CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to Study.

Waste, irrespective of its state i.e. gaseous, liquid or solid must be managed effectively and efficiently in any society to avoid adverse consequences on its people and its environment. The globally accepted waste hierarchy; generally known as the 3Rs – reduce, reuse and recycle has been at the centre of most countries' waste management policies and strategies. This evolved directly from the European Union waste framework directive of 2008 (EU, 2008) and indirectly from that of 1975 (EU, 1975). The hierarchy has evolved into five stages namely: prevention, reduce, reuse, recycling, recovery including energy and safe disposal. Developed countries have been able to implement the Rs principle in waste management strategies and policies to a great extent. Policies and strategies ranging from customers paying for carrier bags to retailers replacing worn out bags at no cost thereby reducing and reusing waste simultaneously; sorting of waste at generation point to recycling banks has made reuse and recycling easier for end-users of goods. Implementation has been possible to a large extent because the infrastructure, energy requirement and trained manpower are available. Unfortunately, the reverse is the case in most developing countries like Nigeria. This is largely due to lack of necessary infrastructure, lack of reliable and constant power supply, bad governance to mention a few. Indeed, while developed countries are aiming at achieving zero waste, developing countries are still grappling with achieving the 3Rs.

In the past, developing countries had the tendency of copying or adapting waste management methods used in developed countries with little success. Some of the reasons for lack of success with implementing these methods were identified by Olanlokun (2012). Some of the preimplementation reasons identified are difference in waste composition which has a bearing on storage and disposal methods while post-implementation reasons include lack of adequate infrastructure, lack of maintenance culture and lack of understanding of the importance of waste disposal and management. Incinerators have been built, used for a limited period and abandoned due to maintenance problems such as lack of spare parts or funds due to paucity allocation in national or local budget. Consequently, open dumps have become the order of the day not excluding areas where the waste management agency or government is responsible for collection, treatment and disposal. Waste is collected with no separation or sorting and taken to a designated dumpsite sometimes referred to as landfills though these are normally large open dumpsites and not mechanically designed landfills. Any minimal volume reduction is achieved through scavengers who are not recognized formally as part of any waste management strategy. Periodically, the refuse at such sites are burnt to reduce the volume. Interestingly, while developed countries are moving away from landfills and looking at innovative ways of dealing with waste sustainably, many developing countries are still forging ahead with landfills, (Ghosh et al, 2017). The collection, transport, treatment, and disposal of solid wastes, particularly wastes generated in medium and large urban centres, have become a relatively difficult problem to solve for those responsible for their management. The problem is even more acute in economically less developed countries, where financial, human, and other critical resources generally are scarce (Diaz and Bakker, 2007). Often when solid waste management strategies are being considered, the focus is generally on municipal waste especially in developing countries; however, there are some peculiar types of wastes that should be given some consideration. These include wastes generated from wastewater management such as the sludge from septic tanks and waste generated in aquaculture. This type of waste varies in size from visibly solid waste matter to suspended and dissolved solids.

Often these contain organisms bearing pathogens that could cause harm to human, animals and the environment at large. Another type of waste often ignored is waste from the timber industry. The lack of focus on timber related waste could stem from the belief that it is a natural occurring matter and would not cause any harm to the environment if not managed or disposed of.

The same problems identified with solid waste management and disposal exists with liquid waste (commonly referred to as wastewater) management and disposal in developing countries like Nigeria. Wastewater can be classified into categories depending on its originating source; domestic, commercial and industrial. In developed countries, wastewater is usually treated before disposal into receiving water bodies or reuse in agriculture and fisheries. The transportation of wastewater is done using extensive sewerage system which includes sewers, manholes, storm overflows etc. Historically, wastewater has been treated and disposed of using unit operations where physical forces dominate and unit processes where contaminants are removed using chemical or biological processes. These are generally grouped together into different levels of treatment classified as preliminary or pre-treatment, primary, secondary and tertiary or advanced (Metcalf and Eddy, 2003). Another major method of wastewater treatment is the Waste Stabilization ponds system in which wastewater is treated using biological and physical processes. In some situations, industrial wastewater is treated to a specified limit onsite before being discharged into the sewerage system. In addition, there are regulatory bodies; equipped with powers to prosecute, ensuring pollution of water bodies is minimised or eliminated completely. In developing countries like Nigeria, sewerage network system is the exception rather than the norm and consequently, wastewater is often disposed of with little or no treatment. Some industries do have some form of waste treatment before discharge such as pharmaceutical and food-related industries; however, typically sewage is directed into a septic tank, while other types of domestic wastewater is directed into a soak-away pit or into open drains or in the worse scenario, poured out onto the ground. Major manufacturing companies such as pharmaceutical and beverages tend to treat wastewater using some varied form of conventional methods before discharging.

Another type of wastewater which has emerged in recent years is aquaculture wastewater. Aquaculture is the wastewater resulting from rearing of fish in a controlled environment. This is a consequence of an increase in demand for cheaper and alternative form of protein for human consumption. It is a known fact that the availability of water is crucial in any community. It is required for human consumption, household maintenance, agricultural, commercial and industrial purposes. Due to various factors such as urbanization and advancement in technology, demand for water has increased globally while global supply remains the same since all the water on earth is in one form or the other part of the hydrological cycle. Consequently, there is an urgent need to re-examine how available resources are managed and investigate how wastewater could be treated for reuse or reintroduced into the hydrological cycle. In developing countries like Nigeria, the tendency has been to adopt the conventional wastewater treatment and disposal methods. Unfortunately, this approach has little or no impact due to various reasons such as inappropriateness of the technology, lack of technical expertise and lack of constant power supply. This invariably leads to unsustainable strategies; there is therefore a need for a paradigm shift from the 'one size fits all' approach to a customized approach that considers peculiar local factors that could otherwise mar the effectiveness of any adopted waste management strategy. In this vein, this study investigates how sawdust can be used to treat aquaculture wastewater.

The production of any wood-based item commences with the felling of trees in forests. Felled trees are transported to mills from where the logs are cut into manageable and market sizes. During the process of cutting into smaller sizes, waste in form of chips, barks and sawdust is generated.

The bulk of the waste is sawdust which is usually fine or coarse powdered in nature. Wood waste will be around for a long time yet, primarily because wood is a natural material. Also, cut trees can be replaced by planting new seedlings though it takes time for trees to mature to the point of felling depending on species. Secondly, due to economic growth, urbanization and industrialization, the volume of wood waste will continue to rise. Wood waste is generated in various forms: bark, cut-offs, shavings and sawdust. Lasode *et al* (2011) estimated the amount of wood waste generated in the established sawmills and plank markets in Ilorin, one of major cities in Nigeria to be $119.522m^3$ daily. It can be expected that similar amounts would be generated from sawmills in other major cities and towns across the country. Unfortunately, the waste generated which comprises mainly of sawdust; a fine powdery material is disposed of in an environmentally less friendly manner. From sawmill operators' perspective, sawdust has no monetary value. The sawdust is left in-situ by the operators until it begins to interfere with access and operation of equipment for wood processing, and subsequently is removed out of the operator's way. A picture of accumulated sawdust and chips prior to removal is shown in Figure 1.1.

Figure 1.1. Sawdust Waste before removal for disposal (Arrow marked 1 shows the heaps of sawdust; Arrow 2 shows handle of spade used for removal)

Sawdust is given out to individuals who use it as a means of erosion control after packing in bags and sacks, bedding material in poultry and making briquettes as a source of fuel for cooking in low income homes and rural areas. Any left-over sawdust is subsequently burnt via open combustion. This is shown in Figure 1.2. At large sawmills or timber markets, sawdust is spread on the grounds or dumped near the site. This is shown in Figure 1.3.

Figure 1.2. Aftermath of sawdust combustion

Figure 1.3. Sawdust left in-situ at a large timber market in Ilorin, Nigeria

1.2 Statement of Problem

The availability of water is crucial in any community; it is required for human consumption, household maintenance, and cleaning. It is also required for agricultural, industrial and commercial purposes. The need for water tends to increase as a community develops or tend to become more urban in nature coupled with public enlightenment. Unfortunately, water cannot be created. Ideally, any type of wastewater should be treated before discharge or reuse, however this is often not the case in developing countries like Nigeria. There is no sufficient record or evidence to show that aquaculture wastewater is treated before discharge within the study area. Aquaculture wastewater in Ilorin, the case study area is also not treated before discharge. The effluent wastewater is discharged into nearby drains which flow into larger channels or directly into streams nearby. In some rare cases, the wastewater is directed into some form of agricultural bed as water for irrigation. Untreated aquaculture wastewater ends in rivers and streams which could be sources of water supply to downstream areas. Such water, if not treated before use can result in human diseases. Where these are not sources of water supply, it could lead to eutrophication which has an impact on the ecosystem and invariably impacting both man and the environment (Asemota, 2011). In addition, conventional methods of wastewater are geared towards treatment at a central point. CFE is disposed off at its point of generation and does not flow into a sewer network which terminates at a wastewater treatment plant. Devi and Gowri (2007) investigated biological treatment of aquaculture effluent wastewater using seaweed and showed this could be an effective method of removing nutrients in aquaculture effluent wastewater. The application of biological treatment method using seaweed would not solve the problem of discharge in the study area as most of the farms within the study area are land locked in nature. Also, there would be the need to harvest the seaweeds periodically to avoid eutrophication which is the result of excess nutrients load in water bodies. Crab *et al* (2007) reviewed nitrogen removal techniques in aquaculture; some of the techniques have recorded relative good success, however they cannot be adapted in developing countries due to either cost or expertise of operation required. Some of the techniques are mechanical filtration, disinfection by ozonation or ultraviolet irradiation. Jia and

Yuan (2016) reviewed the removal of nitrogen from wastewater using microalgae and microalgae-bacterial consortia noting it was a good option but requires a high rate of oxygen production and biomass harvest in a cost effective manner. Oxygen production can be aided by mechanical aeration, however this option might not be feasible for a developing country like Nigeria which is prone to unreliable power supply. Simultaneously, unmanaged sawdust waste is a menace to the environment. Within the study area, sawdust is majorly disposed of by indiscriminate combustion; this results in air pollution which in the long run affects human health and contributes to land degradation. Sawdust management and disposal has been identified as both an environmental issue and possible factor in lung related diseases common amongst timber industry workers. The quest to manage sawdust has led to researchers investigating its use in various forms such as charcoal briquette (Akowuah *et al*, 2012), reinforcing fibre filler in the production of thermoplastic polymer composites (Idrus *et al*, 2011) and the removal of heavy metal ions. Ali *et al* (2012) reviewed low cost adsorbents such as sawdust used in the removal of organic pollutants in various types of wastewater such as dyes and heavy metal ions but did not capture aquaculture wastewater. Both untreated discharged aquaculture wastewater and unmanaged sawdust waste affect human health and the environment at large. This study investigates the possibility of curbing sawdust disposal problem by using it to treat aquaculture wastewater before discharge.

1.3 Justification of Study

Aquaculture is a fast-growing industry globally due to an increase in demand for seafood products and depleted fish stocks in the world's oceans, (Oberdieck and Verreth, 2009). In Nigeria, catfish farming is a fast-growing industry in step with the global trend. Unfortunately, the drawback of this lucrative and sustainable industry is its ability to contaminate both surface and ground water sources through the disposal of its effluent without any treatment. Conventional methods of wastewater treatment are capital intensive in terms of construction, operation and maintenance; and because of lack of required technical expertise and reliable power supply, they are difficult to implement in many developing countries. n If the effluent from catfish farming is to be treated prior to ultimate discharge into the environment, the treatment method has to be relatively cheap to adapt, comparatively easy to operate and maintain and sustainable.

Sawmills across the country are faced with the major problem of disposing the waste generated in form of sawdust and chips. Sawdust, which is disposed of currently in such a manner that has negative consequences on man and his environment, could be the panacea for aquaculture wastewater treatment if it can be converted into a form of activated carbon and utilised as a medium to treat the effluent wastewater before discharge. If this is possible, both the disposal of sawdust and wastewater would be achieved in an environmental friendly and sustainable manner. This study is therefore designed to investigate the potentiality of using sawdust as a medium in treating aquaculture waste.

1.4 Aim and Objectives of the study.

The aim of the study is to investigate the suitability of sawdust waste as a medium for aquaculture effluent treatment.

The objectives to achieve this aim were:

1. Investigate current practice of Catfish Farming Effluent (CFE) and sawdust disposal.
2. Assess the qualities of CFE
3. Examine the adsorption abilities of sawdust, AS and commercial activated carbon (CAC)

4. Investigate the efficiency of AS in the treatment of CFE

1.5. Research Questions

This research study aims to answer the following questions;

1. Do the current disposal methods of CFE and sawdust have any adverse effect on man and the environment?
2. How efficient is AS in the treatment of CFE?
3. Are the adsorption abilities of AS comparable with CAC in the treatment of CFE?
4. Can both solid waste and aquaculture waste water be managed, treated and disposed of in a sustainable manner through the use of modified sawdust in the treatment of catfish farming effluent?

1.6. Scope of Study

Various types of wood are processed at most sawmills in Nigeria including Isoberlina *doka* known locally as 'babo', Daniella *ogea* locally known as 'iya', Gmelina *arborea* locally known as 'malenna' or 'igi-isana', Canarium *schweinfurthii* locally known as 'ako', Afzelia *bipinensis* locally known as 'apa' and Anogesu s*olivera* known locally as 'ayin'. However, for this research, the specie to be used in treating the wastewater is Isoberlina *doka*; locally known as 'babo'. A heterogeneous mixture of unknown species will also be used. This is being considered because at any sawmill, consideration is not given to separating the dust obtained from different species. Sawdust used was restricted to homogeneous specie of wood; Isoberlina *doka* and a heterogeneous mix of sawdust collected from timber markets within Ilorin, a city which is the capital of Kwara State; one of the states in the North Central geo-political zone of Nigeria. It is situated on 8' 50" latitude and 4'54''longitude (www.worldatlas.com). The aquaculture wastewater was restricted to that obtained from catfish '*Clarias geriepenius'* farming done in concrete ponds within the same area. Activation process was restricted to chemical activation using phosphoric acid (also known as orthophosphoric acid) and wastewater treatment method adopted was adsorption.

1.7 Significance of Study

Recycling of sawdust into a form of synthetic activated carbon and utilizing the product in the treatment of aquaculture wastewater means sawdust does not have to be disposed in a haphazard manner which could result in environmental pollution. In Nigeria, like any country of the world, environmental pollution occurs in the three phases of matter. Developed countries appear to have been able to reduce or control environmental pollution to a large extent. Unfortunately, the same cannot be said of developing countries like Nigeria. Vehicular emissions and indiscriminate burning of domestic waste, tyres and sawdust are the main contributors to air pollution in Nigeria. Other contributors are from industrial processes. These emissions are generally of the microscale level, dispersing into the air within a distance of 1kilometer. The emissions tend to occur in built up areas and the accompanying plume rise of these emissions are generally low making it easy for the resulting pollutants to affect human, vegetation and buildings. The current practice of burning sawdust and chips results in air pollution. The effect of air pollution is often not seen immediately because it takes time for the consequences to materialize. Emission pollutants are inhaled by humans and also deposited on their skins. The mode of entry is normally through the nose which is one of the organs of the respiratory system. Other organs are pharynx, larynx, trachea, bronchi and the lungs. It is common for a person to cough or sneeze as the body tries to eliminate the inhaled pollutants. The pollutants not expelled immediately settle in different parts of the respiratory system depending on the size and nature of the pollutant. The respiratory system can be likened to a pipe network where the effectiveness of the pipe is gradually reduced as flow of fluid leaves deposits on the surface or the occurrence of cavitation. Some of the diseases that could result are Bronchial asthma, chronic bronchitis and cancer of the bronchus (lung cancer). Consequences of air pollution can also be seen in vegetation and materials. With respect to vegetation, it could result in fleck (white spots sometimes seen on leaves), eventually, this could result in less growth and consequently smaller yield. With respect to materials, the damage could be aesthetic; an example is the preparation of food using kerosene stoves. If this is done indoors, after a while, it would be noticed that the ceiling has lost its original colour. The use of sawdust in treatment of wastewater would mean reduction in sources of air pollution.

Disposal of untreated liquid wastewater is the norm rather than the exception in most developing countries like Nigeria. Though most of these countries were colonized by European countries, for some reasons, their methods of wastewater treatment management and disposal were not passed on. In the 70s and 80s, some residential estates were built in Lagos with wastewater treatment plants incorporated. An example is Abesan Wastewater Treatment Plant located within Gowon Estate, a low cost housing estate in Abesan, 6.61N, 3.262E (a suburb in Lagos, Nigeria) where the treated effluent was to discharge into Abesan River, an inland freshwater body. Decades after, the treatment plant is no longer functioning as intended. Other examples of residential estates in Lagos which incorporated wastewater treatment plants are 1004 Estate, Satellite and FESTAC towns. These all had water bodies close by that could receive the treated effluent. Decades after, most are no longer functioning as reported by Nwannekanma, 2018. The major bane of these treatment plants is lack of regular maintenance which has now resulted in a need for major rehabilitation work. The article highlighted the case of a treatment plant which was built in 1982 to serve a population of about 50,000. The said plant allegedly has inflow to the plant flowing on streets and drainage system before terminating into the canal where the treated effluent should have been discharged. This has affected water quality of boreholes in the vicinity. Few new residential estates like Lekki county Homes in Lekki, Lagos have some form of wastewater treatment plant built on the estate; anaerobic digesters in series are employed to treat the wastewater before discharge into the river close by. Generally, the *modus operandi* is the septic tank. The septic tank is essentially a sedimentation tank which allows solids to settle to the bottom of the tank as sludge that is removed periodically while the supernatant percolates into the ground with the possibility of contaminating ground water. There is no formal method of sludge treatment. Generally, the septic tank is used for black wastewater while grey wastewater is allowed to flow into cesspit or drain into gutters. In the study area, some residential buildings and schools discharge greywater onto streets. The same method of wastewater disposal method is employed by road side canteens and salons. The consequences of this action include erosion and obnoxious smells which irritates the respiratory system. Untreated effluent from aquaculture farms also contribute to environment pollution through contamination of water bodies. Often antibiotics are used in these farms, invariably these end up in water bodies. Research has shown there is a possible link between antibiotics discarded through wastewater and the emergence of antimicrobial resistance and as rightly pointed out by Hayward (2019), developed countries have to be concerned about how developing countries are managing and disposing their wastewater. A developed country could achieve safe levels but such levels could be jeopardized by the entry of a carrier of resistance genes from a developing country. The Ebola epidemic of 2014 highlights the ease of which this could occur.

Conventional sewerage method of wastewater and management has worked well for developed countries but it does not appear to be the solution for developing countries. Untreated wastewater could end up draining into rivers which are upstream of sources of water supply to a community. There are situations where the river is dammed to allow for diversion into a water treatment plant as in the case of Asa Dam which is located in the study area. A polluted river is more expensive to treat to the stipulated standards for human consumption. Filter beds get clogged up quicker leading to the need for frequent maintenance which could be hindered by lack of regular power supply or available funds to procure chemicals for flocculation and coagulation. It is high time there was a move towards innovative and novel methods of treating wastewater on an individual and or onsite basis without relying on machinery, expertise or electricity. Use of sawdust in treating wastewater could well be the panacea.

Environmental pollution caused by solid waste can be seen everywhere in developing countries. Dumping of refuse on the median of highways which mars the aesthetics of the environment, obnoxious smells from heaps of refuse dumped anywhere convenient for the populace and the burning of these dumps resulting in air pollution are a few examples of environmental pollution caused by improper management and disposal of solid waste. In some cases, solid waste is dumped in rivers, hindering the quality for downstream users. Solid waste dumps encourage the breeding of flies and rats which are vectors for diseases such as cholera, dysentery, typhoid fever and salmonella. In addition, there is the issue of leachate which could percolate into the soil or remain stagnant above the ground resulting in breeding ground for mosquitoes. Diseases triggered by mosquitoes depend on their species, Anopheles is the vector for malaria and Lymphatic Filariasis while Aedes is responsible for Yellow fever and Lymphatic filariasis to mention a few. If sawdust can be used in the treatment of aquaculture effluent treatment, it implies aquaculture farms will no longer contaminate receiving water bodies, which could affect their suitability for use by downstream communities without further treatment. Disposal of sawdust through burning will be eliminated thereby reducing air pollution and leading to a more aesthetically pleasing environment.

1.8 Operational Terms

AC	Activated Carbon
AMS	Activated Mixed Sawdust
AS	Activated Sawdust
BB	Isoberlina Doha (locally referred to as Babo) sawdust
BET	Brunauer-Emmett-Teller
BM	Blind Mix (Heterogenous mix of sawdust)
BOD	Biochemical Oxygen Demand
CAC	Commercial Activated Carbon
CF	Catfish Farming
CFE	Catfish Farming Effluent
COD	Chemical Oxygen Demand
Cc	Coefficient of Curvature
Cu	Coefficient of Uniformity
DA	Dubinin-Astakhov
DFT	Density Functional Theory
DO	Dissolved Oxygen
DR	Dubinin-Radushkevich
GHG	Green House Gases
NESREA	Nigeria Environmental Standards and Regulations Enforcement Agency
RAS	Recirculating Aquaculture Systems
SDG	Sustainable Development Goals
TDS	Total Dissolved Solids

TSS	Total Suspended Solids
WWTP	Wastewater Treatment Plant
UN	United Nations

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Waste Management and Disposal

Waste can be defined as the unwanted residue at the end of an activity or a process. The activity generating the waste could be natural or anthropogenic and either controlled or uncontrolled. Waste can occur in any of the three phases of matter; gas, liquid or solid. Waste in any form, if not well managed can have dire consequences on both man and the environment. Consequently, it is vital that these consequences are eliminated or mitigated in a holistic manner. More often than not, an activity or process will result in more than one type of waste which could be gaseous, liquid or solid; however attention is often given to the one which seems to have a more visible impact and not necessarily the one causing more damage either in the short term or in the long run. There is the tendency to concentrate on solid waste management and disposal because uncollected refuse can be seen unlike indiscriminately discharged untreated wastewater where the damage to the environment is not easily visible. Gaseous waste is hardly considered though to an extent, it is visible as plumes are easily identified. Fumes from burning of tyres, refuse and sawdust are easily visible but apart from the fact that there are laws and regulations concerning air pollution, in developing countries like Nigeria, many vehicles which should be taken off the road due to the exhaust fumes discharged into the environment are still plying the roads and highways. In addition, it appears the populace has not really grasped the consequences of air pollution and so there is no outcry for the government to do anything about it. Indeed, the number of deaths reported regularly due to inhalation of carbon monoxide when generators are used as an alternative to power supply from the grid is an indicator. It is a common sight in urban cities in Nigeria to find commercial motorcycle riders without nose guards despite the exposure to vehicular emissions. The same could be said of liquid waste. Of recent, consequences of oil spills on rivers in the Niger Delta area of Nigeria has been highlighted resulting in oil companies paying compensation. However, this is the exception rather than the norm. Untreated liquid waste discharge has a bearing on the aquatic inhabitants of the receiving water bodies such as fish, crabs and shrimps which are caught for human consumption, There are laws in place regarding effluent discharge but enforcement and prosecution of defaulters are hindered by not enough personnel to do the job and corruption amongst other factors.

2.1.1 Gaseous Waste

Gaseous waste occurs as a result of either natural activities or processes such as volcanic eruptions and bush fires or anthropogenic activities such as manufacturing. It is often not given much consideration till it results in air pollution. Air pollution can be said to occur when gaseous waste exists in concentrations higher than ambient levels resulting in undesirable effects on humans, animals, flora or materials (Kiely, 1996). Air pollution can be classified into three categories or scales depending on duration and distance at which its impact is felt. Micro scale is the class wherein the duration of pollution is a matter of minutes and hours not exceeding 1km; Mesoscale is the category where duration is in terms of hours and days not exceeding 100km; Macro scale is in terms of thousands of kilometres lasting for days and weeks (Kiely, 1996). Certain pollution episodes can cut across the three scales as in the case of the Chernobyl disaster of 1986 (Blakemore, 2019). In Nigeria, waste is burnt regularly without safety measures in place. It is normally done in the open instead of an enclosed area where stack height could influence the type and rise of the resulting plume. In areas where refuse is not collected by authorities, residents in a community burn their refuse as and when desired. In Ilorin, the study area, waste is collected and disposed of by Kwara State Environmental Protection Agency (KWEPA). The refuse is taken to the outskirts of the city where it is burnt. The duration and intensity are mesoscale in nature as it does not last for weeks. The situation is similar with sawmill refuse. The waste is taken to undeveloped land and burnt there.

2.1.2. Liquid Waste

Liquid waste can be described as any waste in liquid form resulting from anthropogenic activities ranging from domestic to industrial. In engineering, this liquid waste is known as wastewater.
Wastewater can be described as water carrying wastes from homes, businesses and industries that is a mixture of water and dissolved or suspended solids (UNEP, 2004) while conventionally, wastewater disposal refers to collection, removal and treatment of wastewater obtained from industrial and urban areas by means of sewerage system and treatment plants. In any society, it is important that wastewater is managed efficiently and effectively in order to prevent negative consequences. Irrespective of the method of wastewater collection, transportation, treatment and disposal; the effluent will ultimately end up either discharged into surface water or infiltrate into ground water. It is therefore imperative that wastewater is treated adequately before disposal. The consequences of not doing so could have grave effects on the community ranging from aesthetics impairment of water bodies, eutrophication to outbreak of diseases particularly when the wastewater has some form of fecal pollution. Some of these diseases include Dysentery, Schistosomiasis, Typhoid fever, Cholera and Hepatitis A. Globally, water pollution is controlled by defining, applying and enforcing effluent standards for wastewater discharge (Ragas et al, 2005); however for developing countries like Nigeria, pollution is still a major problem due to

factors such as lack of infrastructure, economic constraints, unreliable power supply and the low political will and understanding of its impact on the environment.

Wastewater is broadly classified into four categories; domestic, industrial, Infiltration or Inflow and storm water. Domestic wastewater is wastewater discharged from residential buildings, commercial, institutional and public facilities. Industrial wastewater is effluent from diverse industries such as food processing and pharmaceutical. Infiltration/Inflow (I/I) is water that enters a collection system through direct and indirect means. Infiltration is extraneous water that enters the collection system through leaking joints, cracks and breaks while stormwater is runoff resulting from rainfall and snowmelt (Metcalf and Eddy/Aecom, 2014a).

Conventionally, wastewater is treated after collection through a sewerage system by applying physical, chemical and biological processes which are categorized into three; primary, secondary and tertiary. On completion of treatment, the treated wastewater is either discharged unto water bodies or reused in irrigation depending on the level of treatment received. During the various stages of treatment, waste material is generated. The waste material produced during any of the stages of treatment which has not being further processed to reduce pathogens is referred to as Sludge (Metcalf and Eddy/Aecom, 2014b). The conventional approach is an off-site method based on a properly designed sewerage network scheme, uninterrupted power supply and technical expertise.

In developing countries like Nigeria, the conventional approach is not an option primarily because most cities were not built up with a sewerage layout and secondly, the technical expertise required, and power supply needed for effective treatment are not readily available. The wastewater treatment method adopted in Nigeria is the on-site approach using septic tanks which is essentially sedimentation and filtration; sewage settles into a tank while the liquid filters into a soak pit and eventually percolates into the soil. Often, gray water which is water from bathing and washing activities is separated from black water, which is waste that has some form of fecal contamination usually from toilets, by diverting the gray water through the use of drains and gutters into a soak pit or in some cases, into road side sewers or drains or worse, discharged onto the ground nearby with possible consequence of erosion depending on the soil type. The septic tank is emptied periodically depending on how quickly it gets full. Some industries like food processing and pharmaceuticals treat their wastewater to a stipulated level before discharging into natural water bodies.

A type of wastewater which does not fit perfectly into these categories is the effluent from aquaculture farming industry primarily Catfish and Tilapia in concrete ponds. The aquaculture industry which has developed in Nigeria to a great extent in the last two decades has concentrated greatly on improving quality and quantity of fish yield with little or no consideration given to the resulting effluent from the process. The little consideration given has been in terms of recycling the effluent back to be reused either on the aquaculture farm or diverted into small scale vegetable beds. Recycling of the wastewater often referred to as Recirculating Aquaculture System (RAS) which comprises of running the wastewater through filters to remove fish waste and food and then recirculate into tanks (Turcios and Papenbrock, 2014), has inherent challenges for developing countries like Nigeria: unreliable and erratic power supply. The author observed a few had tried RAS in the study area but was told the idea was abandoned due to non-economic cost of self-generation of power. Generally, aquaculture effluent in developing countries is discharged into nearby drains without any treatment. Aquaculture effluent is generally odorous, coloured and with a high concentration of suspended solids. It is normally high in nitrogenous compounds (ammonia, nitrite and nitrate) which are considered major contaminants in aquaculture wastewater (Cao et al, 2007). Nitrogenous wastes can be removed from wastewater using two basic methods which are chemical and biological. Chemical methods are either through adsorption using activated carbon or ion exchange. The biological method is implemented using living organisms. The organisms are used to oxidize ammonia and nitrate (nitrification) and subsequently, nitrate is converted into nitrogen gas (Moulick et al, 2011). Microalgae, which is a photosynthetic microorganism generates oxygen through photosynthesis to satisfy the requirement of bacteria. Simultaneously, contaminating nutrients are removed during the growth cycle, (Jia and Yuan, 2016).

2.1.3. Solid Waste.

Solid waste can be defined as any material that is abandoned by dumping; burning or incineration; or accumulated or stored or treated before being abandoned by being disposed of by dumping, burning or incineration (RCRA, 2012) while Municipal Solid Waste (MSW) can be defined as waste collected by or on behalf of a local authority, (Enviros Consulting Limited, 2007). It comprises mostly household waste and it may include some commercial, institutional and industrial wastes. There is also a type of solid waste classified as hazardous waste; this is any waste or combination of wastes that pose substantial danger, presently or in the future to human, plant or animal life and therefore must be handled or disposed of with special precautions, (Davis and Masten, 2014). The collection, transport, treatment and disposal of solid wastes, particularly wastes generated in medium and large urban centres have become a relatively difficult problem to solve. Taiwo (2009) identified some factors responsible for waste management problem as waste disposal habits of the populace, lack of adequate equipment, attitude to work and corruption. The author observed some of these factors in Ilorin, a major city in Nigeria where the research was carried out. There is a lack of knowledge on the importance of proper waste management. The normal practice is collection and disposal, often followed by open-air burning. There are no structures in place to aid sorting of waste at source, reuse or recycling. Sorting at generation point is almost non-existent in the study area; some form of sorting can be identified at small to medium sized commercial centres (shops, supermarkets or chemists) where empty cartons are kept aside for reuse either directly for packing of goods purchased or indirectly in cases, where members of the community request them for different uses. The time lapse between storage and collection allows for some scavenging. Scavengers, who could be instrumental in waste reduction are viewed as miscreants by the public and are not recognized stakeholders in waste management strategy or policies of the authorities responsible for waste management and disposal. Any sorting at the point of generation is often by scavengers who tend to be specific in what is collected and often end up leaving the waste area unsightly and worse than they met it.

2.1.3.1. Timber Waste

Solid waste generated in timber related industry is unique from most other types of solid wastes as it is usually a single material in two main forms; chips and dust. Consequently, there is no need for sorting or separation. Generally, there are three main areas where timber waste can be expected; sawmills, furniture making industries/workshops and construction sites. Sawmills are the destination points for wood logs after been felled in forests. A sawmill can be described as a facility which processes raw timber into dimensional lumber for shipping or transportation and eventual sale, (Ogunbode *et al*, 2012). Within the study area, timber related waste collection and disposal is not the responsibility of the governing authorities and its agencies. The workers at sawmills and timber markets are responsible for the disposal of any waste generated. The National Environmental Regulations (2009) stipulates that a generator of waste should amongst other things, separate, secure in plastic bags or leak proof bins with tightly fitted lids. This, however, is not the case at sawmills visited during this study. Generally, the waste (the bulk of which is sawdust due to the cutting of wood using tools such as circular band saw) is left in-situ until it becomes a nuisance to workers; at which stage, it is removed by packing into old grain bags and eventually taken to any open field for burning. At some sawmills, sawdust and chips are collected by the populace for uses such as erosion control (the sawdust is put in empty grain sacks and cement bags) and poultry flooring (the sawdust is poured on to the ground like a covering so as to make cleaning excreta and waste easier). In some large sawmills, the waste has become a covering which can be seen on the grounds around the mill; a general trend across the country.

Sawdust has found various uses over the years; varying from use for erosion control, plasterboards and briquettes. Due to its properties as a type of biomass, it has also been utilised as feed for electricity generation (Kimble *et al*, 2008). Ogunbode *et al* (2012) in a study done on sawmill wastes in Minna, a city in North-Central Nigeria, observed that in order to clean up the factory area, most sawmills just burn and/or dump the wood waste to the earth; a general trend in the six geo-political zones of the country. Various researchers have studied sawmills from different perspectives. Agu *et al* (2016) considered health of workers using Abakaliki, a city in South East Nigeria as a case study, concluding that sawmills were not safety compliant consequently there were prevailing respiratory health problems amongst workers. Tobin *et al* (2016) came to a similar conclusion using Egor local government area of Edo State in South-South Nigeria. Akinnubi (2015) investigated knowledge and experience on the importance of health education with particular interest in noise pollution using Ondo State; in South West Nigeria. Similar conclusion with other researchers was arrived at; and that is workers at sawmills were more susceptible to respiratory problems. Respiratory problems originate from inhalation of air pollutants. In humans and animals, there is a respiratory system which circulates necessary gases within the body. The organs of the respiratory system include the nose, trachea, bronchi and lungs. Particulates penetrate the respiratory tract and depending on the size are deposited in different parts of the respiratory system causing different types of diseases. Particulates less than 2.5 micrometers tend to cause the most damage because they are small enough to bypass screening and deposition in the upper respiratory tract but big enough to be deposited in the lower respiratory tract where they can do the most damage. Bronchial asthma occurs as a result of airway resistance. Airway resistance is the narrowing of air passages due to irritating substances inhaled. Asthma attack occurs when the bronchioles in the respiratory system narrows because of a swelling of the mucous membrane and thickening of the secretions. Chronic bronchitis occurs when there is excess mucus and results in cough that lasts for 3 months a year for two consecutive years. Pulmonary emphysema occurs when the surface area for gases exchange is greatly reduced. The surface area is reduced as pollutants are deposited, hindering exchange of gases sufficiently (Davis and Masten, 2014). It is not difficult to understand why sawmill workers would be more susceptible to respiratory problems than other persons in a community in Nigeria. There are two major contributing factors; the size of sawdust particles, during the process of cutting the wood pieces, particles are thrown in the air and are tiny enough to be inhaled by the workers. The other is the lack of use of nose guards or any safety apparel. If the sawdust waste is not cleared promptly, it can easily be blown by wind of little magnitude into the air and inhaled by the workers. Workers in the study area were observed having conversations while cutting timber planks into smaller pieces, thereby making it easier for sawdust to get deposited in the trachea.

Open Dumping and burning of wood waste eventually cause the emission of Green House Gas (GHG) especially methane (CH_4) and carbon monoxide (CO) due to decomposition and combustion respectively (Tillman, 1978). Globally, there is great concern over GHG and its impact on climate change. The United Nations (UN), (2015) set an agenda for sustainable development to be achievable by 2030 under the auspice of Sustainable Development Goals (SDG) of which there are 17. One of these is Goal 13 which is to take urgent actions to combat climate change and its impacts. Nigeria is a signatory to this agenda, if the current burning of sawdust can be stopped, it would be a step in the right direction.

Sawdust is currently being disposed of by employing two components of the waste hierarchy; reuse and recycle. Sawdust is reused by its use as floor bedding in poultry or for mopping up spills. A major way in which sawdust is recycled is in its use as a feed for electrical energy generation due to its biomass characteristics. Biomass refers to renewable organic matter generated by plants through photosynthesis. During photosynthesis, plants combine carbon dioxide from the air and water from the ground to form carbohydrates, which form the biochemical ‘‘building blocks’’ of biomass (Kurchania, 2012). Biomass sources can be classified into three namely; primary, secondary and tertiary (Energy and Environmental Analysis Inc, 2007). Primary source biomass is produced directly by photosynthesis and is taken directly from the land. Examples are residue resulting from harvesting forest and agricultural trees. Secondary source biomass is obtained from processing of primary source biomass using physical, chemical or biological methods. An example of secondary source biomass obtained using physical process is the production of sawdust and chips as a result of cutting logs of wood into smaller sizes. Black liquor obtained as a by-product of pulp processing is an example of secondary biomass produced chemically while manure production by animals is an example of biologically produced secondary biomass. Tertiary source biomass is as a result of post-consumer residue streams such as packaging wastes and construction and demolition wastes (Kimble *et al*, 2008).

Methods used to characterize and compare material properties of biomass include proximate analysis, ultimate analysis, calorific value and rate of de-volatilisation. Proximate analysis gives an idea of bulk components that make up a fuel which relates closely to its combustion behaviour. The objective of ultimate analysis is to determine its major constituents in terms of its elemental chemical composition, rather than its bulk components. The calorific value is a measure of fuel energy content and the rate of de-volatilisation describes how fast it burns. Ultimate analysis of biomass reveals the principal component as carbon which comprises of 30% to 60% of dry matter, oxygen typically 30% to 40% and hydrogen being the third main component making up 5% to 6%. Typically, nitrogen and sulphur (and chlorine) normally make up less than 1% of dry biomass. Chaney (2010), Clarke and Petro (2011) and Akowuah et al, (2012) all reported values within these ranges. Biomass can be converted into energy (heat or electricity) or energy carriers (charcoal, oil, or gas) using thermo-chemical and biochemical conversions technologies (Gravalos et al, 2010). Skodras et al (2004) suggests that utilization of waste wood could contribute to carbon dioxide emission reductions and consequently, the power sector would be complying with the 1997 Kyoto Protocol on Climate Change. Wood waste is already been used to generate electricity. The fuel used to generate electricity by Ridge generating station, Auburndale, USA consists of an estimated 75percent wood waste. The fuel provides enough steam to turn turbines which produce enough electricity, such that after the internal needs are met, about 90percent is sold to the grid (McConnell and Munroe, 2011). In recent years, different biomass materials including sawdust have been investigated for other uses apart from electrical energy generation. One of these is as an alternative to activated carbon. Activated carbon (AC) is derived by subjecting an organic base material such as wood, coal or almond to a pyrolysis followed with activation by exposure to oxidizing gases such as steam and carbon dioxide at high temperatures (Metcalf and Eddy/AECOM,2014b). AC is used extensively as an adsorbent in the treatment of wastewater and contaminated ground water. In the application of AC as an adsorbent, the adsorption process results from interaction between the carbon surface and the adsorbate. The interaction can be electrostatic or non-electrostatic. Activated carbon is the preferred adsorbent for the removal of micro pollutants from an aqueous phase however its widespread use is restricted due to high associated costs (Dias *et al*, 2007); consequently, there has been a trend towards alternatives. An adsorbent is considered low cost if it is abundant, requires little or no processing before use and is a by-product of waste material from waste industry (Zwain *et al*, 2014). Sawdust has all the above characteristics. It is available free and can be collected as a waste of industrial sawmills operations.

