ASSESSING THE USE OF WOOD CHIPS-ACTIVATED CARBON IN THE TREATMENT OF WASTEWATER EFFLUENT

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ABSTRACT

Waste water effluent from sewage treatment process contains organic matter and other inorganic compounds which are harmful to the environment if not treated properly. In particular high levels of BOD_5 and COD in the waste water effluent pose significant risk on aquatic life through the depletion of dissolved oxygen, therefore treating the effluent to the acceptable permissible limits is essential for the health of the ecosystems. The study involved assessing the use of wood chips activated carbon in the treatment of the waste water effluent from the Doko waste stabilization pond and the research involved characterization of the waste water effluent in both the wet and dry seasons and the mean values of BOD_5 and COD in the effluent for the dry season were found to be 172.3mg/l and 269.7mg/l and 129.1mg/l and 217.8mg/l for the wet season and these were higher than the recommended NEMA standards of 50mg/l for BOD_5 and 100mg/l for COD, the study also evaluated the effectiveness of activated carbon in waste water effluent treatment where its adsorption behavior was described by the Langmuir and Freundlich models and the Freundlich model was the best fit for the adsorption of BOD_5 and COD by activated carbon. The adsorption process demonstrated maximum percentage reductions of 75.6% for BOD_5 and 72.4% for COD in the dry season and 80.3% for COD, 82% for BOD_5 for the wet season bringing the BOD_5 and COD values to the NEMA acceptable discharge standards demonstrating the potential of wood chips activated carbon in waste water effluent treatment.

DECLARATION

I, KHARONO MARY NORINE, hereby declare that the content of this report is original and has not been submitted either wholly or in part for the attainment of any academic qualification at any institution or university. The findings and discussions presented are based on my personal research, consultations and knowledge gained throughout the course.

Signature: …………………………………….

Date: ………/………………/……………..

APPROVAL

This is to certify that this report has been done by KHARONO MARY NORINE, and is ready for submission.

Project supervisor:

PROFESSOR ELEANOR WOZEI

Signature…………………………………….

Date………/………………/………...

DEDICATION

I wholeheartedly dedicate this report to my parents, brother, grandmother, siblings and aunt, whose unwavering support, guidance and encouragement have been a cornerstone in the successful completion of this work.

I also extend a special dedication to my supervisor, professor Eleanor Wozei, whose commitment and dedication played a vital role in making this journey both insightful and enriching.

ACKNOWLEDGEMENT

My sincere and heartfelt appreciation goes to the almighty God who blessed me with knowledge, guidance and necessary resources that enabled me to go through this final year journey, it has not been an easy one but special appreciation goes to our supervisor Prof. Eleanor Wozei who endeavored to give us all the guidance throughout the research period, this journey would have been a more tough one without her, I also thank my project partner Ruhingira Johnson who had been a supportive partner towards our final year project research.

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LIST OF ABBREVIATIONS

BOD- Biochemical oxygen demand

COD- Chemical oxygen demand

TSS- Total suspended solids

pH- Potential of hydrogen

NWSC- National water and Sewerage Corporation

NEMA- National Environment Management Authority

EC- Electrical conductivity

TSS- Total suspended solids

DO- Dissolved oxygen

m- meters

mm- millimeters

s- seconds

l- liters

mg/l- milligrams per liter

Kg/m^3- Kilograms per meter cubed

CHAPTER ONE: INTRODUCTION

1.1 PROJECT BACKGROUND

Waste water effluent refers to treated or untreated waste water discharged from a treatment facility or from an industry. Effluents are released into surface waters but if inadequately treated, they introduce microbial and chemical contaminants into public water ways negatively impacting river ecosystems and overall water quality (Bessong et al.,2009). Therefore, it is essential for wastewater treatment systems to ensure the release of high-quality effluents into the environment. In many developing countries, waste water treatment is often inadequate due to rapid urbanization and population growth that results into high hydraulic loadings affecting the capacity of the system and the overall design retention time (US EPA., 2009). This is one of the challenges experienced here in Uganda in regards to waste water treatment as some of the effluents discharged do not meet the NEMA standards for discharge of effluent on land or into water.

In Mbale, there two separate sewer networks, one discharges into the Namatala waste stabilization Pond and the other discharges into the Doko waste stabilization pond. The waste water from Republic Street, police barracks, NWSC offices is treated at the Doko waste stabilization pond and its effluent is discharged into the Nashibiso stream. This accounts for the high levels of pollution into the stream as it's the immediate point source of pollution (Wolukawu., 2023). Pollution of the Nashibiso stream as a result of effluent discharge from the Doko waste stabilization pond has been a major concern (Mafabi., 2023) as the people within the neighborhood areas rely on

the stream to obtain water for domestic use, the overall water quality of the stream is affected by the waste water effluent from the pond.

The waste water effluent samples from the pond were collected both in the dry and wet season and in both the season the values of BOD and COD were 172.3mg/l, 269.7mg/l for the dry season and 129.1mg/l for BOD and 217.8mg/l for COD in the wet season which were above the NEMA set standards, high BOD and COD in waste water effluents poses severe impacts in the environment and ecological systems, excessive BOD and COD levels lead to the depletion of dissolved oxygen in receiving waters leading to hypoxic or anoxic conditions that harm aquatic life (Metcalf and Eddy., 2014).

Therefore, it is very key to ensure that the effluent is properly treated before it is discharged to ensure the health of the ecosystems and also public health. Therefore, the study aims at assessing the use of wood chips activated carbon in waste water effluent treatment to act as a polishing unit to the effluent before it is discharged to ensure environmental and ecosystem health.

Wood chips activated carbon is an excellent choice for waste water effluent treatment as it's a highly porous material with a large surface area and the pores are made of different shapes and sizes which provides active binding sites for BOD and COD adsorption.

1.2 PROBLEM STATEMENT

Referring to the preliminary results obtained from the effluent in both the dry and wet season, some of the parameters of the effluent that was discharged from the Doko waste stabilization pond did not meet the standards for discharge of effluent into water or land, which were set by NEMA, 1999. The mean results on the effluent from the pond for BOD_5 and COD were 172.3mg/l, and 269.7 mg/l respectively for the dry season and 129.1mg/l for BOD_5 and 217.8mg/l for COD for the wet season and this shows that these parameters were higher than the recommended NEMA standards of 50mg/l, 100mg/l for BOD and COD respectively. The effluent is discharged into the Nashibiso stream and this accounts for the high levels of contamination to the river (Wolukawu., 2023), and this overtime affects the water quality and the aquatic life. The BOD_5 and COD values of the water from the stream during the dry season were found to be 116mg/l, 170mg/l respectively, this affects the quality of the water and also possess risk on aquatic life (Mafabi., 2023). High BOD_5 and COD levels indicate a significant presence of organic loads, this affects the receiving ecosystems through the depletion of dissolved oxygen (Sharma., 2021). The purpose of this study is to assess the use of activated carbon from wood chips in the reduction of BOD and COD from wastewater effluent, wood chips activated carbon has a large surface area, is highly porous, the pores on the surface of the activated carbon are of different shapes and sizes and this helps to create numerous active binding sites and this helps in reducing BOD_5 and COD in the waste water effluent.

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1.3 STUDY OBJECTIVES

1.3.1 Main objective

To assess the use of wood chips activated carbon in the treatment of the waste water effluent from the Doko waste stabilization pond

1.3.2 Specific objectives

1. To determine the physicochemical quality of the waste water effluent
2. To determine the reduction of BOD and COD in the wastewater effluent
3. To design a waste water effluent treatment unit

1.4 RESEARCH QUESTIONS

1. What is the physicochemical quality of the wastewater effluent?
2. What is the reduction of BOD and COD from the wastewater effluent?
3. What is the ideal design for the treatment of the wastewater effluent?

1.5 JUSTIFICATION

Wood chips activated carbon is an excellent choice for waste water effluent treatment to reduce BOD and COD due to its large surface area and the pore structure produced during the process of carbonization and activation, which provide excellent adsorptive properties, the activation process significantly enhances the number of micro pores and enlarges the meso pores making it highly effective in adsorbing the organic matter. The availability of cavities or spaces and pores on the activated carbon are vital for the adsorption process (Danish and Ahmad., 2018), the pores formed are of different sizes and shapes which help to form numerous active binding sites which are free for binding with the incoming atoms and molecules, these active binding sites increase the adsorption capacity for the organic molecules present in the waste water effluent because as the organic molecules are sticking and binding onto the wood chips activated carbon their concentration in the effluent decreases and this results into a reduction in BOD and COD concentration (Alsubhi et al., 2020).

The use of wood chips activated carbon demonstrated the potential of treating the waste water effluent to reduce the BOD and COD levels from the waste water effluent as a percentage reduction of BOD and COD for the dry season were 75.6% and 72.4% and for the wet season a percentage reduction of 82% and 80.3% for BOD and COD was achieved which shows the potential of wood chips activated carbon in the treatment of the waste water effluent.

1.6 SIGNIFICANCE OF THE STUDY

Wastewater treatment works and discharge of effluent affects the people downstream of the Nashibiso River in terms of water quality and also affects the aquatic life, the presence of the organic loads in water leads to the depletion of dissolved oxygen leading to aquatic stress since during decomposition of organic matter dissolved oxygen levels reduce and this threatens the aquatic life. The study aimed at how to treat the wastewater effluent from the Doko waste stabilization pond to reduce on the COD and BOD concentration and ensure the effluent meets the set standards of 50mg/ and 100mg/l for BOD and COD respectively before it's discharged to ensure safety of aquatic life (Farhadian et al., 2019). Wood chips are one of the wastes generated daily from various wood work operations like making chairs, beds, cupboards, doors, windows, these wood chips in large quantities their disposal may become problematic (Mallakpour et al., 2021). Therefore, the study looked at how to ensure the health of the public and that of the aquatic life through the use of activated carbon from wood chips to reduce BOD and COD from the effluent to improve on the quality of the water in the Nashibiso stream, to make it safe for use and to also restore the aquatic ecosystem.

1.7 SCOPE OF THE STUDY

Geographical scope

The Doko waste stabilization ponds are located in Mbale city south of Kampala road. The coordinates of the pond are 1^0 04' 50'' N, 34^0 10' 30'' E.

Time of scope

The study was conducted from September 2024 - April 2025

Content of scope

The study involved assessing the use of wood chips activated carbon in the treatment of the waste water effluent, the physicochemical quality of the effluent from the Doko waste stabilization pond were obtained both in the wet and dry season to account for the seasonal variations, the values of COD and BOD_5 from both seasons served as baseline data to assess the effectiveness of the wood chips activated carbon in waste water effluent treatment to reduce the BOD_5 and COD concentrations in the final effluent before it is discharged into the Nashibiso stream.

The study also looked at the design of the waste water effluent treatment unit under the comprehensive guidance by the Metcalf and Eddy design manual, where a proposed polishing unit to the final effluent was designed to ensure the effluent from the pond is further treated in order to meet the NEMA effluent discharge standards before its discharged because in both the seasons the mean results for BOD_5 and COD were above the permissible limits of 100mg/l and 500mg/l.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

Waste water is composed primarily of water but it also contains a variety of pollutants. Its main components include suspended solids, biodegradable dissolved organic matter, inorganic substances, nutrients, heavy metals and harmful pathogens. The organic fraction typically consists of substances such as detergents, proteins, carbohydrates, fats and soaps. Inorganic elements include toxic heavy metals like cadmium and mercury. If these contaminants are not properly treated, they pose serious threats to the environment and public health.

Wastewater treatment is done as a way of ensuring environmental health, however, the discharge of sewage effluent which does not meet the effluent discharge standards has increased over the years due the increase in urbanization and industrialization and this slows down the objective of ensuring environmental health (Shon et al., 2006).

Globally, recent studies provide an estimate of waste water production and management and (Jones *et al*., 2021) provides an approximation of about 359.5 billion m^3 annually, where about 63% of the waste water is collected and 52% of the waste water is treated and this shows that 48% of the wastewater is untreated and this calls for more technologies and ways on how the waste water is treated and effluents properly discharged (Jones, Vliet and Bierkens., 2020). For the waste water that is treated there exist standards at which the final effluent from the treatment should meet before it is discharged, in Uganda much as wastewater effluent discharge permissible limits exist, ensuring compliance to the standards is not done

efficiently and this often leads to discharge of effluents which do not meet effluent discharge standards.

