarrow Na_2SO_4$ (2.7)

Then, the dissolved oxygen concentration is measured at selected intervals. The value of K_a is usually obtained for tap water and then corrected for wastewater. The relationship between the two is given as:

K_a(wastewater) = αK_a(tap water) (2.8)

Where α is between 0.80 and 0.85 in activated sludge reactors. The parameter α is affected by the:

i. temperature of the wastewater
ii. nature of dissolved organic
iii. level of agitation by aeration
iv. characteristics of aeration equipment; and
v. Liquid depth and geometry of aeration basin (Agunwamba, 2001a).

2.11 Kinetics of Bacterial Growth

Bacteria growth kinetics is mathematical expressions for description of bacterial growth. They are used for predictions of the performance of biological processes and translation of qualitative observations into process parameters for the design and operation of the processes (Agunwamba, 2001a).

Rate Equation: One of the most useful equations for description of bacterial growth is the Monod rate equation expressed by

$$\frac{ds}{dt} = \frac{k_o xs}{k_m + s} \qquad (2.9)$$

Where ds/dt is the rate of uptake of substrate, K_o is the maximum specific rate of uptake of substrate; s denotes the concentration of substrate which is the food available for utilization by microbes in the wastewater; x represents concentration of the bacteria (biomass); and K_m is the saturation constant. The Monod rate equation is used to predict the rate of substrate utilization by bacteria for any given concentration of substrate and applies to a culture of bacteria growing on single rate limiting substrate. The Monod model assumes that:

All other substrates and nutrients are present in excess;

The products do not accumulate to the point where they inhibit the rate of reaction;

Bacterial growth is limited by enzyme;

Initially, rate of reaction is proportional to the substrate concentration; and rate or reaction attends a maximum which cannot be exceeded no matter how high the concentration of the substrate is.

The rate of bacterial growth is measured by the parameter called the specific growth rate (μ). The specific growth rate (or fractional growth rate) is the rate of growth of bacteria per unit mass of bacteria (biomass present, per unit time. For instance, a specific growth rate of $0.15d^{-1}$ means that the bacteria culture is growing at the rate of 15% per day (Agunwamba, 2001a).

Mathematically, specific growth rate (μ) is defined by the equation

$$? = \frac{1}{x}\frac{dx}{dt} \qquad (2.10)$$

Where, x is the mass or concentration of bacteria present. The value of μ can be determined from experimental data where the concentration of biomass is measured against time. The slope of a plot of dx/dt versus x will yield μ. The specific yield may also be obtained by regression analysis.

2.11.1 Application of Kinetics to Biological Treatment

Maximum theoretical yields: For young fast growing cultures, the yield is proportional to the quantity of substrate consumed. The relationship between the rate of biomass production (dx/dt) and the rate of consumption of substrate (ds/dt) is:

$$\frac{dx}{dt} = y.\frac{ds}{dt} (2.11)$$

Where;y is called the yield coefficient, that is; the sludge producing potential of a substrate. In aerobic and anaerobic treatment systems a y value of 0.55 and 0.1 respectively in terms of

COD are often used. The yield is not constant but reduced, for example by low growth rate and death under starvation condition. This is accounted for by subtraction of a decay term

That is:

$$\frac{dx}{dt} = y.\frac{ds}{dt} - k_d x \qquad (2.12)$$

The coefficient k_d accounts for death, predation, and so on.

2.11.2 The Kinetics of inhibition

The biological processes are susceptible to inhibition by toxic substances and or unfavorable concentrations of the normal constituents of the growth medium. The effect of inhibition on growth is described by varying the values of the kinetic constants or by adding new and more complex expression into the rate equation. For instance, for competitive inhibition;

$$\frac{\theta x}{y(s_o - s)} = \frac{k_m}{k_o} = \frac{1}{s}\left(1 + \frac{1}{k_1}\right) + \frac{1}{k_o} (2.13)$$

Where; k_1 is the inhibition coefficient (Agunwamba, 2001a).

2.11.4 Completely – Mixed flow reactors

In a completely – mixed reactor, the influent is rapidly dispersed throughout the reactor. The composition of the reactor is uniform. Hence, the effluent has the same contents with the fluid inside the reactor (Fig.2.3).

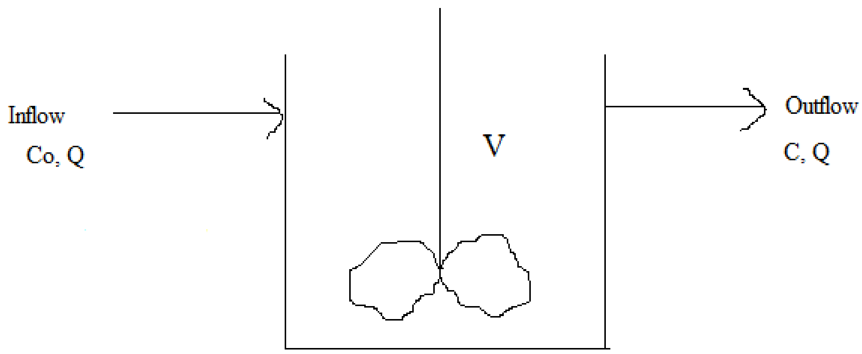


Figure 2.3: Completely mixed flow reactor

Writing a mass balance equation, we obtain;

Accumulation = inflow – outflow + Decay

Mathematically;

$$\frac{Vdc}{dt} + (Q + kV)\frac{c}{V} = \frac{Qc_o}{V} \quad (2.14)$$

The integrating factor is:

$$\exp\int\left(\frac{Q}{V} + k\right)dt = exp\left(\frac{1}{\theta} + k\right)t \qquad (2.15)$$

Where θ is the detention time = Q/V.

Multiplying by the integrating factor we have

$$exp\left(\frac{1}{\theta} + k\right)t\frac{dc}{dt} + \left(\frac{1}{\theta} + k\right)c.exp\left(\frac{1}{\theta} + k\right)t = \frac{c_o}{\theta}.exp\left(\frac{1}{\theta} + k\right)t$$

$$\Rightarrow [exp(\beta t)]' = \frac{c_o}{\theta}.exp(\beta t) \quad (2.16)$$

Where β =1/θ + k

Integrating,

$$C\exp(\beta t) = \int\frac{C_o}{\theta}\exp(\beta t)dt + C_1 \quad (2.17)$$

Where; C_1 is a constant of integration. If the integral is evaluated and the equation expressed in terms of C, then

$$C = \frac{C_o}{\beta\theta} + C_1 \ \exp(-\beta t) \qquad (2.18)$$

If t = 0, c = c_0

Therefore;

$$C_o = \frac{C_o}{\beta\theta} + C_1 \ \rightarrow C_1 \ = \ C_o(1 - \frac{1}{\beta\theta}) \quad (2.19)$$

Eliminating C_1 from Equation (2.19)

$$C = \frac{C_o}{\beta\theta} + C_o\left(1 - \frac{1}{\beta\theta}\right)\exp(-\beta t) \qquad (2.20)$$

Assuming at a steady state: Vdc/dt=0; then,

$$C = \frac{QC_o}{Q+Vk} = \frac{C_o}{1+\theta k} \quad (2.21)$$

(Agunwamba, 2001a)

2.12 Types of WSP and their functions

2.12.1 Anaerobic ponds

Anaerobic ponds are commonly 2-5m deep and receive a high organic BOD loading (> 100g BOD/m^3/day). They contain no dissolved oxygen and algae. Mara and Pearson (1998) suggest that a thin film of *Chlamydomonas*is occasionally seen at the anaerobic pond surface, see typical constructed anaerobic pond in Figure 2.4. The primary function of anaerobic ponds is to remove BOD. The suspended solids settle by gravity to the bottom of pond where they are degraded anaerobically.

Figure 2.4:Anaerobic Treatment Ponds (APs)

Mara and Pearson (1998) argue that a properly designed anaerobic pond can achieve around 60% BOD removal at 20^{o}C and over 70% at 25^{o}C. Anaerobic ponds operate extremely well with a short retention time and it is not good practice to design anaerobic ponds for long retention times. Anaerobic pond functions satisfactorily when the ponds temperature is above 15^{o}C and the pH is above 6. Under these conditions, it is thought that anaerobic oxidation of settled solids is at a maximum with minimum sludge accumulation. When the pond temperature is less than 15^{o}C, BOD removal is caused by sedimentation with significant loss of the hydraulic retention time (Pearson *et al.*, 1987).

Tchobanoglous*et al.* (2003) gave the description of how anaerobic heterotrophic bacteria carry out BOD removal. Acid-forming bacteria, (*Streptococcus, Clostridium*, and *Staphylococcus*), methane-forming bacteria (*Methanobacterium*and *Methanospirillum*), and sulphate-reducing bacteria (*Desulfovibrio*) oxidize the organic compounds contained in raw wastewater to obtain food and energy for growth. The acid-forming bacteria initiate redox reactions within organic compounds contained within the waste. These reactions formed volatile fatty acids (acetate, propionate, and butyrate). The methane-forming bacteria oxidize the volatile fatty acids products and reduce carbon dioxide to form methane gas. If the raw wastewater contains sulphate compounds (SO_4), the sulphate-reducing bacteria oxidize the organic compounds and reduce the sulphates to form sulphides, including hydrogen sulphide gas (H_2S), the source of odour in anaerobic ponds. Kayombo*et al*. (2003) observed that in aqueous solution, hydrogen sulphide is present as either dissolved hydrogen sulphide gas (H_2S), bisulphide ion (HS^{-1}) or sulphide ion (S^{-2}) depending on the pond's pH. A well-designed anaerobic pond with pH of 7.5 favours formation of the less odorous bisulphide ion (Mara and Pearson, 1998). Limiting the concentration of sulphate compounds in raw wastewater to less than 300mg SO_4 per litre is thought to reduce the formation of odorous hydrogen sulphide gas (Gloyna and Episno, 1969). Odour release can be eliminated at the design stage by keeping volumetric BOD loading to less than 350g BOD/m^3/day (Arthur, 1983).

The Ireland Environmental Protection Agency (2010) has suggested operational methods of preventing the release of malodorous compounds by anaerobic ponds. One suggested method is to re-circulate facultative pond effluent to maintain a thin aerobic layer at the surface of the anaerobic pond. This method is considered to prevent the transfer of odours to the air. However, the cost of pumping facultative pond effluent has to be incurred and this can increase the annual operation cost of the system. The second operational method suggested is the addition of lime into the anaerobic pond to increase the ponds pH. This method suppresses the release of odorous gas (H_2S) and favours the formation of non-odorous sulphide compounds. However, this method has also cost implications. The cost of lime can contribute to a substantial increase in the annual operating costs of the WSP. A small amount of sulphide is known to be beneficial in removing heavy metals found in anaerobic ponds.

Oke*et al.* (2006) observed that a small concentration of sulphide in anaerobic ponds can help remove *Vibrio Cholera*. Curtis and Mara (1994) suggests that environmental conditions in facultative and maturation ponds are not effective in removing *Vibrio Cholera*. Therefore, inclusion of an anaerobic pond in a WSP system can reduce health risks associated with the presence of *Vibrio Cholera* in water that is used for unrestricted crop irrigation.

Inclusion of anaerobic ponds in WSP systems has been noticed to reduce significantly the overall land requirement (Mara, 1997; Arthur, 1983). Mara (1997) showed that inclusion of anaerobic ponds in WSP systems can result in a reduction in land requirements of up to ~50% for systems treating typical domestic wastewater. Designers of WSP in developing countries should therefore include anaerobic ponds in their feasibility studies of WSP systems.

2.12.2 Facultative ponds

Facultative ponds normally follow anaerobic ponds in a WSP system. They are usually 1.2 m deep and are geometrically designed to have a high length-to-width ratio (up to 10:1) to simulate a hydraulic plug flow regime (Khan and Ahmed, 1992).

There are two types of facultative pond: primary facultative ponds that receive raw wastewater and secondary facultative ponds that receive settled wastewater effluent from the anaerobic pond. The term facultative is used because both aerobic and anaerobic conditions are found in the pond (Mara and Pearson, 1998). Aerobic conditions are maintained in the upper layers while anaerobic conditions exist towards the bottom of the pond.

Pond depths of less than 1 m are thought to promote the growth of emergent vegetation (Pearson *et al.,* 1987). The shaded environment caused by vegetation is a suitable breeding ground for mosquitoes and snails, both of which may act as vectors of disease (Oke*et al.* 2006). Depths greater than 1.5 m are avoided to ensure that the bulk of the pond is aerobic. (Pearson *et al.,* 1987) observed that greater depths (>1.5 m) cause anaerobic conditions and the pond becomes less resistant to shock loads. The lower anaerobic layer of a facultative pond is dominated by the same anaerobic mechanisms that occur in anaerobic ponds. These conditions are very effective in BOD removal (Kayombo*et al.* 2003).

Facultative ponds are designed for BOD removal based on a surface loading of 100.350 kg BOD/ha day to permit the development and stability of a healthy algae population. This is important because the oxygen for BOD removal used by pond bacteria is mostly supplied by algal photosynthesis (Mara and Pearson, 1998). The pathway of BOD removal in primary facultative pond is shown in Figure 2.5.

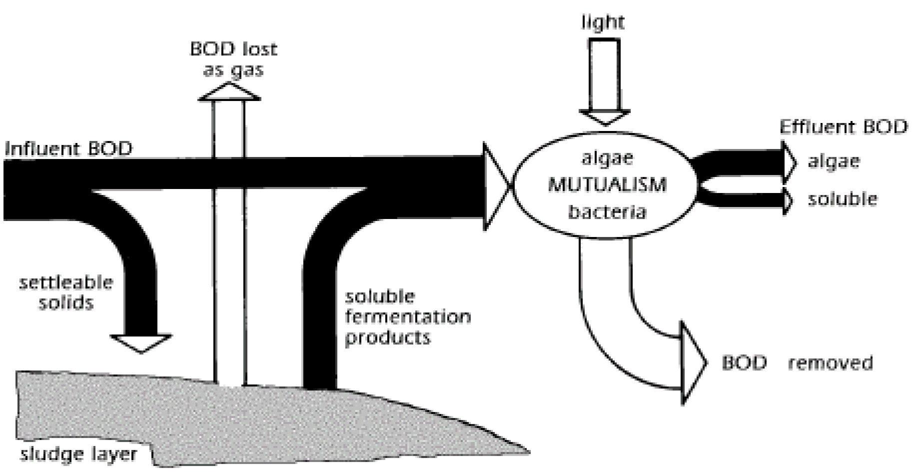


Figure 2.5: Pathways of BOD removal in primary facultative ponds

2.12.2.1 Algae

Facultative ponds are colored dark green due to algae. Sometimes facultative ponds appear red or pink when they are overloaded due to the presence of anaerobic purple sulphide oxidizing photosynthetic bacteria (Mara *et al.* 1992). Pond algae that predominate in turbid waters of facultative ponds are the motile genera such as *Chlamydomonas, Pyrobotrys, and Euglena* (Mara, 2004). These algae species are capable of optimizing their vertical position in the pond water column to incident light intensity and temperature. Non-motile algae such as *Chlorella* are also found in facultative ponds and they rely on mixing initiated by wind and temperature. The mixing mechanisms enable them to access the incident light, allowing them to photosynthesize. The concentration of algae in a healthy facultative pond depends on surface BOD loading and temperature. Mara (2004) estimated a range of 500 - 2000μg chlorophyll *a* per litre. A concentration of pond algae below this range indicates possible failure of the facultative pond.

The majority of the algae occupy a band about 200mm deep that moves up and down the water column, presumably in response to nutrient concentration and incident light during the day (Pearson et al. 1987a). Anaerobic reactions initiated by acid-forming, methane-forming bacteria and sulphate-reducing bacteria in the lower layers may feed volatile fatty acids and sulphides to the upper layer where they may affect the ecology of the pond algae. These products of anaerobic digestion have been observed by Mara and Pearson (1998) to inhibit both growth and production of pond algae. It has been argued by Mara and Pearson (1998) that high ammonia and sulphide concentrations in a facultative pond may result in the replacement of *Euglena* with more tolerant algae species such as *Pyrobotrys*and *Chlorella.*

The algae biomass and its productivity cause a marked diurnal and vertical variation in the levels of dissolved oxygen, pH, sulphide and ammonia. It has been observed that when carbon dioxide is taken up faster than bacterial respiration can supply, the concentration of carbon dioxide drops causing a dissociation of the bicarbonate ion to form carbon dioxide and alkaline hydroxyl (Mara and Pearson, 1998). This raises the pH levels in facultative ponds.

Kayomboet *al*. (2003) observed a rise of pH in facultative ponds exceeding 9.0 and this is important in killing faecal coliforms. Ammonia and sulphide toxicity have been observed to be pH-dependent (Kayomboet *al*. 2003). As the pH of a facultative pond increases, the unionized form of ammonia increases while sulphide production decreases. The effect of this toxicity is to inhibit algae growth and production and these mechanisms are thought to be self-sustaining (Khan and Ahmed, 1992).

2.2.2.2 Mixing

Mara (2004) suggests that wind and heat are the two factors that influence the degree of mixing that occurs within facultative and maturation ponds. It is considered that mixing minimizes hydraulic short-circuiting and the formation of stagnant regions in ponds. Mixing has also been considered to distribute uniformly BOD, algae, oxygen and bacteria throughout the water column. Mixing in WSP attains a certain degree only; the effects of short-circuiting and stagnant regions cannot be eliminated.

In the absence of wind mixing, stratification has been noted to form (Mara, 2004). The less dense upper layer lies on to top of the cooler, denser layer. It has been noted that the two regions are separated by a sharp thermocline (Mara, 2004). Stratification is detrimental to pond performance as it promotes short-circuiting and reduces algal productivity. This agrees with the idea that a complete-mix hydraulic flow model fails to mimic the exact hydraulic flow regime that occurs in WSP (Ukponget *al*, 2006).

2.2.2.3 Bacteria

A wide range of heterotrophic bacteria is found in facultative ponds. Mara and Pearson (1998) and the Ireland Environmental Protection Agency (2010) list *Pseudomonas*, *Archromobacter*, *Beggiato, Alcaligenes, and Bacillus* as some of the aerobic heterotrophic bacteria that remove BOD in facultative ponds. These aerobic heterotrophic bacteria oxidize organic compounds (electron donor) and reduce oxygen (electron acceptor) supplied by pond algae. The products of aerobic heterotrophic reaction are carbon dioxide (CO_2), ammonium (NH_4^+) and phosphate compounds ($PO_4^{2.}$). These products are used by algae for growth and production. Aerobic heterotrophic bacteria are thought to have a mutual relationship with algae.