2.2. Adsorption and Activation

2.2.1. Adsorption

Adsorption is considered the best wastewater treatment method due to its universal nature, inexpensiveness and ease of operation. Adsorption removes soluble and insoluble organic pollutants with a removal capacity possibly up to 99.9 percent (Ali *et al*, 2012). Simplicity of design and convenience are two other factors which makes adsorption a treatment choice (Bhatnagar and Minocha, 2006). Adsorption is a surface phenomenon with common mechanism for organic and inorganic pollutants removal. When a solution containing adsorbable solute meets a solid with a highly porous surface structure, liquid–solid intermolecular forces of attraction cause some of the solute molecules from the solution to be concentrated or deposited at the solid surface. The solute retained (on the solid surface) in adsorption processes is called adsorbate, while the solid on which it is retained is called as an adsorbent. This surface accumulation of adsorbate on adsorbent is called adsorption. This creation of an adsorbed phase having a composition different from that of the bulk fluid phase forms the basis of separation by adsorption technology. In a bulk material, all the bonding requirements (ionic, covalent, or metallic) of the constituent atoms of the material are filled by other atoms in the material. However, atoms on the surface of the adsorbent are not wholly surrounded by other adsorbent atoms and therefore can attract adsorbate. The exact nature of the bonding depends on the details of the species involved, but the adsorption process is generally classified as physisorption which is characteristic of weak Van Der Waals forces or chemisorption which is characteristic of covalent bonding (Rashed, 2013).

Generally, precursors for adsorbents tend to be agricultural or industrial by-products but other waste materials such as polyethylene terephthalate (PET) bottles have also been considered. Ali *et al,* (2011) produced PET bottle-based AC by physical activation and investigated the removal of phenol aqueous solution in a batch process. It was concluded that the high surface produced aided the removal of phenol. The production of activated carbon from agricultural by-products serves the environment in two ways. Firstly, it converts unwanted surplus agricultural wastes (millions of tonnes are produced annually) to valuable adsorbents and secondly, activated carbons are increasingly used in water treatment for removing organic chemicals and metals of environmental concern (Awwad *et al,* 2013). Agricultural by-products have become the standard adsorbents for the reclamation of municipal and industrial wastewaters to potable water quality (Bhatnagar and Minocha, 2006). It is worth noting that studies have been done using these wastes without any form of activation. Bulut and Tez (2007) used sawdust from Walnut tree to investigate the removal of heavy metals (Lead, Nickel and Cadmium). The sawdust was washed, dried and blended to increase its surface area. The blended sawdust was used without activation. Approximately 30%, 65% and 75% removal were observed for Nickel, Cadmium and Lead respectively after 60 minutes. It was concluded that adsorption of these metal ions depended on their initial concentration, temperature and contact time. Parihar and Malaviya (2013) treated textile wastewater with distilled water- washed and dried sawdust. Values of all physicochemical parameters investigated reduced after treatment indicating the sawdust had adsorbed the difference. Similarly, Harmayani and Anwar (2012) used distilled water washed and dried sawdust as an adsorbent to investigate removal of nitrogenous compounds from storm water. It was discovered that the removal rates were better at lower concentrations of the nitrogenous compounds and removal rate was proportional to adsorbent dosage.

2.2.2 Theory of Adsorption

The most important attributes of an adsorbent for any application are capacity, selectivity, ease of re-generation, kinetics, compatibility and cost. Rarely would a single adsorbent be optimal in all attributes. Adsorption capacity is the most important characteristic of an adsorbent. Simply stated, it is the amount of adsorbate taken up by the adsorbent per unit mass or volume of the adsorbent.

This can be expressed by Equation 2.1 (Metcalf and Eddy, 2003);

$$q_e = \frac{(Co - Ce)V}{m} \qquad 2.1$$

where: q_e = adsorbent concentration after equilibrium, mg adsorbate/mg adsorbent

Co = initial concentration of adsorbate, mg/L

Ce = final equilibrium concentration of adsorbate after adsorption has occurred, mg/L

V = Volume of liquid in reactor, L

m = mass of adsorbent, mg

Adsorption normally occurs on the outer surface of the adsorbent and in its pores. The pores are micro-pores which are less than 20 nm, meso-pores which are greater than 20 nm but less than 500 nm and macro-pores which are greater than 500 nm width (Metcalf and Eddy/Aecom, 2014b).

Equilibrium relationship describes the phenomenon governing the retention of adsorbate or its release. Generally, the amount of material adsorbed is determined as a function of the concentration at a constant temperature. The function is known as Adsorption Isotherm. Isotherms are developed by exposing a given amount of adsorbate in a fixed volume of liquid to varying amounts of activated carbon (Metcalf and Eddy/Aecom, 2014b). Various researchers working independently or in collaboration such as Hill-Deboer, Dubinin-Radushkevich, Fowler-Guggenhein, Temkin, Flory-Huggins, Freundlich, Langmuir, Brunauer-Emmett- Tellet (BET) have developed empirical relationships to give a better understanding of adsorption (Ayawei *et al.* 2017).

Freundlich and Langmuir are the most commonly used isotherms. Freundlich is used most commonly to describe the adsorption characteristics of the activated carbon used in water and wastewater treatment. Derived empirically in 1912, the Freundlich isotherm is defined as given in Equation 2.2:

$$\frac{x}{m} = K_f C_e^{1/n} \qquad 2.2$$

where

$\frac{x}{m}$ = mass of adsorbate adsorbed per unit mass, mg adsorbate/g activated carbon

K_f = Freundlich capacity factor, (mg adsorbate /g activated carbon) (L water/mg adsorbate)$^{1/n}$

C_e = equilibrium concentration of adsorbate in solution after adsorption, mg/L

1/n = Freundlich intensity parameter

The constants in the Freundlich isotherm can be determined by plotting log (x/m) versus log C_e and making use of equation 2.2, (Metcalf and Eddy, 2003) which can be rewritten as shown in Equation 2.3

$$\log (x/m) = 1/n \log C_e + \log K_f \qquad 2.3$$

Applying the equation of a straight line, $y = mx + c$ to Equation 2.3 allows a plot of log (x/m) against log C_e which would result in the gradient of the plot, m being equivalent to $\frac{1}{n}$ which is the Freundlich intensity parameter, while the intercept corresponds to log K_f, which is the intensity parameter.

Langmuir Isotherm (Metcalf & Eddy/Aecom 2014b), which is based on rational consideration is defined as

$$\frac{x}{m} = \frac{abC_e}{1+bC_e} \qquad 2.4$$

Where

x/m = mass of adsorbate adsorbed per unit mass of adsorbent, mg adsorbate/g activated carbon

a,b = empirical constants

C_e = equilibrium concentration of adsorbate in solution after adsorption, mg/L.

Equation 2.4 can be written in a linear form to give Equation 2.5

$$\frac{C_e}{x/m} = \frac{1}{ab} + \frac{1}{a}\ Ce \qquad 2.5$$

A plot of Ce/(x/m) against Ce will be linear with the intercept being the constant 1/(ab) and a gradient of 1/a. The values a and b are then utilized in determining the Separation Factor, R_L given in Equation 2.6 in which C_o is the initial concentration of the adsorbate. The Separation factor, a dimensionless parameter is also known as Adsorption Intensity.

$$R_L = \frac{1}{1+b\ C_o} \qquad 2.6$$

Equation 2.7 can be written as

$$\text{Log } R_L = \text{Log } 1 - (\text{Log } 1 + \text{Log } b + \text{Log } C_o) \qquad 2.7$$

$$\text{Log } R_L = -\text{ Log } b - \text{Log } C_o \qquad 2.8$$

The value of b required in Equation 2.8 can be obtained from Equation 2.5 where the constant of the relationship when plotted is $\frac{1}{ab}$, which is the intercept on the Y-axis and the gradient is equivalent to $\frac{1}{a}$.

It follows that a = $\frac{1}{gradient}$ 2.9

And

If the intercept is equivalent to $\frac{1}{ab}$, then b = $\frac{1}{a\ x\ Intercept}$ 2.10

Substituting for the value of a from 2.9,

The value of b is obtained as $\frac{Gradient}{intercept}$ 2.11

R_L and the square of regression coefficient (R^2) of the plot Ce/(x/m) versus Ce are parameters estimated by the Langmuir model used to determine if an adsorption system can be modelled (Adie et al, 2012). The value of R_L gives an indication of the adsorption ability of the adsorbent based on the following assumptions: $R_L = 0$ (is unfavorable); $R_L = 1$ (linear adsorption); $0<R_L<1$ (is favourable), (Mamdouth et al, 2004; Saswati and Ghosh, 2005). Harmayani and Anwar (2012) include an additional category; $R_L >1$ indicates irreversible adsorption.

2.2.3 Use of Sawdust as an adsorbent.

The use of sawdust as an adsorbent has been investigated by many researchers due to its biomass characteristics; biomass being a material that is non-fossil of biological origin. Wood, the structural part of plants is made up of cellulose, hemicellulose and lignin in variable proportions, (Da Rosa, 2009). The carbon content of wood makes it attractive as a precursor for an adsorbent. The greater the carbon content of a lignocellulosic material, the greater the carbon content of the char produced (Viswanathan *et al*, 2009)

Bulut and Tez (2007) investigated the removal of heavy metal ions from aqueous solution using sawdust obtained from Walnut (*Juglansregia*). The sawdust was blended to increase the surface area. Batch experiments were performed at various concentrations of heavy metal ions, different temperatures and different retention times with different amounts of adsorbents. Heavy metal ions were found to be removed but the rate of removal was dependent on the initial concentration, temperature and contact time. Politi and Sidiras (2012) investigated the use of pine (*PinusSylvestris L.*) sawdust as an adsorbent for the removal of dyes and heavy metal using two different approaches; untreated sawdust and sawdust treated with sulphuric acid at a temperature of 100^{o}C using liquid to solid ratio of 10:1 concluding better adsorption was achieved with the treated sawdust. Tashauoei *et al* (2016) investigated the adsorption of lead ions using modified beech (*Fagussylvatica*) sawdust. The modification was achieved by immersion of washed and dried sawdust in sulphuric acid for a specific period, rinsed with distilled water and then immersed in sodium hydroxide for the same duration of time used when immersed in acid. The sawdust was not subjected to any high temperature which is usual in activation. They concluded the modified sawdust could be used as an effective adsorbent having achieved a removal efficiency of 91.3%, though this was dependent on pH, initial concentration of lead ions, adsorbent weight and contact time. Generally, studies appear to have been concentrated on the use of sawdust as an adsorbent in the removal of heavy metal ions and dyes from wastewater; there appears to be no reported study on its use as an adsorbent in the treatment of aquaculture wastewater.

2.2.4. Activation

Activation is done in order to create and develop porosity (volume and size) in the carbon material and consequently, increase its adsorptive capacity (Viswanathan, 2009).

Essentially there are two methods of activation; Physical activation also known as thermal and Chemical activation. Both methods consist of two stages. In the first stage, raw material to be converted into adsorbent is carbonized and in the second stage, the carbonized raw material which is commonly referred to as precursor is activated. Chemical activation can be done in one step unlike physical which requires two steps. Chemical activation has some advantages over physical; it uses lower temperatures, usually gives a higher yield, requires shorter activation time, results in activated carbon with high surface area and gives well developed micro-pore sites (Cruz *et al*, 2012, Vargas *et al*, 2011).

2.2.5 Physical Activation

Awwad *et al* (2013) activated date pits physically within a temperature range of 300^{o}C and 800^{o}C using steam and nitrogen. The activated carbon was used in treating both ground and surface water; a removal rate of over 90% was achieved for Co^{2}+, Pb^{2+}, Zn^{2+} and Fe^{2+}. Ali *et al* (2011) activated waste PET bottles under N_2 and CO_2 atmosphere and investigated its efficacy in the treatment of synthetic phenol wastewater. It was concluded that PET activated carbon had the potential to be a form of treatment for phenol removal in aqueous solutions.

2.2.6 Chemical Activation

Chemical activation consists of impregnating lignocellulosic or carbonaceous raw material with acids, alkalis or salt solutions such as $ZnCl_2$, HNO_3, H_3PO_4, NaOH or KOH (Peláez-Cid and Teutli-León, 2012).

Researchers have used various activating agents with different precursors with the view to producing alternative activated carbon for the removal or reduction of diverse pollutants. Some researchers like Wang and Liu (2010) and Abugu *et al* (2015) carbonized the precursor before impregnation with the activating agent while Sudaryanto *et al* (2006) impregnated with the activating agent before carbonizing.

Wang and Liu (2010) chemically activated *L.gmelinii* sawdust by utilizing potassium hydroxide (KOH) at a mass ratio of 4:1 [KOH: Sawdust], pre-carbonizing at 500^{o}C for 1hour before activating at 750^{o}C for 2 hours and concluded the synthesized activated carbon had a higher adsorption capacity of Hg(II) when compared with commercially available activated carbon. Sudaryanto *et al*, 2006 also used KOH in activating cassava peel waste with alkali to precursor mass ratios ranging from 1:2 to 5:2 and carbonization temperatures of 450^{o}C to 750^{o}C at different times varying from 1hour to 3hours. The study showed the activation time had no significant effect on the pore characteristics of the adsorbent formed though impregnation time and carbonization temperature influenced the pores developed. Abugu et al (2015) activated crushed snail shell and oil bean (*Pentaclethra* m*acrophylla*) using different solutions of H_2SO_4, HCL and H_3PO_4 in the ratio 1:1 (Acid solution: Char) for the adsorption of lead in wastewater from a battery making factory. It was concluded that both adsorbents reduced the concentration of lead though the adsorbents activated with H_3PO_4 gave the best results. Larous and Meniai (2012a) activated sawdust with H_2SO_4 using a ratio 1:10 for the removal of Cu^{2+} ions from aqueous solution and observed that contact time with adsorbent, pH and initial concentration of the adsorbate influenced the adsorption but it still could be an effective adsorbent. Adegoke and Adekola (2010) investigated the removal of phenol in aqueous solution using five different precursors; coconut shell, coconut coir pith, rice husk, shear butter bark and shear butter wood chemically activated with four different agents. It was concluded that all were effective adsorbents, but effectiveness differed based on the raw material and activating agent. In a similar study, Larous and Meniai (2012b) investigated the removal of phenol ions and concluded that removal of phenol ions was equally possible; noting that after three hours, there was no increase in adsorption. Similarly, Hegazi (2013) observed that these same factors influence the adsorption of heavy metals from wastewater in a study using fly ash and rice husk but added that a maximum contact time of 2hours gave the best adsorption. Cruz et al (2012) produced activated carbon from cocoa pod husk using three different activating agents; K_2CO_3, KOH and $ZnCl_2$ carbonized at three different temperatures (500^{o}C, 650^{o}C and 800^oC) in a nitrogen atmosphere. The best result was obtained with $ZnCl_2$, while the activated carbon thus produced attained 80percent removal of arsenic (v) in less than one hour under experimental conditions.

Ara et al, (2013) investigated the removal of Remazol Red, a typical constituent of textile wastewater using $ZnCl_2$ activated sawdust (AS) in a ratio 100ml to 10g in the presence of nitrogen gas. Simultaneously, similar investigation was carried out using commercial activated carbon. It was concluded that AS was a better adsorbent for the removal of Remazol Red dye than the commercial activated carbon. Cao et al, (2006) reiterated the benefits of using agricultural waste in the production of alternative activated carbon and in addition, noted that apart from the known factors that influence the surface area available for adsorption; activation time, activation temperature and mass ratio of activating agent to precursor, the method used in applying the activating agent to the precursor has a bearing on the surface area obtained. Three ways of application of the activating agent potassium hydroxide (KOH) to the precursor which was corn cob was investigated namely: (1) adding the solid KOH directly to carbonised corn cob (2) dissolving the KOH in water to form a saturated solution, after which the carbonised corn was put in and (3) a mixed solution of KOH and soap was used to soak the carbonized corn cob (addition of soap reduces the activation time). Surface areas obtained were 2720, 2723 and 2630 m^2/g respectively all other factors remaining the same. The difference in surface areas of (1) and (2) suggests the method of application is not really crucial and the addition of soap to reduce activation time compromises the surface area. Pandharipande et al (2012) used three different agricultural wastes; rice husk, sugarcane bagasse and sawdust as precursors for activated carbon with ortho-phosphoric acid as the activating agent and investigated their ability to remove potassium dichromate, methyl violet and methyl blue in aqueous solution using different weights of the prepared carbon with constant volume of solution. The study showed all three waste products could be used as precursors for activated carbon though the fact that one precursor was best for the removal of a particular pollutant, it did not follow that it was the best for the removal of the other contaminants.

Both acids and alkalis can be used as activating agents; Hernández-Montoya et al, (2012) reviewed various studies involving synthetic carbon from different precursors and their preparations. An observation noted was increase in the use of ortho-phosphoric acid (H_3PO_4) which was probably due to some environmental advantages such as ease of recovery and high carbon yield. Its role is to accelerate the cleavage of bonds between biopolymers, principally cellulose and lignin. It has been suggested that the increase in the amount of phosphorus improve the volume of micro-pores and meso-pores (Mekarzia *et al*, 2013). Ortho-phosphoric acid allows dehydration at low temperatures, followed by extensive cross-linking that binds volatile matter into the carbon product and thus increases the carbon yield (Fierro et al, 2010).

2.3 Water Quality Indicators

There is a large range of chemical, physical and biological components that affect water quality and hundreds of variables could be examined and measured (Carr and Neary, 2008). Several parameters are used to determine if a water source is polluted or if any effluent discharging into such is polluted. Often, there are general parameters which are used irrespective of the pollution source such as BOD and temperature, while specific parameters will be dependent on the pollution source such as metals. Some variables provide a general indication of water pollution, whereas others enable direct tracking of pollution source (Carr and Neary, 2008)

2.3.1 Dissolved Oxygen (DO)

Dissolved oxygen (DO) refers to the amount of oxygen (O_2) dissolved in water. Oxygen is essential to preserve higher forms of biological life and the effect of a waste effluent can be determined by the oxygen balance of the system (Tebbutt, 1998). DO is usually expressed as a concentration of oxygen in a volume of water (milligrams of oxygen per litre of water, or mg/L). In nature, oxygen from the atmosphere can be mixed into (diffused into) a body of water. The mixing is easiest where water flow is turbulent (for example, where water is tumbling over rocks or where there are waves). Oxygen is also introduced into water by green aquatic plants and algae during photosynthesis (Scecoinstitute.com). Oxygen is only slightly soluble in water and the quantity that can be present in solution is governed by its solubility and partial pressure in the atmosphere, temperature and the concentration of impurities in the water. Rate of biochemical reactions that use oxygen usually increases with temperature. Consequently, dissolved oxygen becomes critical when temperatures are high. DO is desired in wastewater as it prevents the formation of noxious odours (Metcalf and Eddy, 2003). Water at lower temperatures holds more oxygen than water at higher temperatures. For example, pure water at 4°C can hold about 13.2 mg/L DO at 100% saturation, while pure water at 25°C can hold only 8.4 mg/L at 100% saturation. Water with a high concentration of dissolved minerals cannot hold as much DO as pure water (Scecoinstitute.com). Aquatic organisms need DO to stay alive and reproduce; the amount required depends on the specie, the temperature of the water (the higher the temperature, the greater the DO required) and the state of the organism itself (adult, young, active or dormant). The DO available could be influenced by the presence of sediments which could be natural deposits of leaves and dead aquatic plants or sludge deposits from discharged untreated wastewater (Davis and Masten, 2014). The generally accepted minimum level of DO that would support a large population of various fishes is from 4-5 mg/l. Depending on the species however, the minimum level could be as high as 9mg/l. When DO is depleted, there is a change in the ecosystem. Species that cannot tolerate low levels of DO are replaced by nuisance algae and anaerobic organisms (Oram, 2014).

2.3.2 Temperature

Temperature affects speed of chemical reactions, the rate at which algae and aquatic plants photosynthesize, the metabolic rate of other organisms, as well as how pollutants, parasites and other pathogens interact with aquatic residents. A change in temperature is either directly through thermal pollution which is a consequence of industrial cooling water or indirectly through human activities such as construction of impoundments. This change can affect mortality and influence solubility of DO and other materials in the water column. In addition, the amount of any gas including oxygen dissolved in water is inversely proportional to the temperature of the water (Carr and Neary, 2008). Feeding rates of fish tend to increase with temperature so amount of waste generated is often greater when temperatures are higher (Miller and Semmens, 2002).

2.3.3. pH

The measure of hydrogen ion concentration in any type of water is an important quality parameter. It is expressed as pH which is defined as the negative logarithm of the hydrogen-ion concentration as shown in Equation 2.12

$$pH = -\log_{10}[H^+] \tag{2.12}$$

The concentration range suitable for the existence of most biological life typically between 6 and 9 (Fondriest Environmental Inc., 2013). If wastewater is not treated before discharge into receiving water bodies, it could alter the existing concentration. The usual allowable range for treated effluent to be discharged into water bodies is 6.5 to 8.5. This is the usual indicator of good quality water which is typical of most major drainage basins in the world (Metcalf and Eddy/Aecom, 2014a; Carr and Neary, 2008). In water, a small number of water (H_2O) molecules dissociate and form hydrogen (H^+) and hydroxyl (OH^-) ions as represented in Equation 2.13.

$$2H_2O \rightleftharpoons H_3O^+ + OH^- \qquad 2.13$$

If the relative proportion of the hydrogen ions is greater than the hydroxyl ions, then the water is defined as being acidic. If the hydroxyl ions dominate, then the water is defined as being alkaline. The relative proportion of hydrogen ions and hydroxyl ions is measured on a negative logarithmic scale from 1 (acidic) to 14 (alkaline): 7 being neutral (Carr and Neary, 2008). It is important to note that the pH scale is logarithmic. This means that each step on the scale represents a tenfold change in the H^+ concentration. For example, water with a pH of 5 has ten times the number of H^+ ions than water with a pH of 6 and is ten times more acidic (Scecoinstitute.com). Researchers have all come to the conclusion that the pH of untreated effluents often is outside the recommended range and these effluents have detrimental effects on the receiving waters (Akpor and Muchie, 2011; Sarkodie et al, 2014) but often these waters have self-cleansing ability to recover from these effects. However, when pollution is constant and undeterred, they gradually lose that ability and become dead.

2.3.4. Nutrients

Elements that are required for life are called nutrients. The major elements required for metabolism and growth of organisms include carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulphur, magnesium and calcium. In aquatic system, nitrogen and phosphorus are the two nutrients that most commonly limit maximum biomass of algae and aquatic plants (primary producers) which occurs when concentrations in the surrounding environment are below requirements for optimal growth of algae, plants and bacteria (Carr and Neary, 2008). In water and wastewater studies, it is common to use the term nutrients when referring to Nitrogen and Phosphorus as they are considered the nutrients of most importance (Metcalf and Eddy/ Aecom, 2014a). Phosphorus in water is usually measured as total phosphorus, total dissolved phosphorus (i.e. all P that passes through a 0.45 µm pore-size filter), and soluble reactive or ortho-phosphorus. Nitrogen occurs in water in a variety of inorganic and organic forms and the concentration of each form is primarily mediated by biological activity. Phosphorus and Nitrogen are considered the primary drivers of eutrophication of aquatic ecosystem (Carr and Neary, 2008). Mylavarapu (2014) defines eutrophication as a process of water quality degradation. Dissolved nutrients are normally present in small amounts in surface water and in limited concentrations in groundwater. These enables submerged aquatic vegetation to grow and serve as food and habitat for aquatic animals including fish. If the nutrient concentrations in surface waters increase, the growth rate of microscopic algae accelerates and algal growth clouds the water bodies, making it difficult for the vegetation to receive enough sunlight and maintain adequate oxygen levels for supporting life. The natural waterborne vegetation may die, leading to a severe reduction in the available habitat area and food for other aquatic life. Also, the death and decomposition of algae during the normal lifecycle will reduce the dissolved oxygen levels in the water. Methods of reducing nutrients in aquaculture wastewater effluent are still being investigated

2.3.5. Biochemical Oxygen Demand (BOD)

BOD is, not a pollutant but an indicator of organic pollution. It is usually the measurement of the dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter in the water within five days, hence the term BOD_5 (Metcalf and Eddy/Aecom, 2014a) though occasionally the duration of the measurement could exceed five days such as when the effect of nitrifying bacteria is being investigated. The greater the amount of organic matter present in the wastewater, the greater the amount of oxygen used (Davis and Masten, 2014). Discharge of wastewater with high BOD value has a detrimental effect on the receiving water body. It could result in dissolved oxygen not being adequate for existing aquatic life resulting in a change in the ecosystem and algae bloom. The consequence of an algae bloom is reduced light penetration which further impairs the quality of the river.

2.3.6. Chemical Oxygen Demand (COD)

COD, just like BOD is not a pollutant but an indicator of pollution. It is the measure of oxygen equivalent that can be used to oxidized organic material in wastewater chemically using potassium dichromate or potassium permanganate in an acid solution (Metcalf and Eddy/Aecom, 2014a, Tebbutt, 1998). It can be expected that the COD value of a wastewater sample would be greater than the BOD for a few reasons such as: (1) the portion of the soluble carbon removed during the synthesis of new bacterial cells by microorganisms is not measured in the BOD test, (2) many organic substances which can not be oxidized biologically can be oxidized chemically, (3) inorganic substances that are oxidized by dichromate increase the apparent organic content of the sample, (4) certain organic substances may be toxic to the microorganisms used in the BOD test. The COD has a major advantage over BOD in that it can be done within a relatively short time of about 2.5 hours unlike BOD which takes a minimum of 5 days.

2.3.7. Solids

Wastewater contains a variety of solid materials, which are classified depending on what is retained after subjecting the wastewater sample to certain processes. The common classifications used in wastewater analysis are: Total Solids (TS) and Total Suspended Solids (TSS). Total Solids is the residue remaining after a wastewater sample has been evaporated and dried at a specified temperature (103^{o}C to 105^{o}C). TSS is the portion of TS retained on a filter with a specified pore size, measured after being dried at a specified temperature (105^{o}C). It is often used routinely to assess the performance of conventional treatment plants and the need for effluent filtration in reuse application. A variation in TSS is the settleable solids which is suspended solids that would settle out of suspension within a specified time. This often influences retention time in sedimentation tanks. Total Dissolved Solids (TDS) are solids that pass through the filter and are then evaporated and dried at specified temperature. Essentially TDS is the difference between TS and TSS. Other classifications are based on whether the solids are volatile (VS) or fixed (FS). Materials that can be volatilized and burned off when ignited at 500 ± 50^{o}C are termed volatile while fixed solids comprise the remnant after a sample has been ignited (Metcalf and Eddy/Aecom, 2014a). Miller and Semmens (2002) suggest reduction in downstream pollution can be achieved by rapid removal of solids in settleable form before discharge.

2.3.8. Turbidity

Turbidity refers to water clarity. The greater the volume of suspended solids in the water, the murkier it appears and the higher the measured turbidity (Carr and Neary, 2008). It is a measurement of light scattering properties of a solution containing suspended and colloidal properties (Metcalf and Eddy/Aecom, 2014a). If turbidity is high, light cannot penetrate into the depths of water bodies as it should; this would affect plants that require photosynthesis for growth and subsequently, organisms that depend on these plants for metabolism.

2.3.9. Pathogenic Organisms.

These organisms include bacteria, protozoa and viruses. They get into the water majorly through fecal contamination. A common indicator of fecal contamination is the presence of *E-Coli*. This is common in areas without access to good sanitation facilities. Contamination by pathogenic organisms can cause major health problems and occasionally death (Palaniappan et al, 2010). Any waste water with any slight chance of fecal contamination needs to be treated adequately to avoid human misery.

2.4. Wastewater and the need for treatment.

The prevention of pollution of water sources and protection of public health by safeguarding water supplies against the spread of diseases, are the two fundamental reasons for treating wastewater (Akpor and Muchie, 2011). Depending on the source of the wastewater, different indicators of pollution will be of greater concern than others. Conventionally, wastewater treatment consists of three stages namely primary, secondary and tertiary which utilize physical, chemical and biological processes either independently or combined. These processes would often include some form of disinfection to destroy or inactivate microorganisms (Olaolu, 2014). Each of the stages in conventional wastewater treatment will produce waste materials known as Sludge. The conventional way of treatment is most appropriate for a network of pollution sources that culminate at a common point such as municipal wastewater conveyed using a network of sewers;

it is also applicable for industrial wastewater. The presence of a functional conventional treatment plant is not a guarantee that the treated water being discharged is not polluting the receiving river, stream or lagoon as was discovered in a study done by Longe and Ogundipe (2010). The impact from the discharge of a treatment plant into a lagoon was investigated, while some pollution indicators were within limits, BOD was six times greater than the allowable discharge limit. In the study area for this research, conventional wastewater treatment is not the norm as wastewater is conveyed into septic tanks. In some parts of the study area, all manner of wastewater is dumped into open drains, gutters and on the ground without treatment resulting in uncontrollable contamination of the rivers and streams as storm runoff carries the wastewater into these water bodies.

2.4.1. Sludge Management and Disposal

A conventional wastewater treatment plant, which is designed to treat municipal wastewater consists essentially of four main sections. The sections are pre-treatment, primary, secondary and tertiary. Depending on regulatory standards and ultimate use of the treated wastewater, there might not be a need for tertiary or advanced treatment. Solids residue is generated at every stage of treatment. This residue and settled materials settled from raw wastewater is referred to as Sludge (Davis and Masten, 2014). The sludge can be up to 3.0% of the volume of wastewater treated and is in the form of a liquid or semisolid liquid. The sludge obtained from treatment processes can contain as much as 97% water. Sludge treatment therefore is concerned with removing as much water as possible (the water removed can be directed to the treatment plant) and treating the sludge to a safe level such that it can be reused. Waste material generated during pre-treatment process are generally non-biodegradable. Consequently, it can be drained and directed to a landfill. At the primary stage, screens, comminutor and grit chamber are used to stop floating material from going further in the plant while heavier materials settle to the bottom of the reactor. The reactor is referred to as settling or sedimentation tank or clarifier (Weiner and Matthews, 2003). Often, flocculation and coagulation aids are utilized to quicken the rate at which solids settle. The solids obtained are dependent on factors such as characteristics of the untreated wastewater, period of retention, periods between solid removal and degree of purification required (Metcalf and Eddy, 2003). The secondary stage is essentially a biological process in which microorganisms are used to reduce BOD in two distinct ways. The microorganisms are either attached to media such as rock or plastic packing in trickling filter or suspended in solution in the activated sludge (Metcalf and Eddy/Aecom, 2014a). The Trickling filter contains 2-5% solids while Activated Sludge is typically 0.5-2% solids. It is the norm to recirculate some of the sludge generated back into the process; this helps maintain a food to microorganism balance, while the remaining is discharged as waste. The activated sludge process is shown in Figure 2.1. The constituents of sludge generated during the tertiary process depends on the treatment undertaken. Some could result in a chemical sludge difficult to handle and treat as in the case of removal of phosphorus while removal of nitrogen gives a biological sludge similar to that of wasted activated sludge.

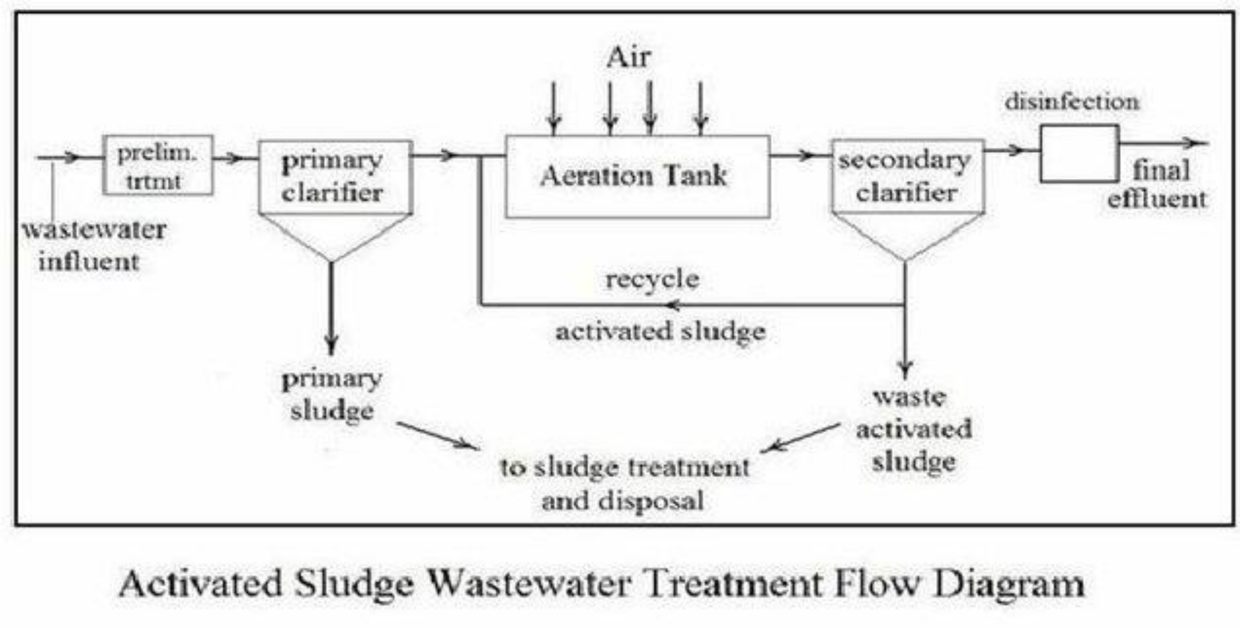


Fig 2.1. The Activated Sludge Process (Sastry *et al.*, 2013)

Management and disposal of sludge is complex for various reasons. Sludge contains the substances responsible for the undesirable character of untreated wastewater and only a small part contains solid. Although variability of sludge affects the treatment and disposal options (Weiner and Matthews, 2003), the basic processes according to Davis and Masten (2014) are

- Thickening: Separating as much water as possible by gravity or flotation
- Stabilization: Converting the organic solids to more inert forms so that they can be handled or used as soil conditioners without causing a nuisance or health hazard through processes known as digestion. The converted solids are referred to as 'Biosolids'.
- Conditioning: Treating the sludge with chemicals or heat so that the water can be readily separated.
- Dewatering: Separating water by subjecting the sludge to vacuum, pressure or drying.
- Reduction: Convening the solids to a stable form by wet oxidation or incineration.

Stringent regulations for producing high quality effluent have an impact on the process of treatment used which in turns impact the quality and quantity of biosolids produced from sludge (Metcalf and Eddy/Aecom, 2014b).

Ultimately, the treated sludge must be disposed of. The options available for disposal are air, water or land. Disposal by air is achieved through incineration. Organics are converted into water and carbon dioxide while organics are converted into non-putrescible residue (Weiner and Matthews, 2003) but there are emissions which can settle in the environment and could still cause harm though it might not be easily traced as the likelihood that the pollutants would settle near the site of incineration is very slim due to dispersion by meteorological factors. There is also the issue of ash disposal. In addition, the damage caused by emissions settlement could easily be one of a meso or macro scale making it difficult to trace its origin. Disposal by water is essentially dumping in the ocean. Due to the growing global concern for marine ecosystem, sludge disposal at sea is no longer encouraged. It is now prohibitory in countries like US, England, Wales and Northern Island. The only viable option is disposal on land. There are a number of ways in which this is achieved; land spreading, landfilling, dedicated land disposal and utilization in the area of composting and co-firing with municipal solid waste (Davis and Masten, 2014). The sludge produced during the process of treating wastewater is used intensively in agriculture as it brings benefits to the soil and plant crops. However, due to the possible presence of contaminating substances and pathogenic organisms, it is necessary to follow the criteria for safe use for health and environment (Bittencourt, 2018). A schematic diagram showing the source of sludge in a wastewater treatment plant and its treatment is shown in Figure 2.2.

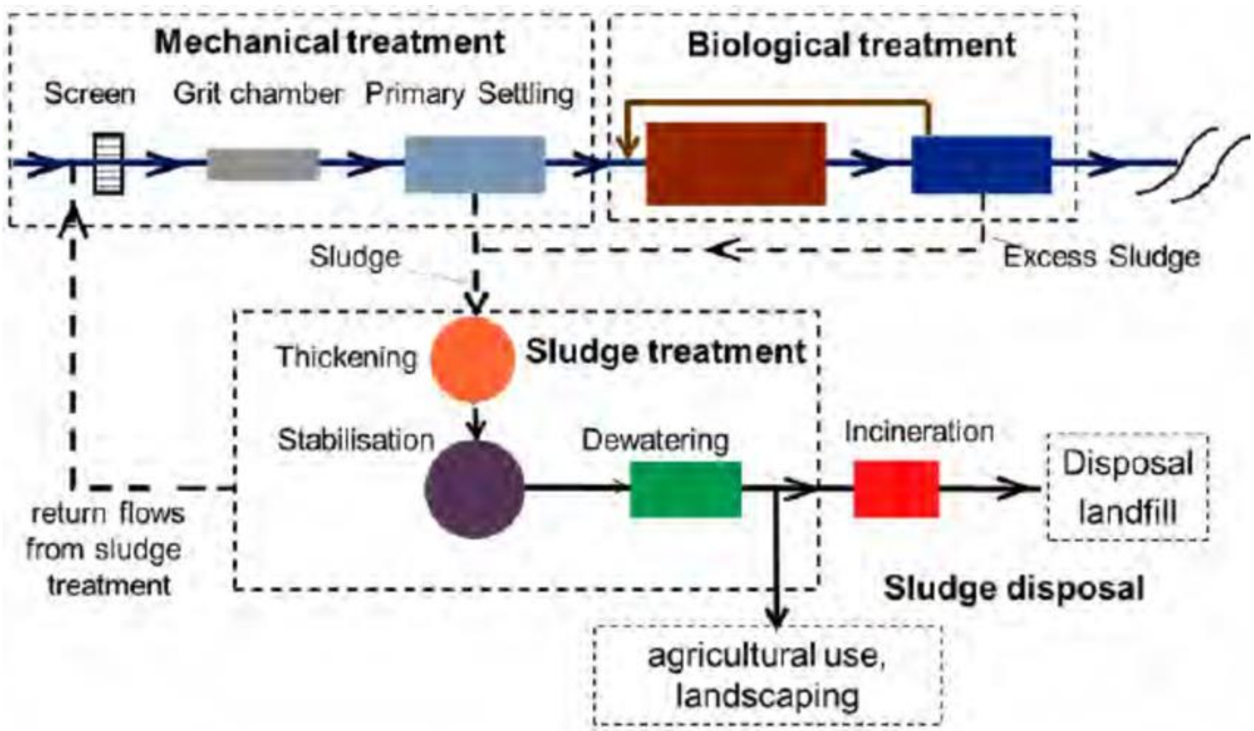


Figure 2.2. Sources and Treatment of sludge at a WWTP. Source: Kroiss *et al*, 2011

Investigation into the potential use of AS as a medium for the treatment of aquaculture would result in the production of sludge which would consist of the AS and any pollutant removed. It is necessary to consider what could be done to the sludge produced to avoid generating another problem in the process of solving one. An option considered in this study is the use of the sludge in horticulture.

2.4.2. Characteristics of Aquaculture Wastewater

The constituents of aquaculture wastewater vary in quantity but essentially it can be expected that certain parameters that could lead to pollution would be present. The common parameters are dissolved solids, suspended solids, nitrogen (in the form of nitrite and nitrate) and phosphorus. In addition, BOD which is an indicator of oxygen demand in receiving water bodies is also considered when discussing aquaculture wastewater. Nitrogenous compounds (ammonia, nitrite, and nitrate) are considered as major contaminants in aquaculture wastewater. Ammonia, the principal nitrogenous waste produced by aquatic animals is the principal nitrogenous waste produced by aquatic animals (Cao *et al*, 2007).