2.1 Characteristics of waste water

Knowing the characteristics of waste water is crucial because it guides the effective management, treatment and design of a treatment system. The characteristics vary based on its source for example municipal, industrial (Welch and Naczk, 1992). The most used characteristic parameters are,

1. Chemical oxygen demand and biochemical oxygen demand, they provide an understanding on the quantity of organic matter present, BOD represents the biodegradable organic matter and COD represents total organic matter.

2. pH and electrical conductivity are indicators of ions in the waste water.

3. Heavy metals and Inorganic salts which are indicators of Industrial pollution.

4. Nitrogen and phosphorus, these are nutrients when discharged cause eutrophication.

2.1.1 Types and Sources of waste water

1. Domestic waste water, this is waste water that is discharged due to human activities, waste water from toilets essentially consists of organic matter, domestic waste water from kitchens, bathrooms and the daily discharge varies depending on for example the hygiene conditions and these waste waters contain organic matter and also products such as detergents and phosphate.

Types of domestic waste water

Grey water or sullage is the domestic waste water exclusive of toilet waste, water from the kitchen and involves waste water from sinks, bathrooms.

Black water, contains excreta, flush water and cleansing materials. It contains both fecal matter and urine.

Brown water, contains fecal matter, flush water minus urine, this mainly applies to urine diverting toilets.

2. Industrial waste water, this includes discharges from industrial processes and the composition depends on the processes in an industry and the waste water maybe from a tannery industry, textile industry, breweries industry, chemical industry and all these produce waste waters of different composition and treatment is required to ensure environmental health.

2.2 Waste water treatment techniques

2.2.1 Non-conventional waste water treatment techniques

Biological treatment relies on microorganisms to break down organic matter, it is a natural process and may take a couple of days. Under biological treatment, stabilization ponds, trickling filters, activated sludge, constructed wetlands are the techniques used to treat the waste water effluent

1. Waste stabilization ponds

Stabilization ponds are open flow through basins especially designed and constructed to aid in the treatment of sewage and biodegradable industrial

wastes. Since they rely on biological processes, use long retention time usually a number of days to treat the waste water.

Waste stabilization ponds are one of the cost-effective methods of municipal waste water treatment, they are not used in the treatment of toxic waste water as it kills the microorganisms, the ponds rely on microbial activity. Waste stabilization ponds are mainly used in hot climates, since they rely on the microorganisms to break down the organic matter and the degradation is intense when the temperature is high.

Waste stabilization ponds are arranged and series, the first pond which is the anaerobic pond, this is followed by the facultative pond and then the maturation pond.

Operation of the ponds

I. **Anaerobic ponds**

Anaerobic ponds are normally 2-5m deep and receive raw waste water and they store solids which settle at the bottom as sludge. Anaerobic ponds do not have dissolved oxygen and the microbial population consist of anaerobic microorganisms. The organic matter in the influent is broken down through fermentation. The anaerobic fermentation process breaks down the organic matter into methane and carbon dioxide when molecular oxygen is not present.

The process starts with the organic substrates being hydrolyzed producing simpler compounds through the enzymes produced by fermentative bacteria.

The next stage is acidogenesis which results into the formation of hydrogen, carbon dioxide, acetate and organic acids.

In the next stage, acetogenesis takes place and the organic acids produced are converted into hydrogen, carbon dioxide, and acetate by the acetogenic bacteria. And in the last stage methanogenic bacteria reduce carbon dioxide to methane by hydrogen utilizing methane bacteria, the gaseous end products resulting from the reactions escape to the atmosphere and this way BOD is removed from the waste water. Well-designed anaerobic pond provides about a 60% removal of BOD5 (Dwivedi., 2022).

II. Facultative ponds

Facultative ponds are normally 1-2 m deep. In the facultative ponds, treatment occurs in different zones that's to say, the anaerobic zone, the aerobic zone.

An aerobic zone is present at the upper layers of the pond because of the availability of oxygen from the photosynthesis of algae and wind aeration, in this zone organic matter is broken down aerobically, the aerobic portion of the pond helps to guard against the release of odors and enables break down of the pollutants by the aerobic bacteria. Deeper in the layers the oxygen is not present and this constitutes the anaerobic zone where the at the bottom the settled suspended organic matter is broken down anaerobically (Dwivedi., 2022).

III. Maturation Ponds

Maturation ponds come in the waste stabilization pond arrangement. They Influent from the facultative ponds flows to the maturation ponds. Maturation

ponds are generally shallower than facultative ponds with depth ranging from 0.5 to 1.5 meters. Their primary purpose is to remove pathogens and they also play a notable role in removing nitrogen and phosphorus although they contribute to some extent to BOD reduction.

The ponds maintain good oxygen levels throughout their depth due to the fact that they receive lower organic loads than anaerobic and facultative ponds (Dwivedi., 2022).

The final effluent comes from the maturation pond and it's discharged into the Nashibiso stream.

2. Constructed wetlands

Constructed wetlands are engineered systems designed to mimic the natural functions of wetlands for the purpose of treating wastewater. They are typically shallow basins filled with soil and planted with water tolerant plants like reeds, these plants play a key role in the treatment process by enhancing microbial activity and facilitating the transfer of oxygen to the root zone.

In the context of wastewater treatment, constructed wetlands are often used after preliminary treatment stages like from septic tanks, waste water treatment facility as the pretreated wastewater flows slowly through the root zone and this way the pollutants are removed from the waste water effluent (Stanbury et al., 2017).

3. Activated sludge

Activated sludge is a mixture of sewage and flocculated activated sludge. In the aeration and oxygen is supplied to enable microorganisms break down

organic matter, some microorganisms flow to the sedimentation tank and are settled out, they clog to the suspended particles and settle down as activated sludge. The activated sludge portion is continuously returned to the process which increases on the microbial population and activity and in this way the waste water becomes treated.

4. **Trickling filters**

Trickling filters biological treatment systems sometimes called percolation filters. The filter consists of a rotating distribution system that runs by gravity, here the microorganisms are not suspended in the mixed liquid but they attach themselves on the fixed bed surface and form a layer of biological slime that absorbs and consumes the waste, the slime consist of bacteria and the accumulating slime slides off the Individual rocks and is collected at the bottom along with treated waste water.

2.2.2 Conventional waste water treatment

This incorporates a number of processes for example, pre-treatment, primary treatment, biological treatment, secondary treatment and disinfection.

a) **Pre-treatment**

As the waste water enters the treatment plants the large floating objects are removed by the screens. The screens can be coarse of fine, the materials that are trapped are then removed and disposed off safely either in a landfill, incinerated or disposed off in areas designated to receive such wastes.

b) **Primary treatment**

The screened waste water then flows to the primary clarifiers where the suspended solids and floating objects are removed. what settles at the bottom

is called primary sludge, there are other types of waste other than the suspended solids for example soaps, oils, grease and these float on top to form scum which can be removed by the help of a skimmer.

c) Biological treatment

Under biological treatment, the wastes are broken down biologically and here trickling filters, activated sludge systems can be utilized, and waste is broken down aerobically.

d) Secondary treatment

The waste water then flows to the secondary sedimentation tanks where the activated sludge settles at the bottom of the tank, the activated sludge can be recycled back to the aeration chamber to increase the microbial activity and population, it can be used in biogas production or sent to the sludge drying beds.

Disinfection and discharge

The waste water produced contains pathogens and disinfection is done to kill the pathogens present and mainly chlorine is used and after disinfection the waste water effluent is then discharged. NEMA has set the maximum permissible limits for the discharge of effluent and that waste water treatment plants, waste stabilization ponds and industries discharging effluent must meet.

Table 1: Effluent discharge permissible standards (National Environment Management Authority., 2020)

Quality	Standards for effluent discharge	Units
BOD	50	mg/l
COD	100	mg/l
pH	6.0-8.0	
Turbidity	300	NTU
Total phosphorus	10	mg/l
Total nitrogen	10	mg/l

2.3 Adsorption

Adsorption is the concentration of a solute which maybe molecules dissolved or suspended in the liquid phase on the surface of a solid. During adsorption molecules bind onto the solid surface or are held of the solid surface by the weak intermolecular forces of attraction.

2.3.1 Types of adsorbents used

Activated carbon, clay minerals, zeolites and these have proved to be efficient in waste water effluent treatment.

2.3.1.1 Activated carbon

 Activated carbon refers to carbon rich substances characterized by a highly developed internal pore structure. It its extensive surface area along with an organized network of micropores and meso pores contribute to its exceptional

ability to adsorb contaminants from the waste water effluent. Recognized worldwide as one the earliest and most extensively utilized adsorbent, activated carbon is commonly employed in the treatment of both municipal and industrial waste water to reduce color, various organic and inorganic pollutants (Liu et al., 2020).

2.3.1.2 Types of activated carbon

The most common forms by which activated can be found include:

Granular activated carbon, which is mainly used in fixed bed adsorption columns. Granular activated carbon can be prepared from hard materials like wood, coconut shell and granular activated carbon is mainly used in column adsorption units and they can be regenerated after use.

Powdered activated carbon, this is mainly used when the pollutant concentration in waste water is low as they can be clogged easily though they have a high surface area for waste waters with high pollution loads for example high levels of suspended solids, granular activated carbon is suitable as it reduces on the frequency of clogging and for waste waters with low contaminants then powdered activated carbon is suitable (Tariq et al., 2022).

2.3.1.3 Methods activation

1. Physical activation

Physical activation is also referred to as thermal activation, it is widely used in the production of activated carbon. The first stage involves carbonization where the biomass such as wood chips undergo thermal decomposition at temperatures between 400-600°C, using the wood chips or any other material without treatment, it leads to the increase in organic matter after they decompose, carbonization removes volatile compounds yielding a carbon rich

char. This method yields activated carbon with well-developed porous structure and is considered more environmentally friendly than the chemical activation

2. Chemical activation

Chemical activation involves treating the carbonaceous precursors with chemical activating agents such as phosphoric acid, potassium chloride, zinc chloride prior to thermal treatment. The method is particularly effective for biomass rich in cellulose and lignin (Sumangala et al., 2021).

2.3.1.4 wood chips activated carbon

In the selection of the type of tree species to be used for production of activated carbon, it depends on its carbon content and cellular structure hardwood like eucalyptus have a complex cellular structure which produces a porous material as compared to soft woods. The wastes from the wood industry are cheaper and available in large quantities. Besides Eucalyptus wood chips having a good cellular structure, the waste is plentiful by product of the wood industry. According to approximate analysis, raw eucalyptus wood chips have a fixed carbon content of 51.99% making it an excellent biomass for the production of activated carbon (Mopoung.,2021).

Carbonization and activation are key steps for activated carbon production; they help in the determination of the surface properties and porosity of the adsorbent.

2.4 Adsorption isotherms

Adsorption is the mass transfer process characterized by the accumulation of substances on the surface of the adsorbate. The equilibrium relationship between the adsorbent and the adsorbate is typically described by the adsorption isotherms at a constant temperature. Accurately fitting experimental data to various isotherm models is essential for identifying the most suitable model for adsorption design.

Equilibrium adsorption isotherms are critical in designing adsorption systems as they help assess the adsorption potential of activated carbon for specific contaminants. A wide range of isotherm models exist and the most widely used adsorption isotherms used are Langmuir and Freundlich adsorption isotherms. The Freundlich adsorption isotherm assumes that adsorption takes place in the multilayer while Langmuir adsorption isotherm assumes adsorption takes place in a monolayer (Rani et al., 2021).

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter presents the methodology employed in the study providing a detail of the procedures used to achieve the research objectives and provides an understanding on how the various tests were systematically performed to achieve the set objectives.

3.2 Research design

The methodological research for this project was based on the quantitative research design to determine the potential of wood chips activated carbon in the reduction of BOD and COD from the waste water effluent. To answer the research questions of the study, the following systematic methods were followed and used to collect, analyze and interpret the data.