2.2.3 Maturation ponds

Maturation ponds are normally used in series with facultative ponds. They are usually 1.1.5 m deep and are geometrically designed to have a high length-to-width ratio (up to 10:1) to simulate a hydraulic plug flow regime (Mara *et al.* 1992). The primary function of maturation pond is to remove excreted pathogens to enable the practice of unrestricted crop irrigation (WHO, 2006). The removal of BOD and nutrients has been observed to take place in maturation ponds.

The size and number of maturation ponds depends on the required bacteriological quality of the final effluent. Maturation ponds show less vertical biological and physicochemical stratification (Mara, 1997), and they are well oxygenated throughout the day. The algal populations in maturation ponds are more diverse than those in facultative ponds, with non-motile genera tending to be more common (Mara and Pearson, 1998). *Chlorella* has often been observed to be the predominant algal species.

The high pH which is often found in maturation ponds increases the toxicity of ammonia as this favors the formation of the more toxic un-ionized form of ammonia.

Efficient removal of excreted pathogens in maturation ponds depend on the effective and efficient design of the ponds (Mara, 1997). Similar mechanisms for removing excreted pathogens operate in both facultative and maturation ponds and that these mechanisms vary seasonally as they are influenced by environmental conditions (Kayombo*et al,* 2003).

Many empirical methods for designing maturation ponds use environmental factors, which are thought to influence pathogen removal. As it is technically difficult to count individual pathogenic bacteria and viruses found in wastewater, WSP design and monitoring are done with faecal coliform bacteria, which are used as a pathogen indicator (Kayombo*et al*, 2003).

2.12.3.1 BOD removal

Wastewater contains high levels of BOD that need to be removed before the treated effluent can be discharged to receiving water bodies. In anaerobic ponds, BOD removal is achieved by sedimentation of settled solids. The settled organic waste is digested anaerobically, resulting into formation of sludge layer. Because anaerobic ponds contain no dissolved oxygen, Tchobanoglous and Angelakis (2000) argue that oxidation of organic compounds by anaerobic heterotrophic bacteria results in the formation of methane, carbon dioxide and sulphides compounds. Intense anaerobic digestion has been reported to occur at temperatures above 15^{o}C with release of biogas (70% methane, 30% carbon dioxide) (Mara and Pearson, 1998). Anaerobic heterotrophic bacteria are sensitive to a pH of less than 6.2. This requires acidic wastewater to be neutralized prior to treatment in anaerobic ponds. A properly designed anaerobic pond with volumetric BOD loading as recommended by Mara *et al*. (1992) can achieve around 60% BOD removal at 20^{o}C and over 70% at 25^{o}C with 1-day retention time.

The settled wastewater that enters the secondary facultative pond is oxidized further by aerobic heterotrophic bacteria. Photosynthesizing algae supply oxygen, which is used by the aerobic heterotrophic bacteria to oxidize the organic wastes. Some oxygen and carbon dioxide has been noted to come from the atmosphere by mass transfer, but the supply of oxygen and carbon dioxide in a facultative pond is thought to be provided mainly by algal-bacterial mutualism (Mara, 1997). In primary facultative ponds, the functions of both anaerobic and secondary facultative ponds are combined. Marais (1974) observed that 30% of the influent BOD leaves the primary facultative pond in the form of methane gas.

A small amount of BOD removal occurs in maturation ponds due to their lower algal concentration (Mara, 1997). These lower algal concentrations in the maturation ponds are due to the decreased supply of nutrients and predation by protozoa and micro-invertebrates such as *Daphnia*. It is suggested by Mara (1997) that 70.90% of the BOD of maturation pond effluents is due to algae.

2.12.3.2 Pathogen removal

Pearson *et al.* (1987), argue the suitability of faecal coliforms as indicators of pathogens in WSP. It is suggested that most faecal coliforms found in WSP are *E.coli.* Studies carried out on the DNA of *E.coli*and some classical pathogens such as shigellae and salmonellae have shown them to have a similar structure, with the notable exception of *Vibrio* spp and *Campylobacter* spp. *Campylobacter* spp. has different DNA structure from *E.coli*, but it has been observed to die more quickly in WSP than faecal coliforms due to its vulnerability to oxygen Pearson *et al.* (1987). The case of *Vibrio cholerae*is well documented byMara (2004). It is thought that the environmental conditions in facultative and maturation ponds fail to remove *Vibrio cholerae*because the DNA structures of this pathogen and faecal coliforms are quite different. Kayombo et al. (2003) showed that anaerobic ponds are very effective in removing *Vibrio cholerae*due to the formation of toxic sulphide compounds. Anaerobic ponds should be the first choice option when treated effluent is to be reused for unrestricted crop irrigation as these ponds have been shown to be very effective in removing *Vibrio cholerae*.

2.12.3.3 Removal of Bacteria

Mara and Pearson (1998) state that faecal bacteria are removed very efficiently in facultative and maturation ponds. The size and number of maturation ponds determine the numbers of faecal coliforms in the final effluent. Anaerobic ponds play a significant role in removing faecal coliforms through the sedimentation of bacteria associated with solids. Mara (2004) and Agunwamba (2001 a) list the principal mechanisms for faecal bacterial removal in facultative and maturation ponds as:

i. Time and temperature,
ii. High pond pH, mainly above 9.4, and
iii. High light intensity together with a high dissolved oxygen concentration.

Mara (1997) used time and temperature parameters to model faecal coliform removal in WSP. Olukanni and Ducoste (2011) observed that faecal coliforms die off in WSP when both time and temperature increase.

High pH values of more than 9.4 have been observed to occur in facultative and maturation ponds due to rapid photosynthesis by pond algae. The high uptake of carbon dioxide by algae causes carbonate and bicarbonate ions to dissociate, resulting in the formation of hydroxyl ions that raises the pond pH to high base values. Faecal bacteria have been observed to die quickly within minutes when the pH exceeds 9.4 Olukanni and Ducoste (2011).

*Vibrio cholerae*has been observed to show resistance to the high pH conditions found in facultative and maturation ponds. Kayombo et al. (2003) showed that anaerobic ponds are very effective in removing the pathogens. It is suggested that the small concentrations of sulphide formed by the sulphate-reducing bacteria destroy *Vibrio cholerae*.

Mara (1997) observed that high light intensity and high dissolved oxygen concentration are very effective in killing faecal coliforms. It has been argued that light of wavelength 425.700 nm is absorbed by the humic substances ubiquitous in wastewater. It has been suggested that photochemical reactions occur within organic molecules, resulting in electronic excitation which persists for a sufficiently long time to damage faecal coliform cells.

2.13 Advantages of WSP

Having appraised the literature on treatment of wastewater in WSP, the advantages of WSP are now presented. Mara (1997) lists the advantages WSP as follows:

1. WSP are very efficient in treating wastewater. Pond systems have been shown to achieve a high degree of BOD removal, excreted pathogen removal (bacteria, virus, protozoa and helminths). This enables the WSP effluent to be reused for unrestricted crop irrigation, restricted crop irrigation and fishpond fertilization.
2. WSP are a flexible treatment process. Ponds can support hydraulic and organic shock loads. Moshe et al. WSP perform satisfactorily when presented with high concentrations of heavy metals (up to 30mg/l).
3. WSP are simple to construct, operate and maintain. They do not need electrical energy for their operation. They utilize the sun as the source of energy that is required by both algae and bacteria.
4. Building costs for WSP are low (Arthur, 1983). The only capital required is the cost of excavation and ground compaction. The operational costs of WSP are also low as the cost of manual labour is low in developing countries.

The principal drawback of WSP is that they require large areas of land. However, in many countries with warm climates where WSP could be a useful way to treat wastewater, land is often readily available.

In summary, this chapter has presented how wastewater treatment is carried out in WSP for the removal of BOD, excreted pathogens and nutrients. It has shown how a well-designed and operated system of anaerobic, facultative, and maturation ponds can function satisfactorily and as intended. The chapter has shown how anaerobic ponds play a significant role. In conclusion, a WSP system is a low cost technology, appropriate for the warm climate areas of developing countries. However, WSP can only be efficient in treating wastewater if they are well designed and properly operated. Anaerobic ponds should always be included in WSP because they significantly reduce the overall land requirement. Furthermore, anaerobic ponds are effective in removing *Vibrio cholerae*, the classic pathogen that has shown resistant to the otherwise hostile environmental conditions in facultative and maturation ponds. This is important if the effluent is to be reused for unrestricted crop irrigation. An anaerobic pond that has been well designed and which is operated properly should not release odours.

2.14 Different Approaches to Design of WSP

Design procedures depend on the type of pond.

2.14.1 Design of Anaerobic Ponds

Anaerobic ponds are designed on the basis of the permissible volumetric organic loading $\lambda_v (g/m^3.d \text{ of BOD}_5)$. The volumetric loading is related to flow rate (Q), influent BOD_5 (L_1) and pond volume (v) by

$$\lambda_v = \frac{L_1 Q}{V} \qquad (2.22)$$

With L_1 and Q usually known, V can easily be computed from which the dimensions of the pond are determined. It is recommended that $100 \leq \lambda_v \leq 400 g/m^3$ to maintain anaerobic conditions and avoid odour nuisance (Pearson *et al*. 1987).

The BOD_5 loading is also given as surface loading and is giving by equation (29) below:

$$\lambda_s = 10\frac{QS_o}{A} \quad (2.23)$$

Where
λ_s = BOD loading, kg/ha.d and is usually read from table. See Table 2.5.

2.14.2 Design of Primary Facultative Ponds

Primary facultative ponds are designed using the first order kinetic model (Kayombo*et al.*2003) already discussed above or the areal BOD loading rate method (Tcholobaloglous and Angelakis, 2000). It is based on the maximum areal BOD_5 loading $(\lambda_{\max})$ which the pond can withstand beforefailure.

However, since ponds are not designed to operate at failure equation (2.23) was modified by Arthur (1983) into

$$\lambda_d = 20T - 60 \quad (2.24)$$

Where λ_d is the design areal loading rate at temperature "T",the area (A) is then calculated from the equation

$$A = 10 L_1 Q \lambda_d \quad (2.25)$$

The secondary facultative ponds are designed based on Marais (1974) model already explained or by the dispersed flow model.

Table 2.5: Values of BOD_5 degradation coefficient

Temperature (^oC)	Surface loading rate (kg BOD /ha· day)
≤10	100
11	112
12	124
13	137
14	152
15	167
16	183
17	199
18	217
19	235
20	253
21	272
22	292
23	311
24	331
25	350
26	369
27	389
28	406
29	424

Reproduced from Mara (1997)

2.14.3 Design of Maturation ponds

Maturation ponds: Maturation ponds are designed mainly to remove pathogenic organisms, especially where the effluent is reused. The following design equation based on the assumption of first-order removal in completely-mixed ponds is recommended for a series of ponds.

$$N_e = \frac{N_i}{(1+K_b\theta_a)(1+K_b\theta_f)(1+K_b\theta_m)^n} \qquad (2.26)$$

Where N_e and N_i are the faecal coliform numbers in 100ml of the final effluent and raw wastewater respectively, K_b is the first order rate constant for faecal coliform removal in d^{-1} the subscripts a, f and m refer to the anaerobic, facultative and maturation ponds respectively, and n is the number of maturation ponds (Mara, 1992). It is a good practice to keep the detention time for each maturation pond less than 3 day. Besides, the BOD loading of the facultative pond must be less than that of the first maturation pond (Mara,1992).

A graphical means for optimal design of the WSP has been proposed (Agunwamba, 1991). It is easily allowed for the incorporation of the area, depth and efficiency constraints into the cost minimization problem considered. Besides, it allowed for optimal choice of the length to width ratio.Little work has been reported on BOD removal kinetics in maturation ponds but it is known that the rate of BOD removal is low for these ponds (kayombo*et al.* 2003).

2.14.4 Other Design Relationships

Apart from the above formulae, other relationships (especially empirical) have also been obtained(Tcholobaloglous and Angelakis, 2000).

$$K = 0.5(1.02)^{Tw-20}(1.15)^{(pH-6)}(0.99784)^{Ls-100} \quad (2.27)$$

Where; T_w, C_s, and L_s, are the water temperature, algal concentration and concentration of soluble BOD_5 loading.

For WSP design in Southeastern Nigeria, the following relationships were found (Agunwamba, 1991). In the case of secondary facultative ponds,

$$\lambda_o = (18.028 - 0.555T)^{T-20} \quad (2.28)$$

$$K_f = 71.865 - 2.567T - 2.923 \times 10^{-5}(OL) - 0.238pH \quad (2.29)$$

Where K_f is the first order coliform bacteria rate constant

It is recommended that treated wastewater used for crop irrigation contain no more than one human intestinal nematode egg per litre of restriction or unrestricted irrigation only and, for unrestricted irrigation only, no more than 1000 faecal coliform bacteria per 100 ml (WHO, 2000). An equation for the design of pond system for egg removal when the effluent is required for restricted irrigation only was derived by regression analysis(Mara *et al.* 1992).

$$R = 100[1 - 0.41\exp(-0.49\theta + 0.0085\theta^2)] \quad (2.30)$$

Where R is the percentage egg removal and θ the hydraulic detention time

2.15 Related works

The related research carried out on treatment of wastewater in waste stabilization ponds are presented in Table 2.6.

Table 2.6: Some related research on treatment of wastewater in WSP

S/No	Researchers	Year	Work done
1	Egwuonwu*et al.*	2014	Design, Construction and Performance Evaluation of a Model Waste Stabilization pond.
2	Olukanni	2013	Evaluation of the Influence of Reactor Design on the Treatment Performance of an Optimized Pilot-Scale Waste Stabilization Pond
3	Inyang*et al.*	2012	Characterization of brewery effluent fluid
4	Utsev and Agunwamba	2012	Effective Positioning of Solar Reflections in Solar Enhanced Waste Stabilization Ponds
5	Olaniyi*et al.*	2012	Effect of Industrial Effluent on the Surrrounding Environment.
5	Agunwamba&Ogarekpe	2010	The Effect of Hydraulic Jump on the Performance of Waste Stabilization Ponds
6	Ukpong*et al.*	2006	Stratification in waste stabilization ponds II: Modelling.
7	Fakayode	2005	Impart assessment of industrial effluent on water quality of the receiving Alaro River in Ibadan, Nigeria.
8	Agunwanba	2001	Effect of tapering on the performance of waste stabilization ponds
9	Agunwanba	1992	Deterministic models of WSP
10	Khan and Ahmad	1992	Performance evaluation of pilot waste stabilization ponds
11	Pearson*et al*.	1987	Water column sampling as a rapid and efficient method of determining effluent quality and performanceof waste stabilization ponds
12	Arthur	1983	Cost effectiveness of WSP

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials/Chemical Reagents and Apparatus/Instruments

Materials/Chemical Reagents

The list of materials and chemical reagents used in the course of this research work are presented in Tables 3.1 to 3.2.

Table 3.1 List of Materials

S/No	Material	Quantity	Source
1	Brewery Wastewater effluent	6400 Liters	Nigerian Breweries wastewater effluent discharge point, Kudendan light industrial layout, Kaduna.
2	Distill Water	4 Liters	Water laboratory, Kaduna Polytechnic
3	Filter Paper	1 pack	Water laboratory, Kaduna Polytechnic

Table 3.2 List of chemical reagents

S/No	Chemical/Reagents	Quantity
1	Sulfuric acid	450 ml
2	Oxalic acid	300 ml
3	Potassium hydroxide	20 g
4	Potassium dichromate	200 ml
5	Methyl orange	Few drops
6	Bromocrysol	Few drops
7	Ferrous Indicator	Few drops
8	Sodium hydroxide	50 g
9	Barium Chloride	50g
10	Silver Nitrate	150 ml
11	Sulphuric acid	200 ml

Apparatus/Instruments

The main Apparatus used for this research work is the designed and constructed Waste stabilization pond. The pond was constructed using concrete blocks and the floor of the pond was blinded with high density concrete using cement mix ratio of 1:2:4 for cement-sand-gravel on weight basis. The design calculations of the constructed pond is shown in appendix A and the summary of the design data are presented in Table 3.3. The list of other apparatus/instruments used is given in table 3.4.

Table 3.3 Summary of pond design parameters/data

Design Parameters		Pond Dimensions	
Temperature	(28 ^oC)	Width	(1.4 m)
Influent flow rate	(0.2 m^3/day)	Length	(2.8 m)
Mean Influent BOD	(1135.5mg/L)	Depth	(1.2 m)
Net Evaporation	(0.612 m^3)	Area	(3.91 m^2)
Cement mix ratio	1:2:4	Volume	(4.7 m^3)

Table 3.4 List of laboratory apparatus and instruments

S/No	Apparatus/Instrument	Model/Capacity	Source/ Manufactures
1	Beakers	250ml, 500ml & 1000ml	Pyrex, England
2	Measuring cylinders	300ml & 500ml	Pyrex, England
3	Pipette	25ml	Pyrex, England
4	Burette	250ml	Pyrex, England
5	Funnel		Pyrex, England
6	Conical flask	300ml & 450ml	Pyrex, England
7	Desiccator		Pyrex, England
8	Turbid meter	2100A	CAMLAB, U.S.A.
9	Conductivity meter	644	METROHM, Swiss.
10	Thermometer	644	METROHM, Swiss.
11	pH Meter	644	METROHM, Swiss.
12	Weighing balance	SPU 2001	OHAUS USA/ Scout Pro.
13	BOD Test Machine	WCG117A	CAMLAB, U.S.A.
14	Stop watch	H 2150WT	Labtronics, India.
15	Heating mantle	CH1800	Corsair Heating & Catering ltd.
16	Oven	MINI/30/CLAD	England

3.2 PROCEDURES

3.2.1 Sample Collection

Description of study area

The brewery wastewater effluent was collected at the discharge point into a stream at Kudendan industrial layout, Kaduna. The discharge point into the stream is situated at Latitude 10^{o}28.043’ N, Longitude 7^{o}23.194’ E and elevation 592.3m above sea level using global position system (GPS) to determine their coordinates and elevation.

Sampling

During this study, initial sampling was conducted for a period of 10 days to study the trend of the physicochemical parameters of the brewery wastewater effluents. The brewery wastewater sample was collected daily at the wastewater discharge point into the stream. The samples were collected in new plastic containers which were pre-cleaned by washing with non-ionic detergents, rinsed using tap water and distilled water before sampling. The containers were rinsed three times with the wastewater sample before being filled with the wastewater and taken for physicochemical analysis. The temperature of the samples was taken at the point of collection using portable digital thermometer and the samples were then transported in cooler boxes.