Studies have been conducted on the impact of aquaculture effluent on the environment. The resulting conclusion is that it has a negative effect on the environment at large. Miod *et al* (2009) investigated effluent from shrimp and fish farms and found dissolved oxygen level had dropped, BOD was high and high concentration of nutrients and suspended solids. All these promote the growth of phytoplankton which could subsequently contribute to eutrophication and loss of aquatic life. Fadaeifard *et al*, (2012) investigated the effect of untreated aquaculture effluent on a stream in Iran and noted increased turbidity which was associated to factors such as colloid particles, organometallic compounds and fish faeces. Boyd and Soongsawang (2012) investigated the effect of effluent from a fisheries research station on stream water quality and observed increase in TSS downstream of discharge point; confirming that untreated effluent can increase TSS of water bodies.

2.4.3 Aquaculture Wastewater Treatment

Several physical, chemical and biological methods used in conventional wastewater treatment have been applied for aquaculture wastewater. Sedimentation has been utilized for solids removal as it is done in Australia (Castine *et al*, 2013) where settlement ponds are used to remove particulate and dissolved nutrients resulting in about 60% reduction in suspended solids, but efficiency is not consistent. In addition, they identified the need for functional improvement to nutrient removal systems. Options suggested to deal with nutrient removal include use of algal biomass and recycling of nutrients through pyrolysis, trickling filters for oxidation of organic matter (Turcios and Papenbrock, 2014). Kioussis *et al*, (2000) investigated the use of polymer hydrogel in batch experiments and achieved over 50%, over 85% and 98% removal of nitrate, nitrite and phosphorus in the form of phosphate respectively. Lin *et al* (2001) used a constructed wetland system while Devi and Gowri (2007) treated aquaculture wastewater using different types of seaweed. Both studies achieved greater than 80% nutrients removal.

2.5. Rearing systems in Aquaculture

2.5.1 Ponds

They are basically static and do not rely on water replacement to maintain water quality. Ponds rely mainly on internal natural processes to purify the water. The biological community acts upon the dissolved wastes and helps to stabilize and recycle waste. Settled solids accumulate and undergo microbial decomposition in the pond sediment (Yeo *et al*, 2004). Typical fishponds are earthen enclosures in which the fish live in a natural-like environment, feeding on the food naturally produced in the pond with the aid of sunlight and nutrients available in the pond water. In order to reach higher yields, farmers introduce nutrients (organic manure) and additional food (grain). Fishpond production, however, remains 'extensive' or 'semi-intensive' (with supplementary feeding) in most countries, where semi-static freshwater systems play an important role in aquaculture. Chemicals and therapeutics are not usually used in such ponds (Bardócz, 2009). Some ponds were observed in the study area, but they were not as common as the artificial concrete ponds. Figure 2.3 shows an earthen pond observed in the study area. Occasionally, they are covered with net like material to prevent loss of fish to flying birds.

Figure 2.3 Earthen fish pond with net covering.

2.5.1.1 Concrete Ponds

These are the most common type of ponds used for fish farming in the study area. They are usually rectangular, made with concrete blocks and access to a steady supply of water. Most farms have borehole systems to ensure adequate supply of water. It is usual for the water in the tank to be changed at regular intervals. Within the study area, farms visited had water drained out within 2 – 3 days and refilled with fresh water. An example of a concrete pond visited is seen in Figure 2.4. Some farms have a network of concrete ponds as shown in Figure 2.5.

2.5.1.2. Non Concrete Ponds

A fish pond can also be made of plastic. This is common in places where availability of land is scarce. On some farms visited, fingerlings were kept in plastic containers before being transferred into concrete ponds. A plastic pond is shown in Figure 2.6.

Figure 2.4. Concrete pond with fingerlings

Figure 2.5. A network of concrete fishponds

Figure 2.6. A Plastic fish tank

2.5.2 Flow-through System

This rearing method is characteristic of cold-water fish hatcheries. High rates of water exchange dilute dissolved waste allowing fish to be reared at high densities in raceways, tanks, and ponds. These systems typically operate with very short water retention times, often less than one hour. High fish density requires the feeding of formulated diets. Rearing units of various sizes and shapes are used, including circular units, but the most common is the linear raceway. Concrete and fiberglass are popular construction materials used in public and large commercial hatcheries. Earthen raceways are found among many smaller private facilities. Very often, water flows from pond to pond before being discharged. To achieve greater production potential, pure oxygen injectors, mechanical aeration, or gravity aeration (where topography permits) are employed between rearing units to maintain dissolved oxygen concentrations. Flow-through facilities discharge large quantities of very dilute effluents, making nutrients recovery difficult (Yeo et al, 2004). In traditional flow-through aquaculture systems, water passes through the culture system only once and is then discharged back to the aquatic environment. The flow of water through the culture system supplies oxygen to the fish and carries dissolved and suspended wastes out of the system. Water is taken from a nearby river, circulated through the farm and treated before being released downstream. All water in the farm is renewed at least once per day. Where more than one farm exists on the same river, it is in everyone's interests that the quality of the out-flowing water from one farm is good, as this then becomes the inflowing water for the next farm (Bardócz, 2009). No farm of the flow through style was observed in the study area used in this research. An example of a flow-through system is shown in Figure 2.7.

Figure 2.7. An example of a flow-through ponds system. Source. Seafoodwatch.org

2.5.3. Recirculation Aquaculture Systems (RAS)

Recirculation Aquaculture Systems (RAS) are land-based systems in which water is re-used after mechanical and biological treatment to reduce the need for water, energy and the discharge of nutrients to the environment. These systems present several advantages, such as: water saving, a rigorous control of water quality, low environmental impacts, high biosecurity levels and an easier control of waste production as compared to other production systems. The main disadvantages are high capital costs, high operational costs, requirements for very careful management (and thus highly skilled labour forces) and difficulties in treating disease (Bardócz, 2009).

Within the study area, one farm had used this method of rearing in conjunction with the artificial concrete pond style but had abandoned it due to the high cost of power supply. In the location where it was situated, power supply was unpredictable and unreliable resulting in reliance on generators at regular intervals for pumping of water into the farm via boreholes and treating of the wastewater before recirculation. An example of a RAS farm is shown in Figure 2.8.

Figure 2.8. A Recirculation Aquaculture System. (Jenner, 2010)

The basic principles of a Recirculation Aquaculture System is shown in Figure 2.9.

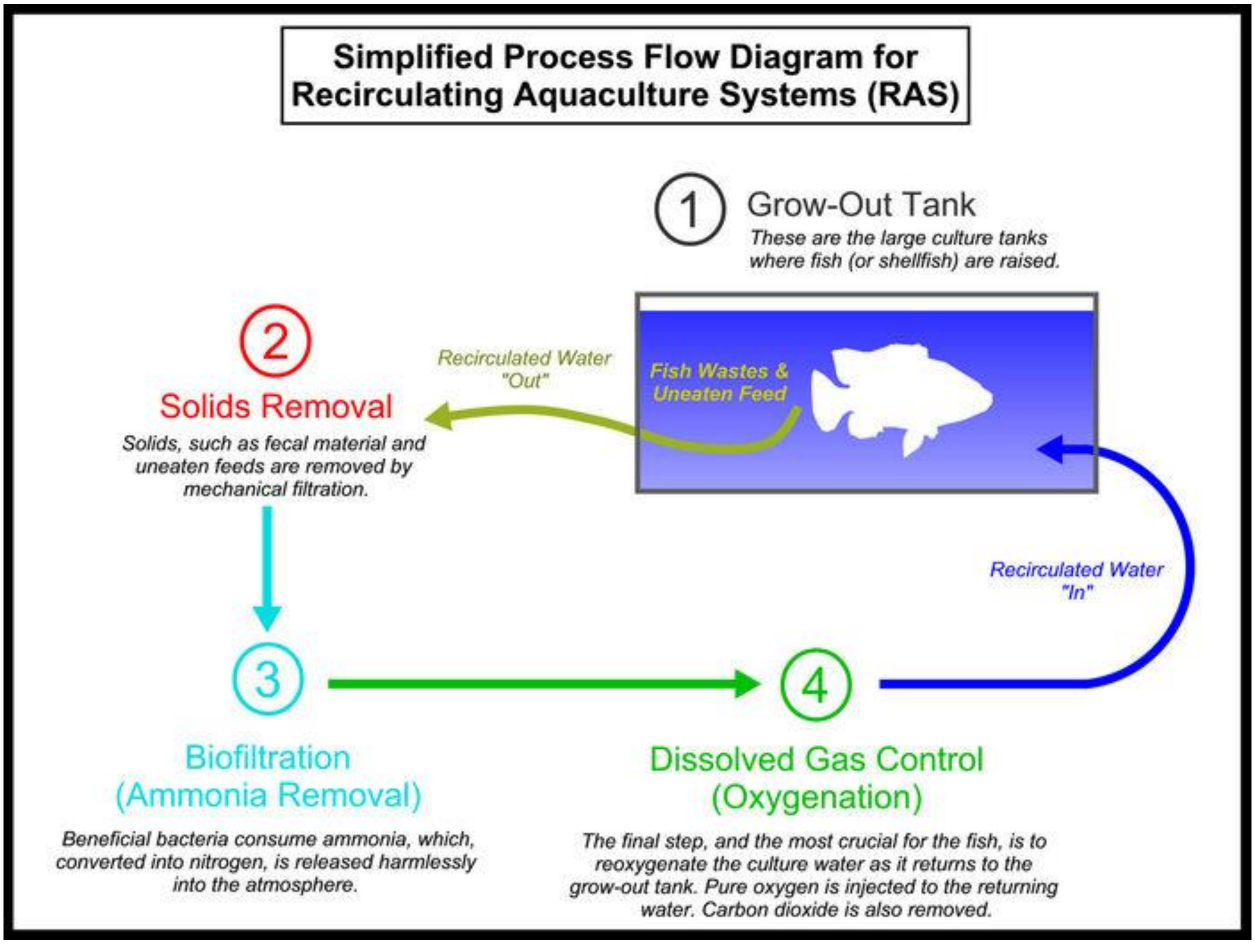


Figure 2.9. Schematic Process Flow for RAS (Source: ccresaquaponics.wordpress.com)

2.5.4. Cage Culture

Essentially, these are constructed cages enclosing the fish, normally situated in lakes and reservoirs of dammed water bodies used for power generation. Well designed and carefully managed cage cultures provide limited but important possibilities for freshwater aquaculture. In certain water bodies, extensive or intensive production of fish in cages can be in line with the sustainable use of natural resources (Bardócz, 2009). Within the study area, no farm was found using this method. This observation fits in with the report of USAID (2010) which noted that though caged farms have been researched in Nigeria since the 1990s, but no commercial fish farm has been developed around use of cages as production units, even though these have met with commercial success in Zimbabwe, Ghana and Uganda. Two different types of a cage farm are shown in Figures 2.10 and 2.11.

Figure 2.10. Caged Farm in open sea. (Financial Tribune, 2016)

Figure 2.11. Caged Farming in a marshy environment. (Source: wiredbugs.com)

2.6 Summary of the Literature

The literature review exposes the following points;

1. Untreated discharged aquaculture effluent has a negative impact on any receiving water body.
2. Developed countries are opting for treatment of aquaculture effluent with trickling filters and constructed wetland systems.
3. Less developed countries generally discharge aquaculture effluent without treatment.
4. Wood waste is mainly disposed of by burning, a method that pollutes the air.
5. Activated sawdust irrespective of the method of activation has the potential to remove heavy ions, dyes and organic pollutants.

6. The removal capacity depends on various factors such as initial concentration, retention time, temperature and activating agent.

7. There seems to be no study done on the use of sawdust as an adsorbent in aquaculture wastewater treatment.

8. The sludge generated as a result of using AS must be disposed of in an environmentally friendly manner.

9. Developing countries like Nigeria need sustainable methods of wastewater treatment that are simple to use and less dependent on the availability of power.

CHAPTER THREE

3.0 MATERIALS AND METHODOLOGY

3.1. Reconnaissance Survey

3.1.1 Current practice of Catfish Farming Effluent (CFE) disposal

Visits were made to several fish farms within Ilorin metropolis, the study area to observe cultivation methods employed and to determine frequency and method of disposal of the effluent. Ilorin is the capital city of Kwara State, one of the thirty six states of the Federal Republic of Nigeria (9.0820^{o}N, 8.6753^{o}E). Figure 3.1 shows the location of Kwara State within Nigeria.

Figure 3.1. Map of Nigeria showing the 36 states including Kwara State. (Oladeji and Sule, 2015)

Kwara State (8.9669^{o}N, 4.3874^{o}E) is divided into sixteen local government areas as shown in Figure 3.2. The catfish farms visited were within the Ilorin metropolis which is enclosed within three local government areas in Kwara State namely: Ilorin South, Ilorin West and Ilorin East

Figure 3.2. Map showing the local government areas in Kwara State. (Kayode et al, 2016)

It was also to establish if any form of treatment was given to the wastewater before discharge. This allowed an informed decision to be taken regarding site selection for effluent collection. Most farms operated a form of flow-through method of breeding.

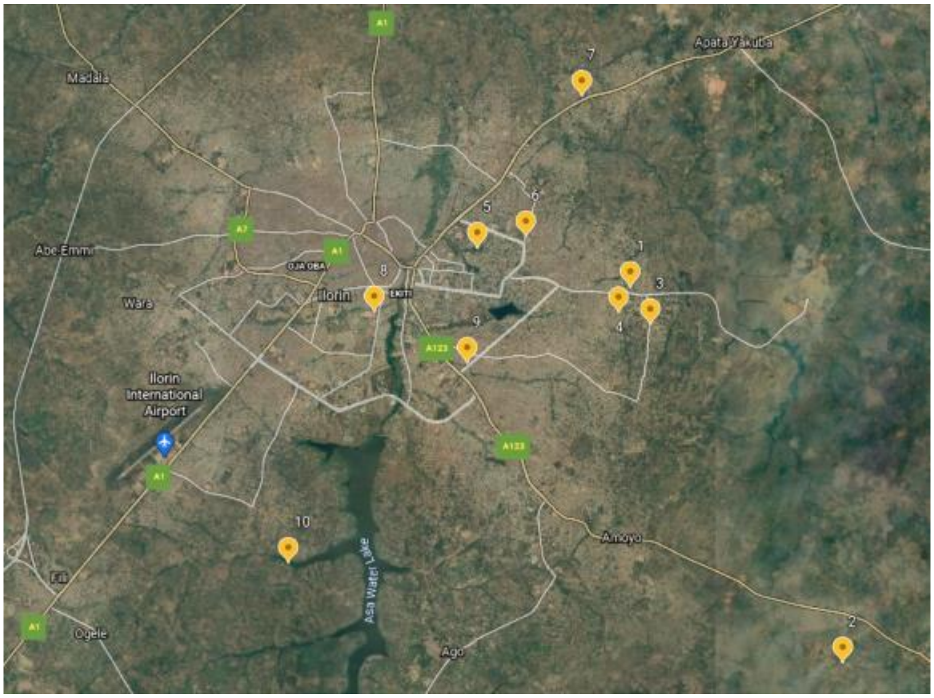


Figure 3.3. Location of Catfish farms visited within Ilorin metropolis, Kwara State, Nigeria

3.1.2. Current Sawdust Disposal Methods

Visits were also made to local timber/plank markets to observe and interact with operators to identify disposal methods used. At the sites visited, a few people were observed collecting the sawdust. Interaction with these people revealed the sawdust was utilized as floor covering in their poultries. At each timber market visited, there was the willingness to give out the sawdust at no cost as it was considered a nuisance. Apprentices were responsible for removing the accumulated residue underneath the circular saw. It is removed by piling into jute-like grain sacks as a temporary measure before it is eventually discarded onto any unused land nearby where it is burnt. Interaction with the workers revealed the ailment common to them is cough related. This points to respiratory problems as mentioned in the literature review. However, it was noticed that the workers have accepted it as a necessary occupational hazard. At the largest timber market/sawmill within the study area, it was noticed that the ground was completely covered with sawdust, suggesting a spreading out of the accumulated sawdust. This was not observed at the smaller timber markets.

3.2. Analysis of untreated CF effluent and comparison with regulatory standards.

Catfish CF effluent was collected midstream from discharge point and taken to the Laboratory for analysis within two hours. The parameters investigated were pH, BOD, COD, DO, Nitrate, Nitrites and Phosphate.

3.2.1 pH

The untreated sample's pH was measured using an electronic pH meter HI 9812-5 Portable pH/EC/TDS/^{o}C Meter, Hanna Instrument. It was calibrated using buffer solution as prescribed in its accompanying leaflet.

3.2.2. BOD

The Winkler method also known as iodometric as described in Standard Method (1995) was employed during the study for obtaining the BOD. The BOD_5 is obtained by subtracting the dissolved oxygen reading obtained after the fifth day from the initial dissolved oxygen obtained at the onset.

3.2.3. COD

COD tests were done using a benchtop Spectrophotometer.

3.2.4. Total Dissolved Solids (TDS)

Some standards refer to Total Dissolved Solids while others refer to Total Suspended Solids. They are not the same but supplement each other. Hanna HI 98136 was used.

3.2.5. Nutrients

Nitrite, Nitrate and Phosphate ions which are commonly referred to as Nutrients were tested according to Standard Methods for the Examination of Water and Wastewater

3.3. Conversion of sawdust into synthetic activated carbon.

Sawdust was collected and taken to the soil laboratory within the Faculty of Engineering and Technology at the University of Ilorin for sieving and washing before impregnation with acid. Materials and equipment used are given in Table 3.1

Table 3.1 Materials and equipment used for activation

Equipment	Reagents	Miscellaneous
Sieves Electronic weighing scale Laboratory Oven Electric kettle Muffle furnace pH meter Thermometer	Potable water Distilled water Ortho-phosphoric acid (H_3PO_4) – (2.5litre bottle produced by BDH Laboratory Supplies, Poole, England was purchased for activation purpose).	Sawdust - (*Isoberlina doka* specie and blind mix) Sacks for collection Measuring cylinder Steel containers Sampling glass containers

3.3.1. Ortho-Phosphoric acid as the activating agent.

The choice of Ortho-phosphoric acid (H_3PO_4) was influenced by literature review. Ortho-phosphoric acid and Zinc Chloride ($ZnCl_2$) are used for lignocellulosic material which has not been previously carbonized while metal compounds such as Potassium Hydroxide (KOH) are used for activation of coal precursors or chars. H_3PO_4 is however preferred to $ZnCl_2$ due to the environmental disadvantages associated with $ZnCl_2$ (Yakout and El-Deen,2011; Hernandez-Montoya *et al*, 2012)

3.3.2. Method for activation in the absence of Nitrogen gas

Two different types of sawdust were collected;

1. Unadulterated *Isoberlinadoka* (baho) – this was achieved by placing a container beneath the circular saw at the timber market to ensure purity
2. The mixed specie which was obtained by thoroughly mixing the sawdust waste in situ at the timber market.

The samples were brought to the soil laboratory of the Faculty of Engineering and Technology, University of Ilorin. Sawdust was sieved through 0.5mm sieve and rinsed with potable water to remove any impurities; it was dried in the laboratory oven at $100^{o}C$ overnight.

Using the electronic scale, an empty steel container was weighed. Its weight was noted, after which sawdust was put in and similarly weighed. The concentrated acid was poured in, using a ratio of 50ml to 100g of sawdust (Pandharipande *et al*, 2012). The mixture was left to stand for one hour at room temperature to allow impregnation by the acid. It was then put into a furnace which had being preheated to $150^{o}C$. It was held at this temperature for one hour, after which the temperature was increased to $450^{o}C$ and held for two hours.

The now activated sawdust - AS (activated 'babo' sawdust) and AMS (activated mixed sawdust) were allowed to cool down to a temperature where it could be handled safely. They were rinsed with slightly warm distilled water several times to remove traces of acid. The rinsing was sustained till the effluent had a pH of minimum of 6.8 and maximum of 7.0. ABS and AMS were then placed in the laboratory oven to allow drying at 120^0C overnight. Once dried, they were kept in an air-tight container pending use. Samples of the plain sawdust and activated sawdust were analyzed using Scanning Electron Microscopy Instrument at Kwara State University's Materials Laboratory, Malete, Kwara State. This is shown in Figure 3.4.

Figure 3.4. SEM at Kwara State University, Malete, Nigeria

The pore size, surface area and volume of the activated sawdust were determined at The Ahmadu Bello University, Zaria, Nigeria using Quantachrome NovaWin Instrument.

3.3.3 Sieve analysis of activated sawdust

Sieve analysis was done for some of the AS produced and the commercially available activated carbon. Comparison was made to determine if there were similarities.

3.3.4. Activation of sawdust in the presence of Nitrogen gas.

The sawdust samples were impregnated with different concentrations of acid; 2M and 4M, subjected to two different activation periods; 1hour and 2 hours using two different temperatures of 350^{o}C and 450^{o}C .

A tabular presentation of the experimental design is given in Table 3.2

Table 3.2 Experimental design of Sawdust Activation

BABO / MIXED SPECIE							
Molarity of Acid							
4M				**2M**			
Time in Furnace							
1HOUR		2HOUR		1HOUR		2HOUR	
Temp in Furnace							
350^{o}C	450^{o}C	350^{o}C	450^{o}C	350^{o}C	450^{o}C	350^{o}C	450^{o}C

A calculated volume of acid based on the molarity been used was poured into a flat bottom flask and distilled water added until the 1litre mark was reached. The acidic solution was used to mix the sawdust species using a ratio 1:1.2 (Pandharipande et al, 2012). Once thoroughly mixed, the mixture was left in situ for the required impregnation time. At the completion of the impregnation time, some of the mixture was weighed and then put into a glass reactor, shown in Figure 3.5 in preparation for activation in the furnace. Both ends were sealed with glass wool.

Figure 3.5. The glass reactor used in the furnace.

Nitrogen gas was introduced into the furnace at the rate of 500ml per min with an average heating rate of between 10^{o}C/min for activating temperature of 450^{o}C and 18^{o}C/min for an activating temperature of 350^{o}C. A schematic diagram of the experimental set up is shown in Figure 3.6

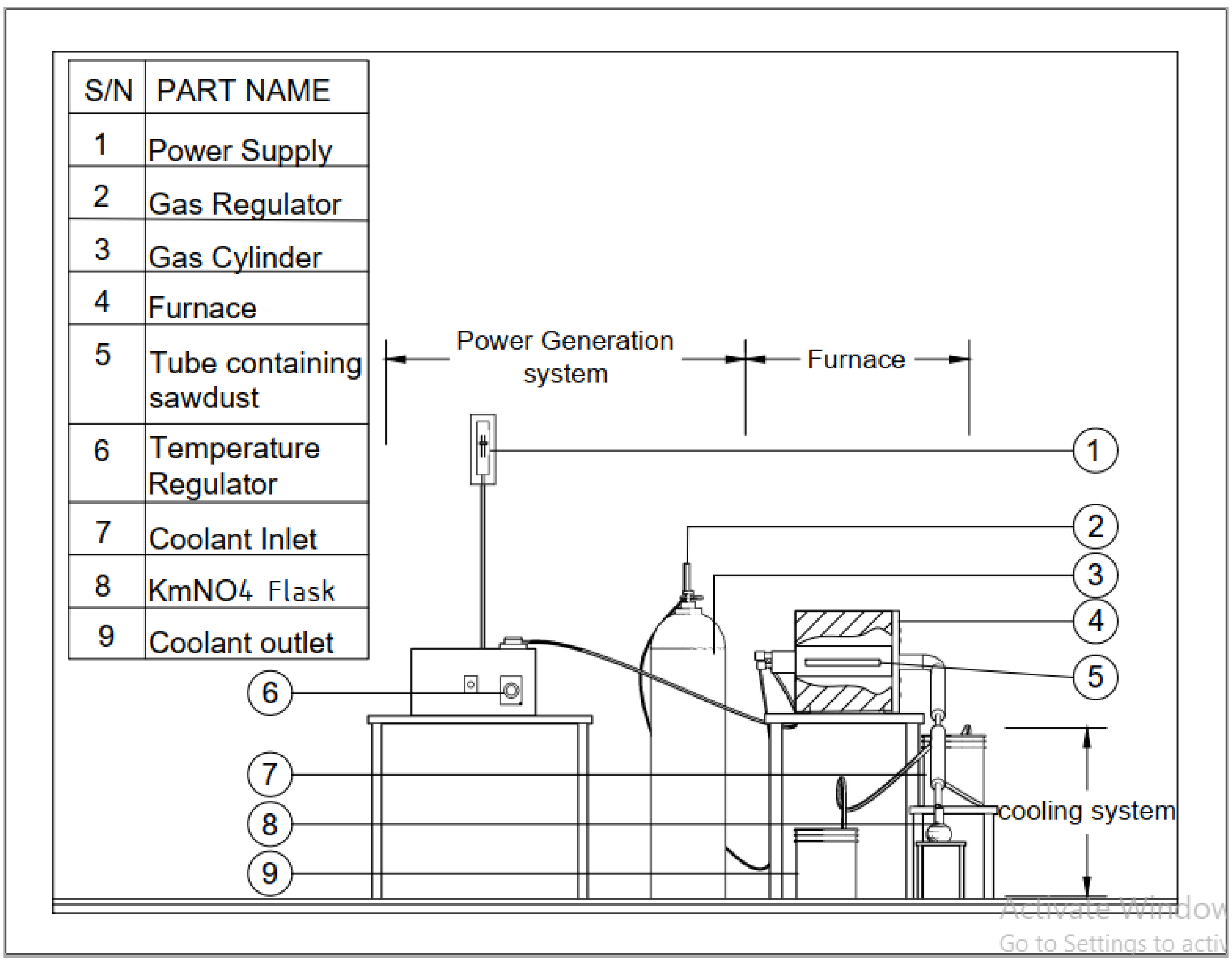


Figure 3.6. The Experimental Set Up for Sawdust Activation

3.4 Determination of retention time used for analysis.

Catfish farm (CF) wastewater was collected from the National Centre for Agriculture Mechanization, (NCAM), Idofian, Kwara State.

At NCAM and all the other concrete pond farms visited, water for the ponds was obtained from bore holes dug within the premises. The concrete ponds were square in shape with dimensions of 0.5m breath, length and width. The tanks were filled with water allowing a freeboard of 0.1m. The water is changed every two or three days. When the water is to be discharged, a pipe with a diameter of 70mm and length of about 1metre which has well-spaced holes of 20mm on its surface area is inserted in a previously blocked drain. The holes on the pipe are to stop the escape of fish into the effluent being discharged. Sometimes the fishes are left in the tank while it is being drained and other times, they are transferred into another tank. The transfer to another tank often occurs when there is a need to clean the tank. If the fishes are left in the tank, it is refilled immediately to avoid getting the fishes distressed.

The wastewater sample was collected in containers that had been washed and rinsed with distilled water. Equal weight of activated sawdust was put into four glass containers and the same volume of 100ml of wastewater was added into these containers subjected to different retention times.

The retention times investigated were 2hrs, 4hrs, 24hrs, and 48hrs. At the end of each retention period, the physic-chemical parameters were analyzed. Parameters investigated were pH, suspended solids, dissolved oxygen, BOD_5 and COD. As a means of determining the effect of the different retention times, the values of these parameters before treatment with activated sawdust (AS) were obtained by subjecting CF wastewater without any adsorbent to the same analysis. This was the control.

100ml of CF wastewater was poured into glass containers containing different weights of AS; 2g, 4g, 5g and 10g. Each weight was put in four different containers to investigate the effect of retention time: 2hrs, 4hrs, 24hrs, and 48hrs. At the end of the designated retention time, the five physic-chemical ambient water quality criteria for surface water were investigated.

3.5. Isotherm Investigations.

Isotherms are equilibrium relationships used to determine the adsorption capability of an adsorbent.

0.25 g of the activated sawdust was placed in each of eleven dry and clean glass jars, duly labelled. A 100 ml mixture of wastewater and distilled water was poured into each jar, with the mixture being of composition given in Table 3.2. The varying volume of wastewater was done to determine the optimum concentration which would give the best adsorption.

Table 3.2. Composition of wastewater and distilled water used in Isotherm Investigation.

Specimen No.	1	2	3	4	5	6	7	8	9	10	11	12
Vol. of WW (ml)	100	90	80	70	60	50	40	30	20	10	0	100
Vol. of distilled water (ml)	0	10	20	30	40	50	60	70	80	90	100	0
Total vol. (ml)	100	100	100	100	100	100	100	100	100	100	100	100
Weight of AS (g)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	

The concentration of nitrate in each sample was noted and the samples were left in-situ for 11 days after which concentrations were noted again.

3.6. Investigation into possibility of Nitrifying Bacteria affecting BOD.

This was done by setting up the experiment for BOD and obtaining the residual oxygen beyond the conventional five days. According to Metcalf and Eddy/Aecom Inc (2014a), it takes 6 to 10 days for nitrifying bacteria to reach a significant number to be able to exert measurable oxygen demand and if nitrifying bacteria is present from the onset, the interference caused can be significant. The analysis was done over eleven days and the BOD curve obtained.

3.7. Disposal of Sludge through use in plant growth.

The use of AS to treat aquaculture will result in the production of sludge. In order to avoid creating another environmental problem while trying to solve the problems of sawdust disposal and aquaculture wastewater, there is a need to consider possible ways of managing the sludge generated. Some of the nutrients required by plants are nitrogen and phosphorous. They are generally obtained from soils (White and Brown, 2010). In conventional WWTP, bio-solids are obtained from sludge which has been treated in accordance with regulatory requirements. Bio-solids are nutrient-rich organic materials. They are applied as fertilizer to improve and maintain productive soils and stimulate plant growth (EPA, n.d.)

This study investigated the possibility of using the spent AS in horticulture. It would be expected that if the AS adsorbed the pollutants such as phosphorus and nitrogenous compounds, these could be transferred into soils used in horticulture and agriculture.

The residual sludge was collected and weighed. Two identical containers were labelled A and B. Enough soil required for planting an ornamental plant was obtained. The same weight of soil was put into each container. In the container labelled A, the equivalent weight of the residual sludge was carefully removed from the soil and replaced with the residual sludge and mixed thoroughly. This was to find out the effect of the sludge on the growth of the plant since the pollutants which are expected to be majorly nutrients from the wastewater should have been captured in the sludge. The second container labelled B was left untouched. Identical seedlings of Euphorbia *milii* was planted into the two containers. The choice of the plant was purely based on the ease of which growth can be assessed. This is shown in Figure 3.5

Figure 3.7. Seedlings used for sludge use investigation.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Current Practice of Catfish Farming Effluent Disposal.

During the reconnaissance survey to determine where to obtain the effluent to be utilised for the study, ten farms were visited. Their locations are shown in Figure 4.1.

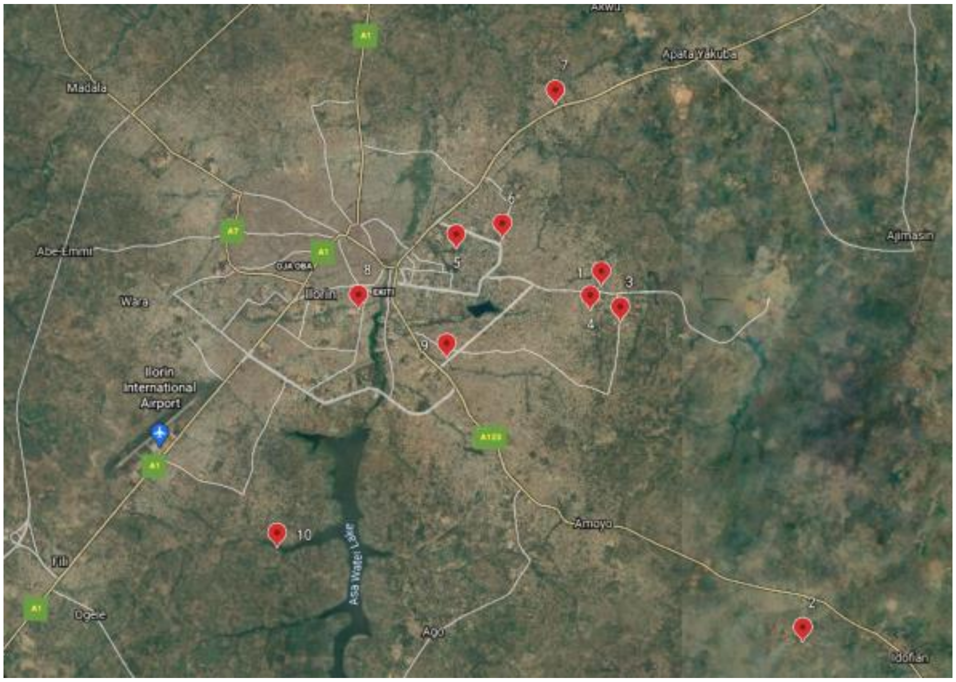


Figure 4.1 Location of catfish farms visited within Ilorin, Kwara State, Nigeria

Three types of ponds were observed in the farms visited; concrete tanks, plastic tanks and earthen ponds. Table 4.1 gives the type of the pond present at each farm, location and discharge method.

Table 4.1. Location of farms visited, types and discharge method

No	Location	Estimated Coordinates	Type of Ponds utilized	Discharge method
1	Almost opposite Winners Chapel, Oke-Odo (near Chapel Secondary School Junction), Ilorin South LGA	8.481787, 4.623856	Concrete	Into nearby drains
2	National Centre for Agricultural Mechanization, JimbaOja, Ilorin South LGA	8.379245,4.68247	Concrete	Discharged into plot of land used for cultivation
3	OkeOdo. Jalala, Ilorin South LGA	8.471524, 4.629363	Black Plastic tanks	Discharged into plant bed
4	MFM Area, Tanke, Ilorin South LGA	8.474816, 4.620613	Concrete Tanks	Discharged into a seasonal stream (8.473611, 4.62222) which is a tributary of River Oyun
5	Flower Gardens' area, Ilorin West LGA	8.492470,4.581542	Both Concrete and earthen ponds	Earthen pond is located within close proximity of Alalubosa river and the concrete ponds discharge into drains which flow into the Alalubosa river.
6	Behind Kwara State Ministry of Health area. Fate/ Basin, Ilorin West LGA,	8.495547,4.594995	Concrete Ponds	Abandoned recirculation, discharge into vegetable bed and drains
7	Off Jebba Road, Oke-Ose area around the Covent just after the bridge, Ilorin East LGA	8.53378,4.60905	No longer producing at time of visit (one of the ones we visited)	In close proximity to Oyun River (8.52746,4.60118)
8	Kwara State Fisheries, Behind Tuyil Industries, Ilorin East LGA	8.475045,4.553013	Plastic and concrete	Into drains which flow into nearby Odo Okun stream
9	Gaa-Akanbi/pipeline Area, Ilorin South LGA	8.461012,4.578746	Earthen ponds	In the proximity of Yalu, a seasonal stream (8.460885,4.577964)
10	Off Egbejila Road, Ilorin West LGA	8.406334, 4.529312	Earthen ponds	Discharges into Asa lake

It should be noted that the where plastic and concrete types were utilised in combination, the plastic tank was used for breeding the fingerlings. This is shown in Figure 4.2. Once the fingerlings were grown out, they were transferred into concrete tanks.

Figure 4.2. Catfish fingerlings in a plastic container.

The effluent disposal method for both concrete and plastic ponds was predominantly draining into nearby channels as done by five of the farms visited. Three farms diverted the effluent for irrigation purposes. A farm had tried recirculation of its effluent, but the lack of constant and reliable power supply meant it had to rely on generating its own power which did not prove cost effective, consequently the practice was abandoned. One of the farms which used its effluent discharge for irrigation is the National Centre for Agricultural Mechanization, Ilorin. The discharge is channeled into a well laid out portion of land on which Chinese Water Green is cultivated for fodder. The discharged effluent flows undulating losing some solids as it moves, then over a raised section into a second chamber where it drains into a water hyacinth pond. The farm manger advised research was ongoing to establish the efficacy of water hyacinth in the removal of pollutants in the effluent. . Time will tell if this will be akin to Dar et al, (2011) in which water hyacinth was used to treat municipal domestic wastewater, as water hyacinth in itself could be an environmental problem if not properly managed. Figure 4.3 shows the effluent discharge pipes (circled for easy identification) from the fish tanks. There is a wall separating the fishpond area from the cultivation and irrigation area. Figure 4.4 shows the discharge pipe on the other side of the wall. Figure 4.5 shows the drain through which the untreated effluent flows. Figure 4.6 shows a section of the water hyacinth plot.

Figure 4.3. Effluent discharge pipes from the catfish tanks.

Figure 4.4. Outflow area leading to Hyacinth pond (circled and numbered).

Figure 4. 5. Flow of discharge towards Hyacinth Pond.

Figure 4.6. Chinese Water Green and Water Hyacinth.

4.2. Quality of Untreated Effluent

The quality of untreated effluent was determined by investigating the following parameters; pH, BOD, TSS, Phosphates, Nitrites, Nitrates and COD. Wastewater is dynamic in nature and it can neither be expected that samples from any pond will be constant in quantity of parameters nor be the same with another pond. Table 4.2. gives values of parameters investigated at the ponds prior to treatment and compared to some effluent standards. The key feature of a water body from a discharge perspective is its assimilative capacity i.e., maximum amount of pollution that can be diluted or degraded without affecting preliminary defined designated best uses (Schellenberg *et al*, 2020). Comparing standards in Table 4.2, it can be observed that Nigeria's limits are considerably higher despite the fact that technological solutions to attain these could be cost intensive. Globally, countries generally set effluent standards for discharge based on the protected use of the discharge. Often, limits for parameters might be set at a minimum or maximum depending on the consequences of the pollutant on the expected destination of the wastewater, treated or not. As in the case of Nigeria, there are two sets of standards; one for effluent discharges and reuse and another set for Fisheries and recreation. The standards for fisheries and recreation being more stringent due to the likelihood of human consumption of fisheries and skin contact with the effluent discharge. the stringent limits could be in place to curb de-oxygenated dead zones in receiving water bodies. It was observed that TSS and Phosphates were the only parameters whereby the values obtained were within the accepted limits for effluent discharge. Parameters which did not satisfy the requirement for discharge were: Nitrite, Nitrate, BOD and COD. This confirms the notion that aquaculture effluent can be harmful to the environment if discharged without treatment. The population of fishes in a pond will be proportional to the amount of waste generated. It can be expected that both organic and inorganic pollutants would increase for the same volume of water used for breeding if the population of fishes increase, similarly the sizes of the fishes would have an impact. Waste material generated by fingerlings would be smaller than that of the same number of matured fishes. Another factor that could be responsible for the high values could be the constituents of the feed given to the fishes. The population size in each pond was not considered in the study.

Table 4.2. Untreated Effluent Parameters with some discharge standards.