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│  Proposal   │     │          │     │           │     │Development of│
│ preparation │ ──> │Literature│ ──> │Preliminary│ ──> │              │
│    and      │     │  review  │     │ findings  │     │  methodology │
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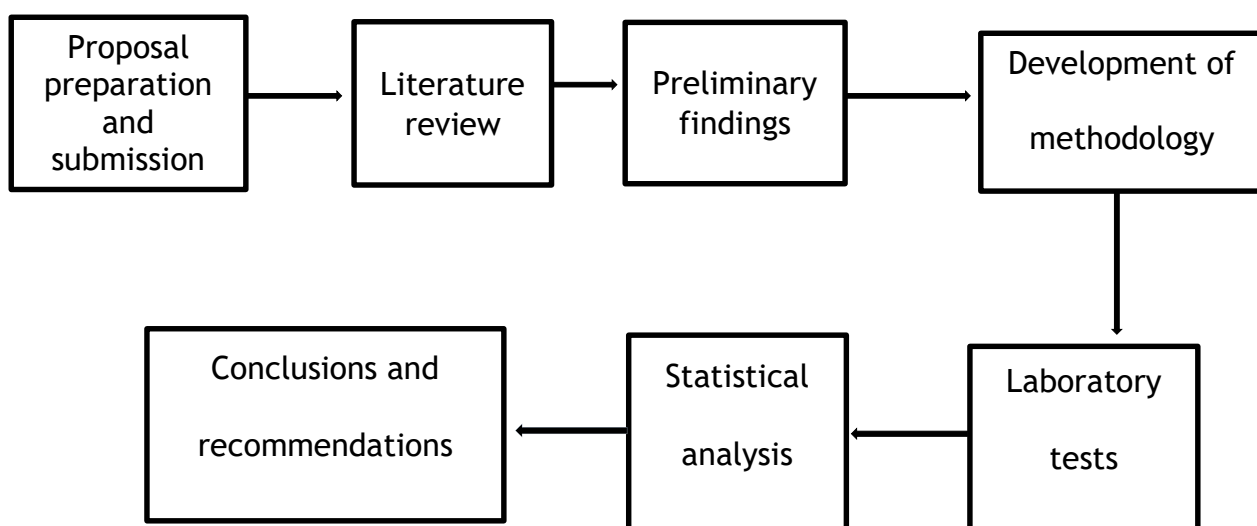
3.3 Sample collection

The sampling bottles were clearly labeled with the date and time of collection and the wastewater effluent samples were collected from the Doko waste stabilization pond discharge point and from the Nashibiso stream, a clean bottle was triple rinsed with the effluent to avoid contamination and it was used to collect and transfer the samples into the clean sampling bottles which were filled to the mark to allow for proper sealing, grab samples in field triplicates were collected to obtain representative sample. The samples were collected in the morning, afternoon and evening to account for the variations in the effluent composition and the samples were collected in the wet and dry seasons to account for the seasonal variations. Grab sampling was employed to collect the samples both in the wet and dry seasons, clean sampling bottles were first rinsed with the waste water effluent sample to avoid contamination.

Since the lab was not within the same locality with where the waste water effluent samples were collected, the samples were placed in the cooler box containing ice packs for preservation during transportation to the laboratory for analysis (U.S. Environmental Protection Agency, EPA).

3.4 Determination of physiochemical quality of the waste water effluent

Determination of the biochemical oxygen demand BOD (APHA 5210B)

This was determined using the Azide modification of Winkler method (oxygen electrode method)

Materials and equipment

- BOD test bottles

- DO meter

- Incubator

- Dilution water

- Graduated cylinder

- Pipette

Reagents used

- Phosphate buffer solution

- Magnesium sulphate solution

- Calcium chloride solution

- Ferric chloride solution

Procedure

I. The dilution water was prepared by adding water to a bottle and saturating it with dissolved oxygen by aerating with organic free filtered air, and this was followed by the addition of the nutrient stock solution of phosphate buffer, calcium chloride, Ferric chloride, and magnesium sulfate 1ml each per a liter of saturated water. The nutrients are added to ensure that the microorganisms have sufficient inorganic nutrients while decomposing the organic matter and the nutrients do not contribute to the consumption of dissolved oxygen in the waste water sample solution.

II. 5ml of the sample were added to a 300ml beaker and the dilution water added up to the 300ml mark and stirred.

III. The initial DO of the samples was measured using an already calibrated DO meter. The samples were then added to the 300ml BOD bottles and

filled to the brim and closed with a stopper to prevent the penetration of oxygen.

IV. The BOD bottles were amber in color to prevent light penetration which promotes photosynthesis.

V. The BOD bottles are then placed in an incubator at a temperature of 20°C for 5 days. The final dissolved oxygen of the samples was then obtained.

VI. The initial dissolved oxygen (D_1) was subtracted from the final dissolved oxygen (D_2) and multiplied by the dilution factor which is the ratio of the volume of the BOD bottle to the sample volume. The biochemical oxygen demand is then obtained from;

$$BOD \text{ (mg/l)} = (D_1 - D_2) \times dilution\ factor$$

Determination of the chemical oxygen demand COD (APHA 520D)

Chemical oxygen demand (COD) determination was achieved using the closed reflux method.

The principle is that under acidic conditions a strong oxidizing agent will oxidize the organic compounds to carbon.

Preparation of the reagents

The reagents required for the experiment were;

• Concentrated sulfuric acid

• Potassium dichromate ($K_2Cr_2O_7$).

• Waste water samples

Apparatus required

• Thermal reactor

• Spectrophotometer

- Test tubes or vials

- Pipette

Procedure

I. 2ml of the wastewater effluent sample were placed in a test tube or vial

II. 2ml of potassium dichromate were then added to the waste water effluent sample as a strong oxidizing agent.

III. 2ml of concentrated sulfuric acid followed, this was to provide an acidic environment so that complete and better oxidation of organic matter can be done due to potassium dichromate.

IV. The vials or test tubes were closed tightly and shaken lightly as it may explode, care is taken because it becomes hot due to the exothermic reaction of sulfuric acid.

V. The test tubes were then placed in a thermal reactor at a temperature of 150°C for 2 hours, after the two hours the digestor is switched off, and the test tubes are removed and left to cool to room temperature for about one hour.

VI. The test tubes were then placed in the spectrophotometer set at a wave length of 620nm and the COD values read. This change in absorbance from the dichromate solution is directly proportional to the COD of the sample in mg/L.

COD as mg O/l = $\dfrac{mg\ O2\ in\ final\ volume\ *1000ml}{ml\ sample}$

Determination of pH (APHA 4500-H)

I. The pH meter was calibrated against the pH buffer 4 and buffer 7 solution. The pH meter is turned on and the protective cap is removed

from the electrode, the electrode is stored in a potassium chloride buffer and is never allowed to dry.

II. The probe was then rinsed with distilled water and dried with tissue, the calibration button on the pH meter was pressed and the probe inserted into a pH buffer 7 first, and when the pH was adjusted up to 7 the probe was removed from the buffer 7 solution, rinsed and dried, the probe was then placed in the pH buffer 4, and when the pH was adjusted to 4 the probe was removed rinsed and dried. The wasted water Effluent samples were shake well to obtain a uniform mixture and placed in a beaker rinsed using waste water and the pH values for the samples were taken.

Determination of electrical conductivity EC

Equipment /Apparatus

Conductivity meter (probe / sensor), Soft tissue

Beaker, (50 ml)

Reagents

- Standard Potassium chloride solution (0.01N):
- Distilled water

Procedure

I. The conductivity cell was rinsed with 3 portions of 0.01 N KCl solution.

II. The temperature of a 4th portion was adjusted to 25.0 ±0.1 °C.

III. The cell was rinsed with distilled water followed by a portion of the waste water effluent sample

IV. The probe was immersed in a beaker containing the waste water effluent sample.

V. The probe was then agitated agitate to free any bubbles from the electrode area.

VI. The EC value of the waste water effluent sample was then read off in µS/cm

Determination of total suspended solids TSS (APHA 2540C)

Reagent

Distilled water

Apparatus / Equipment

- DR 3900 at 630 nm

- Sample Cell

- Beaker

- Measuring cylinder

Procedure

i. The samples were shake thoroughly so as to obtain a homogenous a mixture.

ii. 25 ml of distilled water (blank) and 25 ml of sample were taken and placed in different sample cells.

iii. The spectrophotometer was zeroed with the blank

iv. The concentration in mg/l of the sample was read and recorded at a wave length of 630nm from the spectrophotometer.

3.5 Determination of the reduction of BOD and COD from the waste water effluent

3.4.1 Wood chips collection and preparation

The wood chips were obtained from lucky star workshop in Mbale city, washed with clean water to remove any impurities like sand and wood dust. After washing, the wood chips were dried under the sun for four days to lower the moisture content.

3.4.2 Production of the wood chips activated carbon

I. The dried wood chips were then transported to a furnace in katosi where they were burnt at a temperature of 500°C for 3 hours, at this temperature the properties of the char are not distorted and the ash content is low compared to the carbon content.

II. The produced char was crushed where the different particle sizes were obtained and sieve analysis was performed to enable us obtain the effective particle size of the activated carbon.

III. A number of 8 sieves were staked placed on the electrical shaker and left to run for five minutes

IV. The mass retained on each sieve was noted and recorded and a graph of percentage passing against sieve size was plotted and the effective grain size was obtained which is the D10 from the graph, an effective grain size of 0.6mm was obtained with was in the recommended range of 0.6-0.9mm (Metcalf and Eddy.,2003).

V. The 0.6mm wood chips particles were washed to remove any dust and activated with phosphoric acid and this was aimed at increasing the surface area and porosity of the produced activated carbon.

3.4.3 The reduction of BOD and COD from the waste water effluent

1. The waste water effluent was passed through the prepared activated carbon at different column lengths, the first column was the control, no activated carbon was added and the control acted as the base line condition to determine how much of the organic matter has been reduced from the effluent.

2. Four bottles were prepared and packed with activated carbon at the lengths of 100mm, 140mm, 180mm, 220mm. cotton as a support material was placed at the bottom of the bottle to prevent carbon loss during the experiment, a flow rate of 7ml/min was established for all the columns, and this was determined by placing a hole at the bottle cover using the nail, and then determining how long it takes for the effluent in the bottle to flow out. The initial and final BOD_5 and COD values were obtained following the APHA standards and the reduction was calculated by getting the difference in initial and final concentrations divided by the initial concentration.

3.4.4 Batch adsorption experiment.

1. A fixed amount of waste water effluent, 1000ml was added to the different jars and different amounts of activated carbon were added for example 0g, 10g, 20g, 30g and 40g, the first jar no activated carbon was added and this was used as a blank.

2. A stirrer was used to mix the samples thoroughly in a rotary sequence until equilibrium was achieved. Equilibrium occurs when the further adsorption does not occur. The experiment was carried out in the laboratory at a room temperature of 23˚C.

3. The concentration after equilibrium C_e was obtained, the minimum amount of time allowed for the samples to achieve adsorption equilibrium was 4hours.

4. After the end of the test period following the APHA standards the final BOD_5 and COD concentrations were obtained and the results were analyzed and then plotted to get the adsorption isotherms.(Wegmann et al. 2011).

3.4.5 Breakthrough curve experiment

1. A column test was carried out to obtain the design parameters. A feed with a constant concentration C_o of the waste water effluent was passed through the fresh activated carbon bed at a constant flow rate of 7ml/min, the waste water effluent was allowed flow through the column packed with activated carbon continuously.

2. The samples were collected at the bottom at different intervals of time and the samples were analyzed to obtain the concentration of BOD_5 and COD. The initial concentration and final concentrations at the different time intervals were obtained and a graph of concentration ratio against time was plotted to give the breakthrough curve which was used to obtain the breakthrough and exhaustion time (Chang et al., 2006).

3.5 Design of a waste water effluent treatment unit

This was achieved under comprehensive guidance by the Metcalf and Eddy design manual.

The design considerations included,

Empty bed contact time, the time the waste water effluent remains in contact with the activated carbon.

Bed depth, an adequate bed depth ensures sufficient contact between the waste water and the carbon bed, the bed depth is very crucial as it affects the exhaustion time and the breakthrough time, increase in the bed length increases the exhaustion time as it takes a long time for the mass transfer zone to reach the bottom of the bed, this in turn reduces the time needed the frequently replace the activated carbon or subject it to regeneration. But also, when scaling up the bed length should not exceed the recommended range of 1.8-4m as at higher depths it would result into overlapping of the active binding sites which reduces the efficiency of the bed.