Physicochemical Analysis

The sample analyses were conducted in the water laboratory of Civil Engineering Department, Kaduna polytechnic, Tudun Wada, Kaduna. The Physicochemical parameters were then determined at the water laboratory of Kaduna Polytechnic and they include: Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Turbidity, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5),Electro- Conductivity (EC), pH,Chlorides, and faecal coliform. Portable digital meters were used to measure EC, TDS and pH instantaneously in the laboratory. Samples were kept in the freezer in the laboratory at a temperature of 0 ^{o}C for sample preservation. Turbidity was measured with a turbidity meter. The TSS was measured using the gravimetric method. The measurement of Most Probable Number of *E-coli* was performed by incubating multiple tubes in a water bath at 35°C ± 0.5°C for 3 hours, and then transferred to a water bath at 44.5°C ± 0.2°C. After 21 ± 2 hours, tubes were examined for growth and gas production. Gas production in 24 hours or less was a positive reaction indicating the presence of faecal coli forms.Chlorides contents were analyzed as per Standard methods (APHA, 1998).

The result of the initial ten days analysis was used to design the pond. The pond capacity is 4700 Liters. Provisions were made in the pond to collect samples at different levels of the pond height so as to study the treatment process along the pond stratification of aerobic, facultative and anaerobic zones as shown in plate 1. After the pond was constructed it was filled to capacity with the brewery wastewater effluent. A pick up van was used to transport the wastewater from the collection point to Kaduna Polytechnic where the pond is constructed. Two new 1700 liter plastic Tanks were purchased for the purpose of the wastewater sample collection. The plastic tanks were washed with detergent and rinsed very thoroughly with clean tap water. One of the plastic tanks was placed where the wastewater effluent flows into the river to gather the wastewater. The other plastic tank was placed inside the van and an irrigation water pump was used to pump the wastewater from the collection point to the tank inside the van. The pump was rinsed thoroughly by pumping clean tap water before being used to pump the wastewater into the tank inside the van.

The collected wastewater was transported to the location of the pond in Kaduna polytechnic, behind Civil Engineering Department and offloaded into the pond using the same pump. The pond has been washed with clean water before the wastewater was discharged inside. A steady state condition was assumed after the pond was filled with the wastewater. A 100 liter plastic tank was then elevated to serve as a makeup tank and connected with hose and valve to operate a continuous flow of $0.2m^3$ per day. 2 new 50 liter jerry cans were also used to collect make up wastewater on daily basis. The WSP was set to operate on continuous flow at influent and effluent flow rates of $0.2m^3$ per day. Treated and raw wastewater samples were collected for a period of 27 days for physicochemical analysis. The average daily ambient temperature was also taken for the period of the study.

3.2.2 pH, Temperature and Electrical ConductivityMeasurement Procedure

ThepH, Temperature and Electrical Conductivity were measured using a digital measuring instrument shown in plate 3.1. The instrument was designed to measure pH, temperature and electrical conductivity. The steps for the measurement are listed below:

1. the digital measuring instrument was switched "ON"
2. The instrument was calibrated for pH measurement using standard buffer solution using slop and buffer control knob
3. The probe of the measuring instrument was inserted in the buffer solution and the buffer control knob was adjusted to attain pH 7 (neutral)
4. The probe was then inserted in to the water sample and the pH value was indicated on the meter which was taking and recorded.
5. The mode knob on the instrument was switched to temperature and conductivity measurement to measure the temperature and the electrical conductivity of the test samples and the values were read directly on the meter and recorded.

Plate 3.1: A pH, temperature and electrical conductivity meter

Plate 3.2: A Turbid meter

3.2.3 Turbidity Measurement Procedure

The turbidity of the wastewater and the treated water samples were measured using a digital turbid meter shown in plate 3.2. The measurement procedures are stated below.

1. The turbid meter was warmed for five (5) minute
2. The test corvette was rinsed with distilled water
3. The test wastewater sample was poured in the test corvette
4. The sample was shaken and the side of the test corvette was properly cleaned.
5. The test corvette containing the sample was placed in the corvette apartment.
6. The sample was then covered with corvette cover
7. The turbidity value was read from the turbid meter instrument directly in NTU

3.2.4 Chloride Measurement Procedure

The chloride contents of the wastewater and the treated water samples were determined through analytical method by volumetric analysis using (APHA, 1998) standards. The procedure is summarized below.

1. The burette was rinsed with distilled water

2. 50 ml of silver nitrate ($AgNO_3$) 0.1M was introduced into the burette, it was recorded as initial reading for the water sample
3. 100 ml of wastewater sample was measured and poured into the conical flask.
4. Two drops of methyl orange indicator was introduced into the wastewater sample
5. The wastewater sample was titrated with the 0.1M silver nitrate ($AgNO_3$) until the colour changes to deep pink colour
6. End point was noted and recorded as a final reading.

Calculations

Chloride content of the wastewater was calculated using the relation:

$$Chloride = \frac{Titre\ value\ \times \mathrm{M}\ \times 35.5 \times 10^3}{Vol.of\ wastewater} \quad (3.1)$$

Wheretitre value is the volume of silver nitrate used for titration, M is the molarity of silver nitrate and 35.5 is the molar mass chlorine.

3.2.5 Total Suspended Solid (TSS) Measurement Procedure

An empty filter paper was dried in an oven to remove any moisture content present. It was then weighed with a digital weighing balance (plate 3.3)and used to filter 50 ml of the wastewater sample. The suspended solid was dried in an electric oven (plate 3.4) at a temperature of 100 ^oC for 20 minutes. It was then cooled in a desiccator and finally reweighed. The result of the total suspended solid is then calculated using the relation:

TSS = W2 – W1 (3.2)

Where:W1 is initial weight of filter paper, and

W2 is the weight of filter paper with the dried solid residue

TSS is expressed in mg/L.

3.2.6 Total Solids Measurement Procedure

The total solids contentof the wastewater and the treated water samples were measured by Gravimetric Analysis; that is the method of analysis of solid contents by weight difference (APHA,1998) standards. The procedure is as stated below:

1. The evaporating dishes were washed, cleaned and dried in an oven at 100°C for twenty (20) minutes.
2. The dishes were removed and cooled in a desiccator for 20-30 minutes.
3. The dishes were removed weighed as initial weight using digital weighing balance
4. 50ml of the water sample was poured into the evaporating dishes and heated on a hot plate heater shown in plate 3.5 until all water dries up.
5. The evaporating dishes were transferred into the oven to dry completely at 100 °C for twenty (20) minutes.
6. The dishes were removed and cooled in the desiccators for twenty (20) to thirty (30) minutes.
7. The dishes were removed and weighed as a final weight.

Calculation

$$TS = \frac{FWD - IWD \times 10^6}{50} \qquad (3.3)$$

Where

TS is the total solids in the test sample (mg/L)

FWD is the final weight of dish (g)

IWD is the initial weight of dish (g)

3.2.7 Total Dissolved Solids measurement procedure

The Total Dissolved Solid (TDS) was obtained by taking the difference of the Total Solids and the Total Suspended Solids, i.e.

TDS = Total Solids - Total Suspended Solids (3.4)

Plate 3.3: A digital weighing BalancePlate 3.4: An electric oven

3.2.8 Bio-Chemical Oxygen Demand (BOD_5) Measurement Procedure

The BOD_5 measurement was conducted using the (APHA, 1998) standards. The BOD_5 measuring instrument (shown in plate 3.6) was used to determine the BOD_5 of the wastewater and the treated water samples. The instrument was set for the measurement by connecting it to the power source. It was then adjusted to zero value and air was blown in from the head of the cap to the mercury level. The incubator bottles were washed and rinsed with distilled water and also with the wastewater sampleto eliminate any contaminant before being filled with the wastewater sample. 0.2 g of potassium hydroxide pellets were added to each of the bottles as nutrients. The bottles were each caped to a mercury manometer head. The manometric scale was set to zero reading, and the instrument was switched on and the samples were incubated

Plate 3.5: A hot plate heater **Plate 3.6: A BOD_5 measuringmachine**

at 20 ^{O}C for five days. At the fifth day the BOD_5values were read from the instrument on the scale of the manometer directly in mg/L.

3.2.9 ChemicalOxygen Demand (COD) measurement procedure

The COD of the wastewater and the treated water samples was measured by volumetric analysis using (APHA, 1998) standards. The steps of the measurement procedure are stated below:

1. 50 ml of waste water sample was put in a 500L reflux flask
2. 1 g of silver sulphate (Ag_2S0_4) with broken porcelain pieces / glass beads was added to the sample
3. The flask was immersed in cold water
4. 75ml of Ag_2SO_4 reagent was added slowly while shaking the flask
5. 25ml of 0.25 M potassium dichromate ($K_2Cr_2O_7$) solution was added and was mixed thoroughly in the flask
6. A water condenser and reflux were fixed and the flask was heated for 2 hrs.
7. The condenser was washed with distilled water into flask
8. The flask content was then was diluted with distill water to make 300ml and cooled

9. 2 - 3 drops of ferrous indicator was added and was titrated against of 0.25 M K_2 Cr_2O_7until the first sharp colour changed from blue green to reddish brown
10. Volume of used 0.25 M K_2 Cr_2 $O_7$was recorded as titre value A inml.

Blank Titration

1. 50ml of distilled water was poured into the reflux flask
2. 1g of Ag_2SO_4 + broken porcelain pieces /glass beads was added to the sample
3. The flask was immersed in cold water
4. 75ml of H_2S0_4 was added slowly while shaking the flask
5. 25ml of 0.25 M $K_2Cr_2O_7$solution was added and was mixed thoroughly in the flask
6. The water condenser and reflux were fixed for 24hr
7. 2 - 3 drops of ferrous indicator was added and was titrated against 0.25M $K_2Cr_2O_7$until the first sharp colour changed from blue green to reddish brown.
8. The volume of $K_2Cr_2O_7$used was recorded as Blank titre value B in ml

Calculation:

Volume of sample taken = 50ml

Volume of 0.25 M $K_2Cr_2O_7$used in sample titration = (A) ml

Volume of 0.25 M $K_2Cr_2O_7$used in blank titration = (B) ml

$$COD = = (\mathrm{B} - \mathrm{A}) \times 8 \times 1000/4 \times 50 \quad (3.5)$$

3.2.9: Coliform count Procedure

The bacteriological test was conducted using the most probable number (MPN) method (APHA, 1998). The MPN method is the method of indicating the *E.coli*count in 100 ml of test sample. *E.coli*(*Escherichia coli*) is the most populous bacteria specie that can be found in bacteriological test analysis and their presence indicate the probability of the presence of other species of bacteria.

Preparation of inoculant [potato broth]:

Sweet potato was pealed and chipped to pieces and poured into evaporating dish. About 40-50g of powdered milk was introduced and 450 ml of distilled water was added and heated to boil. It was then cooled and the supernatant (clear layer of the settled mixture) was decanted and used as inoculant.

Preparation of serial dilutions:

1. Three sets of 0.1ml wastewater samples were measured with test samples
2. Three sets of 1ml wastewater samples were measured with test samples
3. Three sets of 10ml wastewater samples were measured with test samples hence making a total of 9 test tubes i.e. serial dilutions.
4. To each test tube 1ml of inoculant was added and 0.1ml of indicator (bromocrysol) was also added and the samples were incubated at 37 ^{O}C for 48 hrs. After the incubation period, gas observation (development) was observed as positive (+ve). The observations were read against the chart in terms of *E.coli*/100ml

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter comprises of the design data and the operational data generated from the constructed pilot waste stabilization pond for the treatment of brewery wastewater effluents. The data were further analyzed to obtain data correlations and reliability.

4.2Pond design and construction

The designed WSP was constructed using concrete walls. It is rectangular in shape and the design calculations are shown in appendix A. The summary of the design data is presented in Table 4.1 and 4.2.

Table 4.1: Design parameters and data of the pilot WSP

Design Parameters		Pond Dimensions	
Temperature	(28 ^oC)	Width	(1.4 m)
Influent Flow rate	(0.2 m^3/day)	Length	(2.8 m)
Mean Influent BOD	(1135.5mg/L)	Depth	(1.2 m)
Net Evaporation	(0.612 m^3)	Area	(3.91 m^2)
Cement mix ratio	1:2:4	Volume	(4.7 m^3)

The volume of the WSP is 4.7 m^3 (4700 litres) and the dimensions 2.8 m, 1.4 m and 1.2 m for length, width and depth respectively. The volume is assumed adequate for a pilot scale pond to postulate the operation of a full scale pond where the effect of the factors enhancing the performance of a WSP such as sunlight, wind and gravity are observed. The depth of 1.2 m chosen is also good for a facultative process where the activities of both aerobic and anaerobic microorganisms will be allowed to occur and the growth of aquatic plants will be disallowed.
When grasses and other plants are allowed to grow in WSP, they become contusive environment for breeding mosquitoeswhich are agents of malaria fever spread. The design temperature was 28 ^oC, which is the mean temperature of the coldest season of the site of the WSP. This is to allow the WSP to function effectively round the year because the activities of

the organic decomposing microorganisms is also dependent on temperature and most tend to be less active or dormant at low temperatures. The BOD loading was an average BOD of the brewery wastewater effluent for a period of ten days following the trend of the factory operations. The wastewater influent flow rate of 0.2 m^3/day was assumed to be adequate for the capacity of the pilot WSP. The net evaporation was 0.612 m^3. The cement mix ratio of 1:2:4 for cement-sand-gravel on weight basis was used. This gives high density concrete which prevents the seepage of the wastewater through the concrete walls and the floor of the pond.

The cost estimate of the pond construction is presented in appendix B and the total cost estimate of the pond construction was two hundred and ten thousand naira (N 210,000) only. The summary of the estimate is presented in Table 4.2.

Table 4.2: Cost estimateof pond construction

Cost of materials	N 186,700
Total labour cost	N 1,5000
Transportation	N 4,300
Miscellaneous	N 4,000
Total Cost	**N 210,000**

4.3Physicochemical parameters of the wastewater

The results of the physicochemical analysis of the raw and stabilized wastewater for a period of twenty seven days (27 day) were recorded and tabulated in Tables C1 to C9 in appendix C. From the results, for the untreated (raw wastewater) the physicochemical parameters were changing with the trend of the activities (type of processes) of production. The range and the mean values were presented in Table 4.3. The mean values of these physicochemical parameters were compared with the NESREA standards for industrial wastewater into receiving water bodies, and the comparisons show that the physicochemical parameters which include pH, temperature, total suspended solids (TSS), turbidity, chlorides, biological oxygen demand (BOD_5), chemical oxygen demand (COD), electrical conductivity (EC), total dissolved solids (TDS) and total coliform were all above the discharge limit values set by NESREA except for the value of temperature, chlorides and total coliform, as presented in Table 4.3.

Table 4.3: Range and mean values of physicochemical parameters of the brewery wastewater compared with NESREA and WHO discharge limits

Parameter	Unit	Range	Mean	NESREA limit	WHO limit
pH		2.2 – 7.7	3.79	6-9	7-8.5
Temperature:	^oC	27 – 35.5	29.7	40	45
TSS:	mg/L	1000 – 1200	1048.9	30	50
Turbidity:	NTU	4.6 – 7.2	6.09	<1	5
Chloride:	mg/L	500.2 – 646.1	573.5	600	200
BOD_5 :	mg/L	800 – 1805	1128.8	30	50
COD:	mg/L	1504 – 3393.4	2122.1	150	100
Conductivity:	µS/cm	700 – 1630	1011.8	400	
TDS:	mg/L	600 – 1100	826.9	2000	1000
Total Coliform:	*E-coli*/100 ml	0 – 2	1	400	400
Mean ambient Temperature	^oC	25 – 36	29	-	-

The mean BOD value was 1128.8 mg/L and the discharge limits are 30 mg/L and 50 mg/L set by NESREA and WHO respectively, this shows that the brewery wastewater is highly polluted and as it did not meet any of the set discharge limit, hence, devoid of dissolved oxygen and thereby needs treatment to meet up with discharge set limits prior to discharge into the environment.

The values of the physicochemical parameters of the treated brewery wastewater in the constructed pilot WSP were also compared with the both NESREA and WHO discharge limit standards to ascertain compliance and these were presented in Table 4.4. The results indicated that after the wastewater stabilization in the constructed WSP, the values of all the physicochemical parameters except for TSS, turbidity and BOD_5 meet up with the discharge limits set by NESREA. These could be attributed to the fact that the WSP was designed as a facultative pond and the BOD loading of the wastewater is very high, thereby a considerable level of BOD removal is not achievable in a single pond.

Table 4.4: Physicochemical parameters of treated wastewater and regulatory limits

S/NO	Parameter	Unit	Treated wastewater	NESREA limits (max. allowable)	WHO limits (max. allowable)
1	pH		6.7	6-9	7-8.5
2	Temperature	^oC	27	<40	45
3	TSS	mg/L	199	30	50
4	Turbidity	NTU	2.0	<1	5
5	Chloride	mg/L	268	600	200
6	BOD_5	mg/L	350	30	50
7	COD	mg/L	660	1000	100
8	Conductivity	µS/cm	287	400	
9	TDS	mg/L	296	2000	1000
10	Total Coliform	*E-coli*/100ml	9	400	400

However, the performanceevaluationof the pond indicated that the pond performance efficiencies for suspended solids, turbidity, chlorides, BOD, COD,conductivity and total dissolved solids are: 81 %, 67.2 %, 53.2 %, 69 %, 68.9 %, 71.6% and 64.2 % respectively at the aerobic layer of the pond; 80. 9 %, 67.2 %, 53.1 %, 68.8 %, 68.6 %, 71.3 % and 64 % respectively at the facultative layer; 80.8 %, 65.5 %, 53.1%, 68.8 %, 68.6 %, 71.3 % and 64 % respectively at the anaerobic layer of the WSP. This is presented in Table 4.5. The efficiency of the WSP for BOD removal at the aerobic, facultative and anaerobic layers of the pond was 69 %. 68.8% and 68.8% respectively. The closeness of the values indicated that there was adequate mixing of the wastewater in the WSP through aeration and thermal radiation. The WSP was designed to reduce the BOD loading by 90 %, and comparing this with the 69 % removal obtained, the performance was found to be satisfactory although can be improved upon through design and operation review.The WHO standard is a worldwide standard that is acceptable and the NESREA standards were derived based on the consideration of the WHO requirements and the prevailing environmental situations in Nigeria and therefore emphasis is made on compliance with NESREA standards.