Parameter & Unit	TDS (mg/l)	TSS (mg/l)	Phosphates(mg/l)	Nitrate(mg/l)	DO(mg/l)	Nitrite(mg/l)	BOD (mg/l)	COD(mg/l)
Nigeria		0.75	3.5	40.0	Minimum (4.0)	0.08	6.0	30.0
Ghana[1]		50	N/A	N/A		N/A	50.0	250.0
Japan[2]		200	120	N/A		N/A	160	160
Pond 1	215	0.019	0.018	66.00	3.00	0.41	39.0	88
Pond 2	210	0.01	0.021	81.65	5.80	0.37	30.0	61
Pond 3	195	0.05	0.014	54.70	5.70	0.08	19.5	72
Pond 4	100	0.703	0.09	16.90	5.00	0.14	36.7	70
Pond 5	110	0.713	0.099	34.30	4.35	0.08	29.6	32
Pond 6	130	0.717	0.002	25.60	3.75	0.08	24.8	17
Pond 7	50	0.714	0.064	22.30	3.35	0.09	13.6	59
Pond 8	120	0.707	0.065	78.10	3.85	0.05	20.0	46

[1] Agodzo *et al*, 2003

[2]MoE- Japan, 2015

4.3. Current Disposal Method of Sawdust within the study area.

The National Environment (Sanitation and Wastes Control) regulations 2009 stipulates that any person who owns or controls a facility or premises which generates waste shall reduce, re-use and recycle waste, to minimize pollution by adopting the following:

a. imbibe cleaner production principles to conserve raw materials and energy;
b. segregate wastes at source;
c. undertake resource recovery, re-use and recycling;
d. ensure safe disposal

Unfortunately, these processes are not in place at sawmills or timber markets visited. Cutting of timber into required sizes was done 5-6 days of the week but wastes generated were left in situ till they began to interfere with production. At such instance, the sawdust is collected into sacks. This is shown in Figure 4.7. Eventually, these are taken outside the premises to an unused land where it is burnt. This is shown in Figure 4.8. If a section of the land being used is saturated, another part is used. From discussions with the timber merchant, at any point, if the land is to be used, a search is made for another piece of land. This is common with timber markets in less developed residential areas. Frequently, people from the community come along to ask for some of the sawdust and chips. In addition, because the collection of the sawdust is not systematic, over the years the ground of the premises has been covered by sawdust. At the largest sawmill in the study area, which is quite close to a stream, sawdust has not only covered the ground but could be seen at the bank of the stream.

Figure 4.7. Sacks of sawdust and chips ready for disposal.

Figure 4.8. Sawdust being burnt on a part of an unoccupied land

4.5. **Conversion of Sawdust to Synthetic Activated Carbon**

A major factor important in the use of activated sawdust as an alternative to activated carbon is its lignocellulosic nature. The constituents of the heterogeneous mix before and after activation were obtained using ultimate analysis and these were compared with the constituents of the commercially available activated carbon. The analysis shows that sawdust is comparable in constituents with commercial AC. The results are given in Table 4.3.

Table 4.3. Ultimate Analysis Results

Constituents	Commercial AC	Blind Mix Sawdust	Activated Blind Mix Sawdust
Carbon Content %	46.40	48.55	44.35
Oxygen	30.50	10.60	40.40
Nitrogen Content	0.60	0.10	0.20
Sulphur Content	0.12	0.15	0.10
Hydrogen Content	5.90	5.50	5.20
Ash Content	2.36	2.58	2.27
Moisture Content	5.88	8.32	6.29

Factors considered in the production of the activated carbon were concentration of impregnating acid, temperature and duration of the pyrolysis.

The first batch of AS produced was done using Babo activated without diluting the acid at a ratio of sawdust to acid of 1.2:1 in a muffle furnace. The impregnation period was for 1hour while activation was done at 450^{o}C. The yield of activated sawdust obtained can be calculated as:

$$\frac{B}{A}\ x\ 100\% \qquad 4.1$$

Where A = Weight of sawdust before impregnation and pyrolysis = 0.732kg

B = Weight of sawdust after impregnation and washing off acid = 0.350kg

% Yield is given by: $\frac{0.350}{0.732}\ X\ 100\%\quad = \quad 47.8\%$

Subsequent batches were produced by varying the molarity of the activating acid, temperature of the reactor and the duration in the reactor. The % yield of AS is shown in Table 4.4.

The mean value of the yield is 42.92% with a standard deviation of 0.28. With 2M activating acid, higher yield was obtained at a temperature of 350^{o}C after 1hour. With the 4M activating acid, the highest yield was obtained at 350^{o}C but after 2hours activating period. There is the possibility that the more concentrated the acid, the sawdust pyrolyzed faster and there is conversion into gases. In addition, the longer the sawdust is in the reactor and higher the temperature, the lower the yield. This can be attributed to the fact that more of gases are produced in such circumstances, (Zafar, 2009). At higher temperatures, more pores are likely developed. It was observed during the study that the longer period of 2hour activation resulted in the laboratory having stronger smell of gas. This was addressed by attaching a pipe from the cooling section of the setup into a flask of potassium permanganate solution. The longer period of activation and higher temperature, however gives a lower yield of synthesized activated as can be seen in Table 4.4. Some AS is lost in the process of rinsing off the activating acid; if there was a foolproof way of rinsing off the acid, the yield could be considerably higher.

Table 4.4 Yield of Activated Sawdust

	Molarity	Time	Temp. °C	Initial Weight g	Final Weight g	Yield %
BABO	2M	1HOUR	350°C	42.83	20.96	48.93
			450°C	43.78	20.08	45.86
		2HOUR	450°C	20.80	6.99	33.60
	4M	1HOUR	450°C	43.78	17.72	40.47
BLIND MIX	2M	1HOUR	350°C	33.15	19.49	58.79
			450°C	15.28	3.628	23.74
		2HOUR	450°C	21.55	6.99	32.43
	4M	1HOUR	350°C	20.61	7.92	38.42
			450°C	17.53	8.46	48.26
		2HOUR	350°C	47.60	28.04	58.90
			450°C	20.33	8.69	42.74

4.5.1 Physical analysis of Activated Sawdust

The pores of both inactivated sawdust and AS were analyzed using the Aspex Explorer Scanning Electron Microscope which was shown earlier in Figure 3.2. The general classification of pores is given in Table 4.5

Table 4.5 Classification of Pores

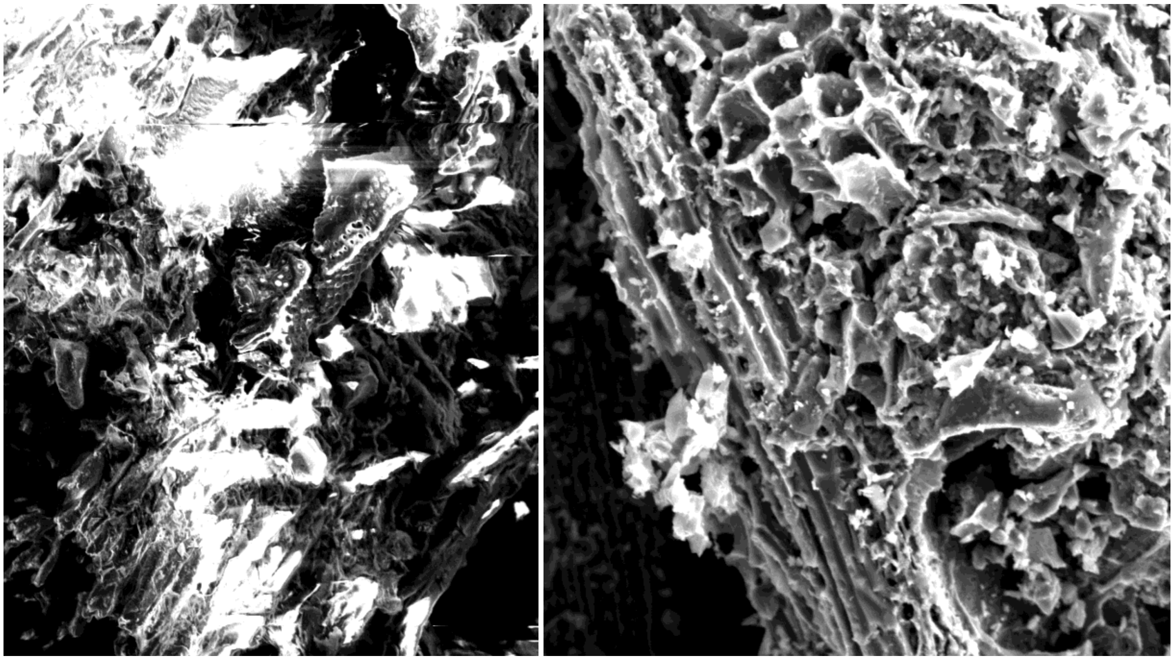
Type of Pore width/diameter (d)	Source of Classification		
	IUPAC [1]	Metcalf & Eddy /Aecom [2]	Dubnin[1]
Micropores	< 2nm	<20nm	< 3nm
Mesopores	>2nm and < 50nm	>20nm and < 500nm	200>d>3
Macropores	>50nm	>500nm	>200

[1] Zdravkov et al, 2007, [2] Metcalf & Eddy/Aecom, 2014b

The pore size and volume of a sample of activated Isoberlina *doka* (BB) sawdust, activated heterogeneous mix (BM) and the commercially available activated carbon were determined using scanning electron microscopy with the following isotherms/methods: Brunauer-Emmet-Teller (BET), Langmuir, Dubnin-Radukevich (DR), DA (Dubnin-Astakov) and DFT (Density Functional Theory). Pores formed during activation process can be classified based on their widths, surface area or volume. Table 4.6 shows an extract from the results obtained. Irrespective of the method used, pore width obtained was less than 20nm. This is ideal for adsorption; It is believed that micropores provide the bulk of the surface involved in adsorption while mesopores allow for adsorption of larger molecules which are not adsorbed by the micropores (Achaw, 2012). The complete results for Samples BB, BM and commercially available AC are given in Appendix. II. Figure 4.6 shows an Isoberlina doka sawdust sample before and after activation. It can be observed that the pores are more defined in II

Table 4.6 Extract from results of Pore Characterization

METHOD		BABO-350 2M 1HR (X)	BLIND MIX-350 2M 1HR (Y)	COMMERCIAL (Z)
BET	Ave. Pore width (nm)	5.749	5.839	6.538
	Micropore Vol. (cc/g)	0.148	0.145	0.147
	Micropore Surface Area (m^2/g)	415.155	409.14	414.984
DFT	Pore Vol (cc/g)	0.115	0.119	0.106
	Surface Area (m^2/g)	96.596	100.292	87.142
	Pore width (mode)(nm)	2.647	2.647	2.647



I   II

Figure 4.9. Babo Sawdust: I - before activation and II –after activation (500x)

4.5.2. Sieve Analysis Results

Sieve analysis was used to classify the type of activated carbon samples before and after activation. The samples were sieved through sieves and the amount of sample which passed through each sieve was noted. Graph of percentage finer than a given diameter of sieve was plotted on a logarithmic scale of the particle diameter. From the graph, the percentage finer than of 10%, 30% and 60% were noted and used in the calculation of Coefficients of Curvature and Uniformity given by Equation 4.2 and 4.3 respectively. These parameters are used to classify soils and related materials in Engineering

Coefficient of Curvature, (Cc) is given by $\frac{D_{30}^2}{D_{60} x\, D_{10}}$ 4. 2

Where D_{10} = the particle size of which 10% of the sample are finer,

D_{30} = the particle size of which 30% of the sample are finer, and

D_{60} = the particle size of which 60% of the sample are finer.

While Coefficient of Uniformity (C_u) is given by

$$\frac{D_{60}}{D_{30}} \qquad 4.3$$

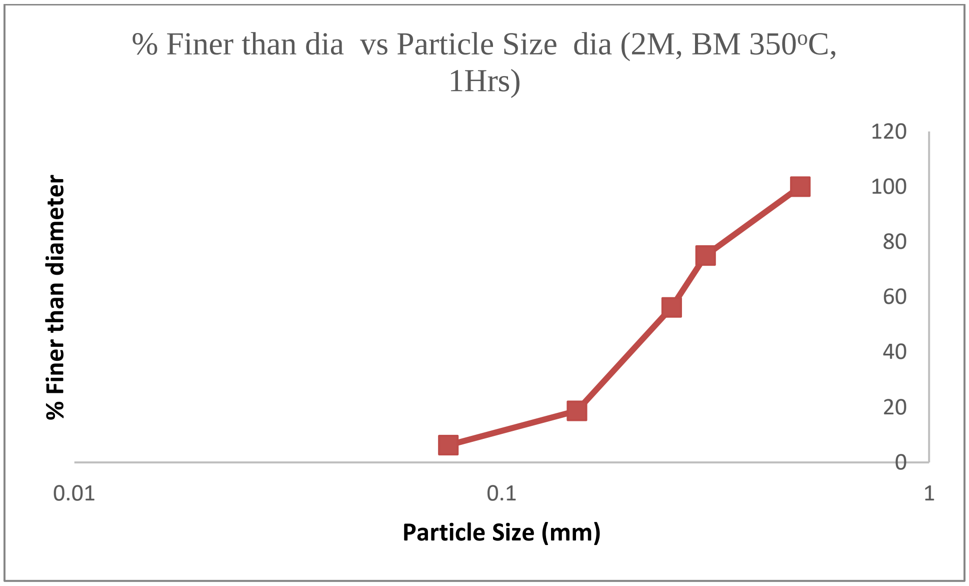


Figure 4.10 Sieve Analysis Plot

An example of the sieve analysis plot is shown in Figure 4.10. All samples had C_c values between 1 and 3, an indication of a uniformly graded material. A uniformly graded material will have lesser volume of voids. A coefficient of uniformity value less than 4 indicates a narrow particle size range. The implication of the As having values between 1 and 3 is that the adsorbate is more likely to stick to the adsorbent. More so with Cu less than 3, the differences in the sizes of the voids will be negligible. The result of the sieve analysis performed on some of the produced AS is presented in Table 4.7., while the remaining plots can be found in Appendix.

Table 4.7 Sieve Analysis Results

Sample	D_{10}	D_{30}	D_{60}	C_u	C_c
AC- Commercial	0.650	0.900	1.180	1.82	1.1
BB No N_2 450 2Hrs	0.098	0.170	0.266	2.73	1.1
BB 2M 450 1Hr	0.082	0.150	0.200	2.44	1.4
Untreated BB	0.250	0.425	0.625	2.60	1.1
BM 2M 450 2Hrs	0.090	0.150	0.212	2.36	1.2
BM 2M 350 1Hrs	0.098	0.180	0.250	2.56	1.3
BM 4M 350 2Hrs	0.090	0.250	0.300	3.33	2.3

4.6. Preliminary Investigations into Retention time and weight of adsorbent for study.

From reconnaissance survey and interactions with those at the farms visited, the ponds were generally emptied after 48hours although some farms went beyond that for reasons such as no available water due to inability to pump from borehole as a result of power outage due to electricity or employee not showing up for duty. In addition, conventional wastewater treatment plants normally design clarifiers with retention time of 48hrs.

The investigations were done to determine the effect of retention time and weight of adsorbent used on the physio-chemical parameters in the effluent wastewater. The observations are shown in Figures 4.11 to 4.15

4.6.1 pH

It can be seen from Figure 4.14 that after 2hours retention time, the pH value was outside the Nigerian limits unlike the other two countries shown where the pH value was within range. Nigerian standards might appear to be stringent to militate against difficulties in treatment of highly acidic or highly alkaline water. It should be noted that the wastewater can be brought within range by adding an appropriate alkali before discharge. Biological activity in water is usually restricted to a fairly narrow pH range of 5-8 (Tebbutt, 1998). All the various weights of adsorbent used in the treatment at the different retention times gave effluent with pH within this range.

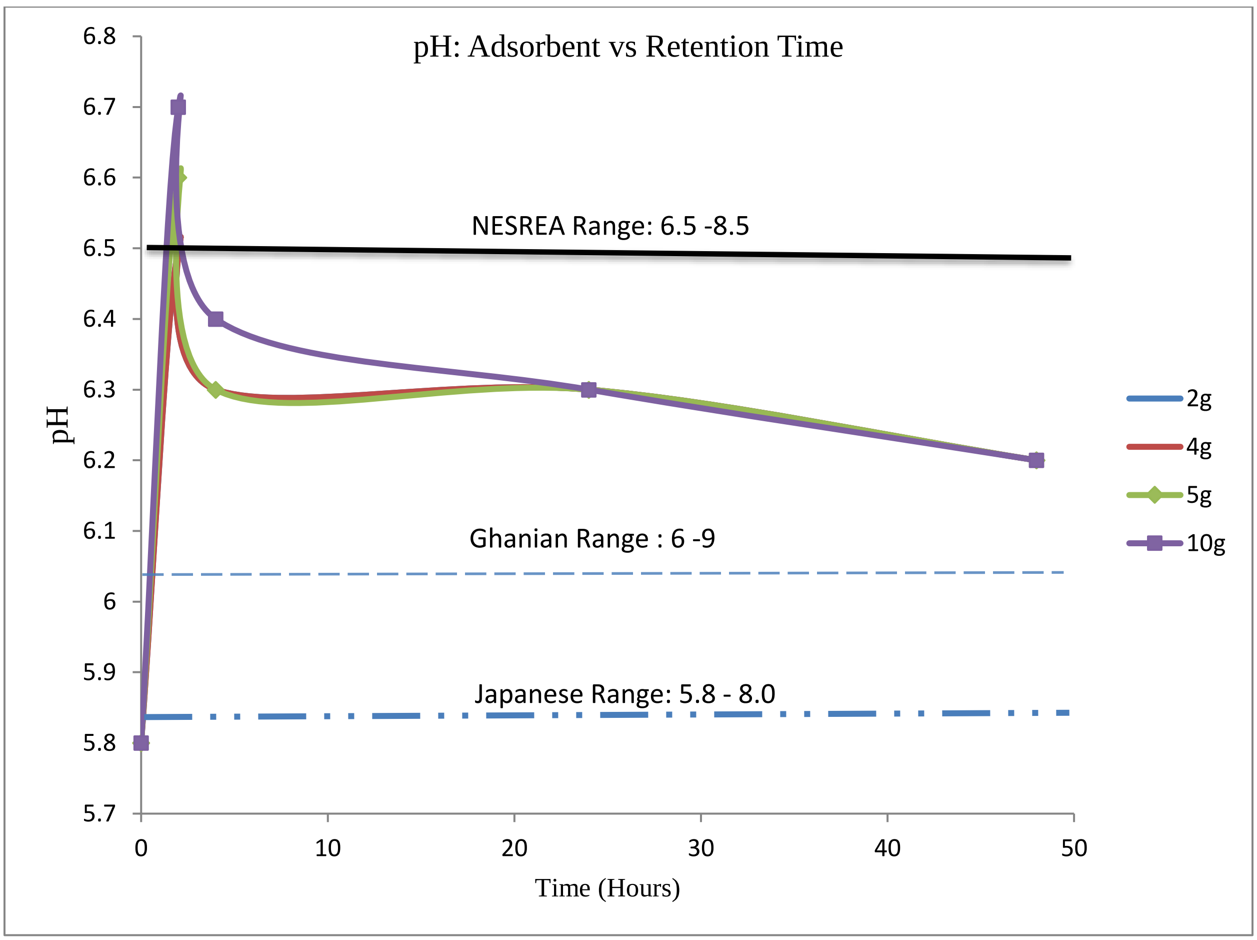


Figure 4.11. Impact of Adsorbent and Retention Time on pH.

4.6.2. TSS

The result of the analysis for TSS is given in Figure 4.15 It shows that though there was a maximum of 43% reduction after 48hours retention time, none was within the limit of 0.75 mg/l set by the NESREA. It is worth noting that other countries have limits exceeding 0.75 mg/l. Two examples are given in Table 4.15. As mentioned earlier, countries set standards based on the desired use of the effluent discharge.

Table 4.8 Some Effluent Discharge Limits

Parameter	Unit	Country			
		Nigeria		[1]Ghana	[2]Japan
		Effluent Discharges & Reuse	Fisheries & Recreation		
Temp	^{o}C			NA	NA
pH		6.5-8.5	6.5-8.5	6.0-9.0	5.8-8.0 (non-coastal), 5.0-9.0 (coastal)
DO	mg/L	Min. 4.0			
BOD	mg/L	*6.0	*3.0	50	160
COD	mg/L	*30.0	*30.0	250	160
TDS	mg/L	NA	NA	1000	NA
TSS	mg/L	0.75	0.25	50	200
NH_4^+	mg/L	2	0.05	1	NA
NO_2^-	mg/L	0.08	0.02	NA	NA
NO_3^-	mg/L	40	9.1	NA	NA
Total N	mg/L	NA	NA	NA	120
Total P	mg/L	0.025	0.025	2	120
PO_4^{3-}	mg/L	3.5	3.5		NA
* Minimum level		[1]Agodzo et al., 2003		[2]MoE- Japan,2015	

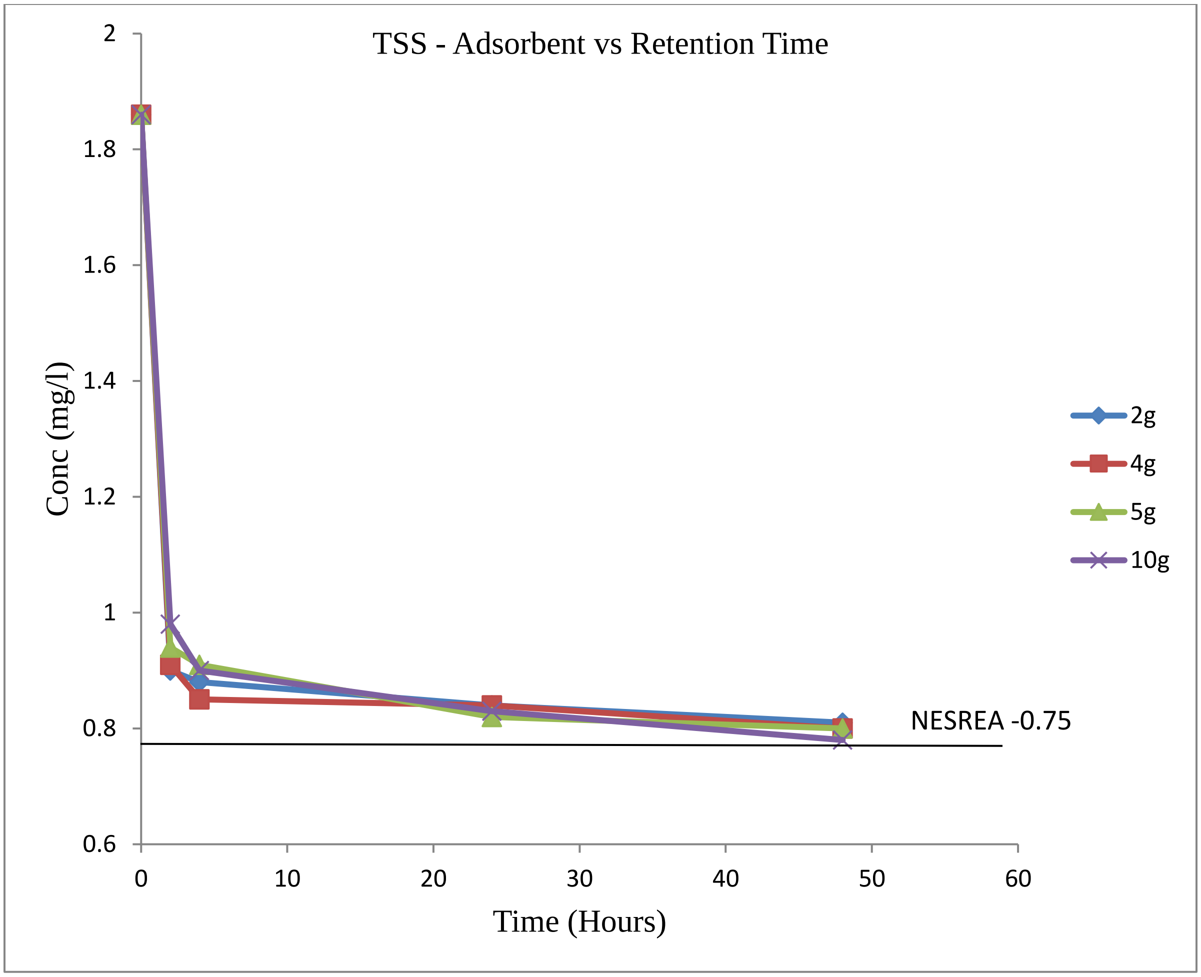


Figure 4.12 Impact of Adsorbent and Retention Time on TSS.

4.6.3. Dissolved Oxygen (DO)

DO is necessary in rivers and streams to maintain higher forms of aquatic life but as temperature of water increases, DO decreases. In addition, DO can be rapidly depleted by oxygen demand of organic wastes and consequently, a minimum limit is usually set for discharge of wastewater.

Figure 4.16 shows the change in DO with different weights of adsorbent at various retention times.

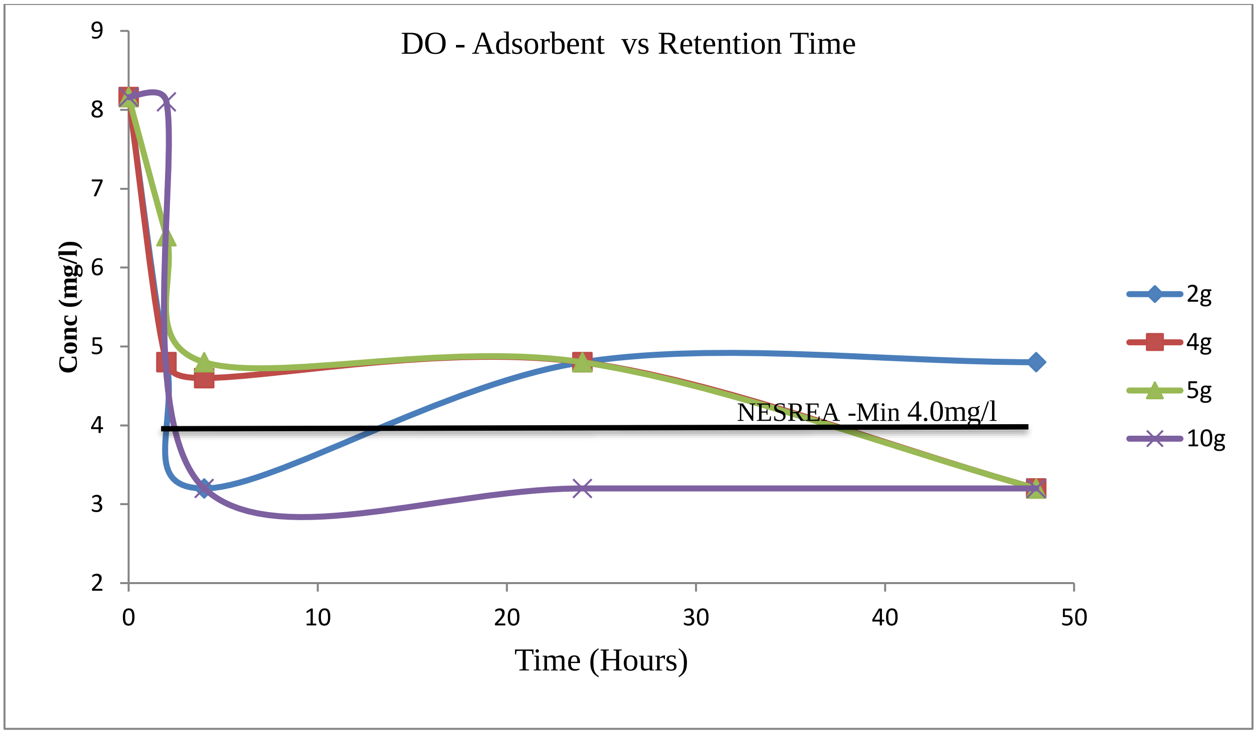


Figure 4.13 Impact of Adsorbent and Retention Time on DO

Initially, DO reduced for all the weights of adsorbent. This can be expected due to the nature of the wastewater sample. However, the reduction was followed by an increase at different rates. This is probably due to organic pollutants occupying the pores in the adsorbent. The 2g weight gave the highest level of DO. The least number of pores available would obviously be obtained with the 2g weight and all its pores would be occupied quicker than the samples with more weights. Once the pores are occupied, microbial activity will commence in the liquid above the pores resulting in a stable dissolved oxygen level, similar to self-purification in rivers.

4.6.4. Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) gives the measure of oxygen required by microorganisms to break down organic matter. A high BOD value indicates a waste high in organic content which would reduce the available DO in the water body if discharged untreated.

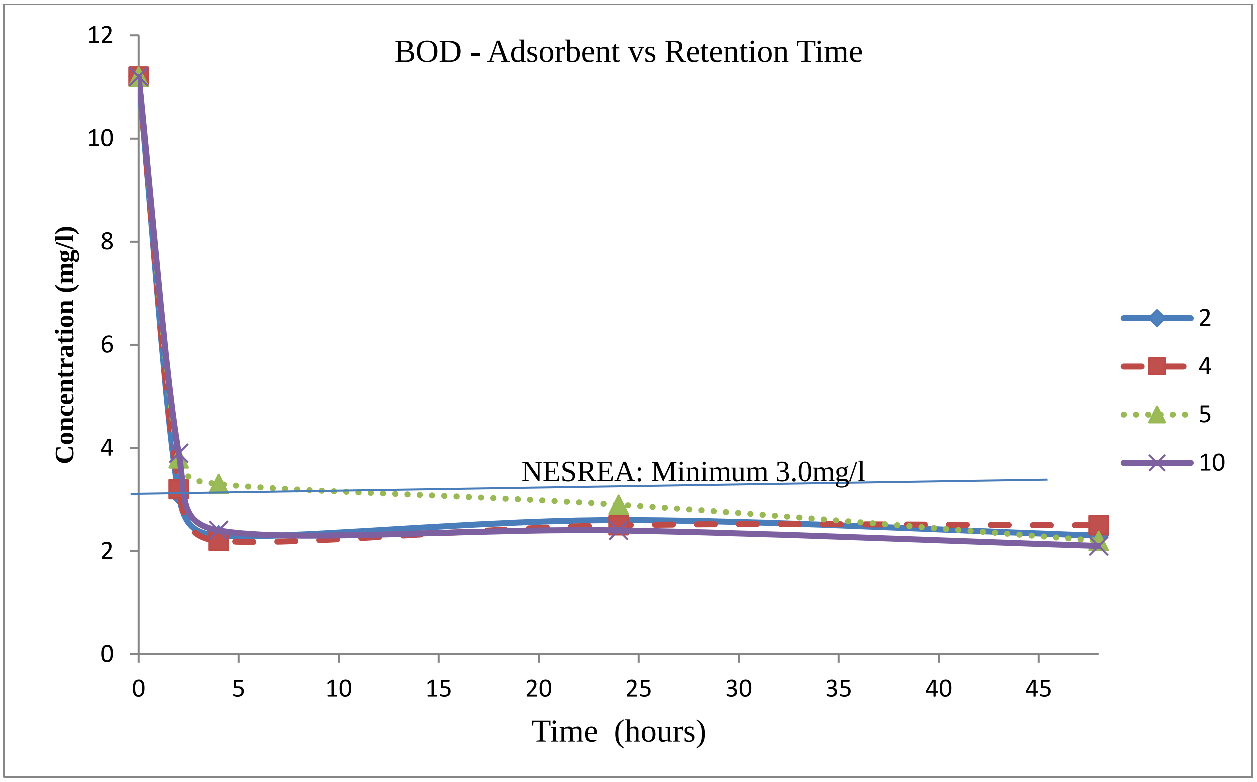


Figure 4.14 Impact of Adsorbent and Retention Time on BOD.

The effect of retention time and different weights of adsorbent can be seen in Figure 4.17. After 48hours retention time, all weights give values within the range of 2.1mg/l to 2.5mg/l which is less than 3.0 mg/l, the minimum value limit set by NESREA. This indicates that at the end of 48hours irrespective of the weight of adsorbent used, the aerobic biological decomposition is complete.

Generally, BOD limits are set at maximum permissible. It can be seen in Table 4.13, that Ghana and Japan had limits set as 50mg/l and 160mg/l. Nigeria has a BOD limit set at a minimum of 6.0 mg/l. The implication is that any wastewater with any BOD value greater than 6.0mg/l can be discharged into drains, streams and rivers. This would increase the organic load of the receiving water body with grave consequences. Higher BOD value means oxygen will be depleted rapidly, leaving a shortage of oxygen for higher form of aquatic life. Such organisms will become stressed, suffocate and die (APHA, 1992). Wastewater is not unique in the sense that if the constituents of samples from the same pond were collected over a period and analyzed, the results would not be the same. All parameters were investigated further and would be reported further on in this study.

4.6.5 Chemical Oxygen Demand (COD)

COD analysis is often done in conjunction with BOD to have an idea of the nature of the wastewater. Unlike BOD which measures the oxygen demand for organic biodegradable, COD measures the oxygen equivalent of the organic material in wastewater that can be oxidized chemically using dichromate in an acid solution (Metcalf and Eddy/Aecom, 2014). One of the advantages of COD is the ability to oxidize substances such as lignin which are difficult to oxidize biologically. For any wastewater sample, COD would always be greater than BOD; the difference depends on the type of wastewater and bacteria doing the degradation. The results of the analysis are given in Figure 4.15

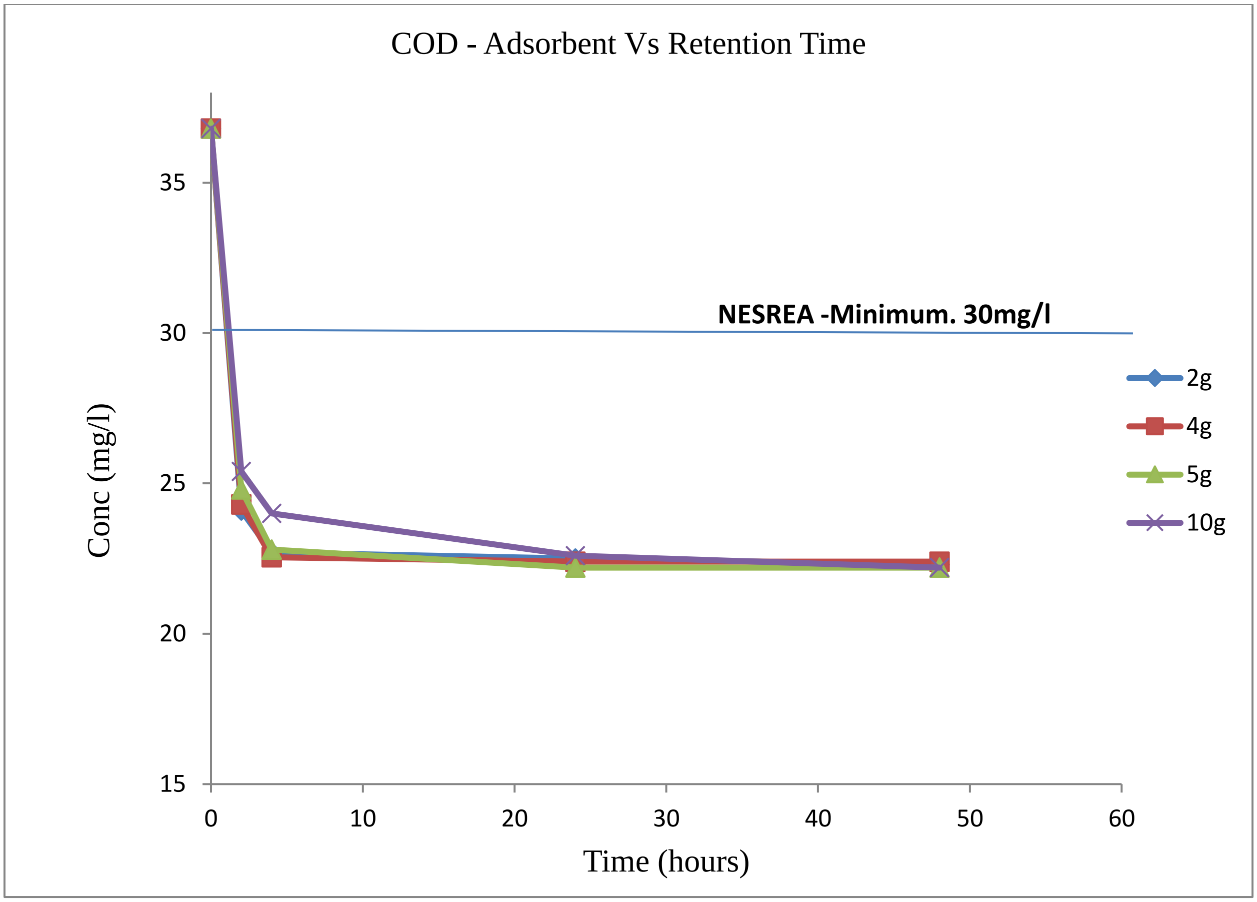


Figure 4.15 Impact of Adsorbent and Retention Time on COD.

The ratio of the BOD to COD for the raw wastewater was 0.304 and that of the activated sawdust treated effluent gave 0.10. Both values fall within the range for typical municipal wastewater as postulated by Metcalf & Eddy/Aecom (2014a). Though the ratios are within generally accepted range, the value for COD for all weights at the end of the detention period did not satisfy the minimum 30mg/l limit set by NESREA though other countries have maximum limits of 160mg/l. It is worth noting that one of the constituents of sawdust is lignin which can be oxidized chemically and there is a possibility this could affect the measure of chemical oxygen demand however oxidation of lignin is not within the scope of this study. It is worth noting that the COD analysis can be completed within a few hours unlike the BOD which takes minimum of five days. The major disadvantage with the use of COD is the lack of knowledge on rate at which biological oxidation would take place.

4.7. Adsorption Characteristics of the Activated Sawdust.

The adsorption ability of the activated sawdust was investigated using the following parameters: TDS, Nitrite, Nitrate and Phosphate.