Flow rate, the flow rate affects the contact time, adsorption capacity and a low flow rate allows for longer contact time between the activated carbon and the effluent leading do better adsorption capacities.

4.0 Introduction

This chapter presents the findings obtained from the various experiments done on the effluent samples. Grab samples of the waste water effluent from the Doko waste stabilization pond both in the wet and dry seasons were used as the baseline data which was used to assess the effectiveness of the activated carbon in waste water effluent treatment.

4.1 Determination of the physicochemical quality of the waste water effluent.

4.1.1 Physicochemical quality of the effluent in the dry season

Table 2: waste water effluent quality results for the dry season

Parameter	Units	Morning	Afternoon	Evening	Mean	SD	Waste water Effluent discharge standards
BOD_5	mg/l	180	169.6	167.3	172.3	3.6	<50
COD	mg/l	278.7	267.3	263.2	269.7	4.2	<100
PH		8.3	8.7	8.6	8.5	0.1	5.5 - 8.5
TSS	mg/l	83.4	93.0	87.3	87.9	2.4	<100
EC	µS/cm	860.2	900.2	895.3	885.2	11.8	<1500

The wastewater effluent quality results from the Doko waste stabilization pond were compared with the NEMA standards for discharge of effluent on land or water and the results show a significant deviation from the permissible limit particularly the BOD_5 and COD.
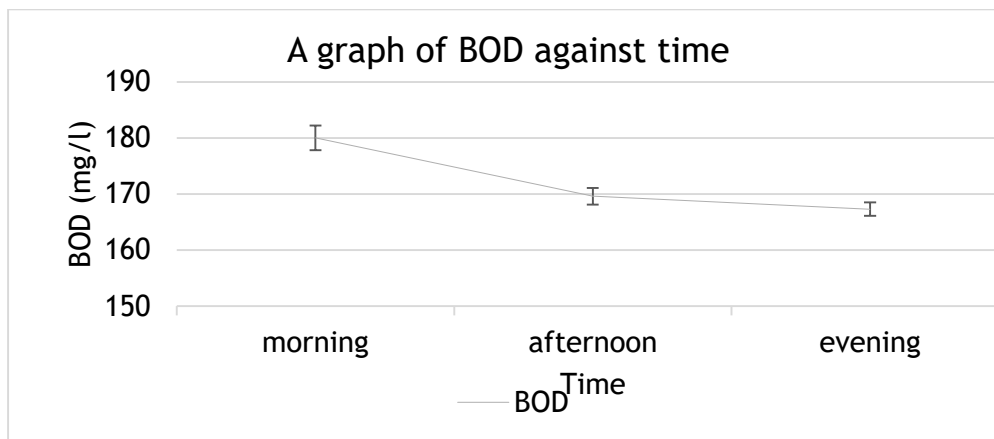
Figure 1: BOD concentration variation with time

An average BOD_5 value of 172.3±3.6mg/l which was above the NEMA set standard of 50mg/l was discharged into the stream.

The high BOD_5 values in the effluent are mainly due to the reduction in the retention time in the anaerobic and Facultative ponds yet most of the BOD is removed them, reducing the time the waste water spends in ponds, reduces the breakdown of organic matter leading to the rise in BOD_5 values. From the analysis it was observed that much as the pond design meets the design standards for designing waste stabilization ponds, it was observed that there was a considerable reduction in the retention time in the anaerobic and facultative ponds and this affects the breakdown of BOD. A well-functioning anaerobic pond removes 60% of BOD, reduction in retention time affects sedimentation and degradation of the organic matter in the ponds affecting the breakdown of organic matter in the ponds. The BOD_5 value deviations throughout the day are mainly due to the increase in microbial activity which increases the breakdown organic thus reducing the BOD_5 (Badre et al., 2023).

A graph of COD against time
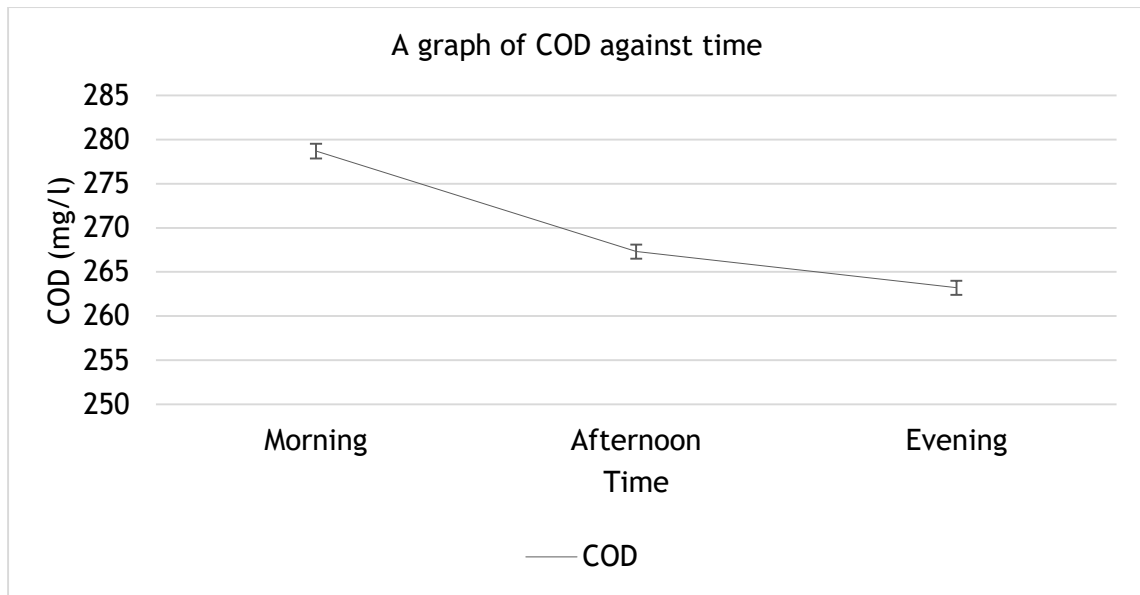
Figure 2: COD concentration variation with time

An average COD value of 269.7±4.2mg/l in the effluent was discharged into the Nashibiso stream which was beyond the NEMA set standard of 100mg/l and this high COD value is mainly attributed to the reduction in the retention time of the ponds this could be due to the increase in the hydraulic loading of the ponds affecting their design capacity and the design retention time thus reducing the efficiency of the ponds in effectively treating the waste water effluent to the required COD values.

A graph of pH against time
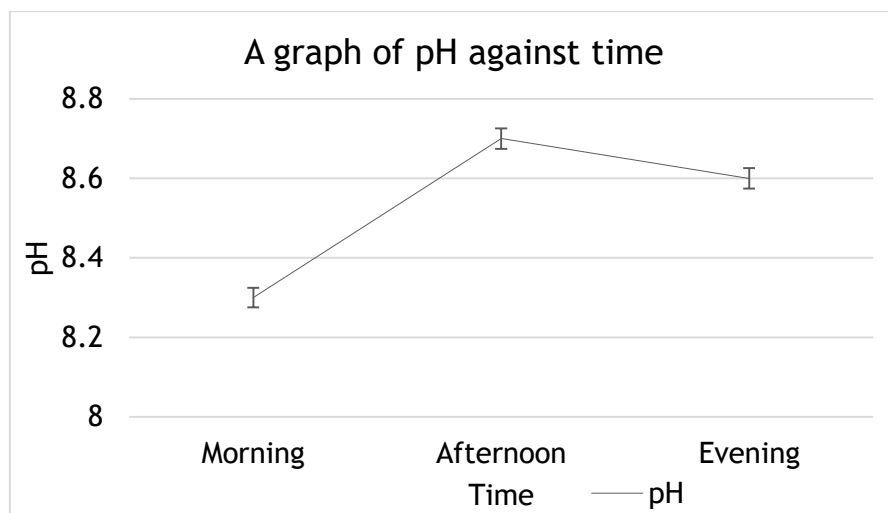
Figure 3: pH variation with time

A pH range of the effluent from the pond was between 8.3-8.7±0.1, the rise in the pH in effluent is mainly due to the dissociation of carbonate and bi carbonate ions in the ponds which leads to the release of hydroxyl ions which leads to a rise in the pH values in the effluent.

A graph of TSS against time
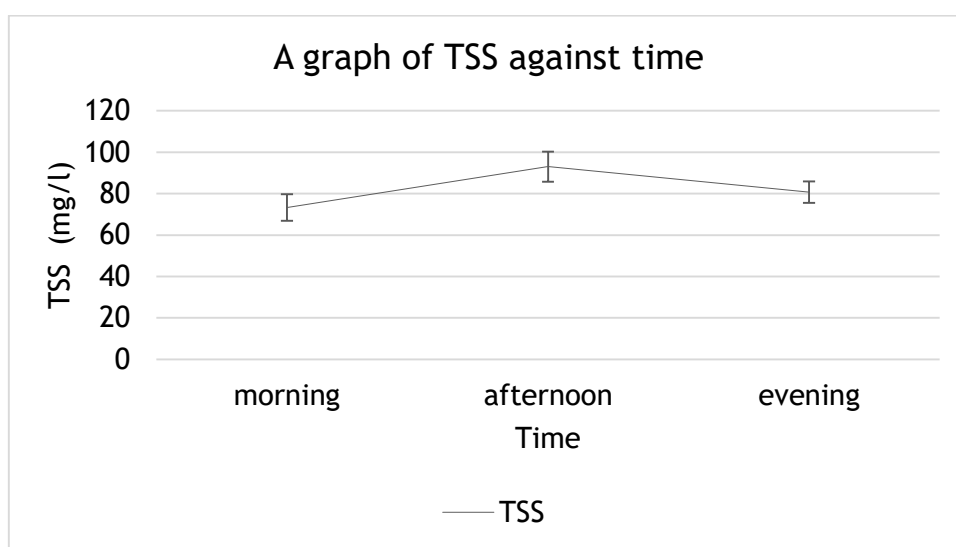
Figure 4: TSS concentration variation with time

On average, TSS value of 87.9±2.4mg/l which was within the recommended NEMA permissible limit for effluent of 100mg/l was discharged into the Nashibiso stream, this means the suspended solids in the effluent actually have enough time to settle out of suspension, the solids which settle out become sludge and desludging of the ponds is done annually to ensure their efficiency in waste water effluent treatment.
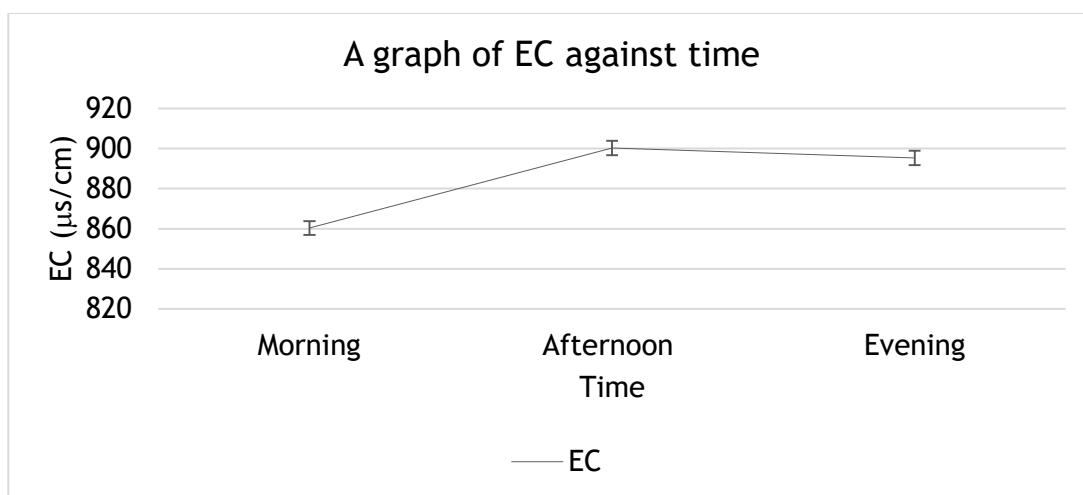
Figure 5: EC variation with time

The EC range in the final effluent was between 860.2-900.2±11.8µS/cm, the electrical conductivity of the effluent was within the recommended NEMA permissible limit of 1500µS/cm. Increase in the EC values is mainly due to evaporation which leaves the dissolved salts and ions that do not evaporate and these contribute to the rise in EC values.