Table 4.5: Performance evaluation of the constructed WSP

S/NO	Parameters	Unit	Performance efficiency (%)		
			Aerobic	**Facultative**	**Anaerobic**
1	Suspended solids	mg/L	81	80. 9	80.8
2	Turbidity	NTU	67.2	67.2	65.5
3	Chloride	mg/L	53.2	53.1	53.1
4	BOD_5	mg/L	69	68.8	68.8
5	COD	mg/L	68.9	68.6	68.6
6	Conductivity	µs/cm	71.6	71.3	71.3
7	Total dis. solids	mg/L	64.2	64	64

4.3.1 Temperature

The range of temperature of the raw brewery wastewater collected was 27- 35.5 ^{o}Cthe mean value was 29.7^{o}C as shown in Table 4.3. The temperature of the treated wastewater in the WSP was 27^{o}C, which indicated that the WSP reduced the temperature of the wastewater. This was achieved due to the cooling effects that takes place as the wastewater settled in the WSP due to evaporation, aeration and other biochemical activities that causes cooling. This temperature value is less than 40 ^{o}Cwhich is the recommended NESREA and WHOlimit for industrial wastewater discharge as presented in Table 4.4. Based on these set limits, the temperature of the treated wastewater in the constructed WSP met the required standard for discharge into the receiving water bodies and will pose no thermal threat on the homeostatic balance of the receiving water body.

4.3.2 Biochemical oxygen demand (BOD) and Chemical oxygen demand (COD)

The results of the analysis of the brewery wastewater effluent carried out showed that the wastewater has average values of BOD and COD of 1128.7mg/L and 2122.1 mg/L respectively, (Table 4.3). These values are high and exceeded the NESREA and the WHO limits for industrial wastewater discharge into the receiving water bodies. The Biochemical oxygen demand (BOD_5) of the wastewater samples varied from 800 to 1805 mg/L, and the COD varied from 1504 – 3393.4mg/L and this indicated higher levels of BOD and COD as shown in Table 4.3. The BOD_5 and COD readings collected from the WSP treated wastewater samples for a period of 27 days were plotted against time and the graphs fitted the polynomial curves as can be seen in Figure 4.1. From these curves, it was shown that the BOD loading of the wastewater was reducing with increase in the retention time nonlinearly until it became constant at the 25th day. The R^2 values for the BOD_5 curves are within the range of 0.974 –

0.9924 and for the COD curves they are within the range of 0.9689 – 0.9781. The R^2value is always between 0 and 1 and the model has stronger correlation and predicts better results when R^2 value is closer to unity.

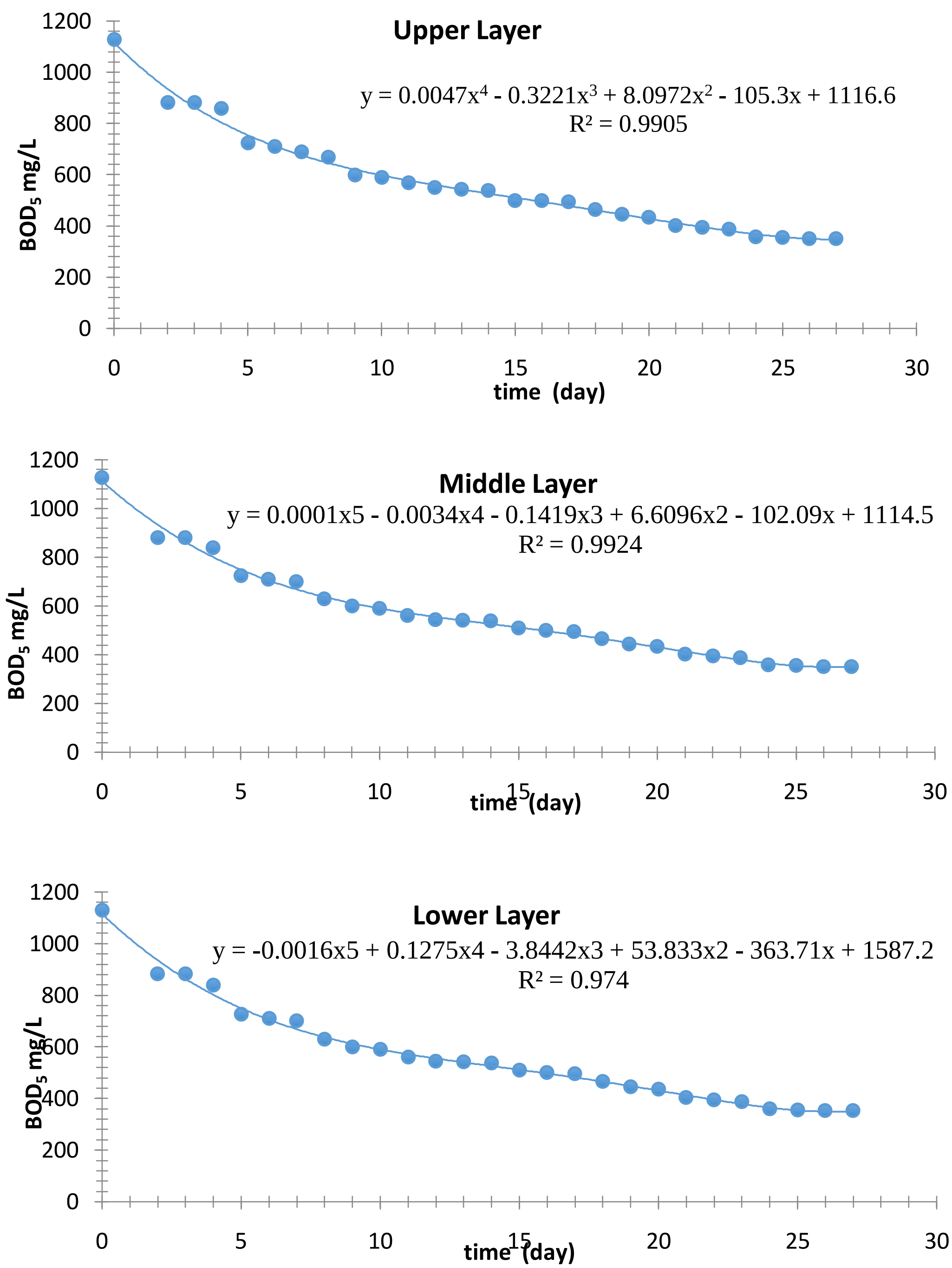


Figure 4.1: Reduction of BOD_5 with retention time at the different layers of the WSP

The regression model of the BOD_5 removal at the upper layer of the WSP (exit zone) predicted that BOD = $0.0047x^4 - 0.3221x^3 + 8.0972x^2 - 105.3x + 1116.6$.The BOD removal is attributed to the symbiotic relationships between the bacteria present and the algae formation. The aerobic bacteria make use of the oxygen produced by the algae to decompose the organic matter content of the wastewater forming carbon dioxide, water and new bacteria cell. The algae on the other hand make use of the carbon dioxide in the presence of sunlight to synthesize energy and produce new cell. Thus as the bacteria feed on the organic matter, they multiply and the BOD reduces. The anaerobic bacteria present also decompose organic matter into methane and water plus formation of new cells. However, adequate mixing reduces the activities of anaerobic bacteria. The BOD reduction pattern at the upper, middle and lower layer are similar, and this is as a result of adequate mixing in the WSP through aeration and the available solar thermal radiation. Figure 4.2 shows that the bacterial activity for the decomposition of organic matter in the wastewater is at maximum in the middle layer of the WSP. This observation may be attributed to the fact that the middle layer favours both aerobic and anaerobic heterotrophic bacteria in comparison to the other layers of the WSP.

The plots of COD versus time are also presented in Figures 4.2. These curves also indicated similar pattern with the plots of BOD_5versus time, and Figure 4.5 shows that the COD removal at the facultative zone of the WSP was the maximum compared with the other layers.Since COD if a measure of the fraction of the dissolved oxygen requirement for both the oxidation of both organic and inorganic components of the wastewater,

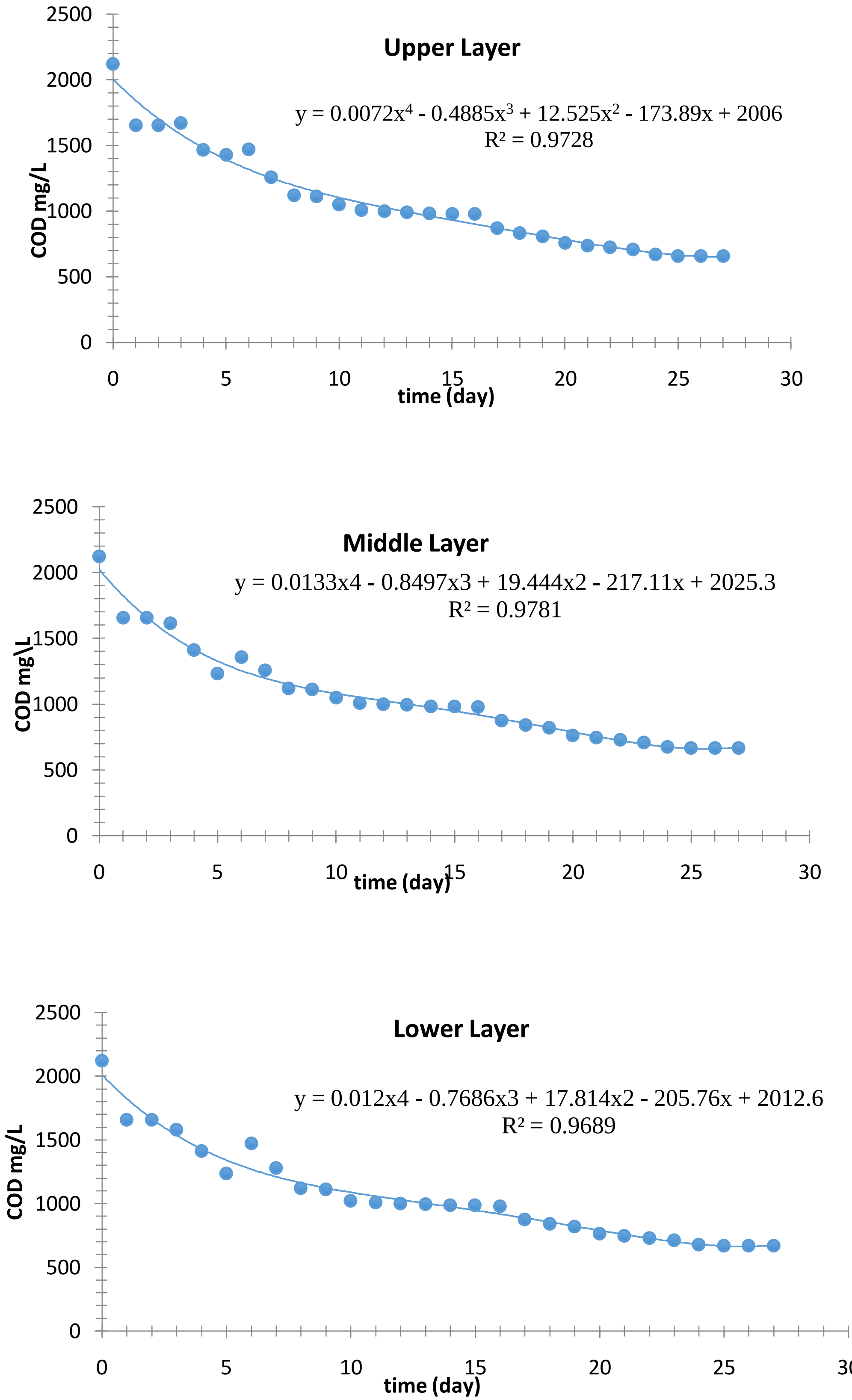
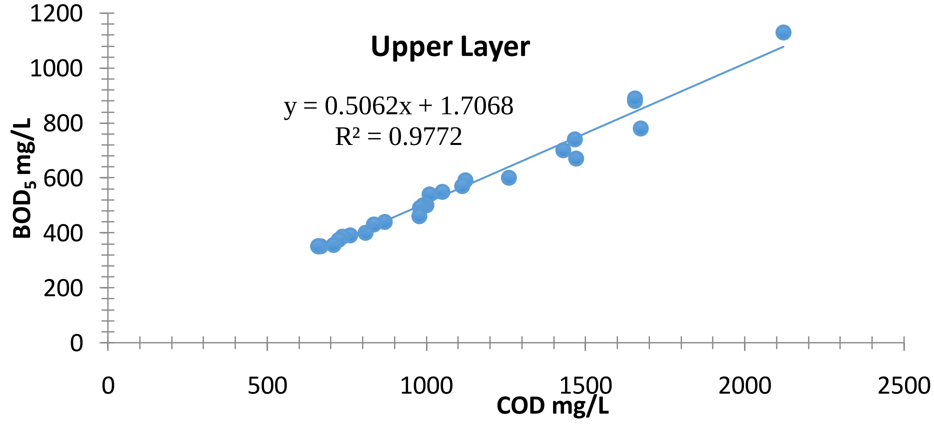
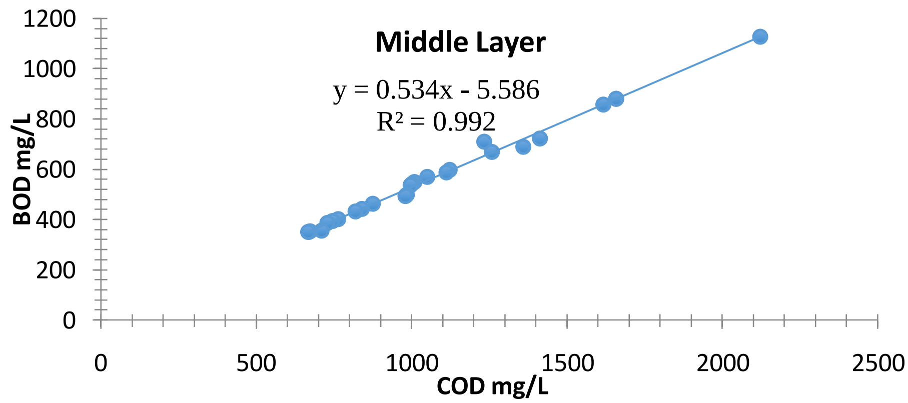


Figure 4.2: Reduction of COD with retention time at the different layers of the WSP

The plot of BOD_5 versus COD indicated R^2 range of 0.9772 – 0.99228 as presented in Figures 4.7 to 4.9. Figure 4.3 shows the regression model of BOD versus COD as $BOD_5 = 0.5062COD + 1.7068$.This gives a correlation between BOD and COD and enables the estimation of COD from BOD_5 data. BOD_5/COD ratios are also useful for prediction of the biodegradability of the wastewater. The BOD_5 and COD data obtained for the stabilized wastewater in the pond at the retention period of 25 days are 350 mg/L and 660 mg/L respectively. The COD of the treated wastewater met the WHO set limit for wastewater discharge; but both the BODand the COD did not conform to NESREA limit. However, based on the percentage removal of these parameters in the pilot WSP,the performance of the WSP for the wastewater treatment was satisfactory for both BOD and COD removal and further reduction of these parameters can be achieved in secondary facultative and maturation ponds.





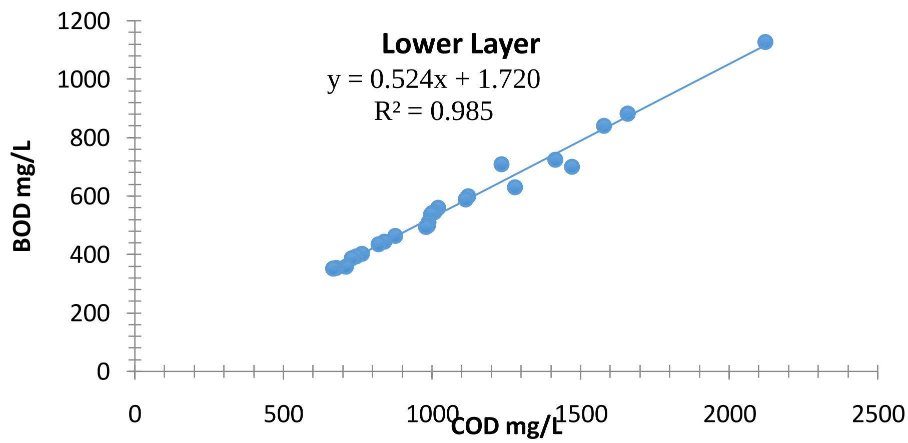
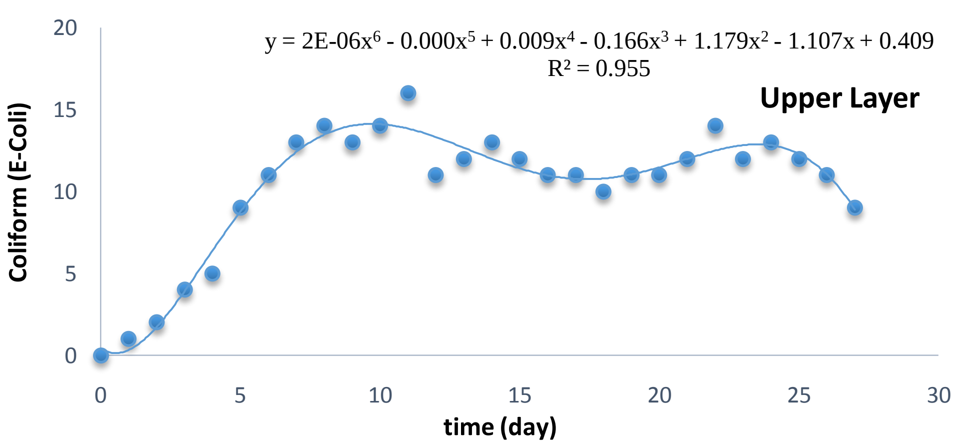
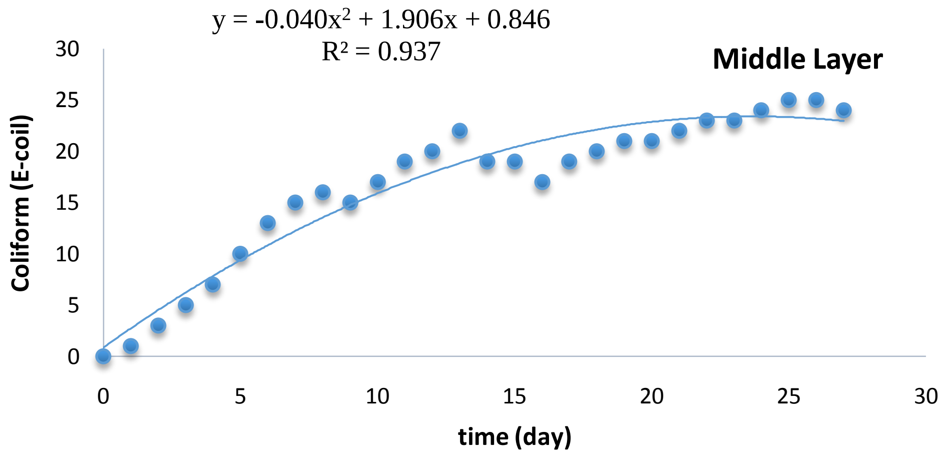


Figure 4.3: of BOD_5–COD correlationacross the WSP

4.3.3 Coliform

The coliform counts was also plotted against time to model how the coliform count increases with time and are presented in Figure 4.4. At the upper layer (aerobic zone) of the pond, the coliform count increased with time until it reached its peak at day 11 with coliform count of 16 *E- coli*/100 mL as can be seen in Figure 4.10 and then declined gradually to 10 *E-coli*/100mL on day 18. This decline in coliform count according to Davis &Mansten, (2004) can be attributed to the release of bactericidal substances by algae formed on the surface of the wastewater inside the pond. According to Mara (1998), the decay of bacteria on the other hand may be as a result of solar radiation, death of bacteria due to depletion of nutrients, decay related to high temperature and reduction of bacteria due to sedimentation process. Other factors such as elevated dissolved oxygen, reduction-oxygenation reaction and high pH are also influence bacteria removal in WSP. The coliform count started to increase again at day 19 and reached 13 *E-coli*/100 mLat day 21, this can be referred to another acceleration phase as a result of re-acclimatization of the bacteria with the environment causing gradual change in population. The decline after day 21 can be referred to the endogenous phase where the death rate becomes greater than the reproduction rate majorly due to depletion of food and sedimentation process. The model equation is represented in the equation shown in Figure 4.10. Similar situation occurred at the facultative zone as the coliform count increased with time at the earlier days, which implied that the bacteria multiplied as they feed on the organic components in the wastewater.