4.7.1 Adsorption Ability for TDS

Langmuir Isotherm for TDS

The plot is based on the equation

$$\frac{C_e}{q_e} = \frac{1}{bQo} + \frac{1}{Qo}C_e \qquad 4.4$$

Where

Ce = concentration at equilibrium

q_e = adsorbate removed at equilibrium

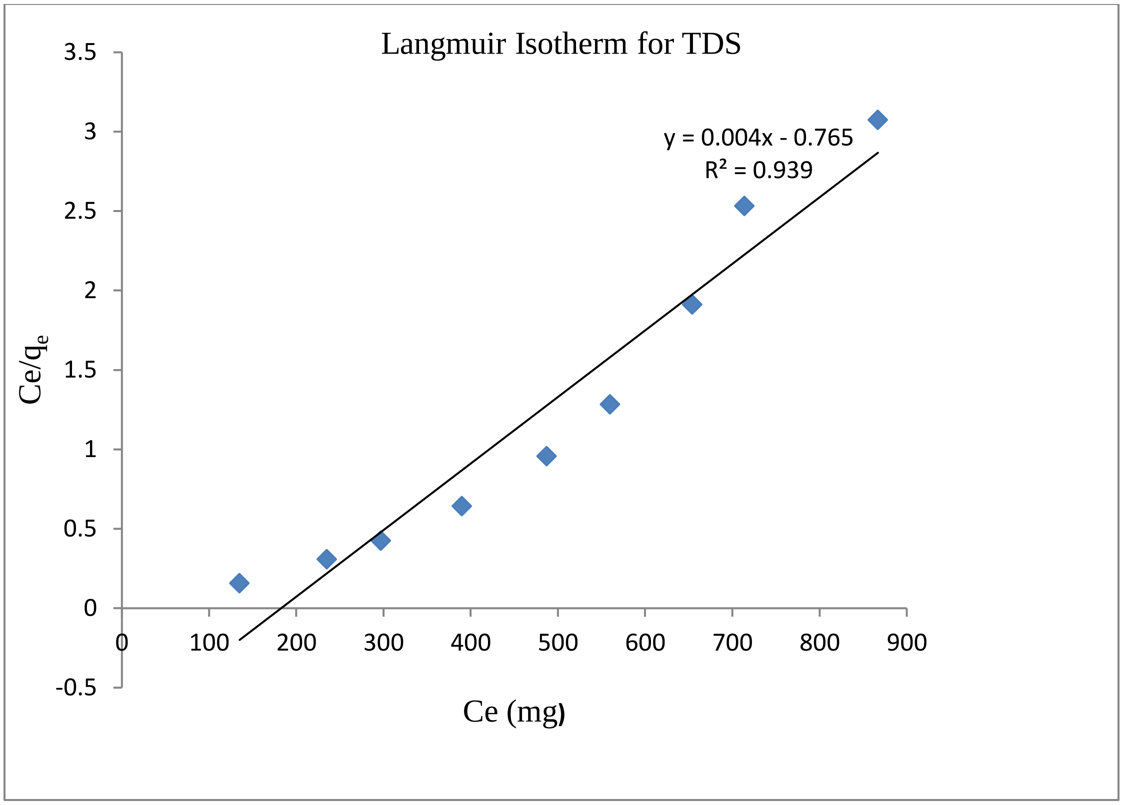


Figure 4.16 Langmuir Isotherm for TDS

Using Microsoft Excel to plot the line of best fit, the slope and the intercept can be obtained from the equation of the line given in Figure 4.16. The equation of a straight line, Y = mx + c corresponds to the equation 4.5. Therefore

$$\frac{C_e}{q_e} = \frac{1}{bQo} + \frac{1}{Qo}C_e$$

$\frac{1}{bQo}$ = c, (intercept of the plot $\frac{C_e}{q_e}$ against C_e) = - 0.765 4.5

$\frac{1}{Qo}$ = m (intercept of the plot $\frac{C_e}{q_e}$ against C_e) = 0.004 4.6

From equation 4.7, $Q_o = \frac{1}{0.004} = 250$

The value from equation 4.7 can be substituted into equation 4.6 to give

$0.004\frac{1}{b}$ = - 0.765 4.7

Therefore b = $\frac{-0.004}{0.765}$ 4.8

From equation 4.7, b has a value of 5.23 x 10^{-3}

The initial concentration of TDS was 996mg/l, the dimensionless parameter, separation factor R_L can be calculated using equation 4.9,

$$R_L = \frac{1}{1+bC0} \quad 4.9$$

Co = Initial concentration of TDS, 996 mg/l

b = constant obtained from equation 4.7

Calculation of R_L gives 1.605 x 10^{-1} which indicates a favourable adsorbent for TDS, Mamdouth et al (2004); Saswati and Ghosh (2005). This is further confirmed with the R^2 value of 0.939 and 0.756 obtained with the Langmuir and Freundlich models respectively. These can be seen in Figures 4.19.and 4.20. With a R^2 value of 0.939, the data fitted the Langmuir model better

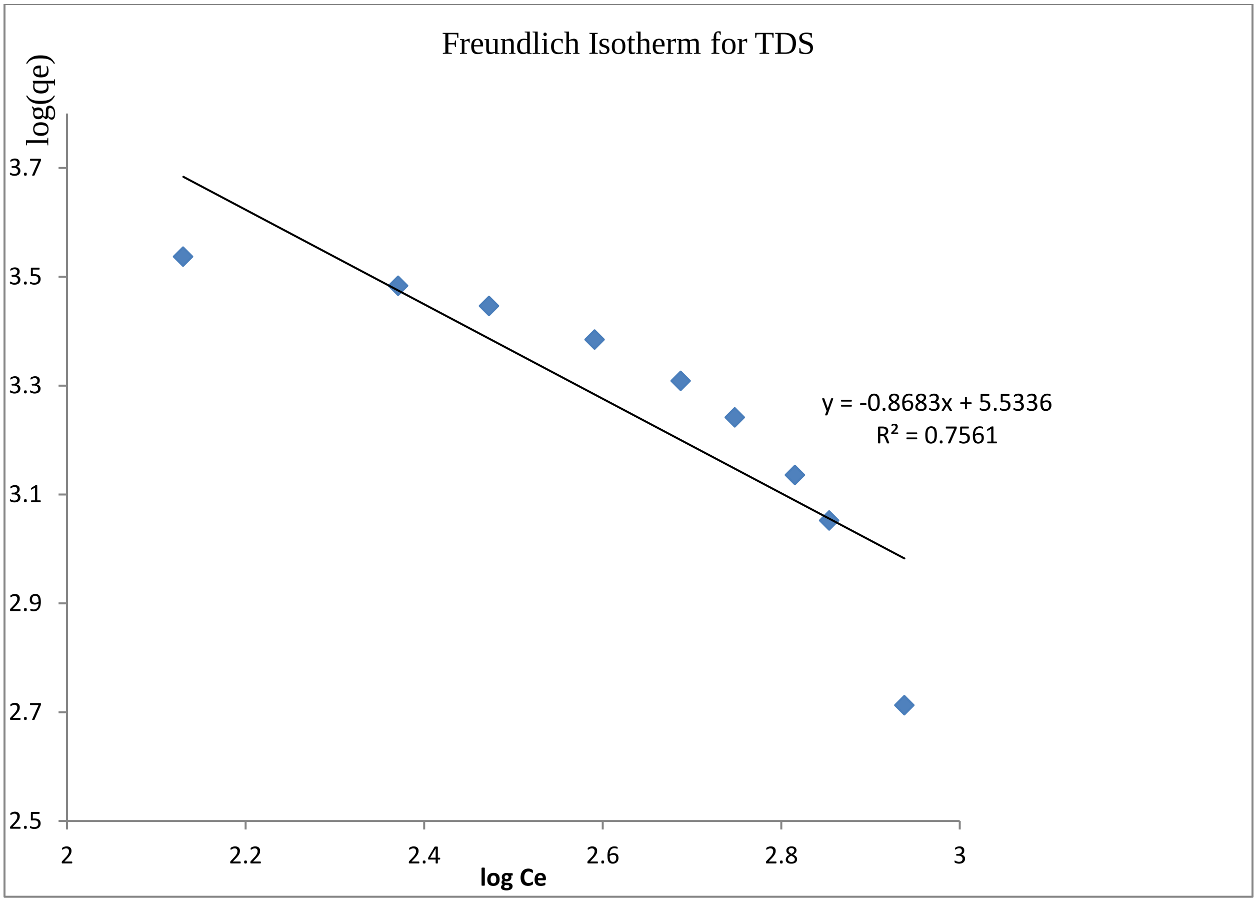


Figure 4.17 Freundlich Isotherm for TDS

4.7.2. Adsorption Ability for Nitrite.

Ammonium Nitrogen $NH4^+$ exists in an aqueous solution as either ammonium ion (NH_4^+) or ammonia gas (NH_3) depending on the pH of the solution in accordance to the equilibrium reaction given in Equation 4.10

$$NH_4^+ \rightleftharpoons NH_3 + H^+ \quad 4.10$$

The dissociation is pH dependent with acidic solution favouring the ammonium ion.

Autotrophic bacteria in wastewater oxidises the ammonium ion to give Nitrite as represented by Equation 4.11

$$2NH_4^+ + 3O_2 \longrightarrow 4H^+ + 2H_2O + 2NO_2^- + \text{Energy}$$

4.11

The presence of nitrifying bacteria could increase the concentration of nitrite if the retention time is not enough to allow the nitrite to be converted to nitrate. The Freundlich Isotherm which can be seen in Figure 4.18 gives a R^2 value of 0.9199 while the Langmuir isotherm gave a R^2 value of 0.0163 as depicted in Figure 4.19. At a point, the concentration of nitrite increased instead of decreasing suggesting oxidation of ammonium ion which could be due to reactions as adsorption takes place.

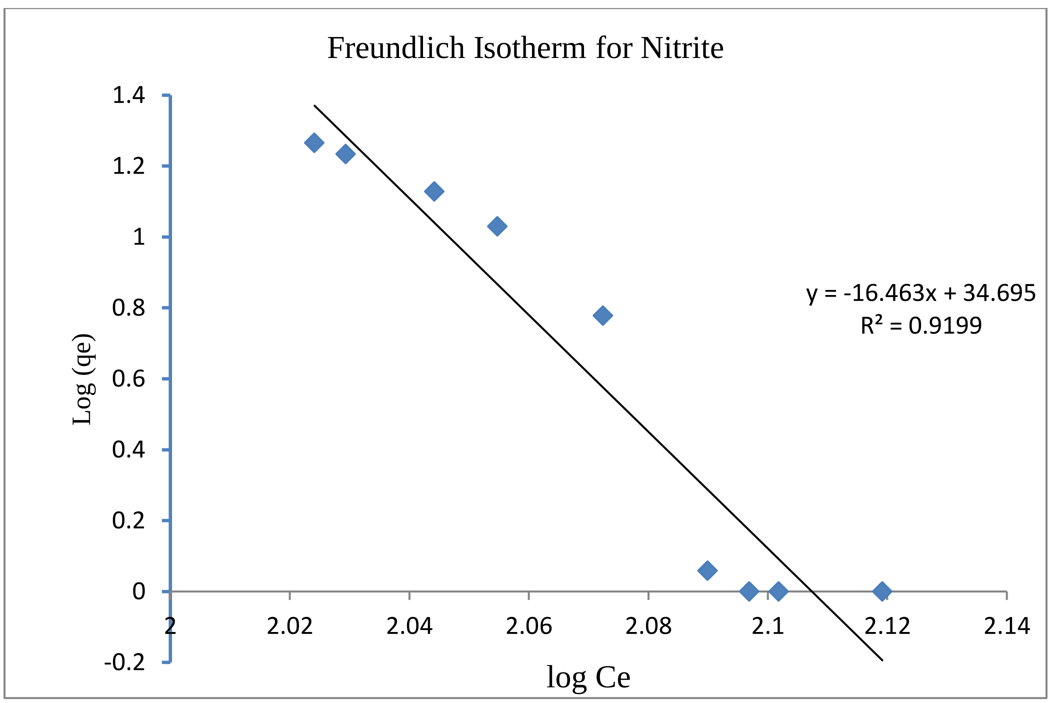


Figure 4.18 Freundlich Isotherm for Nitrite

In a wastewater sample, there is a mixture of organic and inorganic compounds which could result in a depressed adsorptive tendency for the adsorbate. However the adsorptive capacity of the adsorbent may be larger than its adsorptive capacity for a single compound (Metcalf &

Eddy/Aecom, 2014b). Consequently, an adsorbent's apparent inability to adsorb a particular adsorbent while being able to adsorb another adsorbate does not render the adsorbent inefficient.

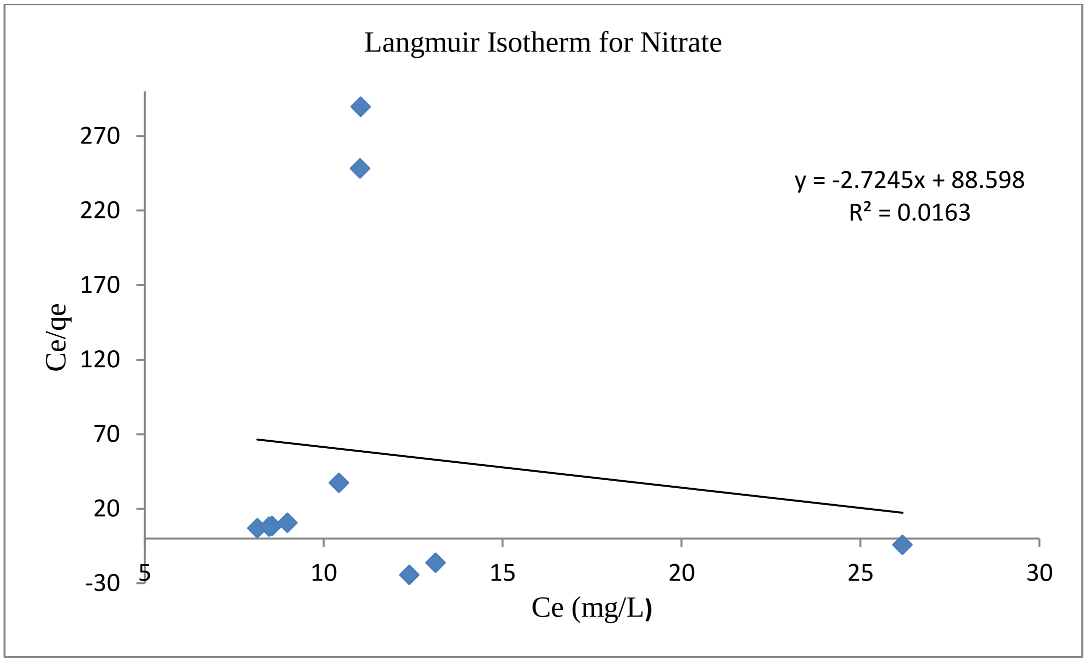


Figure 4.22 Langmuir Isotherm for Nitrate

4.8 Treatment of Effluent Wastewater with adsorbents produced.

The effluent wastewater was treated with the adsorbents produced. The adsorbents were produced under varying conditions and as expected, results obtained varied. The adsorbents used and the conditions under which they were produced can be seen in Table 4.15

Table 4.9 Description of conditions in which adsorbents were made

Sample No	Description	Sample No	Description	Sample No	Description
I	4M BM 350^{O}C 2hrs	VI	2M BM 350^{O}C 1hr	XI	Untreated BB
II	2M BM 450^{O}C 2hrs	VII	2M BB 450^{O}C 1hr	XII	Untreated BM
III	4M BM 450^{O}C 2hrs	VIII	2M BB 350^{O}C 1hr	XIII	0M BB 2hrs 450^{o}C
IV	4M BM 450^{O}C 0.33hrs	IX	Commercial AC	XIV	Raw Effluent
V	4M BM 350^{O}C 1hr	X	Inflow into tank		

* BM = Blind Mix, BB = Babo

4.8.1 Effect on Nitrite Concentration.

There was an initial reduction in concentration of nitrite with all adsorbents but after 48hours, some had an increase in the concentration of nitrite. Figure 4.20 shows the concentration of Nitrite when subjected to activated sawdust prepared under varying conditions. The adsorbents which actually gave reduction in nitrite concentration are shown in Figure 4.21

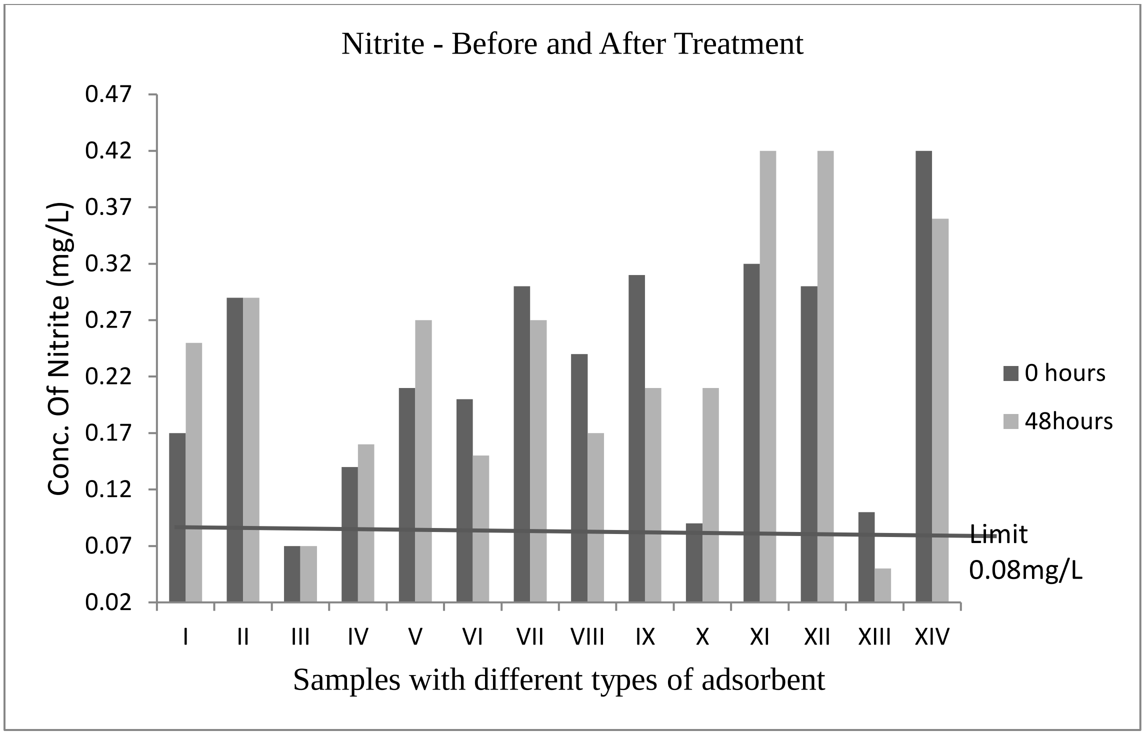


Figure 4.20 Nitrite concentrations before and after Treatment

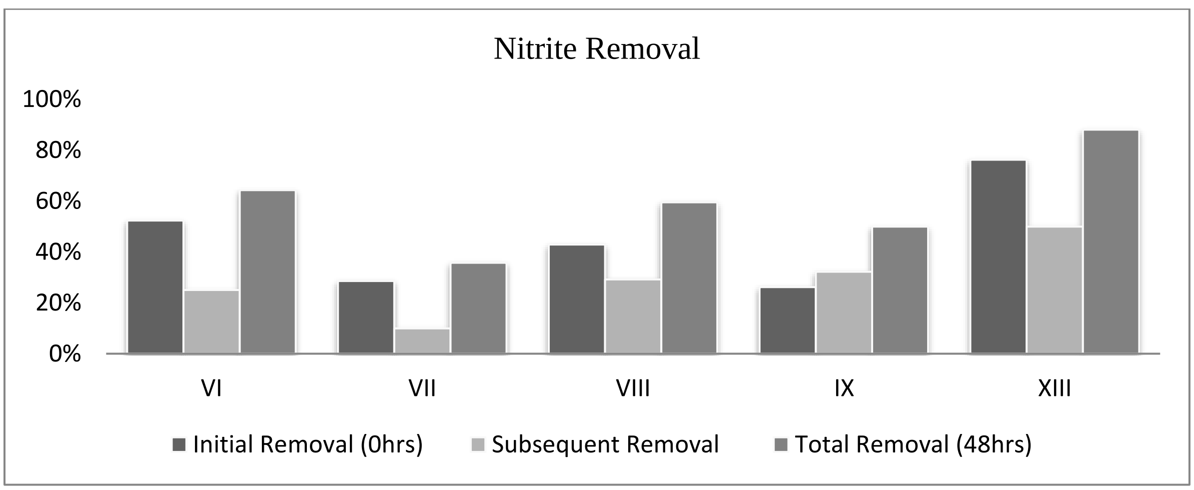
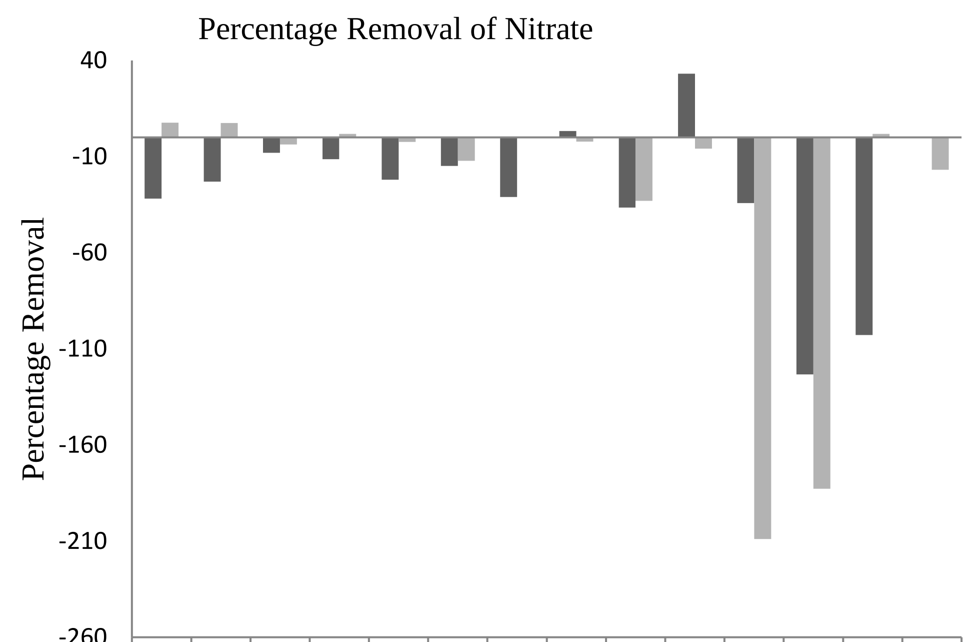


Figure 4.21 Percentage Removal of Nitrite.

The best removal rate was obtained with Adsorbent XIII which was produced in vacuum at a higher temperature and higher activation period of 2 hours; in addition, the acid used in impregnation was not diluted. Absorbent XIII was the only one which gave a treated effluent with a nitrite concentration within allowed limit. The commercially available activated carbon, IX only removed 50%. This shows that activated sawdust could be a replacement for commercially available activated charcoal. The removal achieved by using VIII was almost double of that achieved by VII; both were prepared under the same conditions with the exception being the temperature used. VII was prepared with a temperature of 450^{o}C while VIII was at a temperature of 350^{o}C. VI and VII were prepared with the same conditions, the difference being the precursor used. VI was the BM, while VII was BB.



	I	II	III	IV	V	VI	VII	VIII	IX	IN	XI	XII	XIII	UE
0hrs %initial removal	-32	-23	-8	-11	-22	-15	-31	3.33	-36	33.1	-34	-123	-103	0
48hrs % total removal	7.65	7.45	-3.7	1.76	-2.4	-12	0.2	-2.2	-33	-5.9	-209	-183	1.76	-17

Figure 4.22 Percentage Removal of Nitrate.

It can be seen from Figure 4.22 that the best removal option was with Sample I which is the treatment with adsorbent I, followed closely by Sample II. This was produced using the Blind Mix precursor with 4M acid activated at 350^{o}C at 2hours, while Sample II was produced using Blind Mix impregnated with 2M acid and activated at 450^{o}C for 2hours. This suggests that the more concentrated the acid solution used in impregnating; the lower temperature required to get a suitable adsorbent. It is worth noting that the inflow into the tank after 48hrs also increased its concentration, this is depicted in Figure 4.22 by IN. This implies that there is ongoing nitrification without the impact of the waste. The commercially available AC was not able to remove any nitrate, but rather its application contributed to an increase in concentration. In addition, the untreated effluent without the addition of any adsorbent also increased its concentration; this is shown as Sample UE. However, the best removal still gave an effluent which did not satisfy the maximum permissible level of 40mg/L set by the Federal Government for discharge into surface water.

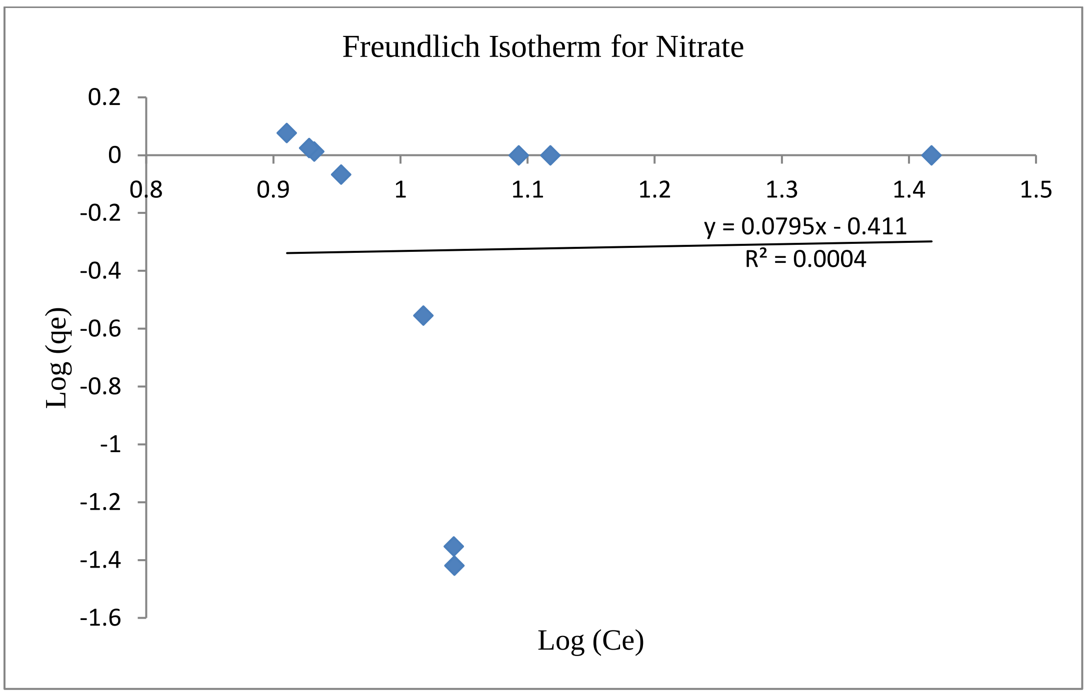


Figure 4.23 Freundlich Isotherm for Nitrate

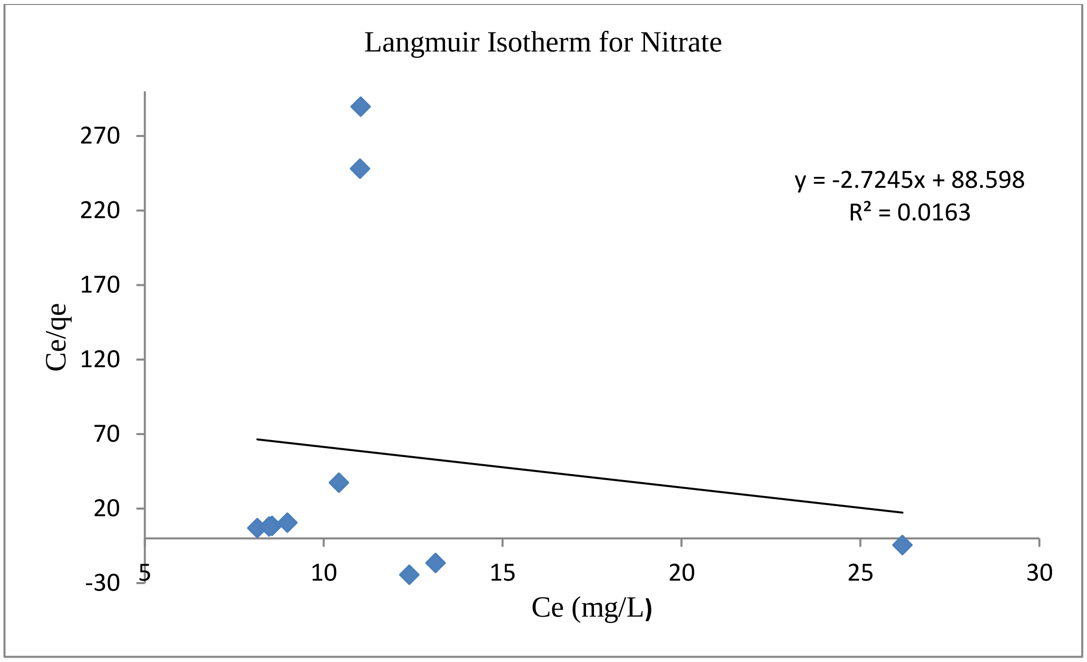


Figure 4.24 Langmuir Isotherm for Nitrate

Similar to Nitrite, the activated sawdust could not adsorb nitrate ions in the effluent. The maximum it adsorbed was 1.2mg/l without any dilution to the wastewater. The Freundlich and Langmuir Isotherms are shown in Figure 4.23 and Figure 4.24 respectively. Consequently, there would be a need to pre-treat the effluent before adsorbent is applied.

4.8.2. Investigation into presence of nitrifying bacteria

A plot of BOD against Time can be used to confirm the presence of nitrifying bacteria. Normally, a carbonaceous BOD stop rising around the fifth day and the curve tends to flatten out in a plateau manner. However, if the BOD curve still rises, it shows nitrification can occur if there is a sufficient number of nitrifying organisms in the wastewater (Metcalf & Eddy/Aecom, 2014). The result of the BOD analysis over 11days is shown in Figure 4.25. From Figure 4.25, it can be observed that the shape of the curve did not flatten out after 8 days, but rather it was still rising.

The plot is manually adjusted to show the possible occurrence of Nitrogenous biochemical oxygen demand (NBOD)

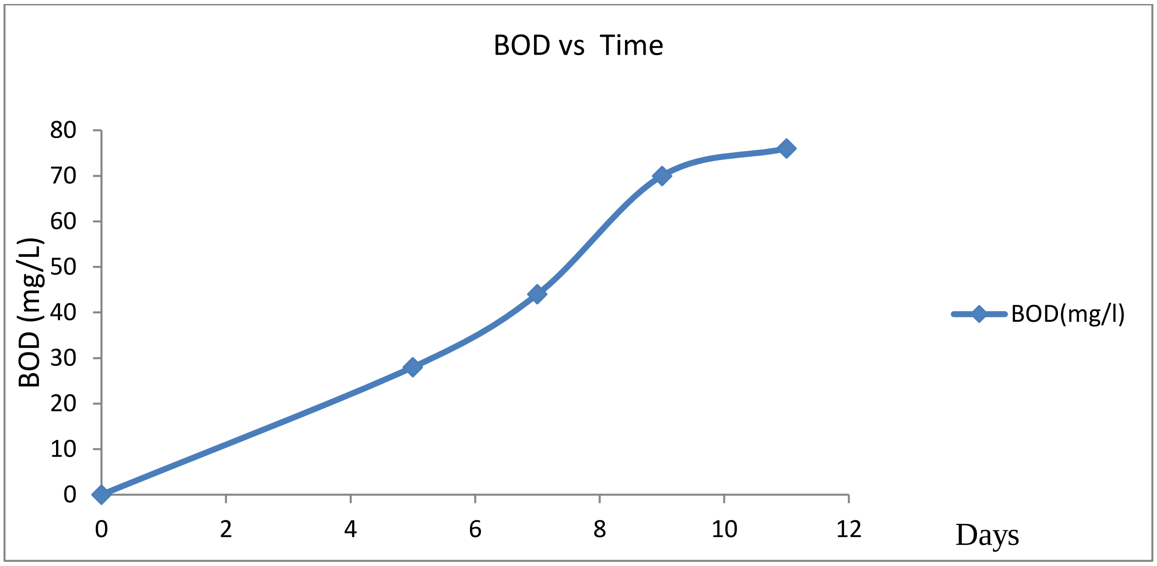


Figure 4.25 BOD plot exceeding 5 days

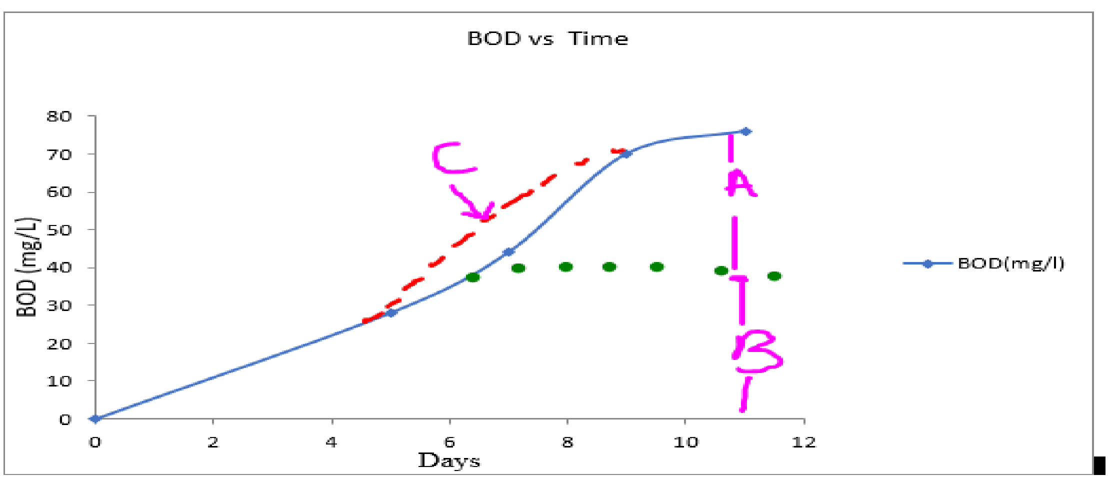


Figure 4.26 Modified BOD plot

In Figure 4.26, the area marked A corresponds to the value of NBOD while the BOD value given by B corresponds to the carbonaceous BOD. If there were enough nitrifying organisms present, the graph would have had the dashed section tagged C and taken a similar shape to Figure 4.30. The dent in the plot between the 6 and 8 days is probably the beginning of the nitrification process as this normally occurs from 5 to 8 days after the start of the incubation process. The presence of enough nitrifying bacteria in a sample would have resulted in a gradual increase in the BOD instead of the steep rise between day 6 and day 8.

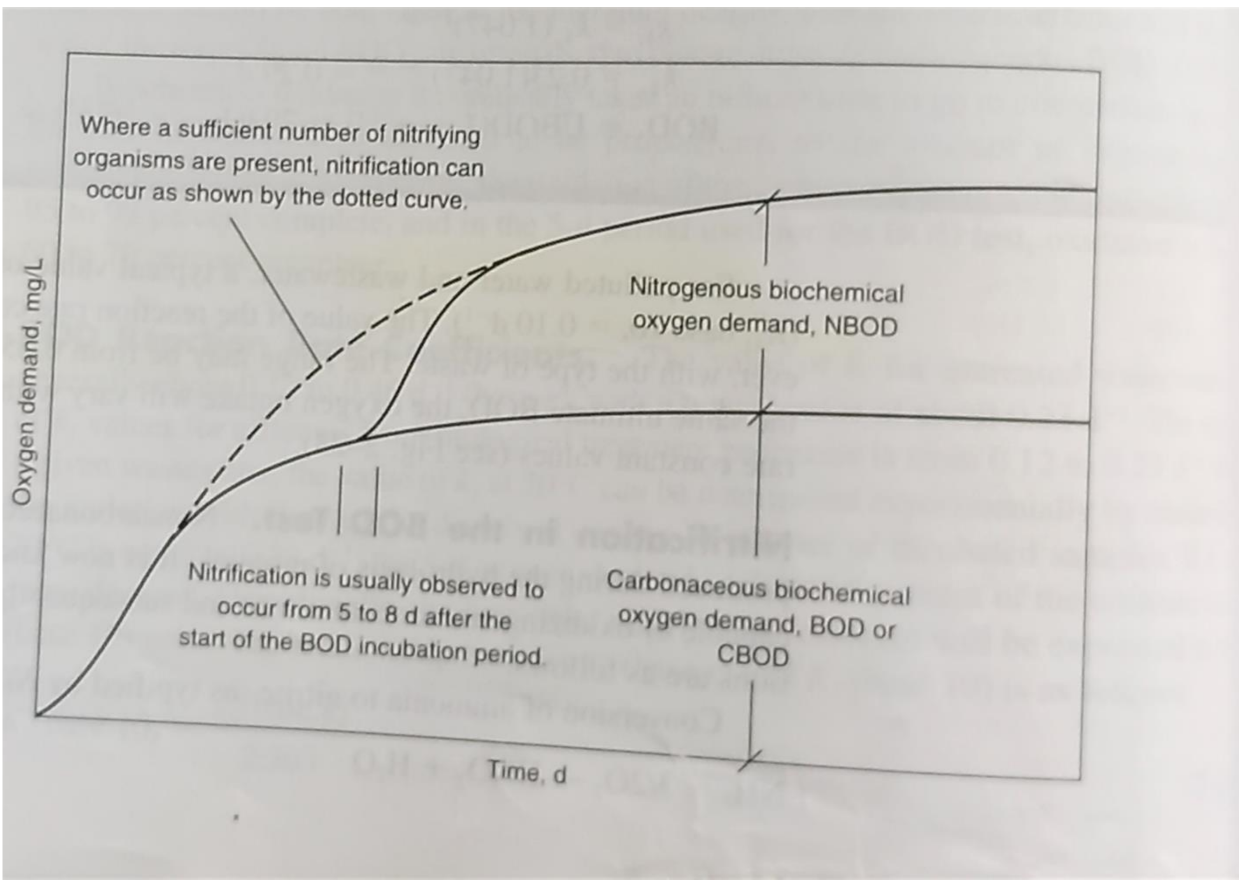


Figure 4.27 Definition sketch for exertion of BOD and NBOD in a wastewater sample, (Metcalf and Eddy/Aecom, 2014a)

4.8.3. Adsorption Ability for Phosphates

Phosphorus can be classified as either particulate or dissolved, with each class being further identified as reactive or non-reactive. The removal of phosphorus is usually investigated by assessing the concentration of orthophosphates which is a type of reactive phosphorus. Reactive orthophosphate includes both soluble forms and those that are loosely attached or adsorbed on to precipitates. Nonreactive forms include acid hydrolysable and digestible forms, which may be an organic form of nonreactive phosphorus. The soluble form of phosphorus found in aqueous solution includes orthophosphates, polyphosphates and organic (digestible) phosphate. Polyphosphates which include molecules with more than one atom of phosphorus undergo hydrolysis in aqueous solution and revert to orthophosphate though it is a slow process (Metcalf & Eddy/Aecom, 2014a).

The sample used for the Isotherm investigation was Sample I. The maximum removal obtained was a mere 6% at day zero and 9% at 48hours. In some cases, there was actually an increase in the phosphate concentration of 23%. However, this has to be put in context. The isotherm investigations were based on determining if there is a linear relationship with the adsorption ability of the activated sawdust and the concentration of the wastewater. The Freundlich and Langmuir Isotherms are given in Figure 4.31 and Figure 4.32. Both isotherms show the inability of sawdust to effectively adsorb phosphate in a predictable manner. When the concentration at equilibrium was compared to the concentration of untreated and undiluted wastewater sample, there was a reduction in the concentration for all the dilutions investigated. There is a possibility the unpredictable nature could be attributed to polyphosphates being present in the effluent and these reverting to orthophosphates at different dilutions but further investigation would be required. It could also suggest that desorption occurs earlier than expected.