4.1.2 Physicochemical quality of the effluent in the wet season

Table 3: waste water effluent quality results for the wet season

Parameter	Units	Morning	Afternoon	Evening	Mean	SD	Waste water Effluent discharge standards
BOD_5	mg/l	135.6	127.4	124.2	129.1	3.5	<50
COD	mg/l	221.5	216.6	215.2	217.8	2.43	<100
PH		7.6	7.9	7.7	7.7	0.1	5.5 - 8.5
TSS	mg/l	100.2	111.5	105.8	105.8	4.6	<100
EC	µS/cm	480.1	510.0	506.8	499.0	13.4	<1500

The higher the concentration of organic matter in the waste water the stronger it is said to be. Waste water strength is often judged by its BOD and the strength of the waste water is governed by the water consumption, in developing countries like Uganda the water consumption is low usually an estimate of 40-100l per person which makes the waste water strong.
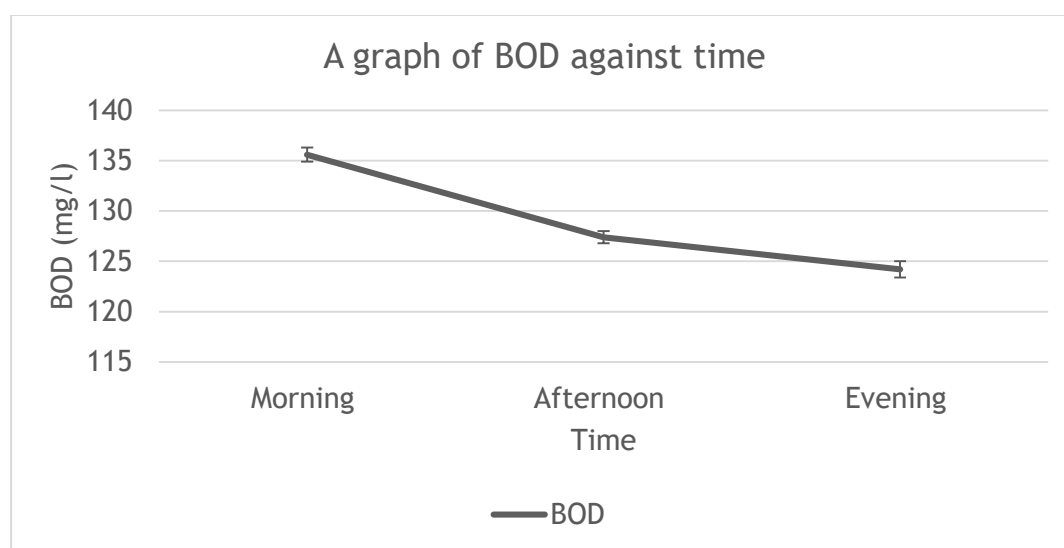
Figure 6: BOD concentration variation with time

An average BOD value of 129.1±3.5 was discharged from the pond in the wet season which was higher than the NEMA effluent discharge standard, the BOD value for the wet season were lower than that of the dry season because the waste stabilization ponds operate in the open therefore when it rains the rain water helps to dilute the waste water present in the ponds, reducing its strength, and this makes the BOD values in the effluent to be lower than the ones for the dry season, therefore the reduction is primarily because of the dilution effect from the rain.
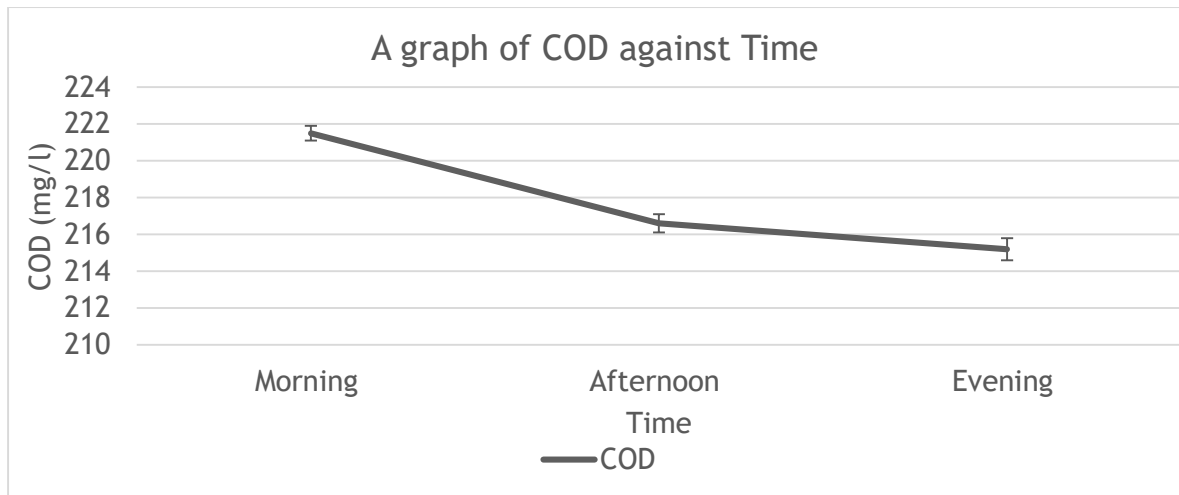
Figure 7: COD concentration variation with time

An average COD value of 217.8±2.43 was, discharged from the pond, the COD values in the wet season were lower than the ones recorded in the dry season, this reduction is primarily due to the dilution effect from the rainfall and this reduces the concentration of COD in the waste water effluent.
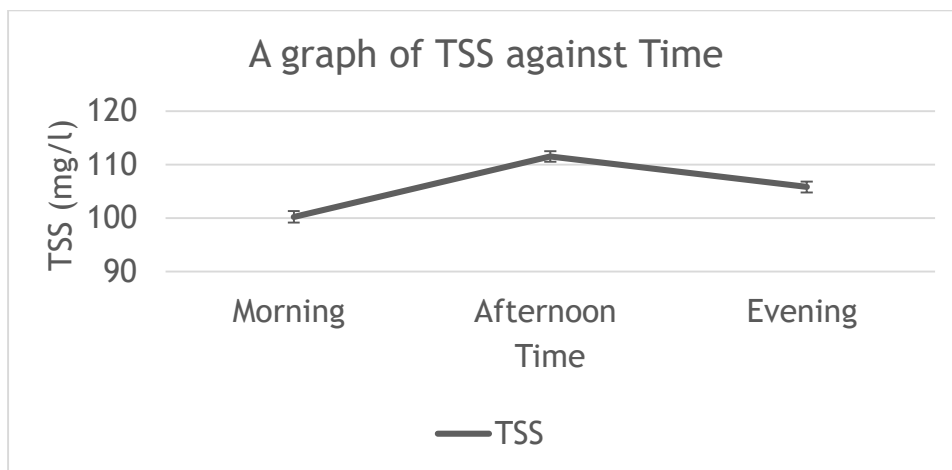
Figure 8: TSS concentration variation with time

An average TSS value of 105.8±4.6mg/l was discharged from the pond and the TSS values were observed to be higher in the wet season than in the dry season this is because rainfall leads to surface runoff introducing additional suspended particles into the effluent and also rainfall increases the hydraulic loading reducing the retention time within the ponds resulting into less time for the solids to settle and this results into higher TSS concentrations in the effluent for the wet season.

Increase in the TSS values in the wet season is also due to increased speed ant which the effluent flows from the pond which results into resuspension of the settled solids and this contributes to the increase in the TSS values.
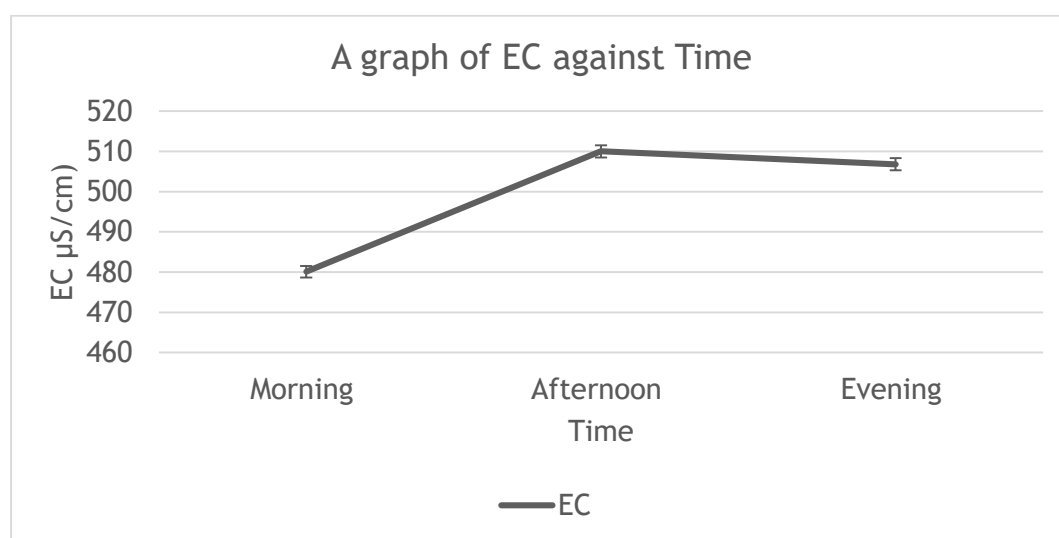
Figure 9: EC variation with time

For the wet season, EC values ranged from 480.1-510±13.4µS/cm. These were observed to be lower than the those recorded in the dry season, this is because the rain water dilutes the concentration salts and ions responsible for EC and this results into overall reduction in the EC values as compared to the dry season. The EC values in the effluent were still with the NEMA set standard of 1500 µS/cm.
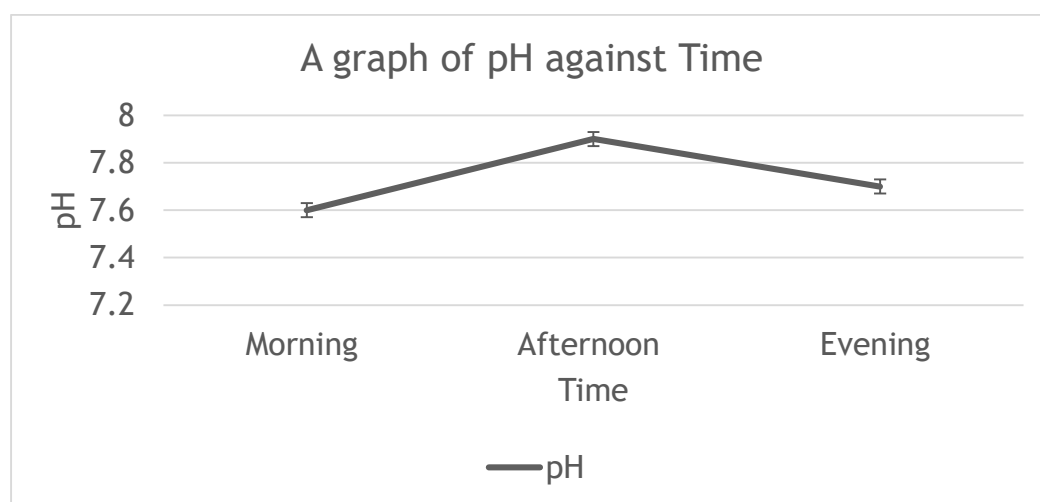
Figure 10: pH variation with time

For the wet season, a pH range of 7.7-7.9±0.1 which was within the recommended range of 5.5- 8.5, cooler temperatures in the wet season slow microbial and algal activities in the ponds, the affects the biological processes like dissociation of carbonate and bi carbonate ions that elevate the pH because of the release of hydroxyl ions from the process and this results into lower pH values in the wet season as compared to the dry season.