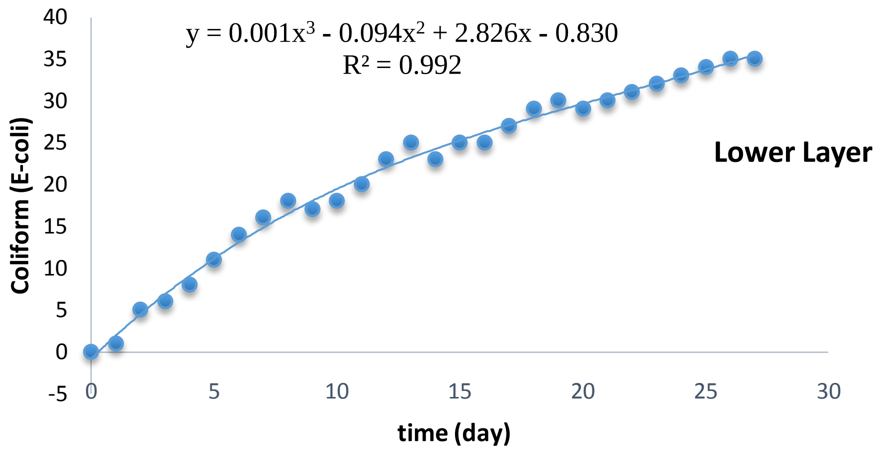
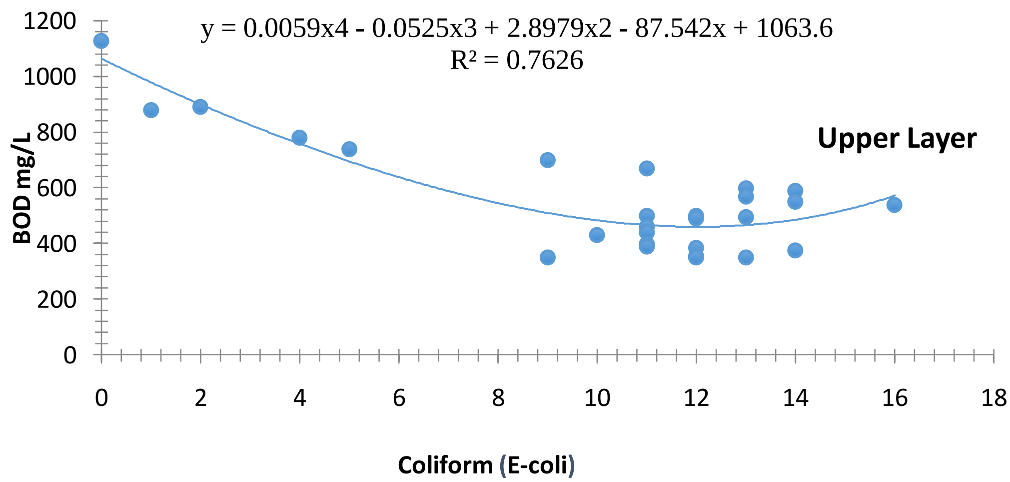


Figure 4.4: Coliform growth curve in the different layers of the WSP

However the coliform count reached a maximum of 25 *E- coli*/100 mL at day 26 before it started to decline again. This showed that the effects of bacteria removal factors discussed above are less at the facultative zone compared to the aerobic zone. At the anaerobic zone, the curve is almost a smooth curve which indicated increase of coliform count with time and reached a maximum of 36 E-coli before it started to decline. This implied that the bacterial activities for biodegradation of organic content was highest at the anaerobic zone and was less hampered by the bacteria removal factors.

Plots of coliform count versus BOD are also presented in Figure 4.5 and the range of the R^2 values is 0.7626 to 0.9879 with the highest at the lower layer of the(anaerobic zone) WSP. This also conformed to the earlier discussion on coliform versus time plots as the coliform count increases with amount of BOD in similar pattern. High coliform count indicates high population of bacteria in the wastewater, and the increase in the population of bacteria depends on the availability of the nutrients they feed upon which is contained in the wastewater in form of organic matter contaminants. However, the bacterial removal is necessary as the presence of the bacteria in the final treated wastewater is undesirable as it can cause high health hazards particularly for animals and mankind, and the removal of these bacteria is often achieved in maturation ponds. The coliform count in the treated wastewater conformed to both NESREA and WHO standards for industrial wastewater discharge.



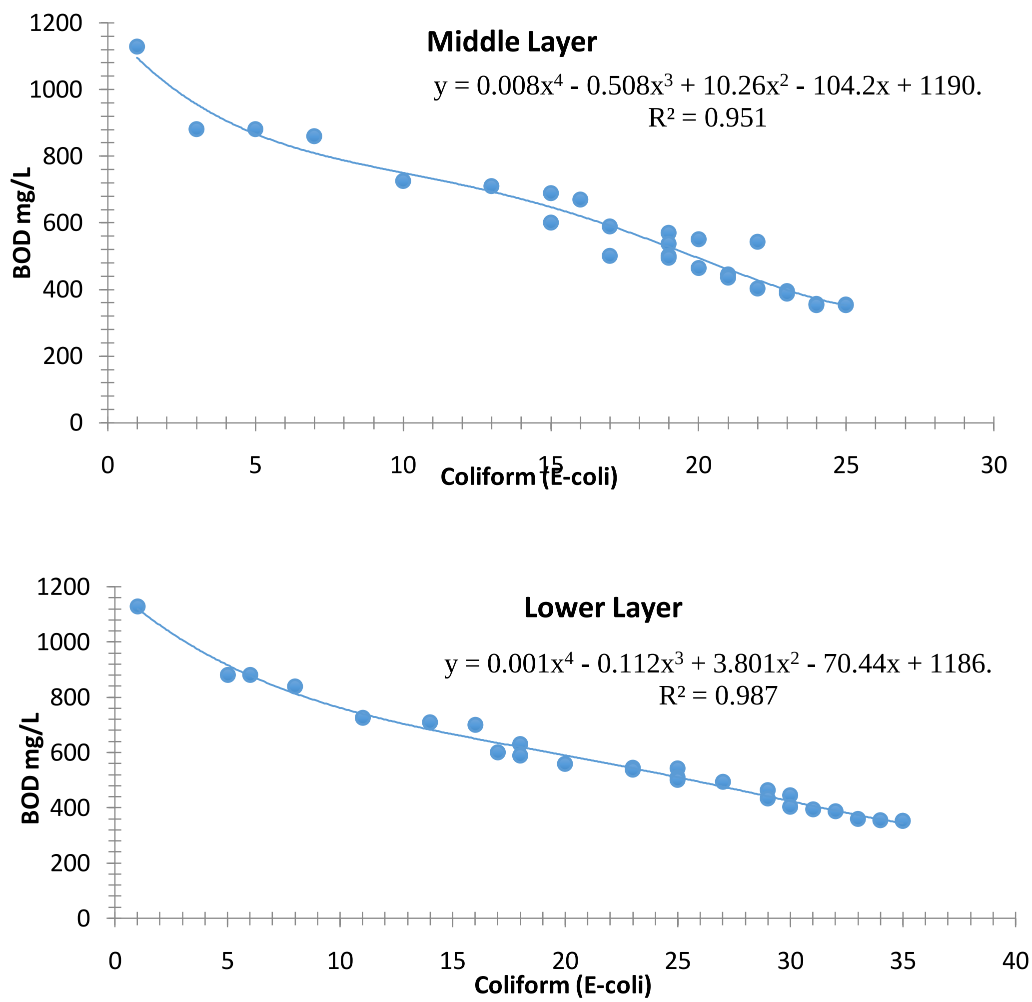
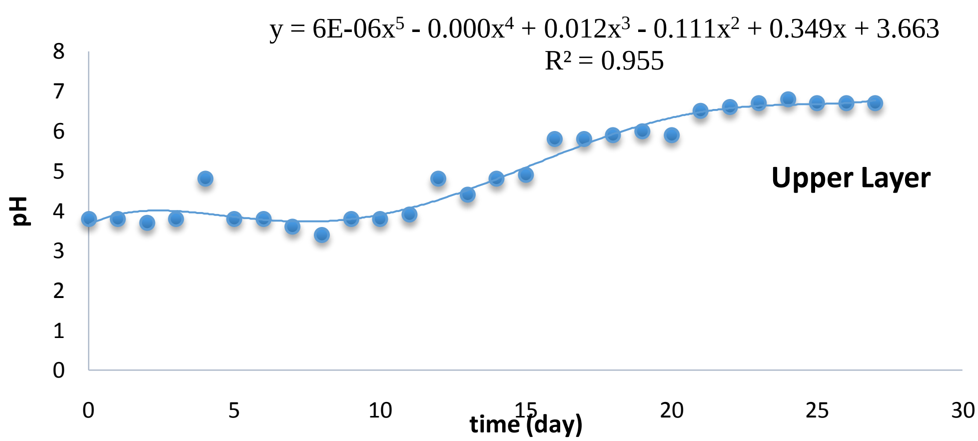
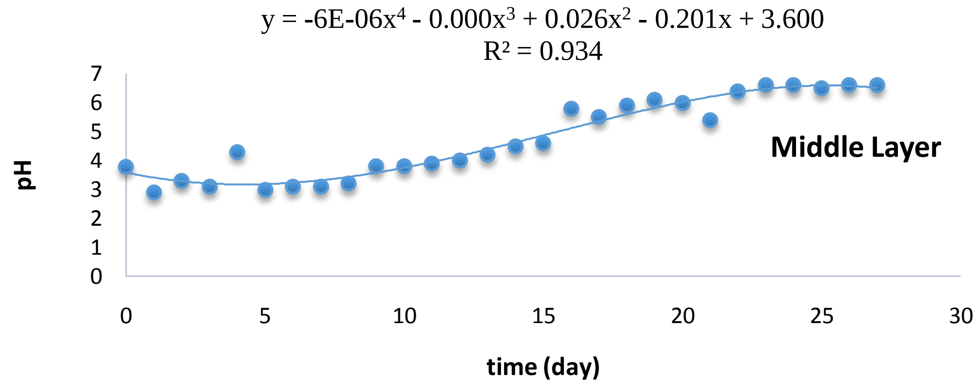


Figure 4.5: BOD reduction curve at different layers of the WSP

4.3.4 pH

The pH values were plotted against time and the curves are presented in Figure 4.6. The pH curves have similar pattern at the upper, middle and lower (aerobic, facultative and anaerobic) layers of the WSP. The determined pH values at day 23 are 6.4, 6.5 and 6.7 in aerobic, facultative and anaerobic zones respectively. The pH of the wastewater was observed to be declining in acidity as the retention time increases until the retention period of 25 days where no further significant variation in pH was recorded. The pH adjustment can be attributed to the entire stabilization processes in the pond which include the sedimentation of organic and inorganic matter into sludgeand the decomposition of the sludge by anaerobic bacteria into methane which is a neutral gas, the oxidation of organic matter into carbon dioxide and water by aerobic bacteria, the utilization of carbon dioxide by algae, the diurnal variation of dissolved oxygen and the mixing effects of wind and thermal radiation of the wastewater in the WSP.The treatment of the wastewater in the WSP reducedthe pH from acidic medium to almost a neutral medium and this shows that the WSP has a very good performance in pH adjustment. The pH of the treated wastewater also conformed to the NESREAlimits for wastewater discharge. Low pH indicates acidity and high pH indicates alkalinity. The acidic nature of the brewery wastewater effluents is responsible for the chemical decomposition of soil noticed at the discharged point which is characterized by soil erosion as can be seen in plate E4.





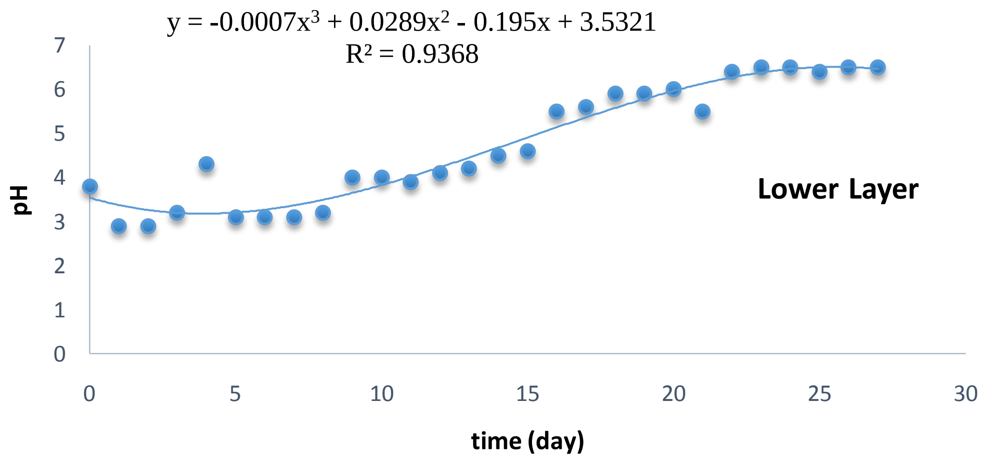
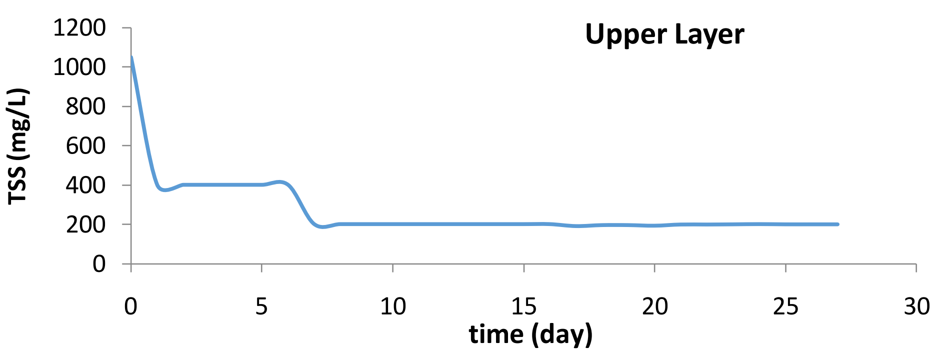
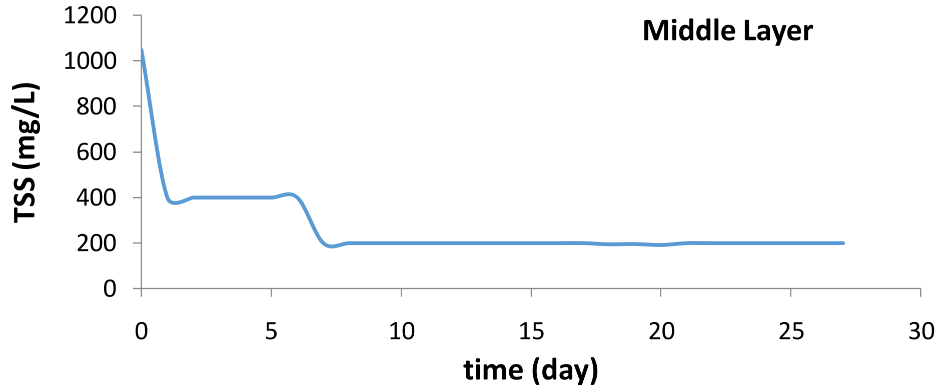


Figure 4.6: pH adjustment across different layers of the WSP

4.3.5 Total suspended solids (TSS)

The range of the TSS measured for the raw wastewater is 1000 to 1200 mg/L and the mean value is 1040 mg/L which is higher than 30and 50 mg/L set limitsrecommended by NESREA and WHO respectively for industrialwastewater discharge (Table 4.4).The plots of TSS versus time are presented in Figure 4.7. From this curves, it was observed that the curves have similar pattern in all the three layers of the pond. There was a sharp drop in TSS in the first two days before it then became constant between second and the fifth day. This sharp decline in TSS for the first three days can be attributed to the high level of contamination of the wastewater and hence causing the quick sedimentation of heavier particles due to gravitational force. The TSS later dropped again from 400 mg/L to 200 mg/L between the fifth and the seventh day, and this further reduction can be attributed to the agglomeration of the finer suspended particles into larger and hence heavier particles which were also pulled to the base as a sludge, this agglomeration effect are probably as the result of flocculation effects of bacterial discharges in the WSP, the activities of algae and bacteria in the decomposition of suspended organic matter and the effect of time on settling of fine suspended particles by gravity. The TSS then became steady throughout the remaining treatment time to the retention period of 25 days without any further reduction. This implies that the remaining suspended particles are very fine and will require coagulation process for further reduction. Even though the NESREA and WHO set limits were not achieved for TSS, the performance of the WSP in reduction of TSS is good as it was able to achieve up 81 % reduction which that implied it functioned well as a sedimentation tank as well as in biodegradation of organic matters.