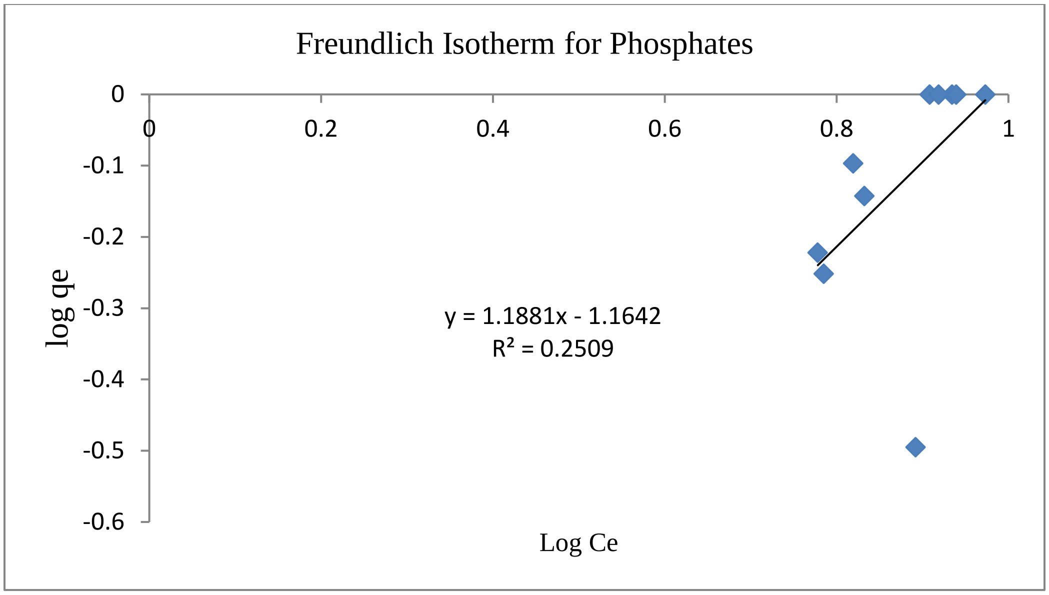


Figure 4.28 Freundlich Isotherm for Phosphates

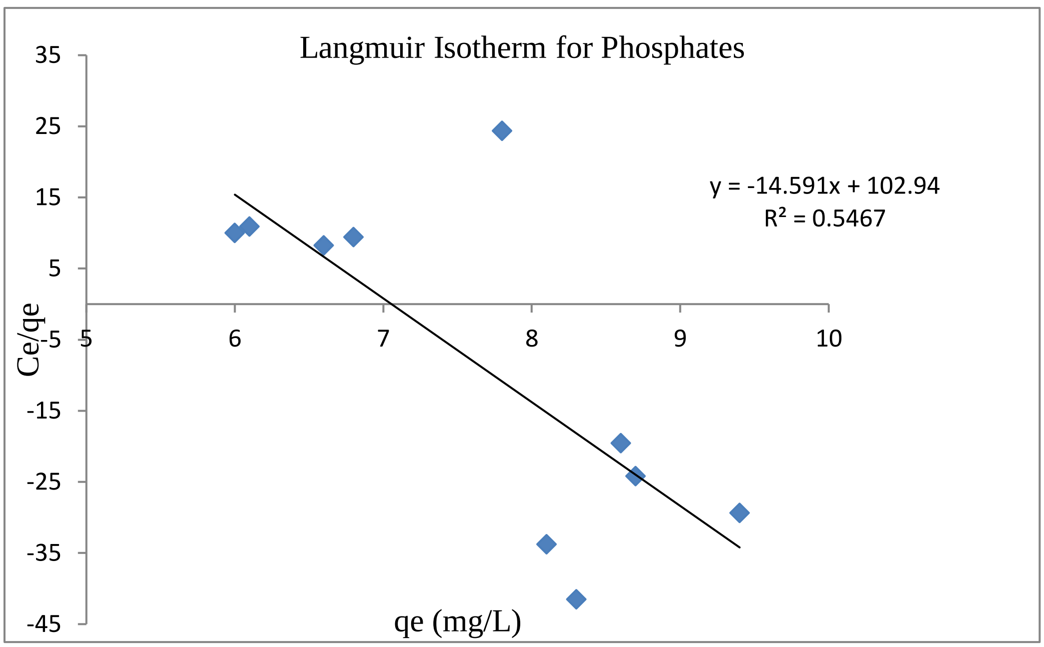


Figure 4.29 Langmuir Isotherm for Phosphates

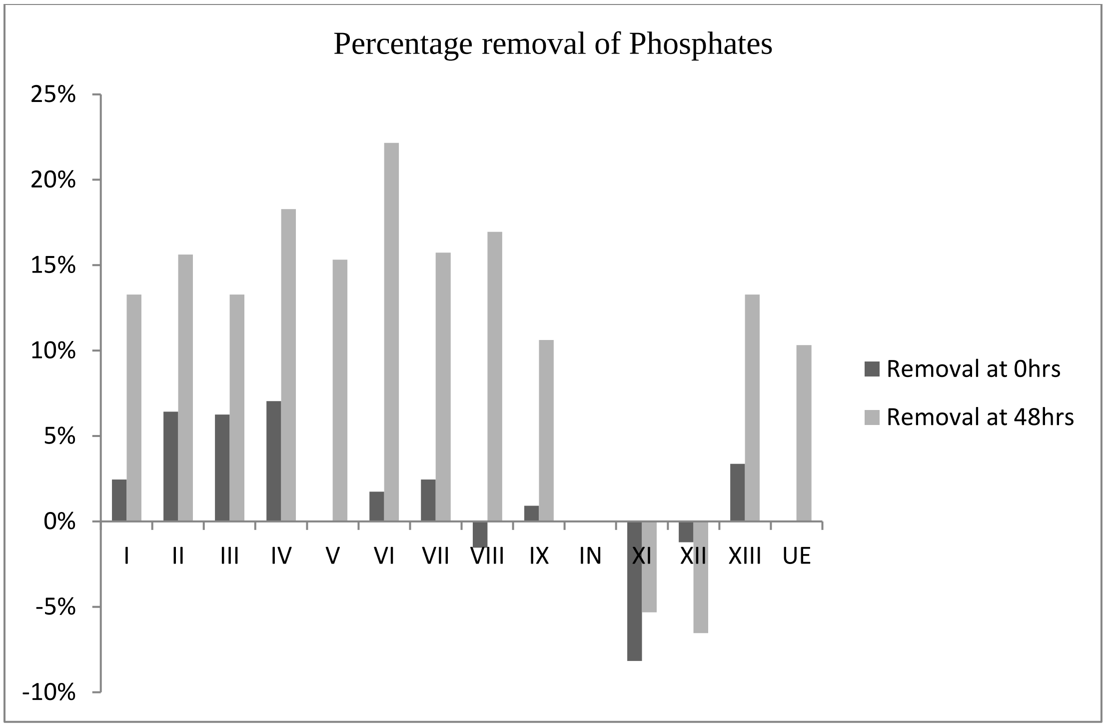


Figure 4.30 Percentage Removal of Phosphate

The percentage removal for phosphate using different adsorbents is given in Figure 4.30. The best removal of 22% was obtained using Sample VI which was the adsorbent produced using blind mix as a precursor with orthophosphate of 2M activated at 350^{o}C for 1 hour. The commercially available activated charcoal (IX) gave 11% removal, half of the value obtained using synthetic activated carbon. This shows activated sawdust can perform better than activated charcoal. The raw effluent had a concentration of 2.45mg/L which was below the allowable limit of 3.5mg/L. XI and XII samples which were untreated Isoberlina *doka* (locally known in the study area as Babo) and the heterogeneous blind mix respectively gave the worst results, instead of removing phosphate ions from the aqueous solution; they appeared to release them into the solution. This highlights the need for activation of sawdust for better removal of pollutants. The raw effluent and inflow into the tank were investigated after 48hrs and removal rate of 10% and 16% were recorded respectively. This suggests an underlying process that reduces phosphates naturally. The removal rate for all the adsorbents shows that the method of preparation has a bearing on the adsorption ability as for some; the rate was slow initially, while others were rapid.

4.8.4. Adsorption Ability of Organic pollutants based on Biological Demand

The ability of the activated sawdust to reduce organic pollutant was investigated using BOD. BOD, unlike other parameters investigated is not a pollutant in itself but an indicator of organic pollution. It is advantageous to reduce BOD of wastewater before discharge into receiving streams to avoid depletion of oxygen which could result in oxygen sag and in a worse scenario, dead water bodies. Figure 4.34 shows the BOD level in the wastewater samples under varying conditions on day zero and after 48hours retention period.

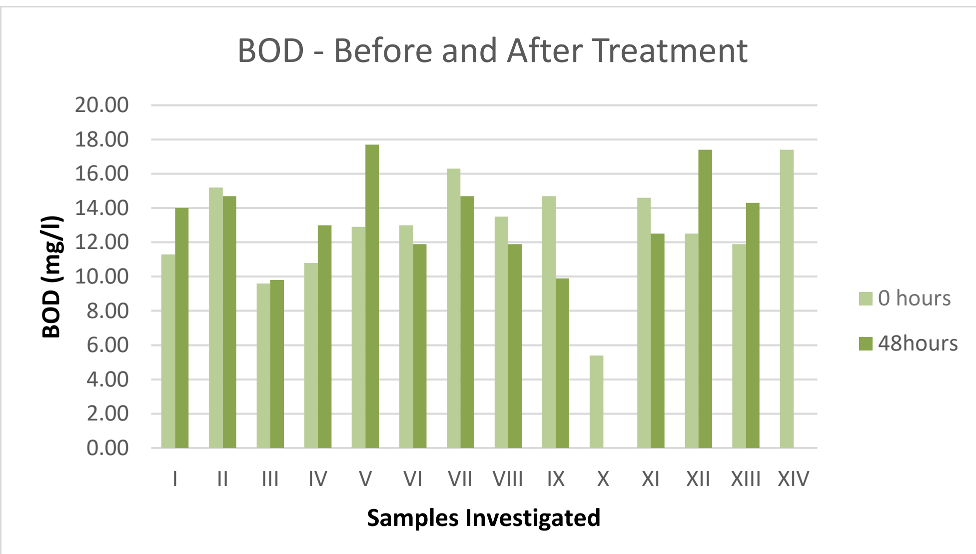


Figure 4.31 BOD values before and after treatment.

From Figure 4.31, it can be observed that there was a reduction in BOD values for all samples when compared with the raw sample which is depicted by XIV. The reduction obtained however, does not meet the requirement of 6.0 mg/l set by NESREA. The only exception is sample X, this is to be expected since X is the inflow into the pond. The adsorbent which gave the worst result was V in that instead of reducing the BOD, it actually increased it. Sample V was produced using a higher concentration of orthophosphoric acid. This might have resulted in soluble forms of reactive orthophosphates which are available for biological metabolism without further breakdown (Metcalf & Eddy/Aecom, 2014a).

Samples VIII and VI gave roughly the same values after 48hours though their rate of reduction varied. The reduction rate for the samples is shown in Figure 4.32

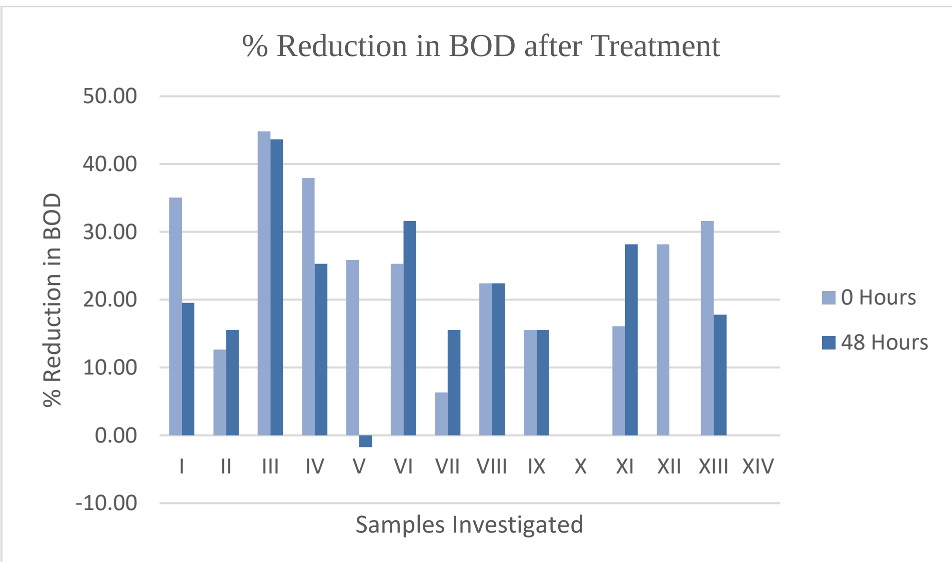


Figure 4.32. Percentage of reduction in BOD.

The rate of reduction varied with samples, some exhibited higher removal rates immediately while some gave higher rates at the end of the 48hours. The best reduction was given by adsorbent III, a BM sample which was produced by impregnating with a more concentrated activating acid at a higher temperature and longer pyrolysis duration. The worst reduction value was given by the un-activated BM (XII) which did not reduce the BOD at all. These two results confirm that if sawdust is to be used to reduce BOD, it needs to be activated. The commercial AC, IX did not reduce up to 20%. This gives credibility to the call for the use of Sawdust as an alternative to commercially available activated carbon. It also supports the argument that adsorption ability depends on activation period, temperature, retention period and activating agent. In situations, where there was an increase in value, it is possible that desorption had progressed but further studies would be required to confirm this.

Figure 4.33 depicts the percentage reduction in BOD using 4 different types of adsorbent produced using 4M orthophosphoric acid. The difference in the production was the temperature at which pyrolysis took place and the activation period.

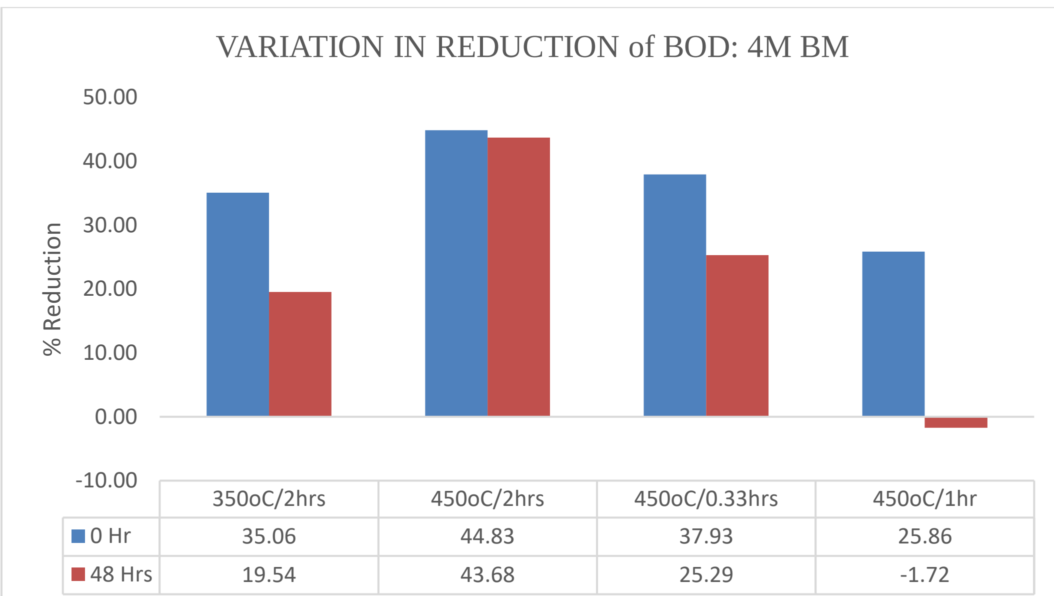


Figure 4.33 Variation in Reduction of BOD: 4M BM

It can be seen that better results were obtained for the adsorbent produced at a higher temperature. Interestingly, adsorbent IV which was in the furnace for 0.33hour due to power failure had a better removal than that produced at a lower temperature for a longer duration. There is a possibility that more pores are formed at a higher temperature thereby giving more sites for adsorption to take place. Increase in activating temperature can result in larger surface areas due to increase porosity, Kaplana and Lee, (2016). However, if the reduction in the concentration of phosphorus is investigated for the same sets of adsorbents produced using 4M acid, the outcome is different. This is depicted using Figure 4.34.

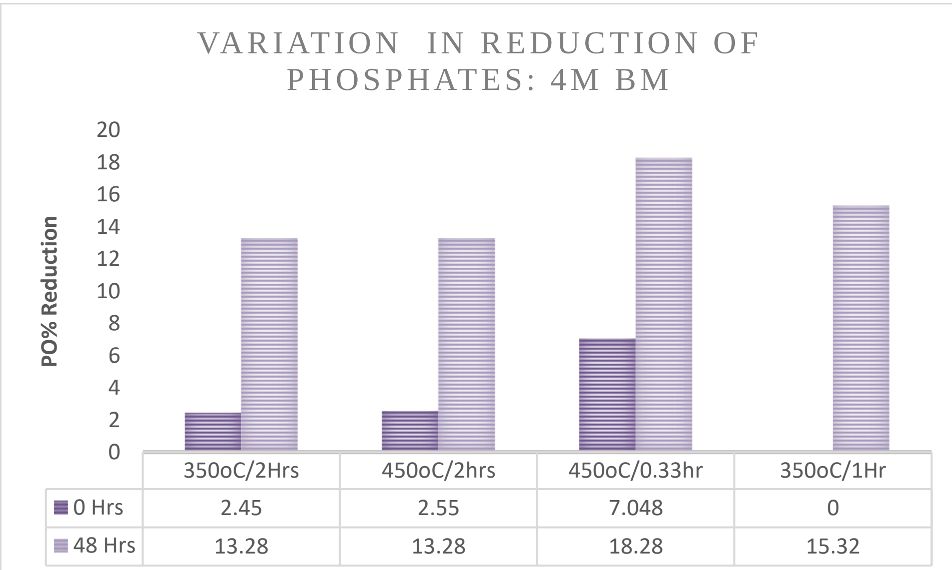


Figure 4.34. Variation in Reduction of Phosphates: 4M BM

It can be observed that the best result for the removal of phosphates was obtained using the adsorbent which was in the furnace for the shortest period. The two which were in for the same length of time, albeit at different temperatures gave the same percentage removal at the end of the 48hours. A comparison of the ones produced at 350^{o}C suggests the shorter the period in the furnace, the better the removal rate of phosphoric pollutants. It implies an adsorbent might be good at removing a type of pollutant but not effective at removing another type.

4.8.5. Adsorption Ability of Organic pollutants based on Chemical Oxygen Demand.

COD is useful in wastewater treatment analysis because it gives an indication of the presence of organic and inorganic pollutants which can not be biodegraded by microorganisms. The wastewater samples were analysed for COD before and after treatment. It can be expected that a wastewater sample would report values for COD and in addition, the COD values can be expected to be greater than BOD since COD measures the value of all organic and inorganic that can be oxidized chemically.

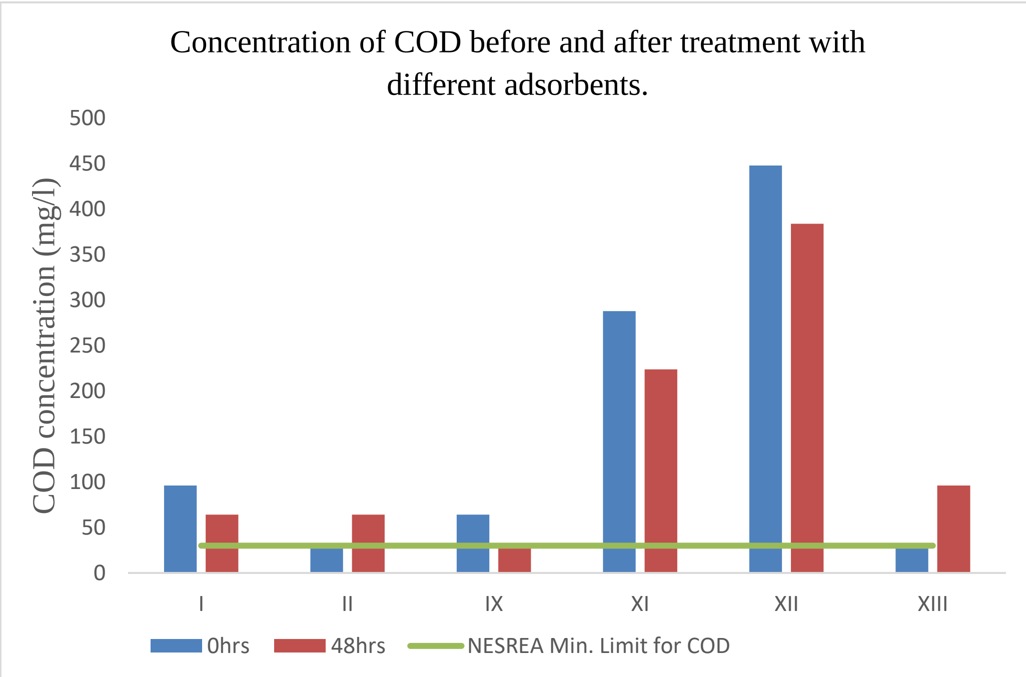


Figure 4.35. Variation in the reduction of COD

The best percentage reduction was obtained with Sample IX which is the commercially available AC. This is in line with what has been observed with other parameters investigated; an adsorbent can not be excellent in treating all parameters. All samples recorded values above the stipulated minimum value of 30mg/l for discharge. However, globally it is expected that COD value should be at a maximum level, rather than a minimum level. A minimum level will result into adverse pollution of the water body.

4.9. Use of sludge in plant cultivation

Figure 4.38. Seedlings after 2 weeks.

Figure 4.39. Seedlings after 4 months in containers A and B respectively

From Figures 4.38 and 4.39, it can be seen that there was no visible negative effect on the growth of plant A. However, if the sludge is to be used in consumable crops, there will be the need to investigate if the sludge should be used as in the form of add-in or partial replacement and in what ratio.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The study was aimed at investigating the suitability of sawdust waste as a medium for treatment of aquaculture effluent with the view of managing both solid waste and liquid waste simultaneously. The treatment method considered was adsorption due to its ease of its operation and negligible dependence on power. The suitability of sawdust was investigated by determination of values of certain physiochemical parameters before and after treatment. This was achieved by converting sawdust into a type of activated carbon prepared under different conditions. Activation of sawdust means the process of enlarging its pores to allow the adsorption of materials by Van der Waal forces. The sawdust was impregnated with orthophosphoric acid of two different concentrations, 2M and 4M. The pyrolysis was done at two temperatures of 350^oC and 450^oC and using two different activation times of 1hour and 2hours. A batch process was employed using a retention period of 48hours. Parameters investigated using standard methods were temperature, pH, BOD, TDS, nitrites, nitrates and phosphorus. Adsorption ability of the adsorbents was investigated using Freundlich and Langmuir Isotherms. The adsorption ability was also compared with that of non-activated sawdust and commercially available activated carbon.

5.2 Conclusions

The following conclusions were drawn from the study:

i. Aquaculture wastewater contain organic and inorganic pollutants that could increase the biological demand of the receiving water bodies and affect the penetration of sunlight which is required by the aquatic organisms for growth. It is therefore necessary to treat aquaculture wastewater before discharge. In the study area, none of the catfish farms treated its wastewater before discharge.

ii. Sawdust has the potential to be used as a medium for aquaculture wastewater treatment through its use as an adsorbent. It can reduce the potential of the wastewater polluting streams and rivers. can be used as a medium for the treatment of aquaculture wastewater. This could be one of the options available to meet two of the targets set for achieving Goal 6 of the sustainable development which is "Ensure availability and sustainable management of water and sanitation for all". 6.3 aims to improve water quality by reducing pollution, halving the proportion of untreated wastewater by 2030 while 6.6 aims to protect and restore water-related ecosystems of streams, rivers etc. It reduced the BOD of the aquaculture wastewater. It reduced the concentration of phosphorus and nitrite but it struggled with the removal of nitrate. It is worth noting that the commercial AC was also not able to reduce the concentration of Nitrate. Interestingly, AS performed better in the reduction of concentration of some parameters.

iii. The investigation showed that if sawdust was to be effective as a medium for aquaculture wastewater treatment, it needs to be activated to increase the surface area and pores available for adsorption of pollutants. This was deduced from the results obtained when non- activated and AS samples were used to treat the wastewater. The non-activated sawdust was not able to reduce the concentration of any of the parameters investigated.

iv. The level of pollutant removal is dependent on preparation method of the sawdust. Some of the factors which had an impact are temperature of the activation process and the concentration of the activating acid. For instance, two varieties of BB which were produced with the same conditions with the exception of temperature of the furnace gave different percentage reduction rates for nitrite concentration. The sample produced at a lower temperature had a higher percentage reduction rate for nitrite concentration. There was a similar occurrence with phosphorus.

v. The synthesized activated carbon performed better than the commercially available AC in the reduction of some parameters' concentrations. A better performance was given by AS in the reduction of Phosphorus and Nitrite.

vi. The use of sawdust as an adsorbent for aquaculture effluent treatment offers a more environmentally friendly option for the management and disposal of sawdust. Its use as an adsorbent will eliminate burning and thereby reduce air pollution. This keys into the SDG 6 which is to take urgent action to combat climate action and its impact.

vii. Organic pollutants were adsorbed better than inorganic pollutants. All the varieties of AS produced gave higher percentage reduction of BOD which is an indicator of organic pollution than other parameters.

viii. In order to avoid situation whereby the process of reducing and treatment of solid and liquid waste results in the generation of another type of waste, the use of the sludge generated as a consequence of the treatment as a soil enhancer in horticulture was investigated. The result shows that it is possible for sludge to be used in horticulture without any negative effect on the plants. This implies zero waste is possible with sawdust.

5.3. Contribution of the Study to the Body of Knowledge.

5.3.1 Knowledge Gap Identified

The following knowledge gaps were identified:

i. There is no recognized established method of aquaculture wastewater treatment which does not rely on power or technical expertise which can be utilized in developing countries.
ii. Sawdust as an adsorbent has been investigated for the removal of dyes from tannery wastewater effluent, the removal of heavy metal ions from synthesized wastewater produced in the laboratory but from all indications, has not been investigated for the treatment of aquaculture wastewater.
iii. If developing countries like Nigeria are to meet the target set for SDGs, there is an urgent need for treatment processes of wastewater which are not power or expertise dependent. Technical expertise could be available but without constant and regular power supply, any available technical expertise is useless.
iv. The main method of management and disposal of sawdust discovered during the study is by burning. Burning of sawdust degrades the land and pollutes the air. Although attempts were made not to burn in the immediate surroundings, it is still done close to residential areas. Consequently, there is a need for other options for the management and disposal of sawdust which do not affect the environment negatively.

v. Various studies have investigated the use of sawdust in different types of wastewater but no consideration had been given to the disposal of the resulting sludge after the use of sawdust as an adsorbent.

5.3.2. Key findings in relation to knowledge gaps

The study was aimed at finding a feasible solution to the lack of established treatment methods for aquaculture wastewater effluent in developing countries. This was done through the use of sawdust as an adsorbent. Treatment of Aquaculture wastewater by adsorption offers a simple and easily adaptable solution which does not require any power supply or technical expertise. However, the effectiveness and efficiency of this method depends to a large extent on the preparation of the adsorbent. This could be influenced by factors like temperature, activation time, retention time and concentration of activating agent.

The study has contributed to knowledge gaps in literature and methodology in relation to the treatment of aquaculture wastewater in a developing country like Nigeria. The study has shown that there is the potential for sawdust waste to be managed through its use as an adsorbent. It reduced the level of BOD, Nitrite, Nitrate, Phosphorus and TDS at different levels though for some adsorbents, the level of nitrate and phosphorus increased. The study also showed that sawdust adsorbent can actually perform better than the commercially available AC in the reduction of some pollutants. It also showed that the sludge produced could be useful as a soil enhancer in horticulture.

5.3.3. Knowledge gap addressed by study

From literature review detailed in chapter two, aquaculture wastewater appears to be used in agriculture or recycled back to the farm if the rearing method is RAS. There appeared to be no established treatment method before discharge for aquaculture wastewater. This study addressed the possibility of treating aquaculture wastewater before discharge with the use of the sawdust adsorbent. Unlike RAS which relies on power supply, treatment by adsorption does not need power supply. The literature review helped in giving an informed decision on the advantages and disadvantages of different activating agents which resulted in the use of orthophosphoric acid as the activating agent. In chapter three, the method of converting sawdust into activated sawdust was detailed and the steps taken to ascertain the reduction in pollution concentration was also considered. Chapter four discussed the results of the investigations

Over twenty previous studies were reviewed in connection with use of sawdust as an adsorbent for wastewater treatment. The parameters of interest in these studies were heavy metals, phenols, dyes, arsenic, lead which could be found in industrial and textile wastewater but none investigated the use of sawdust in the treatment of aquaculture wastewater. This study addressed the possibility of using sawdust in aquaculture wastewater and there was some level of success though the effectiveness of the adsorbent produced depend to a large scale on the method of preparation.

With the exception of septic tanks which technically is not a mode of wastewater treatment, all existing methods of treatment require technical expertise and constant power supply It has also shown that aquaculture wastewater treatment does not require technical expertise. The reduction of some of the concentration of parameters investigated in this study shows it is possible to treat aquaculture wastewater without power supply or skilled personnel. In addition, it shows that burning of sawdust does not have to be the solution to the problem of its management and disposal.

The study gave consideration to the problem of sludge disposal after treatment which other researchers appeared to be silent on. The investigation showed that the sludge does not have to be thrown away indiscriminately but that it could find some use in horticulture.

5.4. Limitation of Study

i. The study was limited to one activating agent, orthophosphoric acid.
ii. Impregnation period of the acid in the sawdust was not captured due to lack of access to necessary equipment at time needed.
iii. Epileptic power supply and faulty equipment hindered production of more varieties of activated sawdust.
iv. Use of sludge in horticulture was superficial

5.5 Recommendations

The following recommendations are made according to the outcomes of this study.

i. Research into the use of other activating agents which give similar benefits of using orthophosphoric acid without tampering with nutrients concentration.
ii. Research into best practice on use of residual sludge in horticulture; either as an add -in component or partial replacement to soil.
iii. Research into the use of the adsorbent in treating other types of wastewater.
iv. Research into the effect of combination and composition of wood species which make up the blind mix in the adsorption ability of the adsorbent.

v. A pilot scheme implementing a treatment pond should be carried out. This is shown in Figure 5.1.

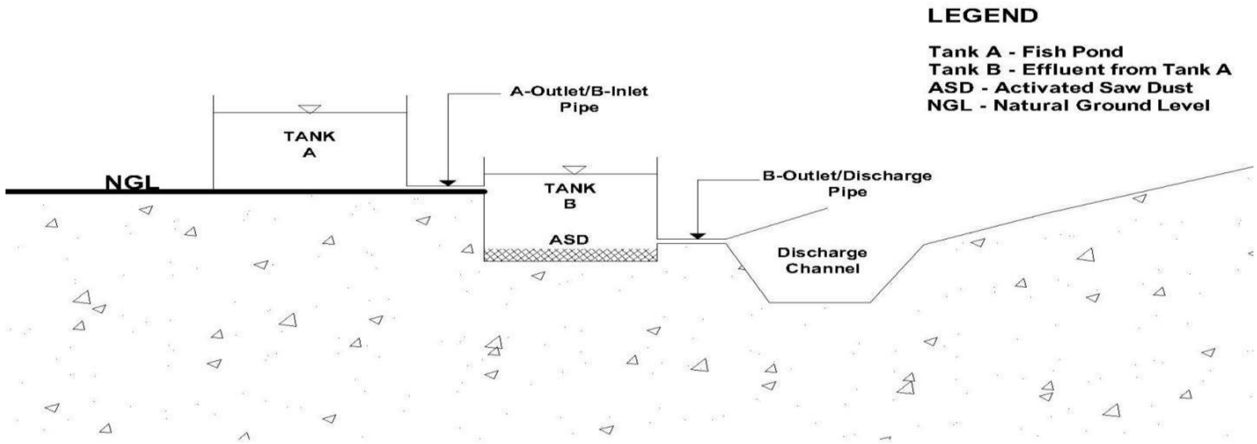


Figure 5.1. Schematic diagram of a proposed scheme implementing AS

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References

Abugu, HO, Okoye, PAC, Ajiwe, VIE, Omuku, PE and Umeobika, UC (2015). Preparation and Characterisation of Activated Carbon Produced from Oil Bean (Ugba or Ukpaka) and Snail Shell. *Journal of Environmental Analytical Chemistry*. 2 (6). 1000165, 1-17. doi:10.4172jreac.1000165

Achaw, O (2012). A Study of the Porosity of Activated Carbons Using the Scanning Electron Microscope, Scanning Electron Microscopy, Dr. Viacheslav Kazmiruk (Ed.), ISBN: 978-953-51-0092-8, InTech, Available from: http://www.intechopen.com/books/scanning-electron-microscopy/a-study-of-the-porosity-ofactivated-carbons-using-the-scanning-elctrom-microscope

Adegoke, HI and Adekola, FA (2010). Removal of Phenol from Aqueous Solution by Activated Carbon Prepared from Some Agricultural Materials. *Advances in Natural and Applied Sciences*, 4(3), 293-298.

Adie, DB, Okuofu, CA and Osakwe, C (2012). Isothermal and Batch Adsorption Studies of the Use of *Borassus Aethiopium* and *CocosNucifera*for Wastewater Treatment. *American International Journal of Contemporary Research* Vol. 2 No. 7; July 2012, 119-130

Agodzo, SK, Hulbers, FP, Chenini, F, Van Lier, JB and Duran, A (2003). Use of Wastewater in Irrigated Agriculture: Country Studies from Bolivia, Ghana and Tunisia Agricultural University Wageningen: Wageningen, The Netherlands, 2003; Volume 2 *In*: Kayode, OF, Luethie, C & Rene, ER (2018). Management Recommendations for Improving Decentralized Wastewater Treatment by the Food and Beverage Industries in Nigeria. *Environments*2018, 5, 41; doi: 10.3390/environments5030041. www.mdpi.com/journal/environments

Agu, AP, Umeokonkwo, CD, Nnabu RC and Odusanya, OO (2016). Health Problems among Sawmill Workers in Abakaliki and Workplace Risk Assessment. *Journal of Community Medicine and Primary Health Care*. 28 (2), 1-10

Akinnubi, CF. (2015). Influence of Sawmill Industries on the Health of Sawmill Workers and Inhabitant of the Environment in Ondo State, Nigeria. *Journal of Educational and Social Research,* 5(2), 299-304. ISSN 2239-978X ISSN 2240-0524.

Akowuah, JO, Kemausuor, F and Mitchual, SJ (2012). Physico-chemical Characteristics and Market Potential of Sawdust Charcoal Briquette. *International Journal of Energy and Environmental Engineering* 2012, 3:20 doi:10.1186/2251-6832-3-20

Akpor, OB and Muchie, M (2011). A review. Environmental and Public Health Implications of Wastewater Quality. *African Journal of Biotechnology* Vol. 10(13), March (2011), 2379-2387. DOI: 10.5897/AJB10.1797 ISSN 1684–5315. Available online at http://www.academicjournals.org/AJB

Ali, E, Tahereh, K and Mansooreh, S (2011). Preparation of High Surface Area Activated Carbon from Polyethyleneterephthalate (PET) Waste by Physical Activation. *Research Journal of Chemistry and Environment*. Vol.15 (2) June (2011), 433-437

Ali, M, Asim, M & Khan, TA. (2012). A review. Low cost adsorbents for the removal of organic pollutants from wastewater. *Journal of Environmental Management*. 113, 170-183

APHA (1992). standard methods for the examination of water and wastewater. 18th ed. American Public Health Association, Washington, DC.

Ara, NJ, Hasan, MA, Rahman, MA, Salam, MA, Salam, A and ShafiqulAlam, AM (2013) Removal of Remazol Red from Textile Wastewater Using Treated Sawdust - An Effective Way of Effluent Treatment. *Bangladesh Pharmaceutical Journal* 16(1): 93-98, 2013

Asemota, L, Alkhaddar, R, Sertyesilisk, B and Tunstall, A (2011). Wastewater Management in Lagos State: Moving Towards a Sustainable Approach. Environmental Quality Management. DOI 10.1002/tqem 20300/Summer 2011, 63 - 72

Awwad, NS, El-Zahhar, AA, Fouda, AM & Ibrahium, HA (2013). Removal of Heavy Metals Ions from Ground and Surface Water Samples using Carbons Derived from Date Pits. *Journal of Environmental Chemical Engineering* 1(2013), 416-423

Ayawei, N, Ebelegi, AN and Wankasi, D (2017). A Review. Modelling and Interpretation of Adsorption Isotherms. *Hindawi Journal of Chemistry*. Volume 2017, Article ID 3039817, 1-11.https://doi.org/10.1155/2017/3039817

Bardócz, T (2009).Technology and production of main freshwater aquaculture types in Europe (Chapter Three**)** *In***:** A Handbook for Sustainable Aquaculture –Project N^{o}; COLL-CT-2006-030384 Sixth Framework Programme. Varadi, L, Bardócz, T & Oberdieck, A (edt), 11-13

Bhatnagar, A and Minocha, AK (2006). Conventional and Non-conventional adsorbents for the removal of pollutants from water – A Review. *Indian Journal of Chemical Technology*. Vol.13. May 2006, 203 -217

Bittencourt, S (2018). Agricultural Use of Sewage Sludge in Parana State, Brazil: A Decade of National Regulation. Recycling 2018, 3, 53; doi:10.3390/recycling3040053. www.mdpi.com/journal/recycling

Blakemore, E (2019). The Chernobyl disaster: What happened, and the long-term impacts. https://nationalgeographic.com/culture. Accessed 11/7/2019.

Boyd, CE and Soongsawang, S (2012). Effects of Effluent from a Fisheries Research Station on stream quality. *North American Journal of Aquaculture* 74(2012), 73-79

Bulut, Y and Tez, Z (2007). Removal of Heavy Metals from Aqueous Solutions by Sawdust Adsorption. *Journal of Environmental Sciences* 19(2007), 160-166

Cao, L, Wang, W, Yang, Y, Yang, C, Yuan, Z, Xiong, S and James, D (2007). Environmental Impact of Aquaculture and Countermeasures to Aquaculture Pollution in China. *Env. Sci. Pollut Res*.14 (7), 452-462

Cao, Q, Xie, K, Lv, Y and Bao, W (2006). Process Effects on Activated Carbon with Large Specific Surface Area from Corn Cob. *Bioresource Technology* (2006), 110-115

Carr, GM and Neary, JP (2008). Water Quality for Ecosystems and Human Health, 2nd Edition, United Nations Environment Programme Global Environment Monitoring Systems (GEMS)/Water, Canada. ISBN 92-95039-51-7

Castine, SA, McKinnon, AD, Paul, NA, Trott, LA and de Nys, R. (2013). A Review. Wastewater treatment for land-based aquaculture: Improvements and value-adding alternatives in model systems from Australia. *Aquaculture Environment Interaction.* Vol. 4: 285– 300, 2013. doi: 10.3354/aei00088

Ccresaquaponics.wordpress.com. Build an aquaponics grow bed https://ccresaquaponics.files.wordpress.com/2012/03/ccresaquaponicsrecirculatingaquaculturesystems28ras29.jpg Accessed 12/7/2019

Chaney, J (2010). Combustion Characteristics of Biomass Briquettes. Thesis submitted to the University of Nottingham, England for the award of degree of Doctor of Philosophy, May 2010.

Clarke, S and Preto, F (2011). Biomass Burn Characteristics. Order no. 11-033 Agdex 737/120 June 2011 Ministry of Agriculture, Food and Rural Affairs, Ontario

Crab, R, Avnimelech, Y, Defoirdt, T, Bossier, P and Verstraete, W. Nitrogen removal techniques in aquaculture for a sustainable production. (Review). Aquaculture 270 (2007) 1–14

Cruz, G, Pirilä, M, Huuhtanen, M, Carrión L, Alvarenga, E ,and Keiski, RL (2012). Production of Activated Carbon from Cocoa (*Theobroma cacao*) Pod Husk.*Journal of Civil and Environment Engineering* 2:2. doi:10.4172/2165-784X.1000109, 1-6.