4.2 Determination of the reduction of BOD and COD from the waste water effluent

4.2.1 Determination of the reduction of BOD and COD for the dry season

Table 4: BOD reduction at the different activated carbon lengths for the dry season

Parameter	Units	Column 1	Column 2	Column 3	Column 4	Column 5
Initial BOD concentration	mg/l	143.7	143.7	143.7	143.7	143.7
Activated carbon length	mm	0	100	140	180	220
BOD$_5$ concentration	mg/l	143.7	45.2	39.8	36.6	36.4
Percentage reduction	%	0	68.6	72.3	74.5	75.6
Contact time	Minutes		18.0	25.1	32.3	39.5

$$Percentage\ reduction\ = \frac{final\ concentration - initial\ concentration}{final\ concentration} \times 100$$

Effect of activated carbon length on BOD concentration
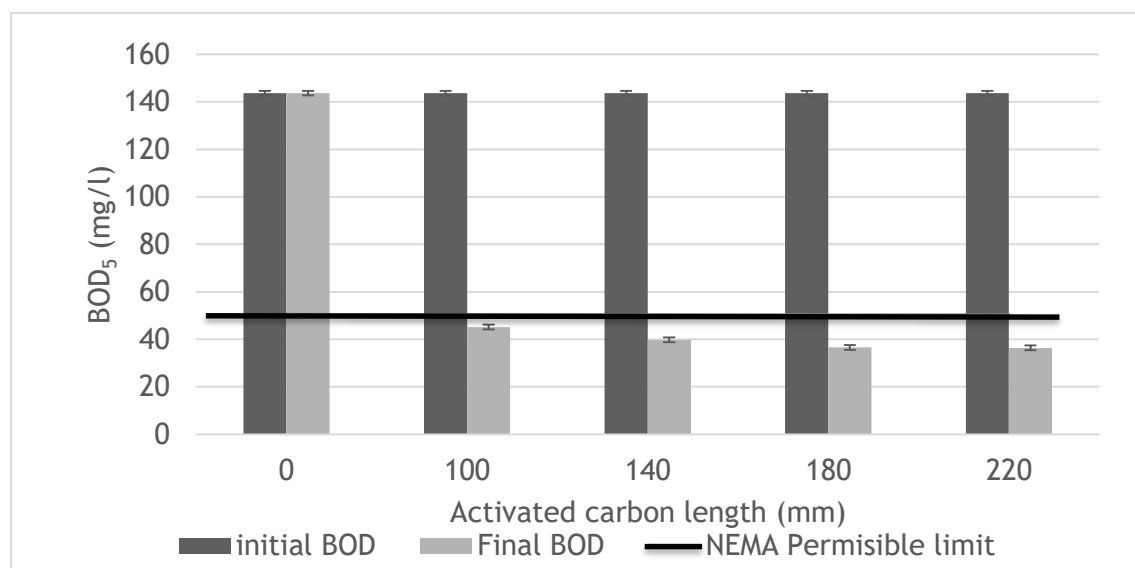
Figure 11: BOD concentration at different activated carbon lengths

Increase in the activated carbon length resulted into decrease in the BOD_5 concentration from the waste water effluent this is because of the increase in the active binding sites and surface area of the activated carbon enabling the BOD to bind onto the active binding sites. The maximum permissible limit was achieved at the different lengths of activated carbon. At a column length of 100mm, the BOD_5 concentration in the effluent reduced from 143.7mg/l to 45.2mg/l at 100mm, 39.8mg/l at 140mm, 36.6mg/l at 180mm and 36.4mg/l at 220mm.

Effect of activated carbon length on BOD reduction

At a length of 100mm a BOD_5 percentage reduction of 68.6% was obtained, with the increase in length of the activated carbon, the percentage reduction of BOD_5 increased to 72.3% at 140mm, 74.5% at 180mm and 75.6% at 220mm, this is because of the increased surface area which provides more vacant sites and surface area for adsorption.

Increase in the percentage reduction of BOD_5 with increase in the activated carbon length is also due to the fact that the BOD molecules travel through longer depths, the liquid path length the effluent pass is increased, allowing the BOD molecules present in the effluent to bind onto the active binding sites of the activated carbon leading to the decrease in the BOD_5 values.

The percentage reduction of BOD_5 increased with increase in the column length however, this was true up to a column length of 180mm, further increase in column length to 220mm did not result into a significant reduction of BOD_5 in the waste water effluent and this is due to the overlapping of the voids making the active binding sites inaccessible (López-Cervantes et al., 2018).

Effect of contact time on the BOD reduction

At a contact time of 18minutes, a BOD_5 percentage reduction of 68.6% was achieved, but with an increase in the contact time, the percentage reduction of BOD_5 from the effluent increased to 72.3% at 25.1minutes, 74.5% at 32.2 minutes and to 75.6% at 39.5minutes, this is because, increase in the contact time increases the time the waste water effluent comes into contact with the activated carbon allowing for more interactions between the organic matter molecules and the adsorption sites of the activated carbon, therefore the biodegradable molecules present in the effluent get enough time to adsorb on to the active binding sites and this leads to the increase in the reduction of BOD_5 from the waste water effluent.

Table 5: COD reduction at the different activated carbon lengths

Parameter	Units	Column 1	Column 2	Column 3	Column 4	Column 5
Initial COD concentration	mg/l	265.7	265.7	265.7	265.7	265.7
Activated carbon length	mm	0	100	140	180	220
Final COD concentration	mg/l	265.7	88.3	79.3	73.8	73.2
Percentage reduction	%	0	66.8	70.1	72.2	72.4
Contact time	Minutes		18.0	25.1	32.3	39.5

Effect of activated carbon length on COD concentration

Figure 12: COD concentration at the different activated carbon lengths

At a column length of 100mm, the COD concentration in the effluent reduced from 265.7mg/l to 88.2mg/l at 100mm, 79.3mg/l at 140mm, 73.8mg/l at 180mm and 72.4mg/l at 220mm. The maximum permissible limit was achieved at the different lengths of activated carbon and increase in the length of activated carbon resulted into decrease in the COD concentration due to the increased surface area and binding sites.

Effect of column length on COD reduction

At a column length of 100mm, a COD percentage reduction of 66.8% was achieved, with further increase in the column length the percentage reduction increased to 70.1% at 140mm, 72.2% at 180mm and 72.4% at 220mm this is because of the increased surface area of the activated carbon which increases the number of free adsorption sites. Initial significant reduction of COD in the effluent was observed, however further increase in the length of the activated carbon bed to 220mm did not result into a significant decrease in COD concentrations.

Effect of contact time on COD reduction

The COD percentage reduction of 66.8% was achieved at a contact time of 18minutes, with increase in the contact time, the percentage reduction increased to 70.1% at 25.1minutes, 72.25% at 32.3minutes and 72.4% at 39.5minutes, this is mainly due to the increase in the contact time between the effluent and the activated carbon and this results into the increased utilization of the vacant sites before equilibrium and this results into increase in the reduction of COD from the waste water effluent. The optimal time was

observed to be 25.1minutes, with further increase in the contact time the percentage reduction was negligible (Barrutia et al., 2019).

4.2.2 Determination of the reduction of BOD and COD for the wet season

Table 6: BOD reduction at the different activated carbon lengths for the wet season

Parameter	Units	Column 1	Column 2	Column 3	Column 4	Column 5
Initial BOD concentration	mg/l	129.1	129.1	129.1	129.1	129.1
Activated carbon length	mm	0	100	140	180	220
BOD_5 concentration	mg/l	129.1	34.9	28.7	27.1	23.2
Percentage reduction	%	0	73.0	77.8	79.0	82.0
Contact time	Minutes		18.0	25.1	32.3	39.5

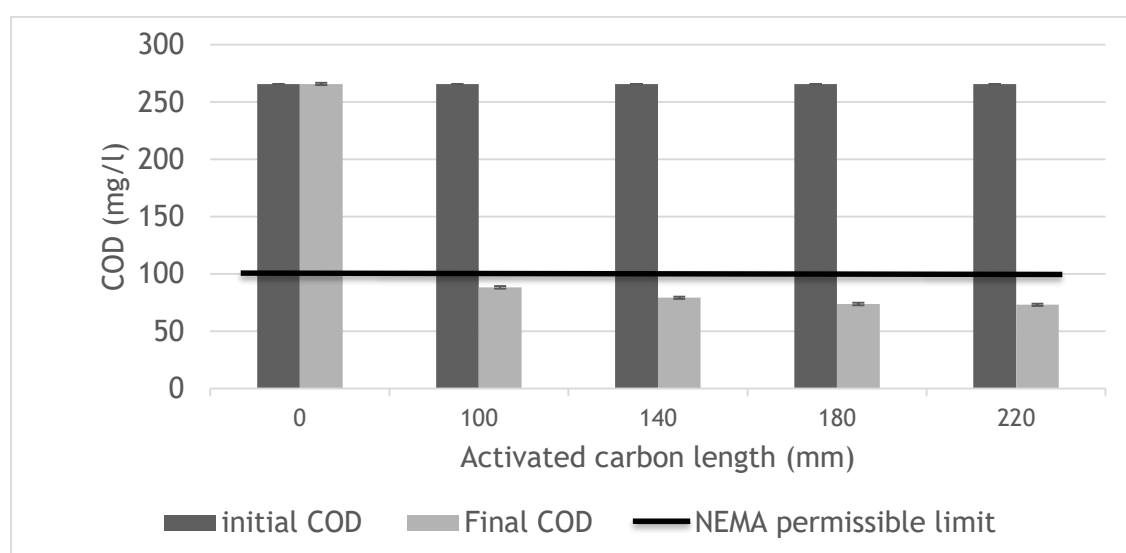**Effect of activated carbon length on BOD concentration**
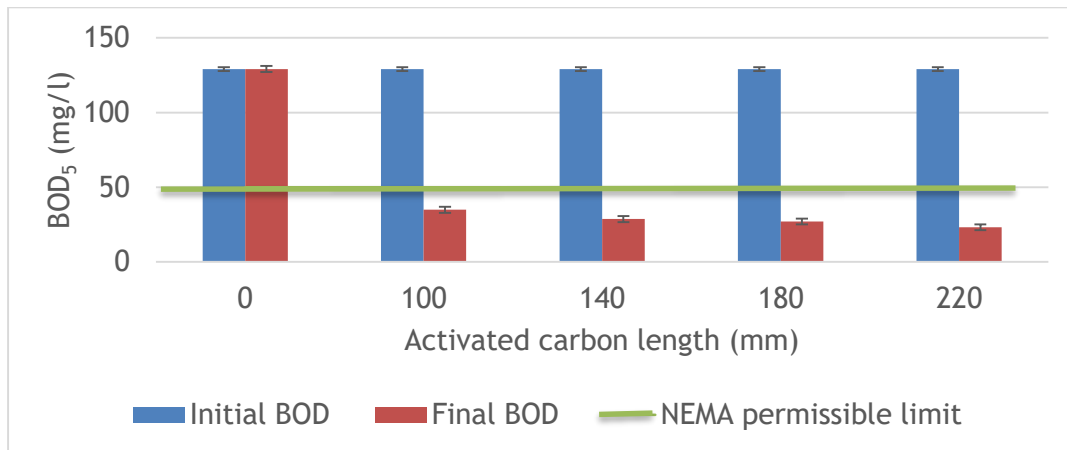
Figure 13: BOD₅ concentration variation with activated carbon length

At a column length of 100mm, the BOD_5 concentration in the effluent reduced from 129.1mg/l to 34.9mg/l at 100mm, 28.7mg/l at 140mm, 27.1mg/l at 180mm and 23.2mg/l at 220mm. Increase in the column length resulted into decrease in the BOD_5 concentration from the waste water effluent this is because of the increase in the active binding sites and surface area of the activated carbon enabling the BOD to bind onto the active binding sites. The maximum permissible limit was achieved at the different lengths of activated carbon.

Effect of activated carbon length on BOD reduction

The BOD percentage reduction of 73.5% at the length of 100mm was obtained, with increase in the length of the activated carbon the percentage reduction increased to 77.8% at 140mm, 79% at 180mm and 82.5% at 220mm, this is because of the increased surface area which increases the number of the active binding sites enabling the BOD to bind onto the active binding sites leading to the reduction of BOD_5 from the final effluent.

Also, as the effluent as passes over a longer depth, it allows the BOD molecules present in the waste water effluent to adsorb onto the active binding sites (sheng et al., 2018).