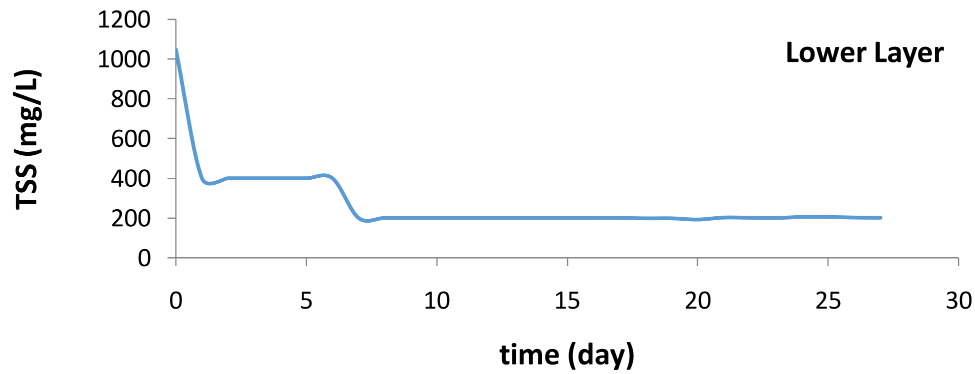
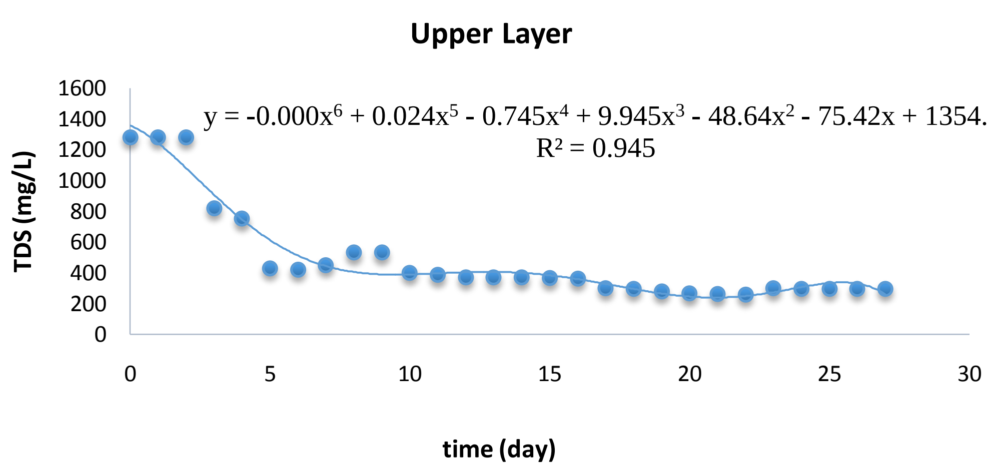


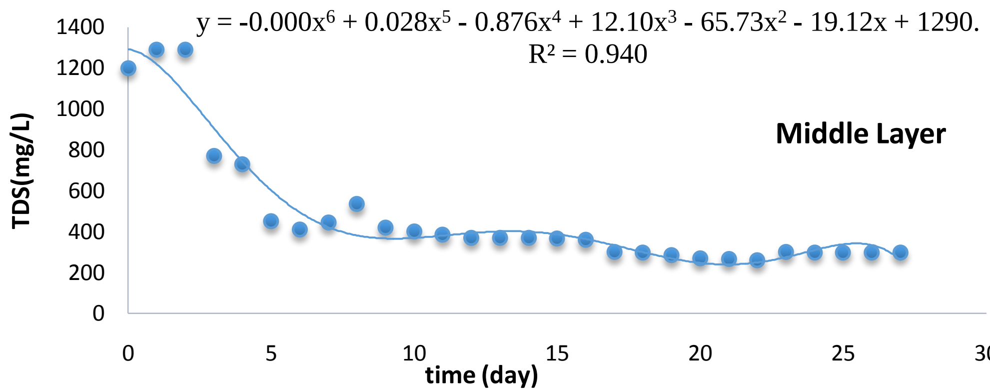
Figure 4.7:Reduction of TSSacross different layers of the WSP

4.3.6 Total dissolved solids (TDS)

The range of the total dissolved solid in the raw wastewater is 600 to 1100 mg/L and the mean value measured for the wastewater samples is 862 mg/L. These values are all within the acceptable limits set by NESREA and WHO as can be seen in Table 4.4.

The plots of TDS versus time in the upper layer (aerobic zone), middle layer (facultative zone) and the lower layer (anaerobic zone) of the pond are similar in trend as there was a sharp drop in the first five days and later became gradually steady towards the remaining treatment retention period as shown in Figure 4.8. This could be attributed to the utilization of these dissolved mineral/solids by the algae and the bacteria for their growth, binding to soil, sedimentation and adsorption processes. The TDS was reduced to 296 mg/L at day 25 of the retention in the WSP. This value conformed to the limits set by NESREA and WHO for industrial wastewater discharge into receiving water bodies and also indicated good performance of the WSP in removal of dissolved solids from the wastewater.





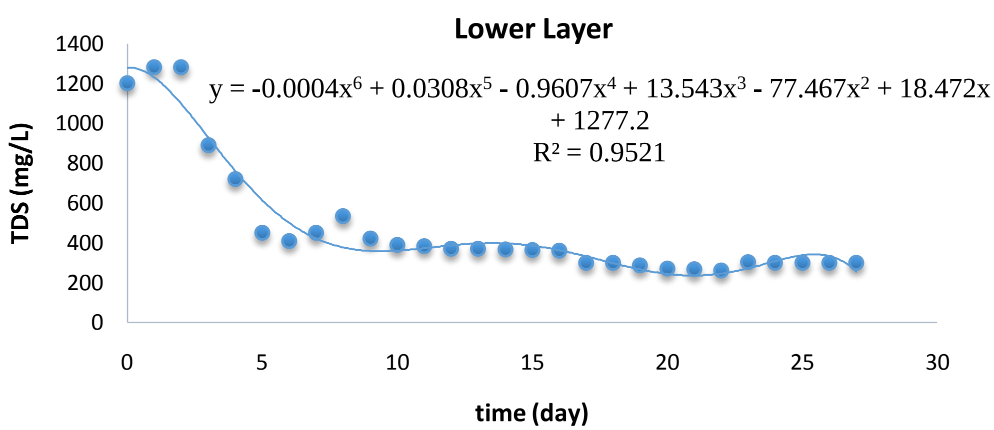
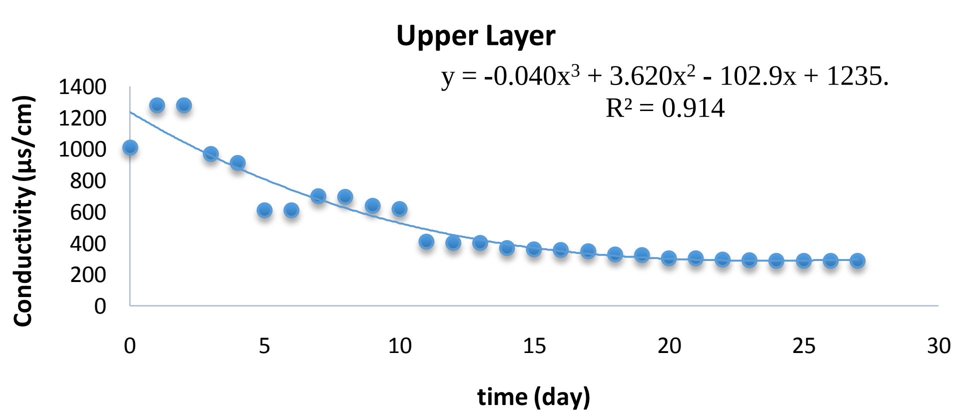


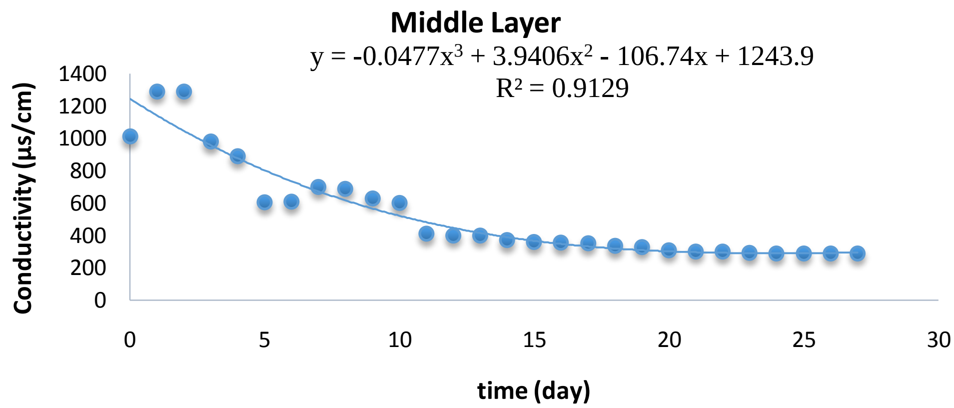
Figure 4.8: TDS reduction across the different layers of WSP

4.3.7 Electrical Conductivity (EC)

The range of electrical conductivity of the wastewater samples was from 940 to 1630 µs/cm and the mean value was 1130µs/cm. The NESREA acceptable limit of conductivity for industrial wastewater discharge to receiving water bodies is 400 µs/cm, as presented in Table 4.4, and this was exceeded in the raw brewery effluent wastewater collected. The plots of EC versus time in the WSP during the retention period for the stabilization of the wastewater are presented in Figures 4.9.

The curves are similar in trend for all the layers of the pond. The EC was reducing as the retention time is increasing and was reduced to 287 mg/L at day 25 of the retention time which conformed to wastewater discharge limits by NESREA. The factors responsible for removal of dissolved solids and neutralization of the wastewater discussed earlier in pH adjustment are also responsible for the reduction of EC in the treated wastewater by the WSP because it is directly related to the total dissolved solids and the pH of the wastewater.





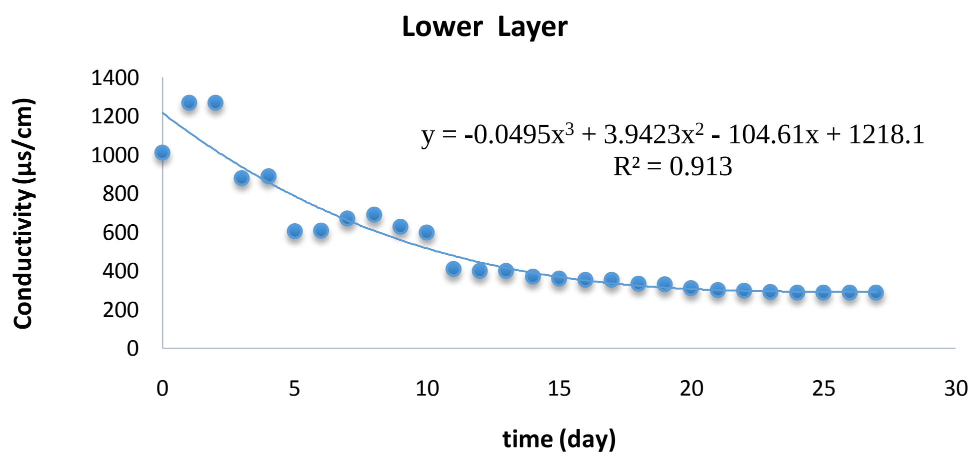
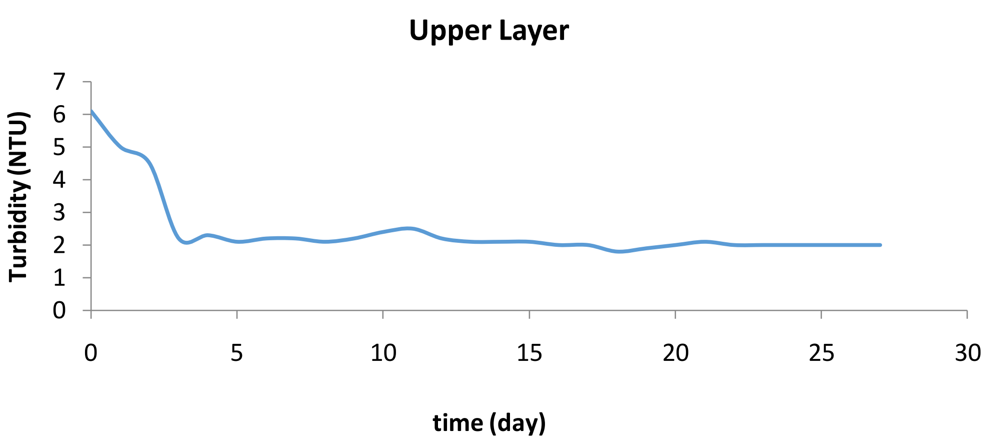


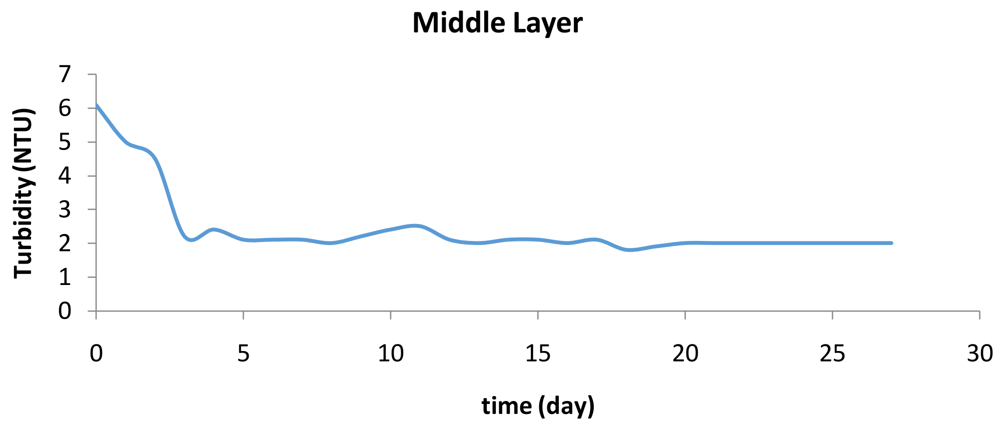
Figure 4.9: Reductionof EC across the different layers of WSP

4.3.8 Turbidity

The turbidity of the wastewater ranged from 4.6 to 7.2 NTU for the period of the study; and the mean value was 5.96 NTU which is higher than <1 NTU as the NESREA limit for industrial wastewater discharge into receiving water body (Table 2.4), which implies that the wastewater has to undergo treatment to attain the recommended wastewater discharge quality. The Turbidity time curves for the WSP treated wastewaters were presented in Figures 4.10. There was a sharp reduction in turbidity in the first 3 days of the retention period and later became gradually steady with little fluctuations over the remaining retention time. The curves are similar for the aerobic, facultative and anaerobic zone of the WSP.

The causes for the reduction in turbidity of the wastewater are the same with those discussed under TSS, since turbidity is the measure of water clarity, the lesser the TSS, the lesser the turbidity. The curves of turbidity versus time and TSS versus time are similar in pattern. The turbidity was reduced to 2.0 NTU at the end of the retention period in the pond. Although the value did not conform to the NESREA limit for wastewater discharge into receiving water body, the performance of the WSP for turbidity removal is good as it reduced the turbidity by 67.2 %. Further reduction can however be achieved in secondary facultative and maturation ponds.





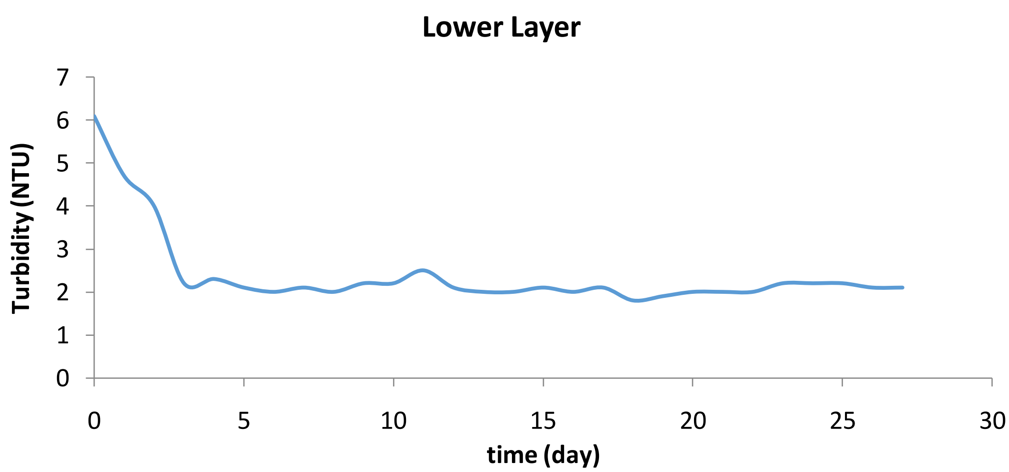
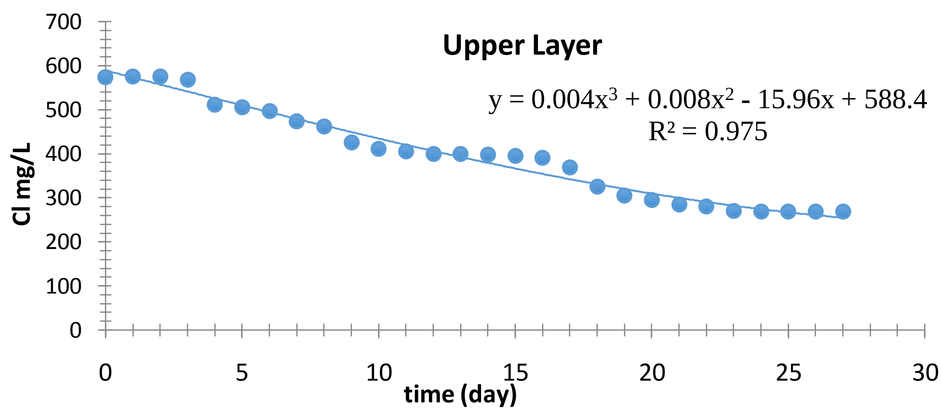


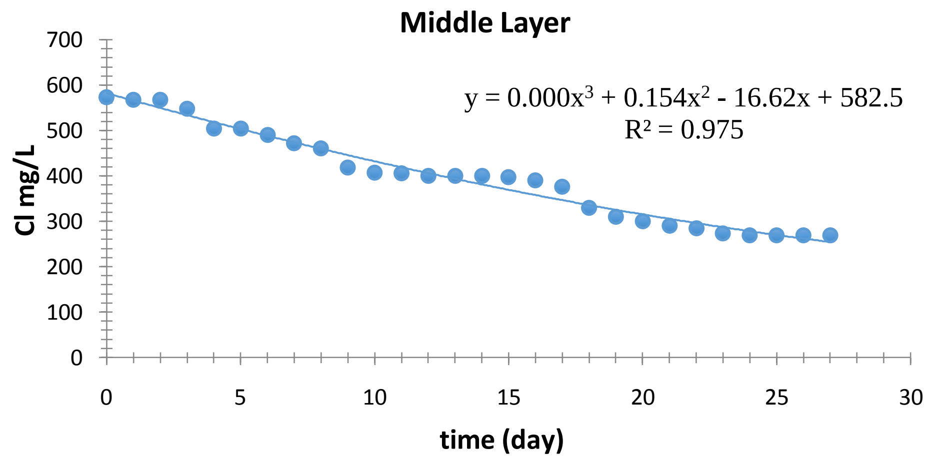
Figure 4.10: Reduction of Turbidityacross different layers of the WSP

4.3.9 Chloride

The range of chloride values for the untreated wastewater recorded was575.1 to 646.12 mg/L and the mean value 1s 618.2 mg/L. The measured chloride levelin the raw is higher than the allowable set limits by NESREA and WHO for industrial wastewater effluent discharge into receiving water bodies, (Table 4.4). The chloride-time curves for the treated wastewater are presented in Figure 4.11. From these curves, it was observed that the chloride content of the wastewater was reducing as the retention time is increasing until the retention period of 25 days after which no much significant reduction were observed. The chloride-time curves have similar trend for all the layers of the WSP.The removal of chloride content can be attributed to the factors responsible for the reduction in electrical conductivity of the wastewater as chloride contents are also a good indicator of electrical conductivity of the wastewater. The higher the chloride content, the higher the conductivity in the water samples.