Da Rosa, A (2009). Biomass (Chapter 13) *In*: Fundamentals of Renewable Energy Process. ISBN 9780123746399, Elsevier Inc, Cambridge, United States. 864 pages

Davis, ML and Masten, SJ (2014). Principles of Environmental Engineering and Science. 3rd Edition. McGraw-Hill, New York. 848 pages

Dar, SH, Kumawat, DM, Singh, N and Wani, KA (2011). Sewage Treatment Potential of Water Hyacinth (*Eichhornia crassipes*). Research Journal of Environmental Sciences, 5, 377-385

Devi, IRP & Gowri, VS (2007). Biological Treatment of Aquaculture Discharge Waters by Seaweeds. *Jr. of Industrial Pollution Control 23 (1) (2007), 135-140*

Dias, JM, Alvim-Ferraz, MCM, Almeida, MF, Rivera-Utrilla, J and Sanchez-Polo, M.(2007). Waste materials for activated carbon preparation and its use in aqueous-phase treatment: A Review. *Journal of Environmental Management* 85 (2007), 833–846

Diaz, LF and Bakker, P. (2007). Solid Waste Management. CalRecovery-United Nations Environment Programme

Energy and Environmental Analysis Inc, (2007).Biomass Combined Heat and Power Catalog of Technologies. A Report for the U.S. Environmental Protection Agency, Combined Heat and Power Partnership, September 2007. Available at: www.epa.gov/chp/documents/biomass_chp_catalog.pdf. Accessed 24/02/2013

Enviros Consulting Limited (2007). Advanced Biological Treatment of Municipal Solid Waste, a report on behalf of the Department for Environment, Food and Rural Affairs (DEFRA), UK as part of The New Technologies Supporter Programme.

EPA.gov (n.d). Agriculture Nutrient Management and Fertilizer https://www.epa.gov/agriculture/agriculture-nutrient-management-and-fertilizer. Accessed 22/07/2019

European Union (1975). European Union's Waste Framework Directive 1975/442/EEC

European Union (2008). European Union's Waste Framework Directive 2008/98/EC

Ezeanya, NC, Chukuma, GO, Nwaigwe, KN, and Egwuonwu, CC (2015). Standard Water Quality Requirements and Management Strategies for Fish Farming (A case study of Otamiri River). *International Journal of Research in Engineering and Technology*. Vol 4(3) 1-5, ISSN: 2319-1163 | ISSN: 2321-7308

Fadaeifard, F, Raissy, M, Faghani, M, Majlesi, A and Farahani, GN (2012). Evaluation of physicochemical parameters of waste water from rainbow trout fish farms and their impacts on water quality of Koohrang stream – Iran. *International Journal of Fisheries and Aquaculture* Vol. 4(8), pp. 170-177, September 2012

Fierro, V, Muniz, G, Bastae, AH, El-Saied, H and Celzard, A (2010). Rice straw as precursor of activated carbons: Activation with ortho-phosphoric acid. *Journal of Hazardous Materials*. 181(240), 27-34

Financial Tribune (2016). Cage Fish Farming Reaches 20kT. July 27, 2016. https://financialtribune.com/articles/economy-domestic-economy/46435/cage-fish-farming-reaches-20kt. Accessed 12/07/19

Fondriest Environmental Inc. (2013) Dissolved Oxygen. Fundamentals of Environmental Measurements. 19 Nov. 2013. https://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/.

Ghosh, SK, Borges, MS, Ghosh, SK, DiMaria, F, Cruvinel, V, Ramos, TB, El-Sheltawi, ST, Fouad, MK, Aremu, AS, Ojowuro, OM, Tivani, C, Seo, Y and El-Hoz, M (2017). Waste Recycling Practices in Some Countries in Asia, Europe, Africa and South America. The 32nd International Conference on Solid Waste Technology and Management, March 19-22, 2017, Philadelphia, USA

Gravalos, I, Kateris, D, Xyradakis P, Gialamas T, Loutridis S, Augousti A, Georgiades A and Tsiropoulous. Z (2010) 'A study on calorific energy values of biomass residue pellets for heating purposes', Forest Engineering: Meeting the Needs of the Society and the Environment, Padova-Italy, July 2010. Available at: www.tesaf.unipd.it/formec2010/proceedings/ab/ab066.pdf. Accessed 03/04/13

Harmayani, K and Anwar, AHMF (2012). Adsorption of Nutrients from Stormwater using Sawdust. *International Journal of Environmental Sciences and Development*. Vol. 3. No. 2, 114-117.

Hayward, K (2019). The wastewater connection to antimicrobial resistance concerns. *The Source* (The magazine of the International Water Association), July 2019. 14-15

Hegazi, HA (2013). Removal of Heavy metals from wastewater using agricultural and industrial waste as adsorbents. *Housing and Building National Research Center Journal* (HBRC) 9, 276 -282

Hernández-Montoya, V, Garcia-Servin J and Bueno-López (2012). Thermal Treatments and Activation Procedures Used in the Preparation of Activated Carbons *In*: Lignocellulosic Precursors Used in the Synthesis of Activated Carbon – Characterization Techniques and Applications in the Wastewater Treatment. VH Montoya & AB Petriciolet (Edt.), Intech, Rijeka, 19-36

Idrus, MAMM, Hamdan, S, Rahman, MR and Islam MS (2011). Treated Tropical Wood Sawdust-Polypropylene Polymer Composite: Mechanical and Morphological Study. *Journal of Biomaterials and Nanobiotechnology*, 2011, 2, 435-444 doi:10.4236/jbnb.2011.24053. Published Online October, 2011 (http://www.SciRP.org/journal/jbnb)

Jenner, A (2010) Recirculating Aquaculture Systems: The Future of Fish Farming? The Christian Science Monitor. February 24, 2010. https://www.csmonitor.com/Environment/2010/0224/Recirculating-aquaculture-systems-The-future-of-fish-farming

Jia, H and Yuan, Q (2016). A review. Removal of Nitrogen from Wastewater using Microalgae and Micro-Algae consortium. Cogent Environmental Science. 1-15 http://dx.doi.org/10.1080/23311843.2016.1275089

Johannson, L and Thunman, H (2007). Solid Fuels *In*: Thermo Chemical Conversion of Biomass Wastes. H Thunman & B Leckner (Edt), Nordic Graduate School, Biofuels GS-2, Chalmers, Göteborg, 19-23 November 2007, 2.1 -2.13

Kaplana, D and Lee, YS (2016). Effects of Temperature and Pore Structure on High Surface Area-Activated Carbon Obtained from Peanut Shells. *J Nanosci Nanotechnol*. 2016 Mar;16(3):2950-5.doi: 10.1166/jnn.2016.12464

Kayode, J, Amoo JO and Ayeni, MJ (2016). Barks Extravitism and Healthiness of Aboriginal Yoruba Populace in Kwara State, Nigeria. *International Journal of Biomedical Papers*. 1, 13-20

Kayode, OF, Luethie, C and Rene, ER (2018). Management Recommendations for Improving Decentralized Wastewater Treatment by the Food and Beverage Industries in Nigeria. *Environments*2018, 5, 41; doi: 10.3390/environments5030041. www.mdpi.com/journal/environments

Kiely, G. (1996). *Environmental Engineering*. McGraw-Hill Book Co, Singapore. 979p.

Kimble, M, Pasdeloup, M and Spencer, C (2008). Biomass Conversion Technologies, Chapter 5 *In* Sustainable Bioenergy Development in UEMOA Member Countries, a report for the United Nations (UN) foundation in partnership with International Centre for Trade and Sustainable Development (ICTSD) and the Energy and Security Group, 45 - 56

Kioussis, DR, Wheaton, FW and Kofinas, P (2000). Reactive nitrogen and phosphorus removal from aquaculture wastewater effluents using polymer hydrogels. *Aquacultural Engineering* 23 (2000) 315–332

Kroiss, H, Rechberger, H and Egle, L (2011). Phosphorus in Water Quality and Management *In*: Integrated Waste Management Volume II, S. Kumar (Edt), InTech, Croatia, 181-214

Kurchania, AK (2012). Biomass Energy *In*: *Biomass Conversion The interface of Biotechnology, Chemistry and Materials*. Baskar C, Baskar S and Dhillon, RS (Edt) 2012, ISBN: 978-3-642-28417-5, 91-123.

Kyoto Protocol (1997). Kyoto Protocol to the United Nations Framework Convention on Climatic Change, Kyoto, Japan. 11th of December, 1997

LabProtocol (2018). http://mcblabprotocols.com/calculator/molarity-of-85-w-w-phosphoric-acid-h3po4/. Accessed 14/9/2019

Larous, SI and Meniai, AH (2012a). Removal of Copper (II) from Aqueous Solution by Agricultural By-Products- Sawdust. *Energy Procedia*. 18, 915-923. Doi: 10.1016/j.egypro.2012.05.106

Larous, SI and Meniai, AH (2012b). The Use of Sawdust as a By-product Adsorbent of Organic Pollutant from Wastewater: Adsorption of Phenol. *Energy Procedia*. 18, 905-914 doi:10.1016/j.egypro.2012.05.106

Lasode, O.A, Balogun, A.O, and Aremu, A.S. (2011). Generation, Management Challenges and Prospects of Wood Waste in Ilorin, Nigeria. *The Nigerian Engineer*, 42-45

Lin, Y, Jing, S, Lee, D, Wang, T (2002). Nutrient removal from aquaculture wastewater using a constructed wetlands system. *Aquaculture*. 209, 169-184

Lokhande, RS, Singare, PU and Pimples, DS (2011). Study on Physico-Chemical Parameters of Waste Water Effluents from Taloja Industrial Area of Mumbai, India. *International Journal of Ecosystem*, 1 (1), 1-9 DOI: 10.5923/j.ije.20110101.01

Longe, EO and Ogundipe, AO (2010). Assessment of Wastewater discharge impact from a sewage treatment plant on lagoon water, Lagos, Nigeria. *Research Journal of Applied Science, Engineering and Technology.* 2(3), 274-282. ISSN: 2040-7467

Mamdouth NN, Kamar TE, Ebrahiem HM and Manssour HM (2004). Adsorption of Iron and Manganese Ions Using Low Cost Materials as Adsorbent. *Adsorpt. Sci. Technol*. 22(1):25-37.

McConnell, L and Munroe, MC (2011). Powering the Grid with Waste. Wood to Energy Case Study. Co-operative Extension Service, University of Florida, Institute of Food and Agricultural Sciences.

Mekarzia, A, Namane, A, Benrachedi, K and Belhaneche-Bensemra, N. (2013). Chemical production and characterisation of activated carbon from waste ‘coffee grounds’. *Int. J. Environment and Waste Management*, Vol. 12, No. 2, 2013, 154-166

.

Metcalf and Eddy, Inc (2003). *Wastewater Engineering: Treatment and Reuse*. 4th Edition. Tata McGraw-Hill Publishing Company Limited. New Delhi. Pages1819.

Metcalf and Eddy/Aecom Inc (2014a). *Wastewater Engineering: Treatment and Resource Recovery*. 5th Edition (Volume 1). McGraw-Hill Education, New York. Pages 1058.

Metcalf and Eddy/Aecom Inc (2014b). *Wastewater Engineering: Treatment and Resource Recovery*. 5th Edition (Volume 2). McGraw-Hill Education, New York. Pages 960.

Miller, D and Semmens, K (2002). Waste Management in Aquaculture. Aquaculture Information Series Publication #AQ02-1. Agriculture and Resource Economic Program, Division of Resource Management, College of Agriculture, Forestry and Consumer Sciences, West Virginia University, Morgantown, USA

Ministry of Environment, Government of Japan (2015). National Effluent Standards. http://www.env.go.jp/en/water/wq/nes.html Accessed 1/4/2019

Miod, MC, Yee LT, Nyanti, L, Ismail, N and Enang, JJJ (2009). Impact of Aquaculture on the Water Quality of Santubong River, Sarawak. International Conference on Water Resources (ICWR2009) 26 – 27 May 2009 | Bayview Hotel, Langkawi, Kedah, Malaysia

Moulick, S, Tanveer, M and Mukherjee, CK (2011). Evaluation of Nitrification Performance of a Trickling Filter with Nylon Pot Scrubber as Media. *International Journal of Science and Nature* Vol. 2(3)2011:515-518 ISSN2229–6441

Mylavarapu, R (2014). Impact of Phosphorus on Water Quality, SL 275, The Soil and Water Science Department, UF/IFAS Extension. Gainesville, FL 32611

National Environmental (Sanitation and Wastes Control) Regulations (2009), Federal Republic of Nigeria Official Gazette. No. 60 Vol.96, B1057-1102

National Environmental (Surface and Groundwater Quality Control) Regulations (2011), Federal Republic of Nigeria Official Gazette. No.136. Vol.98, B693-727

Nwannekanma, B, (2018). ‘Lagos Wastewater plants pack up, spark epidemic concerns’ in Property section, Guardian Newspaper. 16 July, 2018. Htts.m.guardian.ng/property/lag.

Oberdieck, A and Verreth, J, (2009). Preface. SustainAqua- Integrated Approach for A Sustainable and Healthy Freshwater Aquaculture -A handbook for Sustainable Aquaculture. EU Project No.: COLL-CT-2006-030384.

Ogunbode, EB, Fabunmi, FO, Ibrahim, SM, Jimoh, IO and Idowu, OO (2012). Management of Sawmill Wastes in Nigeria: Case Study of Minna, Niger State. *Greener Journal of Science Engineering and Technology Research*, 34-41. ISSN 2276-7835

Oladeji, AS and Sule, BF (2015). Electrical Load Survey and Forecast for a Decentralized Hybrid Power System at Elebu, Kwara State, Nigeria. *Nigerian Journal of Technology* (NIJOTECH) Vol. 34 No. 3, July 2015, pp. 591 – 598. ISSN: 0331-8443 www.nijotech.com http://dx.doi.org/10.4314/njt.v34i3.23

Olanlokun, OK (2012). Scavenging: A Vital Key in Sustainable Solid Waste Management. Proceedings of 4th Annual & 2nd International Conference of Civil Engineering, Civil_2012, University of Ilorin, Ilorin, Nigeria. 335-346

Olaolu, TD, Akpor, OB and Akor, CO (2014). Pollution indicators and pathogenic microorganisms in wastewater treatment: Implication on receiving waterbodies. *International Journal of Environmental Protection and Policy*. 2(6), 205-212.

Oram, B (2014). Dissolved Oxygen in Water. The Water Research Center. Http://www.water-research.net/index.php/dissovled-oxygen-in-water. Accessed 24/02/2016

Parihar, A and Malaviya, P (2013). Textile Wastewater Treatment using Sawdust as Adsorbent. *International Journal of Environmental Sciences.* Vol.2. No.3, 110-113.

Palaniappan, M, Gleick, PH, Allen, L, Cohen, MJ, Christian-Smith, J and Smith, C (2010). Clearing the Waters: A focus on water quality solutions. Ed by Ross, N. United Nations Environment Programme. ISBN: 978-92—807-3074-6

Pandharipande, SL, Urunkar, YD and Singh, A. (2012). Characterization and Adsorption Studies of Activated Carbon Prepared from Rice Husk, Sugarcane Bagasse and Sawdust. *International Journal of Advanced Engineering Technology*. Vol. III, Issue III, July-Sept, 2012, 60-62

Peláez-Cid, AA and Teutli-León, MMM (2012). Lignocellulosic Precursors used in the Elaboration of Activated Carbon *In*: Lignocellulosic Precursors Used in the Synthesis of Activated Carbon – Characterization Techniques and Applications in the Wastewater Treatment. VH Montoya & AB Petriciolet (Edt.), Intech, Rijeka, 1-14.

Politi, D and Sidiras, D (2012). Wastewater Treatment for Dyes and Heavy Metals using Modified Pine Sawdust as Adsorbent. *Procedia Engineering* 42 (2012), 1969 – 1982

Ragas, AMJ, Scheren, PAGM, Konterman, HI, Leuven, RSEW, Vugteveen, P, Lubberding, HJ, Niebeek, G and Stortelder, PBM. (2005). Effluent Standards for Developing Countries:

combing the technology and water quality-based approach. *Water Science and Technology* 152(9), 133-144.

Rashed, MN (2013) Adsorption Technique for the Removal of Organic Pollutants from Water and Wastewater *In*: Organic Pollutants-Monitoring, Risk and Treatment. Rashed, MN (Edt.). Intech, Croatia. http://dx.doi.org/10.5772/54048 ISBN– 978-953-51-0948-8, pp172-194

Resource Conservation and Recovery Act (RCRA), (2012). Code of Federal Regulations, (USA) Title 40. Vol. 27, section 261.2. Retrieved from: www.gpo.gov/fdsys/pkg/CFR-2012-title40-vol27/xml/ on 27-Jan-2014.

Sarkodie, PA, Agyapong, D, Larbi, GO and Owusu-Ansah, E (2014). A Comparative Study of the Quality of Wastewater from Tema Oil Refinery (TOR) against EPA standards and its effects on the Environment. *Civil and Environmental Research*, Vol 6 (6), 85-91. ISSN 2224-5790 (paper), ISSN 2225-0514 (online)

Sastry, SVAR, Rao, BS and Nahata, K (2013). Study of Parameters Before and After Treatment of Municipal Waste Water from an Urban Town. *Global Journal of Applied Environmental Sciences* ISSN 2248-9932 Volume 3, Number 1 (2013), pp. 41-48

Saswati G. and Ghosh UC. (2005): Studies on Adsorption Behaviour of Cr (VI) on Synthetic Hydrox Stannic oxide. *Water SA* 31(4):597-602

Scecoinstitute.com/support/documents/how water quality indicators work. Accessed 02-Oct-2018.

Schellenberg, T, Subramanian, V, Ganeshan, G, Tompkins, D and Pradeep, R (2020). The Evolving Context of Urban Wastewater Discharge Standards in Sustainability–The Case of India. *Front. Environ. Sci. 8:30.* doi: 10.3389/fenvs.2020.00030, 1-23

Seafood https://www.seafoodwatch.org/ocean-issues/fishing-and-farming-methods. Accessed 12-Jul-2019

Skodras G, Grammelis P, Kakaras E and Sakellaropoulous GP (2004**).** Evaluation of the environmental impact of waste wood co-utilisation for energy production. *Energy* (29) 2004, 2181- 2193

Standard Methods for the Examination of Water and Wastewater (1995) Ed. Eaton, AD, Clesceri, LS & Greenberg, AE. American Public Health Association, Washington

Sudaryanto Y, Hartono SB, Irawarty, W, Hindarso, H and Ismadji, S (2006). High surface area activated carbon prepared from cassava peel by chemical activation. *Bioresource Technology* 97 (2006), 734–739

Taiwo, AA (2009). Waste Management towards Sustainable Development in Nigeria. A Case Study of Lagos State, *International NGO Journal* (2009) 4 (4), 173-179.

Tashauoei HR, Hashemi S, Ardani R, Yavari Z. And Asadi-Ghalhari, M. (2016). Adsorption of Lead from Aqueous Solution by Modified Beech Sawdust. *J. Saf. Environ. Health Res* 1(1), 11–16

Tebbutt, THY (1998). Principles of Water Quality Control. 5th Edition, Butterworth Heinemann, Oxford. Pages 280.

Tillman DA (1978). Wood as an Energy Resource. Academic press N.Y. pp 65-85.
USEPA (United State Environmental protection Agency (2005). Environmental Education *In*: Management of Sawmill Wastes in Nigeria: Case Study of Minna, Niger State. *Greener Journal of Science Engineering and Technology Research*. Ogunbode, EB, Fabunmi, FO, Ibrahim, SM, Jimoh IO and Idowu, OO. (2012). ISSN 2276-7835, 34-41.

Tobin, EA, Ediagbonya, TF, Okojie OH and Asogun, DA (2016). Occupational Exposure to Wood Dust and Respiratory Health Status of Sawmill Workers in South-South Nigeria. *Journal of Pollution Effects and Control*. 4(1)1-6 http://dx.doi.org/10.4172/2375-4397.1000154

Turcios, AE and Papenbrock, J (2014). A Review. Sustainable Treatment of Aquaculture Effluents – What can We learn from the Past for the Future. *Sustainability* 2014, 6, 836-856

UN (2015). Transforming Our World: the 2030 Agenda for Sustainable Development. A.RES/70/1

UNEP/WHO/HABITAT/WSSCC (2004) Guidelines on Municipal Wastewater Management, UNEP/GPA, Co-ordination Office, The Hague, Netherlands

USAID MARKETS (2010) Best Management Practices for Fish Farming Package of Practices (POP), USAID Markets Programme – Nigeria, March 2010

Vargas, AMM, Cazetta, AL, Garcia, CA, Moraes, JCG, Nogami, EA, Lenzi, E, Costa, WF and Almeida, VC (2011). Preparation and Characterization of Activated Carbon from a new raw lignocellulosic material Flamboyant (Delonixregia) Pods. *Journal of Environmental Management 92 (2011)*, 178-184

Viswanathan, B, Neel, PI and Varadarajan, TK (2009). Methods of Activation and Specific Application of Carbon Materials. National Centre for Catalysis Research, Indian Institute of Technology, Madras

Wang, R and Liu, S. (2010). Activated Carbon from Extracted Sawdust Waste with Alkaline Activation by Physical Mixing. *Forest Products Journal*, May 2010, Vol. 60, No. 3, 276-281. **doi:** http://dx.doi.org/10.13073/0015-7473-60.3.276

Weiner, RF and Matthews R (2003). Environmental Engineering. 4th ed. Elsevier, Pages 484

White, PJ and Brown, PH (2010). Plant Nutrition for Sustainable Development and Global Health. *Annals of Botany*, Volume 105. Issue 7, June 2010. 1073-1080. https://doi.org/10.1093/aob/mcq085

Wiredbugs.com https://wiredbugs.com/fish-farming-business-in-nigeria/ accessed 12/07/2019

Worldatlas.com https://www.worldatlas.com/af.ng/kw/where-is-ilorin.html accessed 21/04/2018.

Yakout, SM and El-Deen, GS (2016). Characterization of activated carbon prepared by phosphoric acid activation of olive stones. *Arabian Journal of Chemistry* (2016) 9, S1155–S1162

Yeo, SE. Binkowski, FP & Morris, JE (2004).Aquaculture Effluents and Waste By-Products Characteristics, Potential Recovery, and Beneficial Reuse. *NCRC Technical Bulletins*. 6.

Zdravkov, BD, Cermák, JJ, Šefara, M and Janků, J (2007). Pore classification in the characterization of porous materials: A perspective. Central European Journal of Chemistry (2007), 5(2), 385-395

Zwain, HM, Vakili, M. and Dahlan, I (2014). Waste Material Adsorbents for Zinc Removal from Wastewater: A Comprehensive Review. *International Journal of Chemical Engineering*. Volume 2014, Article ID 347912, doi: http://dx.doi.org/10.11

PUBLICATIONS

Sule BF**,** Olanlokun, OK and Oladipupo, GS. (2019**).** Impact of Aquaculture Waste on Receiving Streams. *The Journal of Solid Waste Technology and Management*-Conference Proceedings, The 34th International Conference on Solid Waste Technology and Management, March 31 – April 3, 2019, Annapolis, MD, USA, 574-582, www.solid-waste.org@widener.edu, published by Widener University, Chester, PA, USA

Olanlokun, OK and Sule, B.F. (2017). Sawdust Management and Disposal through use in Aquaculture Wastewater Treatment. *The Journal of Solid Waste Technology and Management*-Conference Proceedings, The 32nd International Conference on Solid Waste Technology and Management, March 19-22, 2017. Philadelphia, USA, 196 – 206, www.solid-waste.org@widener.edu, published by Widener University, Chester, PA, USA

Olanlokun, O.K. and Sule, B.F. (2017). Effect of Absorbent Mass and Retention time on Sawdust-Treated Aquaculture Wastewater Effluent. *Journal of Research Information in Civil Engineering. Vol.14 (1)* 1211-1226

Appendix I Pore characterization Results of BET Plot for Sample Y (BB)

Quantachrome NovaWin - Data Acquisition and Reduction
for NOVA instruments
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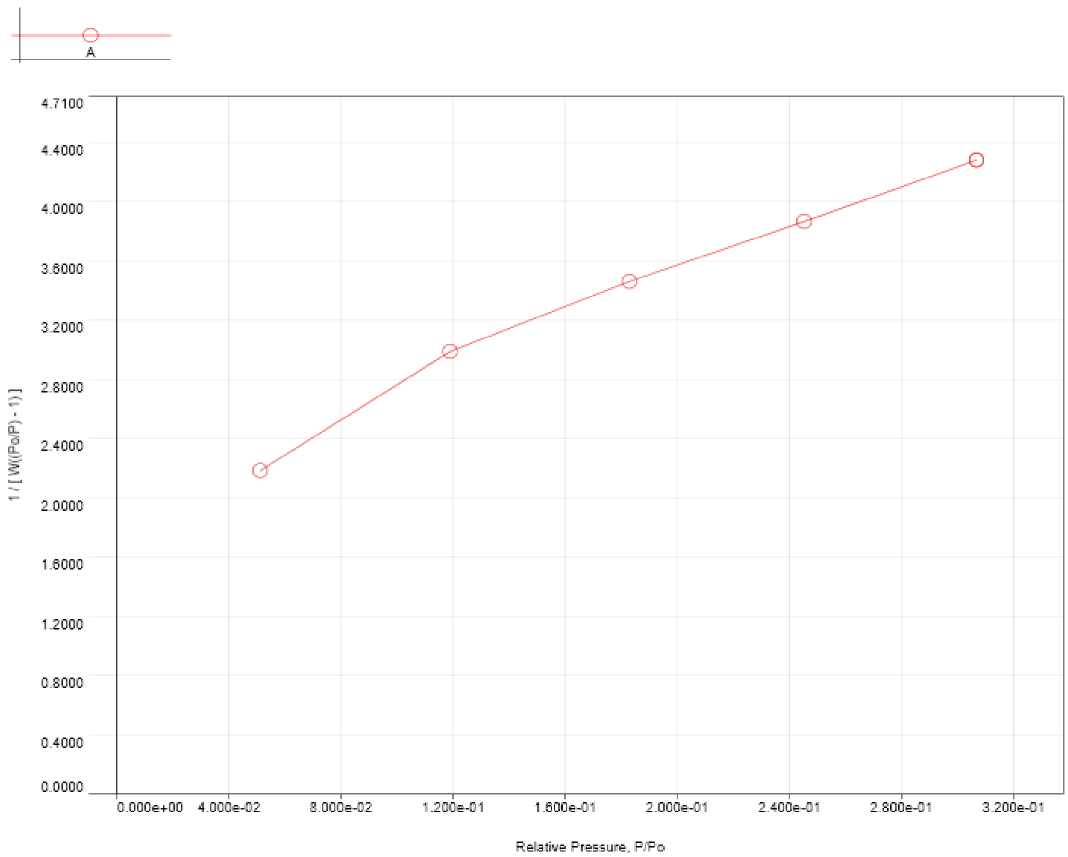
Analysis			**Report**		
Operator:	Abdulrahman Abdulkareem**Date:**2008/03/12		**Operator:**	Abdulrahman Abdulkareem	**Date:**2018/12/11
Sample ID:	Sample Y	**Filename:**	Sample Y.qps		
Sample Desc:		**Comment:**			
Sample weight:	0.12 g	**Sample Volume:**	1 cc		
Outgas Time:	3.0 hrs	**OutgasTemp:**	250.0 C		
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K		
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)
Analysis Time:	121.3 min	**End of run:**	2008/03/12 16:16:25	**Instrument:**	Nova Station A
Cell ID:	1				

Multi-Point BET Plot

Data Reduction Parameters

Adsorbate	Nitrogen	Temperature	77.350K		
	Molec. Wt.: 28.013	Cross Section:	16.200 Å²	Liquid Density:	0.808 g/cc



BET summary

Slope =	7.967
Intercept =	1.913e+00
Correlation coefficient, r =	0.990636
C constant=	5.165
Surface Area =	352.490 m²/g

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Report id:{359149675:20181211 134105893} Page 1 of 1

Quantachrome NovaWin - Data Acquisition and Reduction
for NOVA instruments
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version 11.03

Analysis			**Report**		
Operator:	Abdulrahman Abdulkareem**Date:**2008/03/12		**Operator:**	Abdulrahman Abdulkareem **Date:**2018/12/11	
Sample ID:	Sample Y	**Filename:**	Sample Y.qps		
Sample Desc:		**Comment:**			
Sample weight:	0.12 g	**Sample Volume:**	1 cc		
Outgas Time:	3.0 hrs	**OutgasTemp:**	250.0 C		
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K		
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)
Analysis Time:	121.3 min	**End of run:**	2008/03/12 16:16:25	**Instrument:**	Nova Station A
Cell ID:	1				

Multi-Point BET

Data Reduction Parameters Data

Adsorbate	Nitrogen	Temperature	77.350K		
	Molec. Wt.: 28.013	Cross Section:	16.200 Å²	Liquid Density:	0.808 g/cc

Multi-Point BET Data

Relative Pressure [P/Po]	Volume @ STP [cc/g]	1 / [W((Po/P) - 1)]	Relative Pressure [P/Po]	Volume @ STP [cc/g]	1 / [W((Po/P) - 1)]
5.11240e-02	19.7404	2.1838e+00	2.45255e-01	67.2588	3.8656e+00
1.18927e-01	36.1535	2.9872e+00	3.06870e-01	82.7900	4.2787e+00
1.82912e-01	51.7627	3.4602e+00			

BET summary

Slope =	7.967
Intercept =	1.913e+00
Correlation coefficient, r =	0.990636
C constant=	5.165
Surface Area =	352.490 m²/g

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Report id:{284608618:20181211 134219104} Page 1 of 1

Langmuir Data for Characterisation of Sample BB (Y)

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Analysis				**Report**		
Operator:	Abdulrahman Abdulkareem	**Date:**2008/03/12		**Operator:**	Abdulrahman Abdulkareem	**Date:**2018/12/11
Sample ID:	Sample Y	**Filename:**	Sample Y.qps			
Sample Desc:		**Comment:**				
Sample weight:	0.12 g	**Sample Volume:**	1 cc			
Outgas Time:	3.0 hrs	**OutgasTemp:**	250.0 C			
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K			
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)	
Analysis Time:	121.3 min	**End of run:**	2008/03/12 16:16:25	**Instrument:**	Nova Station A	
Cell ID:	1					

Langmuir

Data Reduction Parameters Data

Adsorbate	Nitrogen	Temperature	77.350K		
	Molec. Wt.: 28.013	Cross Section:	16.200 Å²	Liquid Density:	0.808 g/cc

Langmuir Data

P/Po	P/Po/W [(g/g)]	P/Po	P/Po/W [(g/g)]
5.11240e-02	2.0721e+00	2.45255e-01	2.9176e+00
1.18927e-01	2.6320e+00	3.06870e-01	2.9657e+00
1.82912e-01	2.8273e+00		

Langmuir summary

Slope = 3.27878
Intercept = 2.08942
Correlation coefficient, r = 0.907

Surface Area = 1062.139 m²/g

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Report id:{8160906:20181211 13424208} Page 1 of 1

DR Method Pore Characterisation for Sample BB (Y)

Quantachrome NovaWin - Data Acquisition and Reduction
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version 11.03

Analysis				**Report**			
Operator:	Abdulrahman Abdulkareem	**Date:**2008/03/12		**Operator:**	Abdulrahman Abdulkareem	**Date:**2018/12/11	
Sample ID:	Sample Y	**Filename:**	Sample Y.qps				
Sample Desc:		**Comment:**					
Sample weight:	0.12 g	**Sample Volume:**	1 cc				
Outgas Time:	3.0 hrs	**OutgasTemp:**	250.0 C				
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K				
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)		
Analysis Time:	121.3 min	**End of run:**	2008/03/12 16:16:25	**Instrument:**	Nova Station A		
Cell ID:	1						

DR method

Data Reduction Parameters Data

DR method	Affinity coefficient (ß): 0.3300						
Adsorbate	Nitrogen	Temperature	77.350K				
	Molec. Wt.: 28.013	Cross Section:	16.200 Å²	Liquid Density:	0.808 g/cc		
	Critical Temp.: 126.200 K	Critical Press.:	33.500 atm	SuperCritic. K.:	1.000		
Adsorbent	Carbon						
	DR. Exp (n): 2.000						

DR method Data

Log2(P/Po)	Weight Adsorbed [(g)]	Log2(P/Po)	Weight Adsorbed [(g)]
1.667650e+00	2.9607e-03	3.725663e-01	1.0087e-02
8.551062e-01	5.4223e-03	2.632158e-01	1.2417e-02
5.442866e-01	7.7633e-03		

DR method summary

Slope =	-4.278e-01
Intercept =	1.431e-02
Correlation Coefficient =	0.9839
Average Pore width =	5.749nm
Adsorption energy =	4.523 kJ/mol
Micropore volume =	0.148 cc/g
Micropore surface area =	415.155 m²/g

Analysis
Operator: Abdulrahman Abdulkareem **Date:**2008/03/12
Sample ID: Sample Y **Filename:**

Report
Operator: Abdulrahman Abdulkareem **Date:**2018/12/11
Sample Y.qps

DA Method Micropore Analysis Data continued

Diameter [nm]	dV(d) [cc/nm/g]	Diameter [nm]	dV(d) [cc/nm/g]
4.66000e+00	4.43903e-02	5.34000e+00	2.83738e-02
4.68000e+00	4.37982e-02	5.36000e+00	2.80128e-02
4.70000e+00	4.32144e-02	5.38000e+00	2.76571e-02
4.72000e+00	4.26389e-02	5.40000e+00	2.73065e-02
4.74000e+00	4.20716e-02	5.42000e+00	2.69611e-02
4.76000e+00	4.15123e-02	5.44000e+00	2.66207e-02
4.78000e+00	4.09610e-02	5.46000e+00	2.62852e-02
4.80000e+00	4.04175e-02	5.48000e+00	2.59545e-02
4.82000e+00	3.98818e-02	5.50000e+00	2.56287e-02
4.84000e+00	3.93538e-02	5.52000e+00	2.53076e-02
4.86000e+00	3.88334e-02	5.54000e+00	2.49911e-02
4.88000e+00	3.83205e-02	5.56000e+00	2.46792e-02
4.90000e+00	3.78150e-02	5.58000e+00	2.43719e-02
4.92000e+00	3.73167e-02	5.60000e+00	2.40689e-02
4.94000e+00	3.68257e-02	5.62000e+00	2.37703e-02
4.96000e+00	3.63417e-02	5.64000e+00	2.34761e-02
4.98000e+00	3.58648e-02	5.66000e+00	2.31860e-02
5.00000e+00	3.53948e-02	5.68000e+00	2.29002e-02
5.02000e+00	3.49316e-02	5.70000e+00	2.26184e-02
5.04000e+00	3.44751e-02	5.72000e+00	2.23407e-02
5.06000e+00	3.40253e-02	5.74000e+00	2.20670e-02
5.08000e+00	3.35820e-02	5.76000e+00	2.17972e-02
5.10000e+00	3.31451e-02	5.78000e+00	2.15312e-02
5.12000e+00	3.27146e-02	5.80000e+00	2.12691e-02
5.14000e+00	3.22904e-02	5.82000e+00	2.10107e-02
5.16000e+00	3.18724e-02	5.84000e+00	2.07559e-02
5.18000e+00	3.14605e-02	5.86000e+00	2.05048e-02
5.20000e+00	3.10545e-02	5.88000e+00	2.02573e-02
5.22000e+00	3.06545e-02	5.90000e+00	2.00133e-02
5.24000e+00	3.02603e-02	5.92000e+00	1.97727e-02
5.26000e+00	2.98718e-02	5.94000e+00	1.95356e-02
5.28000e+00	2.94890e-02	5.96000e+00	1.93018e-02
5.30000e+00	2.91118e-02	5.98000e+00	1.90713e-02
5.32000e+00	2.87401e-02		

DA method summary

Best E =	0.807 kJ/mol
Best n =	1.000
DA Micropore Volume =	0.318 cc/g
Pore Diameter (mode)=	2.800e+00 nm

Analysis				**Report**			
Operator:	Abdulrahman Abdulkareem	**Date:**2008/03/12		**Operator:**	Abdulrahman Abdulkareem	**Date:**2018/12/11	
Sample ID:	Sample Y	**Filename:**	Sample Y.qps				
Sample Desc:		**Comment:**					
Sample weight:	0.12 g	**Sample Volume:**	1 cc				
Outgas Time:	3.0 hrs	**OutgasTemp:**	250.0 C				
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K				
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)		
Analysis Time:	121.3 min	**End of run:**	2008/03/12 16:16:25	**Instrument:**	Nova Station A		
Cell ID:	1						

DFT method Pore Size Distribution

Data Reduction Parameters Data

DFT method	**Calc. Model:** N2 at 77 K on carbon (slit pore, NLDFT equilibrium model)				
	Rel. press. range: 0.0000 - 1.0000			**Moving pt. avg:** off	
Adsorbate	Nitrogen	Temperature	77.350K		
	Molec. Wt.: 28.013	Cross Section:	16.200 Å²	**Liquid Density:**	0.808 g/cc

DFT method Pore Size Distribution Data

Pore width [nm]	Cumulative Pore Volume [cc/g]	Cumulative Surface Area [m²/g]	dV(d) [cc/nm/g]	dS(d) [m²/nm/g]
1.6879	5.1183e-04	6.2262e-01	2.8988e-03	3.4348e+00
1.7656	5.2490e-04	6.3744e-01	1.6832e-04	1.9066e-01
1.8469	8.9115e-03	9.7193e+00	1.0320e-01	1.1175e+02
1.9319	1.6694e-02	1.7776e+01	9.1544e-02	9.4771e+01
2.0208	2.2766e-02	2.3785e+01	6.8286e-02	6.7582e+01
2.1138	2.2966e-02	2.3975e+01	2.1580e-03	2.0418e+00
2.2111	3.0779e-02	3.1041e+01	8.0292e-02	7.2625e+01
2.3129	4.6077e-02	4.4270e+01	1.5032e-01	1.2998e+02
2.4194	5.9936e-02	5.5726e+01	1.3018e-01	1.0761e+02
2.5307	7.7213e-02	6.9381e+01	1.5515e-01	1.2262e+02
2.6472	9.8366e-02	8.5362e+01	1.8159e-01	1.3719e+02
2.7691	1.1904e-01	1.0029e+02	1.6966e-01	1.2254e+02

DFT method summary

Pore volume =	0.119 cc/g
Surface area =	100.292 m²/g
Lower confidence limit =	1.688 nm
Fitting error =	2.441 %
Pore width (Mode) =	2.647 nm
Moving point average :	off

Analysis			**Report**		
Operator:	Abdulrahman Abdulkareem**Date:**2008/03/12		**Operator:** Abdulrahman Abdulkareem **Date:**2018/12/11		
Sample ID:	Sample Y	**Filename:**	Sample Y.qps		
Sample Desc:		**Comment:**			
Sample weight:	0.12 g	**Sample Volume:**	1 cc		
Outgas Time:	3.0 hrs	**OutgasTemp:**	250.0 C		
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K		
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)
Analysis Time:	121.3 min	**End of run:**	2008/03/12 16:16:25	**Instrument:**	Nova Station A
Cell ID:	1				

Area-Volume Summary

Data Reduction Parameters Data

	Thermal Transpiration: on	**Eff. mol. diameter (D):** 3.54 Å		**Eff. cell stem diam. (d):** 4.0000 mm	
t-Method	**Calc. method:** de Boer				
BJH/DH method	**Moving pt. avg.:** off				
DR method	**Affinity coefficient (ß):** 0.3300				
HK method	**Tabulated data interval:** 1				
SF method	**Tabulated data interval:** 1				
DFT method	**Calc. Model:** N2 at 77 K on carbon (slit pore, NLDFT equilibrium model)				
	Rel. press. range: 0.0000 - 1.0000			**Moving pt. avg:** off	
Adsorbate	Nitrogen	**Temperature**	77.350K		
	Molec. Wt.: 28.013	**Cross Section:**	16.200 Å²	**Liquid Density:**	0.808 g/cc
	Critical Temp.: 126.200 K	**Critical Press.:**	33.500 atm	**SuperCritic. K.:**	1.000
Adsorbent	Carbon				
	DR. Exp (n): 2.000				