Table 7: COD reduction at the different activated carbon lengths for the wet season

Parameter	Units	Column 1	Column 2	Column 3	Column 4	Column 5
Initial COD concentration	mg/l	217.8	217.8	217.8	217.8	217.8
Activated carbon length	mm	0	100	140	180	220
Final COD concentration	mg/l	217.8	59.5	54.2	46.4	42.8
Percentage reduction	%	0	72.6	75.1	78.7	80.3
Contact time	Minutes		18.0	25.1	32.3	39.5

Effect of activated carbon length on COD concentration

At a column length of 100mm, the COD concentration in the effluent reduced from 217.8mg/l to 59.5mg/l at 100mm, 54.2mg/l at 140mm, 46.4mg/l at 180mm and 42.8mg/l at 220mm. The maximum permissible limit was achieved at the different lengths of activated carbon and increase in the length of activated carbon resulted into decrease in the COD concentration due to the increased surface area and binding sites.
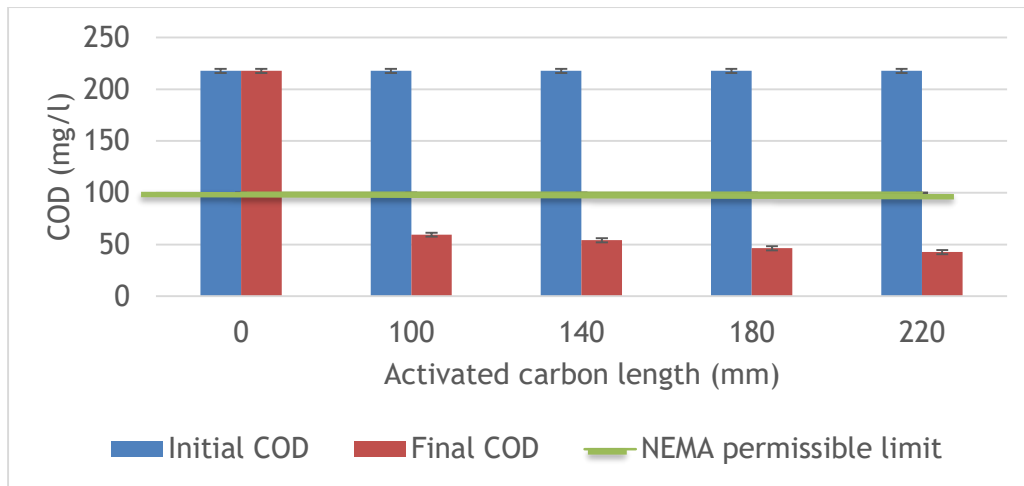
Figure 14: COD concentration at the different activated carbon lengths

Effect of activated carbon length on COD reduction

At the length of 100mm, a COD percentage reduction of 72.6% was achieved, with increase in the length of the activated carbon, the percentage reduction increased to 75.1% at 140mm, 78.7% at 180mm and 80.3% at 220mm, this is because increase in the column length results into increase in the surface area and the number of binding sites available for adsorption, the organic matter present is able to adsorb onto the vacant sites leading the increase in the reduction COD from the final effluent because as the effluent is passing through the activated carbon the COD molecules adhere onto the active binding sites leading to the increase in the percentage reduction of COD (Barrutia et al., 2019).

Effect of contact time on BOD and COD reduction

Increase in the column length resulted into increase in the contact time and this resulted into increase in the reduction of BOD and COD from the waste water effluent because of increase in the interaction and contact between the effluent and the activated carbon and this results in the increase in the reduction of BOD and COD from the waste water effluent.

4.2.3 Adsorption isotherms

4.2.3.1 Freundlich adsorption isotherm

$$Q_{e=} -\frac{V}{m} \times (C_{e-}C_0)$$

Where,

Q_e is the adsorbent phase concentration

V is the volume of the waste water effluent

M is the mass of the activated carbon

C_e is the equilibrium concentration

Table 8: Freundlich adsorption data for COD and BOD

For BOD					
parameter	units	Jar 1	Jar 2	Jar 3	Jar 4
Mass of activated carbon	mg	10	20	30	10
Volume of effluent V	l	1.00	1.00	1.00	1.00
Final BOD concentration C_e	mg/l	115	58.7	38.5	31.3
Adsorbent phase concentration Q_e	mg/g	2.87	4.25	3.51	2.82
ln Q_e	mg/g	1.05	1.45	1.26	1.04
ln C_e	mg/l	4.74	4.07	3.65	3.44
For COD					
Final COD concentration C_e	mg/l	165.9	84.2	45.6	35.8
Adsorbent phase concentration Q_e	mg/g	9.98	9.08	7.34	5.75
ln Q_e	mg/g	2.3	2.2	1.34	1.28
ln C_e	mg/l	5.11	4.43	3.82	3.58

Freundlich adsorption isotherm assumes that the adsorbent surface is heterogenous containing a variety of sites with different affinities for adsorption. Each site is capable of adsorbing the contaminants in the effluent and adsorption occurs in a non-uniform manner, therefore the Freundlich adsorption model describes a multilayer adsorption process due to the uneven distribution of the adsorption energies across the surface. The mathematical representation of the model is represented below

$q_e = K_f C_e^{1/n}$

$Adsorption\ capacity\ qe\ =\ 1.5706{\times}31.3^{\frac{1}{0.3175}}$

$Adsorption\ capacity\ for\ BOD\ =\ 806.2 mg/g$

$Adsorption\ capacity\ for\ COD$

$Adsorption\ capacity\ qe = 1.14{\times}35.8^{\frac{1}{0.4503}}$

Adsorption capacity for COD = 321.87mg/g

Where,

K_f is the adsorption equilibrium constant

1/n is the constant of Freundlich isotherm which is generally between 0 and 1, and is obtained from the graph as the gradient of the line

The value of 1/n indicates the impact of the adsorbate concentration on the adsorption capacity, the less the 1/n value, the greater the adsorption capacity, the adsorption process is easy if 1/n is between 0.1 and 0.5.

When 1/n is less than one, the adsorption is favorable and when 1/n is greater than one the adsorption becomes unfavorable which leads to a decrease in the adsorption capacity.

In our case the value 1/n which is the gradient of the equation, for BOD was 0.3175 and COD the value was 0.4503 which are less than one and they are

between o.1 and 0.5, and this brought us to a conclusion that the Freundlich adsorption isotherm is favorable for organic matter adsorption by the wood chips activated carbon.

The Freundlich adsorption isotherm exhibits higher correlation coefficient for the activated carbon the correlation coefficients for BOD and COD were 0.9878 and 0.8063 which are considerably a better fit compared to the Langmuir adsorption isotherm. Therefore, the adsorption by the wood chips activated carbon takes place in the multi-layer rather than the mono layer.
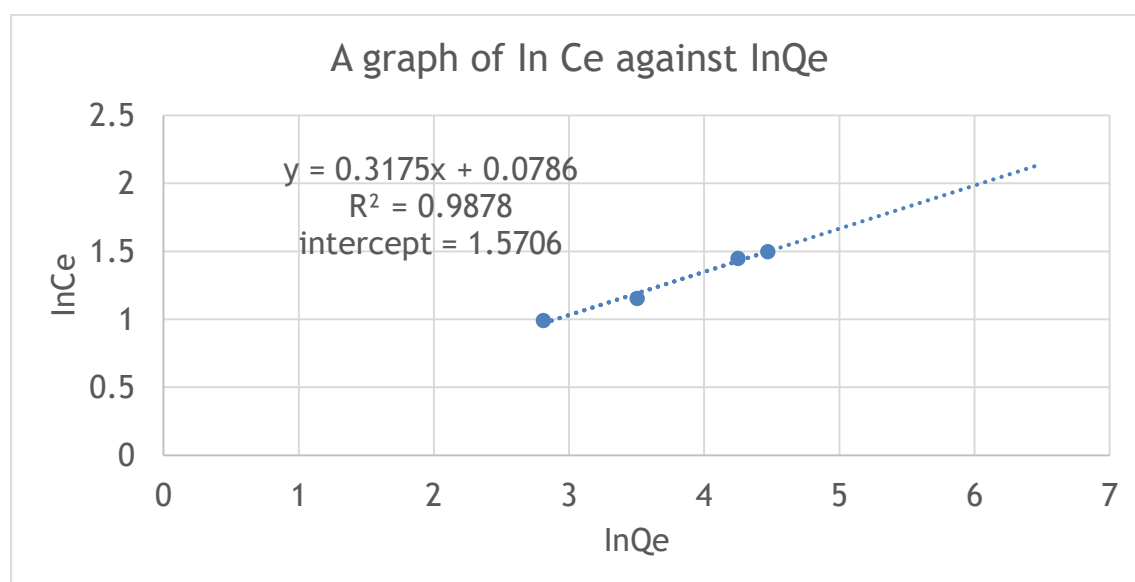
Figure 15: Freundlich adsorption isotherm for BOD
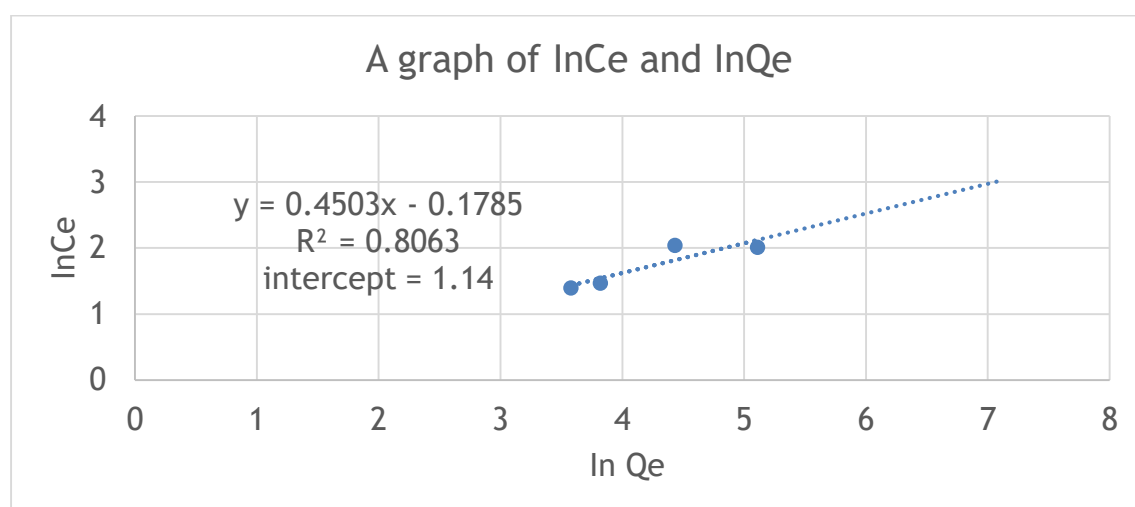
Figure 16: Freundlich adsorption isotherm for COD

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4.2.3.2 Langmuir adsorption isotherm

Table 9: Langmuir adsorption data for BOD and COD

For BOD					
parameter	units	Jar 1	Jar 2	Jar 3	Jar 4
Mass of activated carbon	mg	10	20	30	10
Volume of effluent V	l	1.00	1.00	1.00	1.00
Final BOD concentration C_e	mg/l	115	58.7	38.5	31.3
Adsorbent phase concentration Q_e	mg/g	2.87	4.25	3.51	2.82
$\dfrac{1}{Q_e}$	mg/g	0.348	0.235	0.285	0.356
$\dfrac{1}{C_e}$	mg/l	0.0087	0.017	0.024	0.032
For COD					
Final COD concentration C_e	mg/l	165.9	84.2	45.6	35.8
Adsorbent phase concentration Q_e	mg/g	9.98	9.08	7.34	5.75
$\dfrac{1}{Q_e}$	mg/g	0.100	0.110	0.136	0.174
$\dfrac{1}{C_e}$	mg/l	0.006	0.012	0.022	0.028

Langmuir adsorption isotherm model is developed on the assumption that adsorption is constant and independent of surface coverage. It assumes that adsorption occurs on localized sites with no interaction between the

adsorbate molecules and that maximum adsorption occurs when the surface is covered by a monolayer adsorbate.