The chloride content in the wastewater was reduced to 268 mg/L at the retention period of 25 days, a 53.2 % removal, and the final value conformed to the NESREA limits for industrial wastewater discharge into receiving water bodies. This also shows that the WSP demonstrated good performance in chloride content removal in the treatment of the brewery wastewater.





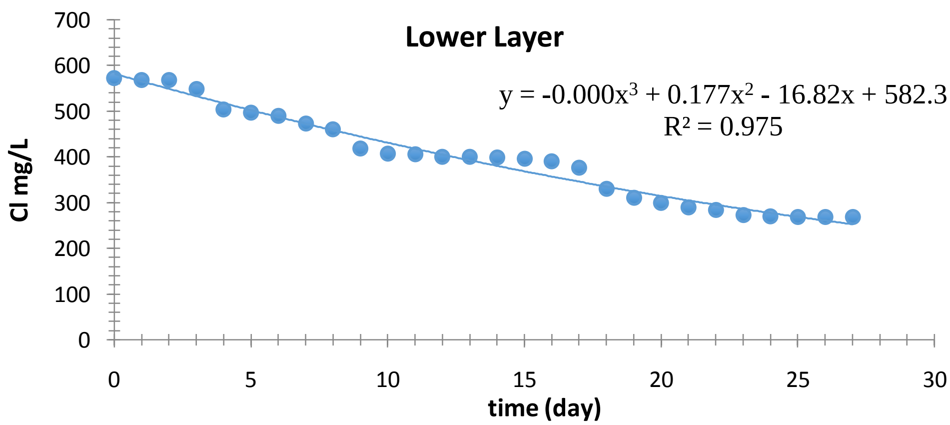


Figure 4.11: Chloride removal across the different layers of the WSP

4.4 Reaction Rate constant

The reaction rate constant for BOD removal was evaluated using Thomas' method. This is obtained by the plot of $(t/y)^{1/3}$ versus time as shown in Fig. 4.12. The rate constant calculated is 0.088 per day. The reaction rate constant is an important parameter used in the design calculations of WSP. This value is lower than that obtained for WSP design in South Eastern Nigeria for sewage treatment which is 0.27 per day (Agunwamba, 2001). This difference can be attributed to variation in the type of wastewater, and climatic conditions which greatly influences the factors that affects pond performance such as temperature and solar radiation. The pond was designed as a primary facultative pond and gave a good performance.

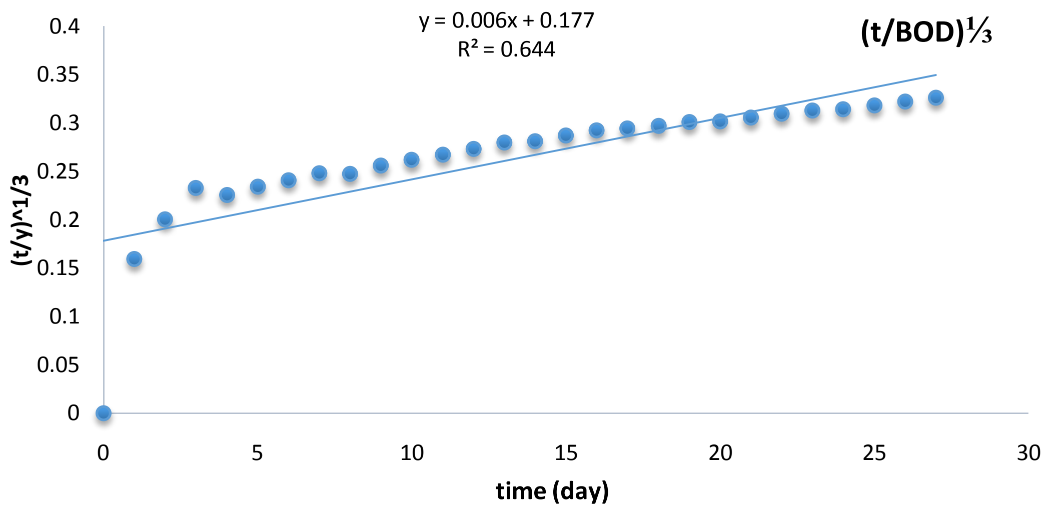


Figure 4.12: Thomas' method curvefor BOD removal rate constant.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

From the findings of these studies, the following conclusions are drawn:

1. A pilot waste stabilization pond of 4.7 m^3 (4700 litre) capacity was designed and fabricated using concrete walls to treat brewery wastewater effluents with dimensions of 2.8 m, 1.4 m, and 1.2 m, for length, width and depth respectively.

2. The retention period of 25 days of the brewery wastewater considered in the WSP resulted to reduction of the following parameters:pH, Temperature, Total suspended solids (TSS), turbidity, chlorides, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), electrical conductivity (EC), and total dissolved solids (TDS)from the initial mean values of 3.76, 29.7 ^{O}C, 1048.9 mg/L, 6.09 NTU, 573.5 mg/L, 1128.8 mg/L, 2122.1 mg/L, 1011.8 µS/cm and 826.9 mg/L to 6.7, 27^{O}C, 199 mg/L, 2.0 N TU, 268 mg/L, 350 mg/L, 660 mg/L,287 µS/cm and 296 mg/L respectively.The percentage reduction for suspended solids, turbidity, chlorides, BOD, COD, conductivity and total dissolved solids are: 81 %, 67.2 %, 53.2 %, 69 %, 68.9 %, 71.6 % and 64.2 % respectively.
3. The performance efficiency of the pilot WSP for BOD removal was 76.7%.
4. The reaction rate constant for BOD removal was 0.088 /day.
5. The regression model for BOD removal was:

   $BOD = 0.0001t^5 - 0.0034t^4 - 0.1419t^3 + 6.6096t^2 - 102.09t + 1114.5$
6. The BOD-COD correlation model obtained was BOD = 0.531COD – 1.960.

It is finally concluded that the pond has a good performance as a primary facultative pond for brewery wastewater stabilization since it has significantly reduced the BOD loading of the wastewater and the kinetic parameters obtained would be useful in scale up design for brewery wastewater effluent in full scale WSP.

5.2 Recommendations

The following are recommended based on the results obtained from this research work:

1. Further studies should be carried out to improve the pond performance efficiency.

2. The effect of influent flow rate on the performance of the WSP should also be investigated.
3. Further studies should be carried out on the suitability of WSP for the treatments of other types of industrial wastewater effluents.

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Appendix A

Design of a Pilot Waste Stabilization Pond for Treatment of Brewery Wastewater Effluent

Design Methodology

Design parameters:

The parameters for the design of waste stabilization ponds (WSP) are

i. Temperature

ii. Wastewater influent flow rate

iii. BOD

iv. Net Evaporation

Specifications

Flow: Design a pilot waste stabilization pond of $0.2m^3$per day. This is selected and assumed to be adequate for research study WSP pilot pond. The pilot stabilization pond is expected to treat wastewater effluent from the brewery before being discharged into surface water body.**Influent BOD_5**

From the characterization of the brewery waste water carried out, the average BOD_5 of the Wastewater is 1135.5mg/L (See table A1)

Temperature: Mean ambient temperature in the coldest season in Kaduna metropolis where the pond is sited is $28^{O}C$

Pond depth = 1.2 m (adequate for aerobic and facultative ponds(Tchobanoglous, 2000).

Expected BOD removal ranges from 80 – 95 % (extracted from design parameters for anaerobic and facultative stabilization ponds(Tchobanoglous, 2000).

For 90% BOD removal the BOD removal is

$0.90 \times 1135.5 = 1021.95$mg/L

Therefore

Effluent BOD = 1135.5-1021.95 = 113.55mg/L

Facultative ponds can be designed on the basis of kinetic or empirical models. In this design the kinetic model approach was used.

Table A1:Average Data of the Analysis of Wastewater Samples

PARAMETER	UNIT	VALUE
PH	-	3.56
Temperature	^{o}C	29.34
Suspended solids	mg/L	1040
Turbidity	NTU	5.96
Chloride	mg/L	618.2
BOD_5	mg/L	1135.5
COD	mg/L	2134.74
Conductivity	µs/cm	1130
Total Dissolved Solids	mg/L	862
Total Coliform	E-coli/100ml	0.7

BOD (Biological oxygen demand), COD (Chemical oxygen demand)

Kinetic Model Design

The simple approach to the rational design of facultative pond assumes they are completely mixed reactors in which BOD_5 removal follows first-order kinetics (Marais, 1974).

The rational equation for the design is given as

$$L_e/L_i = 1/(1 + k_1 t) \qquad \text{(A1)}$$

Where

L_i = the influent wastewater BOD (mg/L)

L_e= effluent (treated) wastewater BOD (mg/L)

t = Retention time; (days)

Rearranging equation (2):

$$t = (L_i/L_e - 1)(1/k_1) \qquad \text{(A2)}$$

The area of the pond is calculated using the below equation:

$A = Qt/D$ (A3)

Where Q is the wastewater volumetric flow rate (m^3/day), D is the Pond depth (m), and A is the area of pond (m^2).

Substituting “t” from equation (A2) into equation (A3) the area becomes:

$A = (Q/Dk_1)\ (L_i/L_e - 1)$ (A4)

The value of k_1 at 20 ^oC was found to be 0.3 day^{-1} (Mara, 1986), and its variation with temperature T is described by the Arrhenius equation below:

$k_T = k_{20}\Theta^{(T-20)}$(A5)

Where

Ɵ is the Arrheniusconstant, whose value is usually between 1.01-1.09. The Urban water Technology Centre, Dundee proposed value of Ɵ as 1.05 and equation (A5) becomes:

$k_T = 0.3(1.05)^{(T-20)}$(A6)

Hence from equation (A6) above, using the mean air temperature in the coldest season in Kaduna as given in the above data,

$k_T = 0.3(1.05)^{(28-20)}$

$k_T = 0.44\ day^{-1}$

Using equation (A2), the retention time; t is calculated;

$t = [(1135.5/113.55) - 1]\ (1/0.44)$

$t = 20.5\ days$

This is approximately 21 days.

From equation (A4), the pond area is calculated as:

$A = (Q/Dk_1)\ (L_i/L_e - 1)$

$A = (0.2/1.2 \times 0.44)\ [(1135.5/113.55) - 1]$

$A = 3.4\ m^2$

Considering area increase of 15% to take care of net evaporation;

Therefore;

$A = 1.15 \times 3.4$

$A = 3.91\ m^2$

The Pond Volume for a rectangular shaped pond is given as;

$V = A \times D$ (A7)

$= 3.91 \times 1.2$

$= 4.692\ m^3$

The volume of 4.7 m^3 for the pond will be adequate.

The length- width ratio for stabilization pond is within the range of 2-3:1

(EPA 1997, South Australia Pond Guidelines)

Taking a length-width ratio; L/W of 2:1

Then;

$L/W = 2/1 = 2$

$L = 2W$

$But\ A = L \times W$

$= 2W \times W = 2W^2$

Therefore;

$2W^2 = 3.91$

$W = \sqrt{1.955}$

$= 1.398$

Hence:

$L = 2W = 2 \times 1.398$

$= \quad 2.8m$

Conversion of total pond volume from m^3 to liters:

Conversion factor: 1000 liters = $1m^3$

$4.7 \times 1000 = 4700$ liters

Hence:

The total pond volume *is 47*00 liters

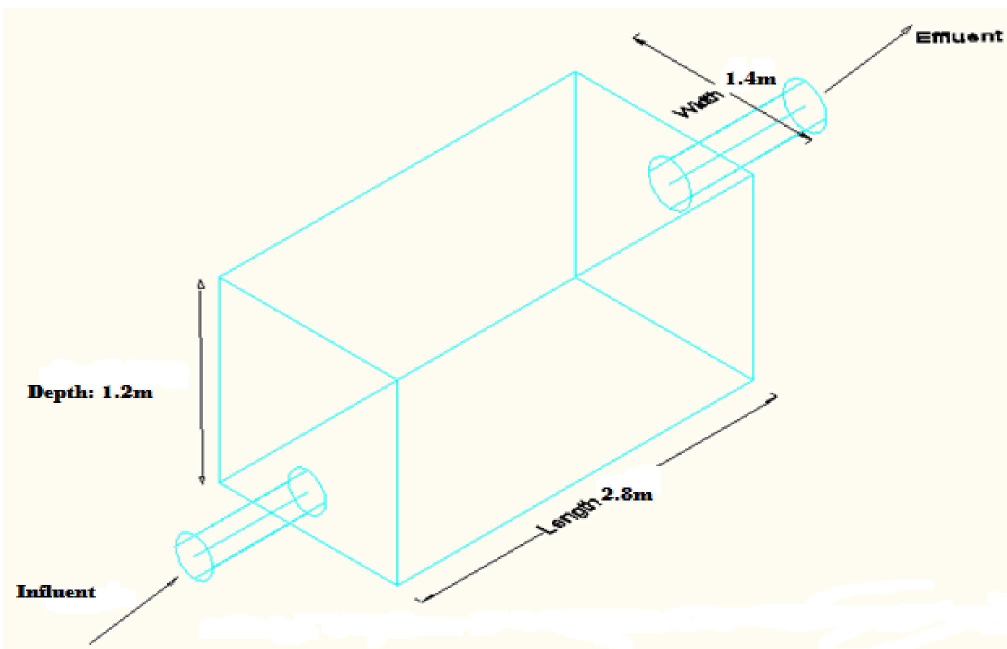

Figure A1: Sketch of designed pond configuration

Appendix B

B1.0 Cost Estimation of the Constructed Waste Stabilization Pond

B1.1 Cost of material for construction

The materials that are required for the construction of the pond are:

i. 9” concrete blocks
ii. Sharp sand
iii. Plaster sand
iv. Gravels (stones)
v. Cement (Dangote)
vi. Level graduation meter
vii. PVC pipes
viii. Flow control valves (gate valves)
ix. Paints

B1.2 Quantification of materials

9” concrete blocks are to be used for the pond construction.

Standard configuration for 9” concrete blocks is 22.5cm by 45.0cm

The length of the pond= 2.8 m which will require eight 9” concrete blocks

The width of the pond= 1.4 m which will require three 9” concrete blocks

The height of the pond= 1.2m, the foundation= 0.45m

Therefore the height plus the foundation = 1.65m which will require eight 9” concrete blocks

Therefore the total number of blocks required = 8×3×8 = 192 blocks

The cost of one 9” concrete blocks = N 700

For 192 blocks = 700 × 192 = N 134,400

Sharp sand required for construction: 9 wheel barrows

Cost of 1 wheel barrow of sand = N 800

Cost of 9 wheel barrows of sand = 800 × 9 = N 7,200

Quantity of plaster sand required: 9 wheel barrows

Cost of 1 wheel barrow of plaster sand = N B800

Cost of 9 wheel barrows of sand = 800 × 9 = N 7, 200

Quantity of gravels required: 7 wheel barrows for the foundation

1 wheel barrows = N 1,200, therefore 7 wheel barrows = 7×1200 = N 8,400

Quantity of cement required (Dangote cement):

i. 3bags for laying blocks
ii. 4 bag for flouring and foundation
iii. 3 bags for plastering

Hence, total quantity of cement required = 3+4+3=10 bags

Cost of 1 bag of Dangote cement = N 900

Hence, total cost of cement = 1900 × 10 =N 19,000

Level graduation meter: Plastic type = N 2,000

Plumbing Plastic pipes/hoses = N 2,000

Paints = N 5,000

Three (3) flow gate valve, at N 500 each = N 1,500

100 liter plastic tank = N 1,500

B1.3 Labor cost:

i. Construction = N10,000

ii. Plumbing = N 3,000

iii. Painting = N 2,000

B1.4 Total labor cost = N 15,000

B1.5 Transportation cost = N 5,000

B1.6 Miscellaneous = N 2,000

Table B1: Cost of construction materials

S/No	Material	Cost (N)
1	9” blocks (144 pieces)	134,400
2	Sharp sand (7 wheel barrows)	7,200
3	Plaster sand (6 wheel barrows)	7,200
4	Gravels (5 wheel barrows)	8,400
5	Dangote cement (5 bags)	19,000
6	Level graduation meter: (Plastic type)	2,000
7	Plastic pipe/hoses	2,000
8	Paints	5,000

9	Three (3) flow gate valve	1,500
10	Total cost	186,700

Table B2: Total cost estimate of pond construction

Total labour cost	N 15,000
Transportation	N 4,300
Miscellaneous	N 4,000
Total Cost	**N 210,000**

Therefore the total cost required for constructing the pond is two hundred and ten thousand naira only (N 210,000).