Surface Area Data

SinglePoint BET	2.498e+02 m²/g
MultiPoint BET	3.525e+02 m²/g
Langmuir surface area	1.062e+03 m²/g
BJH method cumulative adsorption surface area	4.427e+02 m²/g
DH method cumulative adsorption surface area	4.725e+02 m²/g
t-method external surface area	3.525e+02 m²/g
DR method micropore area	4.152e+02 m²/g
DFT cumulative surface area	1.003e+02 m²/g

Pore Volume Data

BJH method cumulative adsorption pore volume	2.166e-01 cc/g
DH method cumulative adsorption pore volume	2.221e-01 cc/g
DR method micropore volume	1.475e-01 cc/g
HK method micropore volume	6.855e-02 cc/g
SF method micropore volume	1.970e-02 cc/g
DFT method cumulative pore volume	1.190e-01 cc/g

Pore Size Data

BJH method adsorption pore Diameter (Mode Dv(d))	2.132e+00 nm
DH method adsorption pore Diameter (Mode Dv(d))	2.132e+00 nm
DR method micropore Pore width	5.749e+00 nm
DA method pore Diameter (Mode)	2.800e+00 nm
HK method pore Diameter (Mode)	3.675e-01 nm
SF method pore Diameter (Mode)	4.523e-01 nm
DFT pore Diameter (Mode)	2.647e+00 nm

Results of Pore Analysis for Sample X (Isoberlina *doka* –'BH' sawdust)

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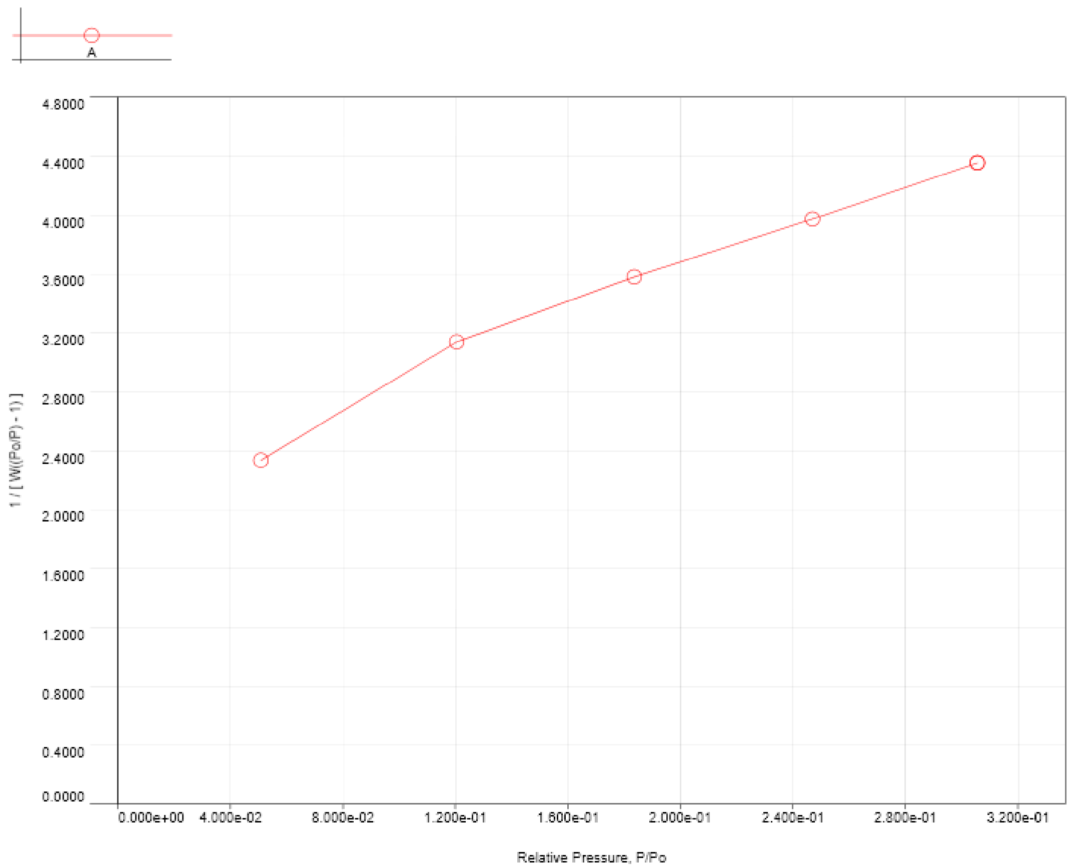
Analysis				**Report**	
Operator:	Abdulrahman Abdulkareem **Date:**2008/03/12			**Operator:** Abdulrahman Abdulkareem	**Date:**2018/12/11
Sample ID:	Sample X	**Filename:**	Sample X.qps		
Sample Desc:		**Comment:**			
Sample weight:	0.12 g	**Sample Volume:**	1 cc		
Outgas Time:	3.0 hrs	**OutgasTemp:**	50.0 C		
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K		
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)
Analysis Time:	107.1 min	**End of run:**	2008/03/12 0:50:58	**Instrument:**	Nova Station A
Cell ID:	1				

Multi-Point BET Plot

Data Reduction Parameters

Adsorbate	Nitrogen	Temperature	77.350K		
	Molec. Wt.: 28.013	Cross Section:	16.200 Å²	Liquid Density:	0.808 g/cc



BET summary

Slope =	7.694
Intercept =	2.080e+00
Correlation coefficient, r =	0.989829
C constant=	4.698
Surface Area =	356.276 m²/g

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Analysis			**Report**		
Operator:	Abdulrahman Abdulkareem**Date:**2008/03/12		**Operator:**	Abdulrahman Abdulkareem	**Date:**2018/12/11
Sample ID:	Sample X	**Filename:**	Sample X.qps		
Sample Desc:		**Comment:**			
Sample weight:	0.12 g	**Sample Volume:**	1 cc		
Outgas Time:	3.0 hrs	**OutgasTemp:**	50.0 C		
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K		
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)
Analysis Time:	107.1 min	**End of run:**	2008/03/12 0:50:58	**Instrument:**	Nova Station A
Cell ID:	1				

Multi-Point BET

Data Reduction Parameters Data

Adsorbate	Nitrogen		Temperature	77.350K		
	Molec. Wt.:	28.013	Cross Section:	16.200 Å²	Liquid Density:	0.808 g/cc

Multi-Point BET Data

Relative Pressure [P/Po]	Volume @ STP [cc/g]	1 / [W((Po/P) - 1)]	Relative Pressure [P/Po]	Volume @ STP [cc/g]	1 / [W((Po/P) - 1)]
5.07830e-02	18.3321	2.3350e+00	2.46890e-01	66.0051	3.9739e+00
1.20424e-01	34.9037	3.1385e+00	3.05591e-01	80.8544	4.3548e+00
1.83533e-01	50.2305	3.5806e+00			

BET summary

Slope =	7.694
Intercept =	2.080e+00
Correlation coefficient, r =	0.989829
C constant=	4.698
Surface Area =	356.276 m²/g

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Analysis					
Operator:	Abdulrahman Abdulkareem Date:2008/03/12		Report Operator: Abdulrahman Abdulkareem Date:2018/12/11		
Sample ID:	Sample X	Filename:	Sample X.qps		
Sample Desc:		Comment:			
Sample weight:	0.12 g	Sample Volume:	1 cc		
Outgas Time:	3.0 hrs	OutgasTemp:	50.0 C		
Analysis gas:	Nitrogen	Bath Temp:	273.0 K		
Press. Tolerance:	0.100/0.100 (ads/des)	Equil time:	60/60 sec (ads/des)	Equil timeout:	240/240 sec (ads/des)
Analysis Time:	107.1 min	End of run:	2008/03/12 0:50:58	Instrument:	Nova Station A
Cell ID:	1				

Langmuir

Data Reduction Parameters Data

Adsorbate	Nitrogen		Temperature	77.350K		
	Molec. Wt.:	28.013	Cross Section:	16.200 Å²	Liquid Density:	0.808 g/cc

Langmuir Data

P/Po	P/Po/W [(g/g)]	P/Po	P/Po/W [(g/g)]
5.07830e-02	2.2164e+00	2.46890e-01	2.9928e+00
1.20424e-01	2.7605e+00	3.05591e-01	3.0240e+00
1.83533e-01	2.9235e+00		

Langmuir summary

Slope = 2.94710
Intercept = 2.24872
Correlation coefficient, r = 0.891

Surface Area = 1181.675 m²/g

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Analysis			**Report**		
Operator:	Abdulrahman Abdulkareem**Date:**2008/03/12		**Operator:** Abdulrahman Abdulkareem	**Date:**2018/12/11	
Sample ID:	Sample X	**Filename:**	Sample X.qps		
Sample Desc:		**Comment:**			
Sample weight:	0.12 g	**Sample Volume:**	1 cc		
Outgas Time:	3.0 hrs	**OutgasTemp:**	50.0 C		
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K		
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)
Analysis Time:	107.1 min	**End of run:**	2008/03/12 0:50:58	**Instrument:**	Nova Station A
Cell ID:	1				

DR method

Data Reduction Parameters Data

DR method	**Affinity coefficient (ß):** 0.3300				
Adsorbate	Nitrogen	**Temperature**	77.350K		
	Molec. Wt.: 28.013	**Cross Section:**	16.200 Å²	**Liquid Density:**	0.808 g/cc
	Critical Temp.: 126.200 K	**Critical Press.:**	33.500 atm	**SuperCritic. K.:**	1.000
Adsorbent	Carbon				
	DR. Exp (n): 2.000				

DR method Data

Log2(P/Po)	Weight Adsorbed [(g)]	Log2(P/Po)	Weight Adsorbed [(g)]
1.675165e+00	2.7494e-03	3.690520e-01	9.8994e-03
8.450885e-01	5.2348e-03	2.650802e-01	1.2126e-02
5.421168e-01	7.5335e-03		

DR method summary

Slope =	-4.413e-01
Intercept =	1.410e-02
Correlation Coefficient =	0.9845
Average Pore width =	5.839nm
Adsorption energy =	4.453 kJ/mol
Micropore volume =	0.145 cc/g
Micropore surface area =	409.140 m²/g

Analysis
Operator: Abdulrahman Abdulkareem **Date:**2008/03/12
Sample ID: Sample X **Filename:** Sample X.qps

Report
Operator: Abdulrahman Abdulkareem **Date:**2018/12/11

DA Method Micropore Analysis Data continued

Diameter [nm]	dV(d) [cc/nm/g]	Diameter [nm]	dV(d) [cc/nm/g]
4.66000e+00	4.60206e-02	5.34000e+00	2.95131e-02
4.68000e+00	4.54124e-02	5.36000e+00	2.91398e-02
4.70000e+00	4.48127e-02	5.38000e+00	2.87718e-02
4.72000e+00	4.42213e-02	5.40000e+00	2.84092e-02
4.74000e+00	4.36381e-02	5.42000e+00	2.80517e-02
4.76000e+00	4.30630e-02	5.44000e+00	2.76994e-02
4.78000e+00	4.24960e-02	5.46000e+00	2.73522e-02
4.80000e+00	4.19369e-02	5.48000e+00	2.70099e-02
4.82000e+00	4.13857e-02	5.50000e+00	2.66726e-02
4.84000e+00	4.08423e-02	5.52000e+00	2.63401e-02
4.86000e+00	4.03066e-02	5.54000e+00	2.60124e-02
4.88000e+00	3.97784e-02	5.56000e+00	2.56894e-02
4.90000e+00	3.92577e-02	5.58000e+00	2.53710e-02
4.92000e+00	3.87445e-02	5.60000e+00	2.50572e-02
4.94000e+00	3.82385e-02	5.62000e+00	2.47478e-02
4.96000e+00	3.77398e-02	5.64000e+00	2.44429e-02
4.98000e+00	3.72481e-02	5.66000e+00	2.41424e-02
5.00000e+00	3.67635e-02	5.68000e+00	2.38461e-02
5.02000e+00	3.62859e-02	5.70000e+00	2.35540e-02
5.04000e+00	3.58150e-02	5.72000e+00	2.32662e-02
5.06000e+00	3.53510e-02	5.74000e+00	2.29824e-02
5.08000e+00	3.48936e-02	5.76000e+00	2.27026e-02
5.10000e+00	3.44427e-02	5.78000e+00	2.24268e-02
5.12000e+00	3.39984e-02	5.80000e+00	2.21549e-02
5.14000e+00	3.35604e-02	5.82000e+00	2.18869e-02
5.16000e+00	3.31287e-02	5.84000e+00	2.16227e-02
5.18000e+00	3.27033e-02	5.86000e+00	2.13622e-02
5.20000e+00	3.22840e-02	5.88000e+00	2.11054e-02
5.22000e+00	3.18707e-02	5.90000e+00	2.08522e-02
5.24000e+00	3.14634e-02	5.92000e+00	2.06025e-02
5.26000e+00	3.10619e-02	5.94000e+00	2.03564e-02
5.28000e+00	3.06663e-02	5.96000e+00	2.01137e-02
5.30000e+00	3.02763e-02	5.98000e+00	1.98745e-02
5.32000e+00	2.98919e-02		

DA method summary

Best E =	0.780 kJ/mol
Best n =	1.000
DA Micropore Volume =	0.322 cc/g
Pore Diameter (mode)=	2.840e+00 nm

Analysis				**Report**		
Operator:	Abdulrahman Abdulkareem	**Date:** 2008/03/12		**Operator:**	Abdulrahman Abdulkareem	**Date:** 2018/12/11
Sample ID:	Sample X	**Filename:**	Sample X.qps			
Sample Desc:		**Comment:**				
Sample weight:	0.12 g	**Sample Volume:**	1 cc			
Outgas Time:	3.0 hrs	**OutgasTemp:**	50.0 C			
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K			
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)	
Analysis Time:	107.1 min	**End of run:**	2008/03/12 0:50:58	**Instrument:**	Nova Station A	
Cell ID:	1					

DFT method Pore Size Distribution

Data Reduction Parameters Data

DFT method	Calc. Model: N2 at 77 K on carbon (slit pore, NLDFT equilibrium model)				
	Rel. press. range: 0.0000 - 1.0000			Moving pt. avg: off	
Adsorbate	Nitrogen	Temperature	77.350K		
	Molec. Wt.: 28.013	Cross Section:	16.200 Å²	Liquid Density:	0.808 g/cc

DFT method Pore Size Distribution Data

Pore width [nm]	Cumulative Pore Volume [cc/g]	Cumulative Surface Area [m²/g]	dV(d) [cc/nm/g]	dS(d) [m²/nm/g]
1.6879	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00
1.7656	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00
1.8469	7.3712e-03	7.9822e+00	9.0702e-02	9.8221e+01
1.9319	1.4966e-02	1.5845e+01	8.9340e-02	9.2489e+01
2.0208	2.1005e-02	2.1821e+01	6.7911e-02	6.7211e+01
2.1138	2.1357e-02	2.2154e+01	3.7838e-03	3.5800e+00
2.2111	2.9495e-02	2.9516e+01	8.3650e-02	7.5662e+01
2.3129	4.4918e-02	4.2852e+01	1.5154e-01	1.3103e+02
2.4194	5.8890e-02	5.4402e+01	1.3125e-01	1.0850e+02
2.5307	7.6312e-02	6.8170e+01	1.5645e-01	1.2364e+02
2.6472	9.7519e-02	8.4192e+01	1.8206e-01	1.3755e+02
2.7691	1.1469e-01	9.6596e+01	1.4095e-01	1.0180e+02

DFT method summary

Pore volume =	0.115 cc/g
Surface area =	96.596 m²/g
Lower confidence limit =	1.688 nm
Fitting error =	2.412 %
Pore width (Mode) =	2.647 nm
Moving point average :	off

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Analysis				**Report**			
Operator:	Abdulrahman Abdulkareem	**Date:** 2008/03/12		**Operator:**	Abdulrahman Abdulkareem	**Date:** 2018/12/11	
Sample ID:	Sample X	**Filename:**	Sample X.qps				
Sample Desc:		**Comment:**					
Sample weight:	0.12 g	**Sample Volume:**	1 cc				
Outgas Time:	3.0 hrs	**OutgasTemp:**	50.0 C				
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K				
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)		
Analysis Time:	107.1 min	**End of run:**	2008/03/12 0:50:58	**Instrument:**	Nova Station A		
Cell ID:	1						

Area-Volume Summary

Data Reduction Parameters Data

	Thermal Transpiration: on	Eff. mol. diameter (D): 3.54 Å		Eff. cell stem diam. (d): 4.0000 mm	
t-Method	Calc. method: de Boer				
BJH/DH method	Moving pt. avg.: off				
DR method	Affinity coefficient (ß): 0.3300				
HK method	Tabulated data interval: 1				
SF method	Tabulated data interval: 1				
DFT method	Calc. Model: N2 at 77 K on carbon (slit pore, NLDFT equilibrium model)				
	Rel. press. range: 0.0000 - 1.0000			Moving pt. avg: off	
Adsorbate	Nitrogen	Temperature	77.350K		
	Molec. Wt.: 28.013	Cross Section:	16.200 Å²	Liquid Density:	0.808 g/cc
	Critical Temp.: 126.200 K	Critical Press.:	33.500 atm	SuperCritic. K.:	1.000
Adsorbent	Carbon				
	DR. Exp (n): 2.000				

Surface Area Data

SinglePoint BET	2.444e+02 m²/g
MultiPoint BET	3.563e+02 m²/g
Langmuir surface area	1.182e+03 m²/g
BJH method cumulative adsorption surface area	4.385e+02 m²/g
DH method cumulative adsorption surface area	4.682e+02 m²/g
t-method external surface area	3.563e+02 m²/g
DR method micropore area	4.091e+02 m²/g
DFT cumulative surface area	9.660e+01 m²/g

Pore Volume Data

BJH method cumulative adsorption pore volume	2.146e-01 cc/g
DH method cumulative adsorption pore volume	2.200e-01 cc/g
DR method micropore volume	1.454e-01 cc/g
HK method micropore volume	6.600e-02 cc/g
SF method micropore volume	1.786e-02 cc/g
DFT method cumulative pore volume	1.147e-01 cc/g

Pore Size Data

BJH method adsorption pore Diameter (Mode Dv(d))	2.138e+00 nm
DH method adsorption pore Diameter (Mode Dv(d))	2.138e+00 nm
DR method micropore Pore width	5.839e+00 nm
DA method pore Diameter (Mode)	2.840e+00 nm
HK method pore Diameter (Mode)	3.675e-01 nm
SF method pore Diameter (Mode)	4.523e-01 nm
DFT pore Diameter (Mode)	2.647e+00 nm

Results of Pore Analysis for Sample Z (Commercial Activated Carbon)

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Analysis				**Report**			
Operator:	Abdulrahman Abdulkareem	**Date:** 2008/03/12		**Operator:**	Abdulrahman Abdulkareem	**Date:** 2018/12/11	
Sample ID:	Sample Z	**Filename:**	Sample Z .qps				
Sample Desc:		**Comment:**					
Sample weight:	0.12 g	**Sample Volume:**	1 cc				
Outgas Time:	3.0 hrs	**OutgasTemp:**	250.0 C				
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K				
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)		
Analysis Time:	114.9 min	**End of run:**	2008/03/12 21:36:04	**Instrument:**	Nova Station B		
Cell ID:	2						

Multi-Point BET

Data Reduction Parameters Data

Adsorbate	Nitrogen		Temperature	77.350K			
	Molec. Wt.:	28.013	Cross Section:	16.200 Å²	Liquid Density:	0.808 g/cc	

Multi-Point BET Data

Relative Pressure [P/Po]	Volume @ STP [cc/g]	1 / [W((Po/P) - 1)]	Relative Pressure [P/Po]	Volume @ STP [cc/g]	1 / [W((Po/P) - 1)]
5.88110e-02	14.7600	3.3872e+00	2.32751e-01	56.7881	4.2741e+00
1.07707e-01	26.4522	3.6511e+00	3.07160e-01	75.3558	4.7072e+00
1.82751e-01	44.5324	4.0177e+00			

BET summary

Slope =	5.251
Intercept =	3.074e+00
Correlation coefficient, r =	0.999392
C constant=	2.708
Surface Area =	418.333 m²/g

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Analysis				**Report**			
Operator:	Abdulrahman Abdulkareem	**Date:**2008/03/12		**Operator:**	Abdulrahman Abdulkareem	**Date:**2018/12/11	
Sample ID:	Sample Z	**Filename:**	Sample Z .qps				
Sample Desc:		**Comment:**					
Sample weight:	0.12 g	**Sample Volume:**	1 cc				
Outgas Time:	3.0 hrs	**OutgasTemp:**	250.0 C				
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K				
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)		
Analysis Time:	114.9 min	**End of run:**	2008/03/12 21:36:04	**Instrument:**	Nova Station B		
Cell ID:	2						

Langmuir

Data Reduction Parameters Data

Adsorbate	Nitrogen	Temperature	77.350K		
	Molec. Wt.: 28.013	Cross Section:	16.200 Å²	Liquid Density:	0.808 g/cc

Langmuir Data

P/Po	P/Po/W [(g/g)]	P/Po	P/Po/W [(g/g)]
5.88110e-02	3.1880e+00	2.32751e-01	3.2793e+00
1.07707e-01	3.2579e+00	3.07160e-01	3.2614e+00
1.82751e-01	3.2835e+00		

Langmuir summary

Slope =	0.25913
Intercept =	3.20793
Correlation coefficient, r =	0.663
Surface Area =	13439.253 m²/g

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Analysis				**Report**			
Operator:	Abdulrahman Abdulkareem	**Date:**2008/03/12		**Operator:**	Abdulrahman Abdulkareem	**Date:**2018/12/11	
Sample ID:	Sample Z	**Filename:**	Sample Z .qps				
Sample Desc:		**Comment:**					
Sample weight:	0.12 g	**Sample Volume:**	1 cc				
Outgas Time:	3.0 hrs	**OutgasTemp:**	250.0 C				
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K				
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)		
Analysis Time:	114.9 min	**End of run:**	2008/03/12 21:36:04	**Instrument:**	Nova Station B		
Cell ID:	2						

DR method

Data Reduction Parameters Data

DR method	Affinity coefficient (ß): 0.3300				
Adsorbate	Nitrogen	Temperature	77.350K		
	Molec. Wt.: 28.013	Cross Section:	16.200 Å²	Liquid Density:	0.808 g/cc
	Critical Temp.: 126.200 K	Critical Press.:	33.500 atm	SuperCritic. K.:	1.000
Adsorbent	Carbon				
	DR. Exp (n): 2.000				

DR method Data

Log2(P/Po)	Weight Adsorbed [(g)]	Log2(P/Po)	Weight Adsorbed [(g)]
1.514232e+00	2.2137e-03	4.008263e-01	8.5170e-03
9.365518e-01	3.9673e-03	2.627950e-01	1.1302e-02
5.448510e-01	6.6789e-03		

DR method summary

Slope =	-5.533e-01
Intercept =	1.430e-02
Correlation Coefficient =	0.9921
Average Pore width =	6.538nm
Adsorption energy =	3.977 kJ/mol
Micropore volume =	0.147 cc/g
Micropore surface area =	414.984 m²/g

Analysis			**Report**		
Operator:	Abdulrahman Abdulkareem	**Date:**2008/03/12	**Operator:**	Abdulrahman Abdulkareem	**Date:**2018/12/11
Sample ID:	Sample Z	**Filename:**	Sample Z .qps		

DA Method Micropore Analysis Data continued

Diameter [nm]	dV(d) [cc/nm/g]	Diameter [nm]	dV(d) [cc/nm/g]
4.66000e+00	5.96532e-02	5.34000e+00	3.90154e-02
4.68000e+00	5.89090e-02	5.36000e+00	3.85385e-02
4.70000e+00	5.81738e-02	5.38000e+00	3.80682e-02
4.72000e+00	5.74476e-02	5.40000e+00	3.76042e-02
4.74000e+00	5.67303e-02	5.42000e+00	3.71465e-02
4.76000e+00	5.60218e-02	5.44000e+00	3.66950e-02
4.78000e+00	5.53222e-02	5.46000e+00	3.62496e-02
4.80000e+00	5.46313e-02	5.48000e+00	3.58102e-02
4.82000e+00	5.39491e-02	5.50000e+00	3.53768e-02
4.84000e+00	5.32756e-02	5.52000e+00	3.49494e-02
4.86000e+00	5.26105e-02	5.54000e+00	3.45277e-02
4.88000e+00	5.19540e-02	5.56000e+00	3.41117e-02
4.90000e+00	5.13059e-02	5.58000e+00	3.37014e-02
4.92000e+00	5.06661e-02	5.60000e+00	3.32967e-02
4.94000e+00	5.00346e-02	5.62000e+00	3.28974e-02
4.96000e+00	4.94113e-02	5.64000e+00	3.25036e-02
4.98000e+00	4.87960e-02	5.66000e+00	3.21151e-02
5.00000e+00	4.81889e-02	5.68000e+00	3.17319e-02
5.02000e+00	4.75896e-02	5.70000e+00	3.13540e-02
5.04000e+00	4.69982e-02	5.72000e+00	3.09811e-02
5.06000e+00	4.64147e-02	5.74000e+00	3.06133e-02
5.08000e+00	4.58388e-02	5.76000e+00	3.02505e-02
5.10000e+00	4.52705e-02	5.78000e+00	2.98926e-02
5.12000e+00	4.47098e-02	5.80000e+00	2.95396e-02
5.14000e+00	4.41565e-02	5.82000e+00	2.91914e-02
5.16000e+00	4.36106e-02	5.84000e+00	2.88478e-02
5.18000e+00	4.30720e-02	5.86000e+00	2.85089e-02
5.20000e+00	4.25406e-02	5.88000e+00	2.81746e-02
5.22000e+00	4.20163e-02	5.90000e+00	2.78449e-02
5.24000e+00	4.14991e-02	5.92000e+00	2.75195e-02
5.26000e+00	4.09888e-02	5.94000e+00	2.71986e-02
5.28000e+00	4.04853e-02	5.96000e+00	2.68820e-02
5.30000e+00	3.99887e-02	5.98000e+00	2.65697e-02
5.32000e+00	3.94987e-02		

DA method summary

Best E =	0.653 kJ/mol
Best n =	1.000
DA Micropore Volume =	0.370 cc/g
Pore Diameter (mode)=	3.000e+00 nm

Quantachrome NovaWin - Data Acquisition and Reduction
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Analysis				**Report**		
Operator:	Abdulrahman Abdulkareem	**Date:**2008/03/12		**Operator:** Abdulrahman Abdulkareem	**Date:**2018/12/11	
Sample ID:	Sample Z	**Filename:**	Sample Z .qps			
Sample Desc:		**Comment:**				
Sample weight:	0.12 g	**Sample Volume:**	1 cc			
Outgas Time:	3.0 hrs	**OutgasTemp:**	250.0 C			
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K			
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)	
Analysis Time:	114.9 min	**End of run:**	2008/03/12 21:36:04	**Instrument:**	Nova Station B	
Cell ID:	2					

DFT method Pore Size Distribution

Data Reduction Parameters Data

DFT method	**Calc. Model:** N2 at 77 K on carbon (slit pore, NLDFT equilibrium model)				
	Rel. press. range: 0.0000 - 1.0000			**Moving pt. avg:** off	
Adsorbate	Nitrogen	**Temperature**	77.350K		
	Molec. Wt.: 28.013	**Cross Section:**	16.200 Å²	**Liquid Density:**	0.808 g/cc

DFT method Pore Size Distribution Data

Pore width [nm]	Cumulative Pore Volume [cc/g]	Cumulative Surface Area [m²/g]	dV(d) [cc/nm/g]	dS(d) [m²/nm/g]
1.7656	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00
1.8469	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00
1.9319	6.3222e-03	6.5450e+00	7.4371e-02	7.6992e+01
2.0208	1.2652e-02	1.2809e+01	7.1181e-02	7.0447e+01
2.1138	1.3278e-02	1.3402e+01	6.7384e-03	6.3755e+00
2.2111	2.1587e-02	2.0917e+01	8.5390e-02	7.7236e+01
2.3129	3.6990e-02	3.4237e+01	1.5135e-01	1.3088e+02
2.4194	5.0917e-02	4.5749e+01	1.3082e-01	1.0814e+02
2.5307	6.8226e-02	5.9429e+01	1.5544e-01	1.2284e+02
2.6472	8.9349e-02	7.5387e+01	1.8134e-01	1.3700e+02
2.7691	1.0562e-01	8.7142e+01	1.3357e-01	9.6474e+01

DFT method summary

Pore volume =	0.106 cc/g
Surface area =	87.142 m²/g
Lower confidence limit =	1.766 nm
Fitting error =	2.978 %
Pore width (Mode) =	2.647 nm
Moving point average :	off

Analysis			**Report**		
Operator:	Abdulrahman Abdulkareem	**Date:**2008/03/12	**Operator:** Abdulrahman Abdulkareem	**Date:**2018/12/11	
Sample ID:	Sample Z	**Filename:**	Sample Z .qps		
Sample Desc:		**Comment:**			
Sample weight:	0.12 g	**Sample Volume:**	1 cc		
Outgas Time:	3.0 hrs	**OutgasTemp:**	250.0 C		
Analysis gas:	Nitrogen	**Bath Temp:**	273.0 K		
Press. Tolerance:	0.100/0.100 (ads/des)	**Equil time:**	60/60 sec (ads/des)	**Equil timeout:**	240/240 sec (ads/des)
Analysis Time:	114.9 min	**End of run:**	2008/03/12 21:36:04	**Instrument:**	Nova Station B
Cell ID:	2				

Area-Volume Summary

Data Reduction Parameters Data

	Thermal Transpiration: on	**Eff. mol. diameter (D):** 3.54 Å	**Eff. cell stem diam. (d):** 4.0000 mm
t-Method	**Calc. method:** de Boer		
BJH/DH method	**Moving pt. avg.:** off		
DR method	**Affinity coefficient (ß):** 0.3300		
HK method	**Tabulated data interval:** 1		
SF method	**Tabulated data interval:** 1		
DFT method	**Calc. Model:** N2 at 77 K on carbon (slit pore, NLDFT equilibrium model)		
	Rel. press. range: 0.0000 - 1.0000		**Moving pt. avg:** off
Adsorbate	Nitrogen	**Temperature** 77.350K	
	Molec. Wt.: 28.013	**Cross Section:** 16.200 Å²	**Liquid Density:** 0.808 g/cc
	Critical Temp.: 126.200 K	**Critical Press.:** 33.500 atm	**SuperCritic. K.:** 1.000
Adsorbent	Carbon		
	DR. Exp (n): 2.000		

Surface Area Data

SinglePoint BET	2.272e+02 m²/g
MultiPoint BET	4.183e+02 m²/g
Langmuir surface area	1.344e+04 m²/g
BJH method cumulative adsorption surface area	4.271e+02 m²/g
DH method cumulative adsorption surface area	4.532e+02 m²/g
t-method external surface area	4.183e+02 m²/g
DR method micropore area	4.150e+02 m²/g
DFT cumulative surface area	8.714e+01 m²/g

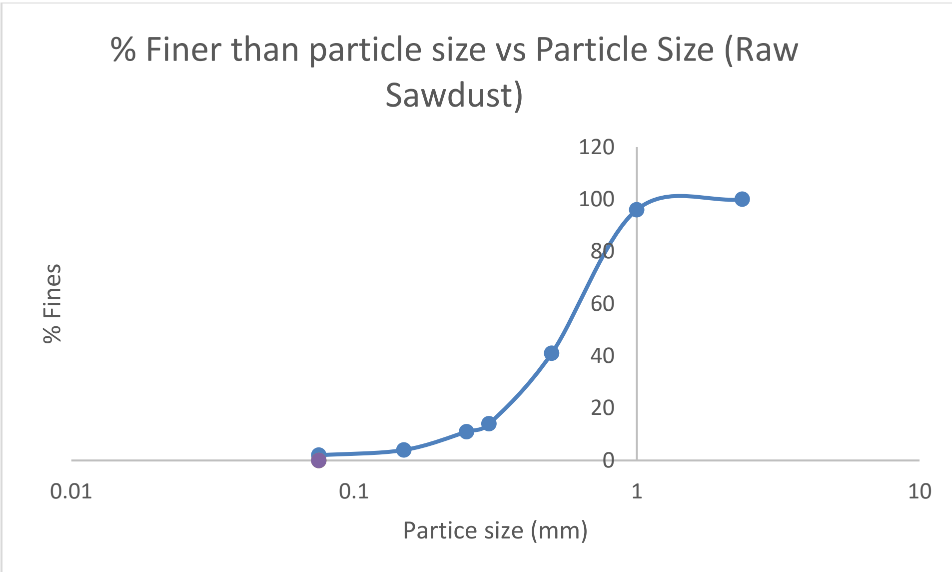
Pore Volume Data

BJH method cumulative adsorption pore volume	2.111e-01 cc/g
DH method cumulative adsorption pore volume	2.158e-01 cc/g
DR method micropore volume	1.475e-01 cc/g
HK method micropore volume	5.757e-02 cc/g
SF method micropore volume	9.279e-03 cc/g
DFT method cumulative pore volume	1.056e-01 cc/g

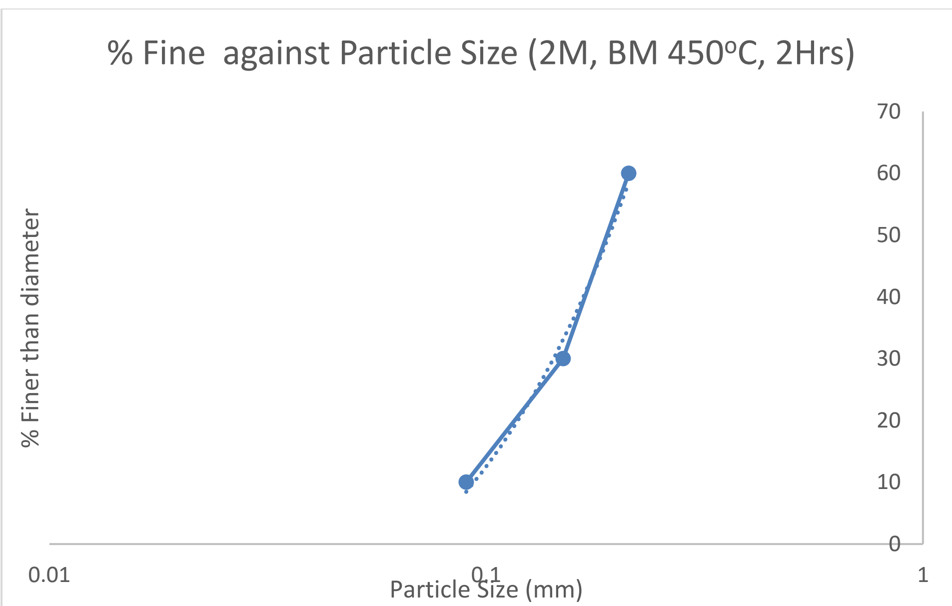
Pore Size Data

BJH method adsorption pore Diameter (Mode Dv(d))	2.100e+00 nm
DH method adsorption pore Diameter (Mode Dv(d))	2.427e+00 nm
DR method micropore Pore width	6.538e+00 nm
DA method pore Diameter (Mode)	3.000e+00 nm
HK method pore Diameter (Mode)	1.847e+00 nm
SF method pore Diameter (Mode)	3.479e+00 nm
DFT pore Diameter (Mode)	2.647e+00 nm

APPENDIX III



Sieve Analysis Plot for Raw BM sample



Sieve Analysis Plot for Heterogenous specie

APPENDIX IV

Table 1. Results used in determination of retention time for experiments

		DO (mg/l)	BOD (mg/l)	COD (mg/l)	TSS(mg/l)	pH Value
1	A-RAW	8.16	11.20	36.80	1.86	5.80
2	B-10G2H	8.10	3.90	25.40	0.98	6.70
3	C-5G2H	6.40	3.80	24.80	0.94	6.60
4	D-4G2H	4.80	3.20	24.30	0.91	6.50
5	E-2G2H	4.80	3.10	24.10	0.90	6.50
6	F-10G4H	3.20	2.40	24.00	0.90	6.40
7	G-5G4H	4.80	3.30	22.80	0.91	6.30
8	H-2G4H	3.20	2.30	22.70	0.88	6.30
9	I-4G4H	4.60	2.20	22.55	0.85	6.30
10	J-2G24H	4.80	2.60	22.50	0.84	6.30
11	K-4G24H	4.80	2.50	22.40	0.84	6.30
12	L-5G24H	4.80	2.90	22.20	0.82	6.30
13	M-10G24	3.20	2.40	22.60	0.83	6.30
14	N-2G48	4.80	2.30	22.30	0.81	6.20
15	O-4G48	3.20	2.50	22.40	0.80	6.20
16	P-5G48	3.20	2.20	22.20	0.80	6.20
17	Q-10G48	3.20	2.10	22.20	0.78	6.20

Table 2. Results of efficacy test of AS produced

	AVE pH DAY ZERO	48hrs	TDS (mg/l) DAY ZERO	48hrs	P P (mg/l)		BOD (mg/l) DAY ZERO	48hrs
I	4.90	5.30	300	330	2.39	2.12	11.30	14.00
II	5.25	5.05	300	440	2.29	2.07	15.20	14.70
III	2.25	1.95			2.39	2.12	9.60	9.80
IV	3.75	3.45	400	475	2.28	2.00	10.80	13.00
V	4.95	4.80	260	290	2.45	2.07	12.90	17.70
VI	4.25	3.65	590	695	2.41	1.91	13.00	11.90
VII	5.05	4.85	270	470	2.39	2.06	16.30	14.70
VIII	4.95	4.15	295	415	2.49	2.03	13.50	11.90
IX	5.45	5.00	515	485	2.43	2.19	14.70	9.90
X	5.35	6.35	200		2.42	2.04	5.40	
XI	6.05	7.45	395	370	2.65	2.20	14.60	12.50
XII	6.25	6.65	380	330	2.48	2.58	12.50	17.40
XIII	2.35	5.95		300	2.37	2.61	11.90	14.30
XIV	6.65	2.15	440		2.45	2.12	17.40	

Table 3. Results of efficacy test of AS produced continued

	Nitrate(mg/l) Zero Hrs	48hrs	Nitrite(mg/l) Zero Hrs	48hrs	Average DO Zero Hrs	48hrs
I	19.82	16.20	0.17	0.25	1.80	2.30
II	18.50	13.92	0.29	0.29	2.65	2.70
III	16.25	15.61	0.07	0.07	1.50	1.80
IV	16.76	14.78	0.14	0.16	1.85	2.25
V	18.35	15.40	0.21	0.27	2.10	2.85
VI	17.29	16.87	0.20	0.15	2.25	2.05
VII	19.71	15.02	0.30	0.27	2.85	2.70
VIII	14.54	15.37	0.24	0.17	2.35	2.05
IX	20.53	20.00	0.31	0.21	2.70	1.95
X	10.06	10.65	0.09	0.21	0.85	1.60
XI	20.18	17.58	0.32	0.36	2.55	2.30
XII	33.60	46.46	0.30	0.42	2.30	3.05
XIII	30.50	42.54	0.10	0.35	2.05	2.75
XIV	15.05	14.78	0.42	0.05	3.05	1.05