Appendix C

The results of the Analysis of Wastewater samples

The raw wastewater samples collected for a period of 27 days and the treated wastewater in the constructed waste stabilization pond (WSP) were analyzed for water quality parameters. The results of the analysis were presented in tables C1 to C8.

R represents raw wastewater sample and the number indicates the number of the day the sample was collected. T represents treated sample, while S1, S2 and S3 represents the samples collected from the waste stabilization pond (WSP) at aerobic zone, facultative zone and anaerobic zone respectively. The WSP was operated at a flow rate of $0.2m^2$/day on a continuous steady state flow at an average ambient temperature of 29^oC over the retention period.

Table C1Results of the analysis of raw and treated brewery wastewater effluent

Sampling time	Day1				Day 2				Day 3			
Mean ambient tempt. (^{o}C)	29				28.5				29			
Parameter	**R1**	**TS1**	**TS2**	**TS3**	**R2**	**TS1**	**TS2**	**TS3**	**R3**	**TS1**	**TS2**	**TS3**
pH	2.6	3.8	2.9	2.9	4.2	3.7	3.3	2.9	7.7	3.8	3.1	3.2
Temperature (^{o}C)	31	28.5	28.5	28.5	29.2	29.1	29.1	29.1	28.1	28	28	28
TSS (mg/L)	1200	400	400	400	1200	400	400	400	1000	400	400	400
Turbidity (NTU)	7.2	5.0	5.0	4.7	6.5	4.5	4.5	4.0	4.6	2.2	2.2	2.2
Chloride (mg/L)	631.9	575.1	568	568	639	575.1	568	568	646.1	568	548.7	548.7
BOD_5 (mg/L)	1650	880	882	882	1250	880	882	882	1805	890	860	840
COD (mg/L)	3102	1654.4	1658.16	1658.16	2350	1654.4	1658.16	1658.16	3393.4	1673.2	1616.8	1579.2
Conductivity (µs/cm)	1470	1280	1290	1270	1180	1280	1290	1270	1630	970	980	880

TDS (mg/l)	760	1280	1200	1200	600	1280	1290	1280	1100	820	770	890
Coli form (E-coli/100ml)	0	1	1	1	1	2	3	5	0	4	5	6

Table C2: Results of the analysis of raw and treated brewery wastewater effluent

Sampling time	**Day4**				**Day 5**				**Day 6**			
Mean ambient tempt. (°C)	29				28				27.5			
Parameter	**R4**	**TS1**	**TS2**	**TS3**	**R5**	**TS1**	**TS2**	**TS3**	**R6**	**TS1**	**TS2**	**TS3**
pH	7.2	4.8	4.3	4.3	2.3	3.8	3.0	3.1	2.2	3.8	3.1	3.1
Temperature (°C)	32	29	29	29	35.5	27	27	27	27.2	27.1	27.1	27.1
TSS (mg/L)	1000	400	400	400	1000	400	400	400	1000	400	400	400
Turbidity (NTU)	5.7	2.3	2.4	2.3	5.0	2.1	2.1	2.1	6.2	2.2	2.1	2.0
Chloride (mg/L)	639	511.2	504.1	504.1	631.9	505.2	504.1	497	624.8	497	489.9	489.9
BOD_5 (mg/L)	1110	780	725	725	1300	740	710	710	990	700	690	700
COD (mg/L)	2086.8	1466.4	1413.76	1413.76	2444	1430	1234.8	1234.8	1861.2	1470.4	1359.6	1470.4

Conductivity (µs/cm)	1120	910	890	890	960	610	605	605	1020	610	610	610
Sampling time			**Day7**				**Day 8**				**Day 9**	
TDS (mg/l)	1000	750	730	720	720	430	450	450	960	420	410	410
Mean ambient tempt. (^oC)			28				28.5				29	
Coli form (E-coli/100ml)	1	5	7	8	1	9	10	11	0	11	13	14
Parameter	**R7**	**TS1**	**TS2**	**TS3**	**R8**	**TS1**	**TS2**	**TS3**	**R9**	**TS1**	**TS2**	**TS3**
pH	2.3	3.6	3.1	3.1	2.3	3.4	3.2	3.2	2.4	3.8	3.8	4.0

Table C3: Results of the analysis of raw and treated brewery wastewater effluent

Temperature (^oC)	29	27	27	27	27.6	27	27	27	27	26.5	26.5	26.5
TSS (mg/L)	1000	200	200	200	1000	200	200	200	1000	200	200	200
Turbidity (NTU)	6.1	2.2	2.1	2.1	6.0	2.1	2.0	2.0	6.2	2.2	2.2	2.2
Chloride (mg/L)	603.5	472.8	472.8	472.8	608.5	461.5	461.5	461.5	582.2	426	418.9	418.9
BOD_5 (mg/L)	1200	670	670	630	900	600	600	600	1500	590	590	590
COD (mg/L)	2256	1258.4	1258.4	1278.4	1692	1122	1122	1122	2828	1112.8	1112.8	1112.8
Conductivity(μs/cm)	1000	700	700	670	1000	695	690	690	940	640	630	630
TDS (mg/l)	920	450	445	450	880	530	534	534	800	430	420	420
Coli form (E-coli/100ml)	1	13	15	16	1	14	16	18	2	13	15	17

Table C4: Results of the analysis of raw and treated brewery wastewater effluent

Sampling time	Day 10				Day 11				Day 12			
Mean ambient tempt. (^oC)	29				30				31			
Parameter	**R10**	**TS1**	**TS2**	**TS3**	**R11**	**TS1**	**TS2**	**TS3**	**R12**	**TS1**	**TS2**	**TS3**
pH	2.4	3.8	3.8	4.0	2.3	3.9	3.9	3.9	2.8	4.8	4.0	4.1

Temperature (^oC)	27.1	27	27	27	30	26.9	26.5	26.5	29.2	27	27	27
TSS (mg/L)	1000	200	200	200	1000	200	200	200	1200	200	200	200
Turbidity (NTU)	6.1	2.4	2.4	2.2	6.0	2.5	2.5	2.5	6.0	2.2	2.1	2.1
Chloride (mg/L)	575.1	410.9	407.5	407.5	575.1	405	406	406	568	400	401	401
BOD_5 (mg/L)	900	570	570	560	1000	550	550	545	890	540	543	542
COD (mg/L)	1692	1050.5	1050.5	1020.2	1880	1010	1010	1008	1673.2	1001	1001	1000
Conductivity (µs/cm)	980	620	620	600	870	410	410	410	902	400	400	400
TDS (mg/l)	880	400	400	390	780	385	385	384	860	370	370	370
Coli form (E-coli/100ml)	1	14	17	18	0	16	19	20	1	11	20	23

Sampling time	**Day13**				**Day 14**				**Day 15**			
Mean ambient tempt. (^oC)	30				30.5				29			
Parameter	**R13**	**TS1**	**TS2**	**TS3**	**R14**	**TS1**	**TS2**	**TS3**	**R15**	**TS1**	**TS2**	**TS3**
pH	2.4	4.4	4.2	4.2	2.8	4.8	4.5	4.5	3.9	4.9	4.6	4.6

Temperature (^oC)	30	26.8	26.6	26.6	29	27.1	27.1	27.1	29	27	27	27
TSS (mg/L)	1000	200	200	200	1000	200	200	200	1000	200	200	200
Turbidity (NTU)	6.2	2.1	2.0	2.0	6.5	2.1	2.1	2.0	6.3	2.1	2.1	2.1
Chloride (mg/L)	568	400	401	401	568	398	400	400	568	395	397	397
BOD_5 (mg/L)	800	535	538	538	1110	500	500	510	900	495	500	500
COD (mg/L)	1504	990	996	996	2086.8	985	985	988	1692	980	985	985
Conductivity (µs/cm)	890	400	400	400	900	370	370	370	800	360	360	360
TDS (mg/l)	560	370	370	370	860	368	368	368	870	365	365	365
Coli form (E-coli/100ml)	1	12	22	25	2	13	19	23	2	12	19	25

Table C5: Results of the analysis of raw and treated brewery wastewater effluent

Sampling time	**Day16**	**Day 17**	**Day 18**
Mean ambient tempt. (^oC)	29	29	29

Parameter	R16	TS1	TS2	TS3	R17	TS1	TS2	TS3	R18	TS1	TS2	TS3
pH	4.8	5.8	5.8	5.5	4.8	5.8	5.5	5.6	4.8	5.9	5.9	5.9
Temperature (^oC)	29	27	27	27	29	26.6	26.6	26.6	31	26.9	26.9	26.9
TSS (mg/L)	1000	200	200	200	1100	190	200	200	1100	195	195	198
Turbidity (NTU)	6.4	2.0	2.0	2.0	6.5	2.0	2.1	2.1	6.5	1.8	1.8	1.8
Chloride (mg/L)	560.9	390.5	390.5	390.5	553.8	369.2	376.3	376.3	500.2	325.1	330.5	330.5
BOD_5 (mg/L)	905	490	495	495	910	460	465	465	900	440	445	445
COD (mg/L)	1701.4	978	980	980	1710.8	870	876	876	1692	835	840	840
Conductivity (µs/cm)	770	355	355	355	710	350	353	353	715	330	335	335
TDS (mg/l)	600	360	360	360	670	300	300	310	675	295	298	298
Coli form (E-coli/100ml)	2	11	17	25	1	11	19	27	1	10	20	29

Table C6: Results of the analysis of raw and treated brewery wastewater effluent

Table C7:Results of the analysis of raw and treated brewery wastewater effluent

Sampling time	Day19	Day 20	Day 21

Mean ambient tempt. (°C)	30				30				28.5			
Parameter	**R19**	**TS1**	**TS2**	**TS3**	**R20**	**TS1**	**TS2**	**TS3**	**R21**	**TS1**	**TS2**	**TS3**
pH	4.8	6.0	6.1	5.9	4.7	5.9	6.0	6.0	2.6	6.5	5.4	5.5
Temperature (°C)	30	27	27	27	29	26.9	26.9	26.9	31	27	27	27
TSS (mg/L)	1120	195	196	198	1200	190	192	192	1200	198	200	202
Turbidity (NTU)	6.6	1.9	1.9	1.9	6.6	2.0	2.0	2.0	7.2	2.1	2.0	2.0
Chloride (mg/L)	550.1	305.3	310.5	310.5	513.5	295	300.5	300.5	631.9	285	290	290
BOD_5 (mg/L)	905	430	435	435	906	400	402	403	1000	390	395	395
COD (mg/L)	1701.4	810	820.5	820.5	1703.28	760	763	765	3102	736	745	745
Conductivity (µs/cm)	716	325	330	330	700	305	310	310	1470	300	302	302
TDS (mg/l)	782	280	285	285	778	265	270	270	960	260	266	266
Coli form (E-coli/100ml)	2	11	21	30	2	11	21	29	2	12	22	30

Table C8: Results of the analysis of raw and treated brewery wastewater effluent

Sampling time	Day22				Day 23				Day 24			
Mean ambient tempt. (°C)	29				28				27.5			
Parameter	**R22**	**TS1**	**TS2**	**TS3**	**R23**	**TS1**	**TS2**	**TS3**	**R24**	**TS1**	**TS2**	**TS3**
pH	4.2	6.6	6.4	6.4	7.7	6.7	6.6	6.5	7.2	6.8	6.6	6.5
Temperature (°C)	29.2	27	26.7	26.6	28.1	27	27	27	32	27	27	27
TSS (mg/L)	1000	198	200	201	1000	199	200	200	1000	200	200	205
Turbidity (NTU)	6.5	2.0	2.0	2.0	4.6	2.0	2.1	2.2	5.7	2.0	2.2	2.2
Chloride (mg/L)	639	280	285	285	646.1	270	273	273	639	268	270	270
BOD_5 (mg/L)	1250	385	388	388	1005	375	377	377	1110	355	357	359
COD (mg/L)	2350	725.5	730	730	3393.4	708	710	710	2086.8	669	674	677
Conductivity (µs/cm)	1180	295	299	299	1330	290	293	293	1120	287	290	290
TDS (mg/l)	600	258	260	260	1100	299	300	302	1000	296	299	299
Coli form (E-coli/100ml)	0	14	23	31	0	12	23	32	1	13	24	33

Table C9: Results of the analysisof raw and treated brewery wastewater effluent

Sampling time	Day25				Day 26				Day 27			
Mean ambient tempt. (°C)	28.5				29.5				29			
Parameter	**R25**	**TS1**	**TS2**	**TS3**	**R26**	**TS1**	**TS2**	**TS3**	**R27**	**TS1**	**TS2**	**TS3**
pH	2.3	6.7	6.5	6.4	2.2	6.7	6.6	6.5	2.3	6.7	6.6	6.5
Temperature (°C)	35.5	27.2	27	27	29	27	26.9	26.9	29	27	26.9	26.9
TSS (mg/L)	1000	199	200	205	1000	199	200	202	1000	199	200	201
Turbidity (NTU)	5.0	2.0	2.1	2.2	6.2	2.0	2.0	2.1	6.1	2.0	2.0	2.1
Chloride (mg/L)	631.9	268	269	269	624.8	268	269	269	603.5	268	269	269
BOD_5 (mg/L)	1300	350	355	355	990	350	352	352	1200	350	352	352
COD (mg/L)	2444	660	669	669	1861.2	660	667	667	2256	660	667	667
Conductivity (µs/cm)	960	287	290	290	1050	287	290	290	1000	287	290	290
TDS (mg/l)	720	296	299	299	960	296	298	298	930	296	298	298
Coli form (E-coli/100ml)	0	12	25	34	1	11	25	35	1	9	24	35

Appendix D

D.1 Calculation of Results

D.1.1 Performance efficiency of the pilot pond based on physicochemical parameters

The efficiency (ή) is given:

$$ή = {Ci - Ce}/{Ci} \times 100\%$$

Where:

Ci is the parameter in the raw (influent) wastewater

Ce is the parameter in the treated (effluent) wastewater

1. **Temperature Reduction**

Aerobic Zone

$$ή = {29.7 - 27}/{29.7} \times 100\% = 9.1\ \%$$

Facultative zone

$$ή = \text{m}\ {29.7 - 26.9}/{29.7} \times 100\% = 9.4\ \%$$

Anaerobic zone

$$ή = {29.7 - 26.9}/{29.7} \times 100\% = 9.4\ \%$$

2. **Removal of Suspended Solids (SS)**

Aerobic Zone

$$ή = {1048.9 - 199}/{1048.9} \times 100\% = 81\ \%$$

Facultative zone

$$ή = {1048.9 - 200}/{1048.9} \times 100\% = 80.9\ \%$$

Anaerobic zone

$$ή = 1048.9 - 201 / 1048.9 \times 100\% = 80.8\ \%$$

3. Reduction of Turbidity

Aerobic Zone

$$ή = 6.09 - 2.0 / 6.09 \times 100\% = 67.2\ \%$$

Facultative zone

$$ή = 6.09 - 2.0 / 6.09 \times 100\% = 67.2\ \%$$

Anaerobic zone

$$ή = 6.09 - 2.1 / 6.09 \times 100\% = 65.5\ \%$$

4. Reduction of Chlorides

Aerobic Zone

$$ή = 573.5 - 268 / 573.5 \times 100\% = 53.2\ \%$$

Facultative zone

$$ή = 573.5 - 269 / 573.5 \times 100\% = 53.1\ \%$$

Anaerobic zone

$$ή = 573.5 - 269 / 573.5 \times 100\% = 53.1\ \%$$

5. BOD_5 removal

Aerobic Zone

$$ή = {}^{1128.8 - 350}/_{1128.8} \times 100\% = 69\ \%$$

Facultative zone

$$ή = {}^{1128.8 - 352}/_{1128.8} \times 100\% = 68.8\ \%$$

Anaerobic zone

$$ή = {}^{1128.8 - 352}/_{1128.8} \times 100\% = 68.8\ \%$$

6. **COD removal**

Aerobic Zone

$$ή = {}^{2122.1 - 660}/_{2122.1} \times 100\% = 68.9\ \%$$

Facultative zone

$$ή = {}^{2122.1 - 667}/_{2122.1} \times 100\% = 68.6\ \%$$

Anaerobic zone

$$ή = {}^{2122.1 - 667}/_{2122.1} \times 100\% = 68.6\ \%$$

7. **Reduction of Electrical Conductivity**

Aerobic Zone

$$ή = {}^{1011.8 - 287}/_{1011.8} \times 100\% = 71.6\ \%$$

Facultative zone

$$ή = {}^{1011.8 - 290}/_{1011.8} \times 100\% = 71.3\ \%$$

Anaerobic zone

$ή = 1011.8 - 290 / _{1011.8} \times 100\% = 71.3\ \%$

8. **Reduction of Total Dissolved Solids (TDS)**

Aerobic Zone

$ή = 826.9 - 296 / _{826.9} \times 100\% = 64.2\ \%$

Facultative zone

$ή = 826.9 - 298 / _{826.9} \times 100\% = 64\ \%$

Anaerobic zone

$ή = 826.9 - 298 / _{826.9} \times 100\% = 64\ \%$

D.1.2 Evaluation of BOD removal rate constant (k)

According to Thomas method of BOD removal rate constant (k), the plot of $(t/y)^{1/3}$ versus time gives a linear graph.

Where:

t = time in days and y = BOD_5 in mg/L

The rate constant k; is given by:

$$k = 2.61\frac{b}{a}$$

Where: 'b' is the slope and 'a' is the intercept.

From the graph as presented in figure 4.34;

a = 0.177 and

b = 0.006.

Therefore;

$$k = 2.61 \frac{0.006}{0.177}$$

k = 0.088 per day

Appendix E

Pictures of sample collection process and pond operation

Plate E1: Brewery wastewater sample collection point.

Plate E2: Water pump used to pump wastewater into collection tank

Plate E3: Pickup van used to convey wastewater to pond site

Plate E4: Stream into which wastewater is discharged

Plate E5: Wastewater being discharged into the pond

Plate E6: Pond being operated to stabilize wastewater

Plate E7: Pond with algae formation on the surface of the wastewater

Plate E8: Pond protected against the effect of rainfall

Plate E9: Front view of the pond