Ce is the liquid phase concentration at equilibrium (mg/l)

Qe is the amount of organic matter absorbed per unit weight of wood chips activated carbon (mg/g).
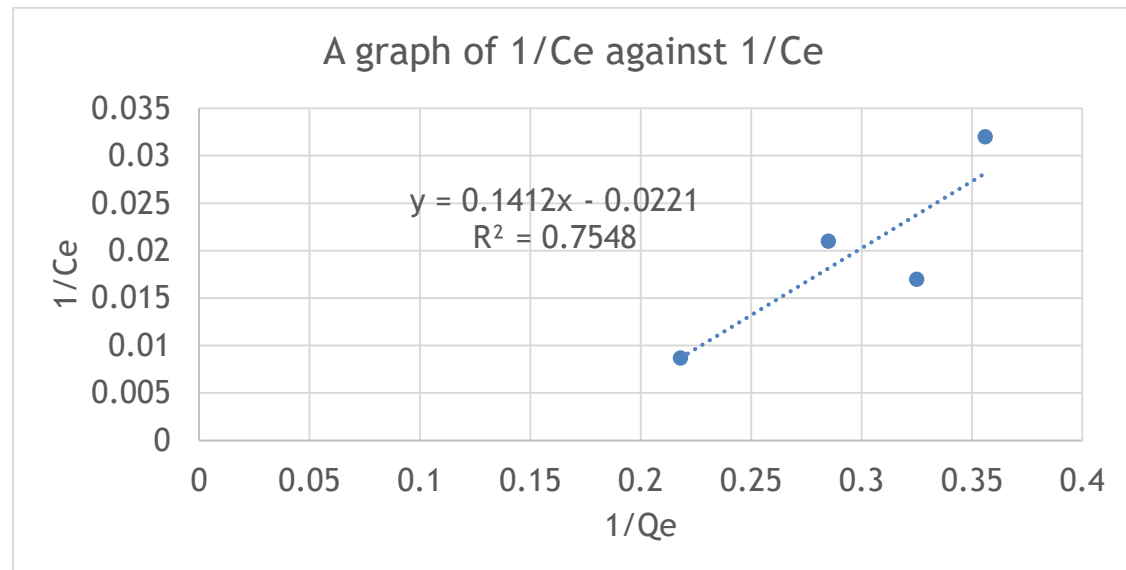
Figure 17: Langmuir adsorption isotherm for BOD
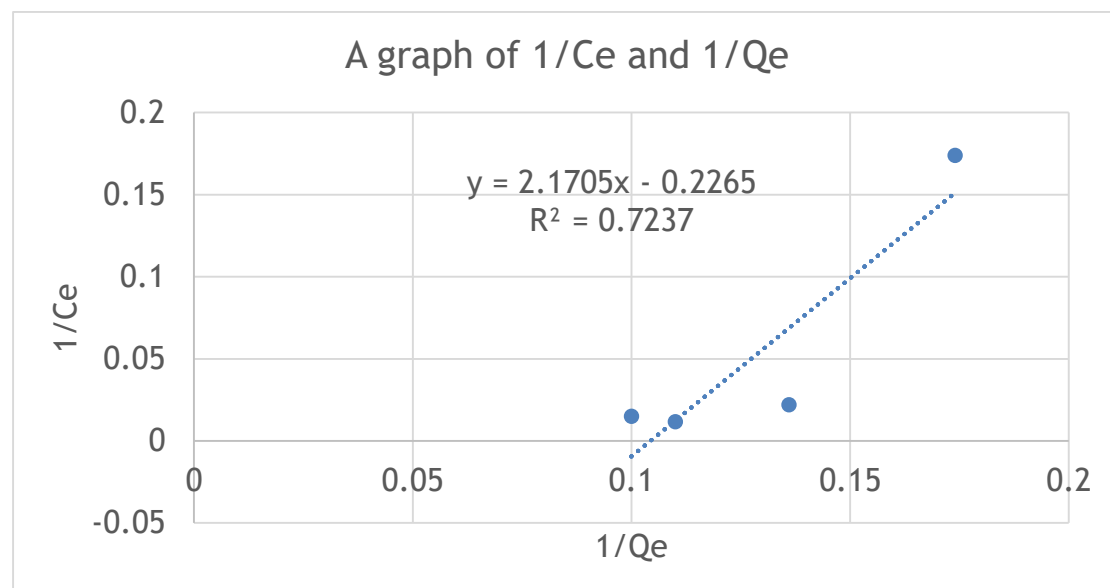
Figure 18: Langmuir adsorption isotherm for COD

4.2.3.4 Breakthrough curve

The time required to reach 5% of initial concentration is breakthrough time. The exhaustion time is the time of operation when effluent concentration reaches to the 95% value of inlet concentration. Meaning the outlet contains 95% of the organic matter as the one incoming to the bed. The initial BOD concentration (C_o) was 143.7mg/l and the initial COD (C_o)value was 265.7mg/l

Table 10: Breakthrough curve results for BOD and COD

Time (minutes)	Final BOD Concentration C (mg/L)	BOD (C/C_o)	Final COD Concentration C (mg/L)	COD (C/C_o)
0	0.08	0.00	0.13	0.00
10	0.22	0.00	0.31	0.00
20	0.59	0.00	0.76	0.00
30	1.61	0.01	1.87	0.01
40	4.28	0.03	4.55	0.02
50	11.07	0.08	10.93	0.04
60	26.23	0.18	25.36	0.10
70	55.17	0.38	54.76	0.21
80	90.88	0.62	103.53	0.39
90	119.37	0.82	162.43	0.61
100	134.92	0.92	211.23	0.79
110	141.73	0.97	240.64	0.90
120	143.40	0.99	259.47	0.96
130	143.56	1.00	264.54	1.00
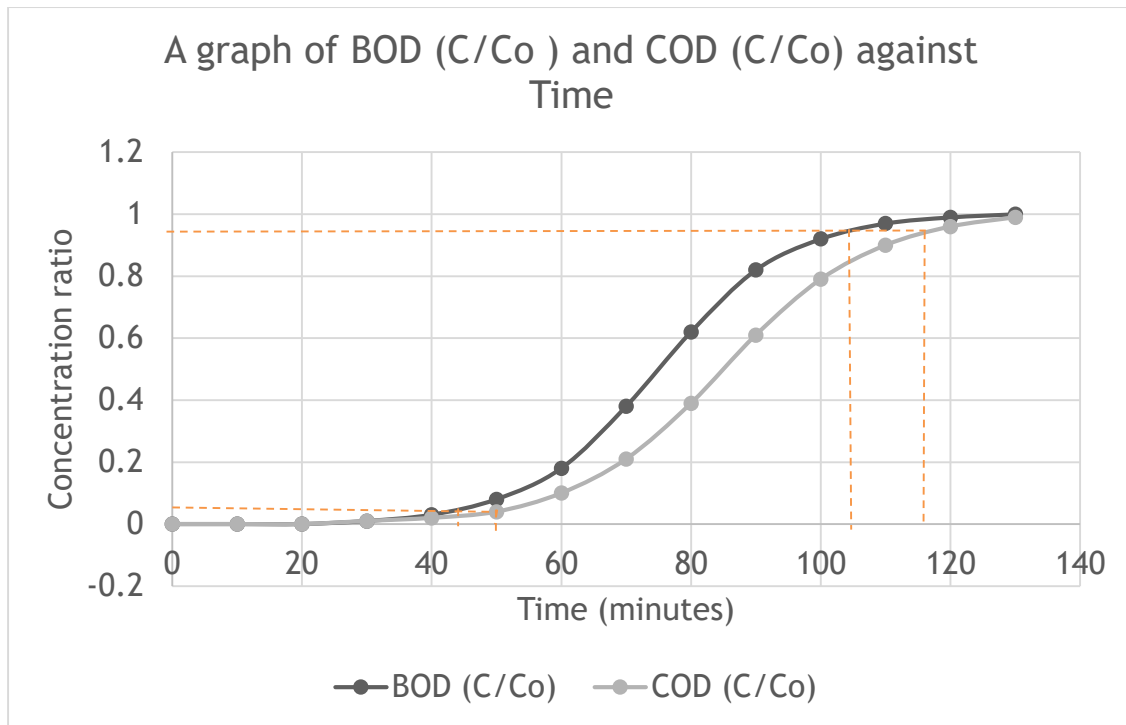
Figure 19: Breakthrough curves for BOD and COD

From 0-35minutes, the bed is said to be in equilibrium, as a feed with constant concentration C_o of the effluent is passed through a fresh column of activated carbon, the initial concentration at the outlet is zero but after a while the concentration increases because most of the voids are occupied by the organic matter present in the effluent and adsorption takes place in the mass transfer zone.

From 35-49minutes for BOD and 30-42minutes for COD, the concentration starts to increase because the length of the mass transfer zone changes and moves downwards to the bottom of the bed and this way the unused portion of the bed reduces because the BOD and COD binds onto the active binding sites.

At t=43minutes for COD and t= 50minutes for BOD, breakthrough occurs meaning the mass transfer zone has reached the bottom of the bed, at this

point it means breakthrough has occurred and the time at which breakthrough occurs is known as breakthrough time.

At t= 104minutes for BOD and t= 118minutes for COD, exhaustion occurs and when saturation reaches, the concentration at the outlet equals the concentration at the inlet, meaning the activated carbon has lost the adsorption capacity and can no longer adsorb and at this point it's advisable to replace the activated carbon of regenerated to restore its capacity.

Strategies

During the operation of the activated carbon bed in a continuous manner, there exists breakthrough and exhaustion time, from the analysis the breakthrough time of 43 and 50 minutes and exhaustion time of 104 and 118minutes were obtained for BOD and COD respectively, at exhaustion time the activated carbon has to be replaced or regenerated to restore the adsorption capacity, the exhaustion times were 104 and 118minutes, meaning after 118minutes maximum the activated carbon bed has to be replaced or regenerated, during the operation of a large scale unit, this is not feasible taking into account the costs of producing activated carbon as well as regeneration costs.

As a strategy to increase the breakthrough time and exhaustion time, it involves increasing the length or height of the activated carbon bed, and the length of the activated carbon bed should not exceed 1.8-4m, increase in the column length increase the time the mass transfer zone shifts to the bottom of the bed and at the column length of 1.8-4m, activated carbon bed can operate on average for 6-8months before regeneration or replacement of the activated carbon is required, therefore after using a prototype to treat the

waste water effluent, that length is then used to scale up the column length for a large scale unit, and we obtained a column length of 3m which is within the recommended range 1.8-4m (Metcalf and Eddy., 2003).

Velocity, the greater the velocity the shorter the exhaustion and breakthrough time, so if long exhaustion and breakthrough time is required since it reduces the need to replace or regenerate the activated carbon all the time, then a smaller velocity is used, and to ensure this, we provided a provision for the equalization chamber to ensure the approach velocity into the activated carbon bed is reduced.

4.3 Design of the waste water effluent treatment unit

Though the different parameters were affected differently in the dry and wet season, (Makuwa et al., 2022) noted that the efficiency of the activated carbon bed in waste water effluent treatment in reducing BOD and COD proved to be consistent across all seasons as the BOD and COD values of the treated effluent showed effective compliance when measured against the set permissible standards in both the dry and wet seasons.

Since the BOD and COD concentrations where high in the dry season as compared to the wet season, to design for the worst-case scenarios the design mainly focused on the parameters from the dry season.

The design was done following the Metcalf and Eddy design manual which provides guidance on how to design a system using activated carbon by the help of a small-scale design test. A small-scale test is carried out to mimic a large-scale operation, the principle is to help in determining the adsorptive capacity of the granular activated carbon under conditions similar to the ones done in the field. Scaling of the information obtained from a small-scale

design helps to predict the performance of the full-scale unit (Metcalf & Eddy.,2003).

Design for a large-scale unit (Metcalf & Eddy.,2003).

Table 11: Design calculation for full-scale design

Parameter	Check against manual (Metcalf and Eddy 4th Edition)	Check by supervisor
Stabilization pond flow rate= 1200m³/day Flow rate(Q) = $\frac{1200(m^3/day)}{24(h)}$ = 50m³/h **Approach velocity (v_{ls})** Q = Av_{ls} $$v_{ls} = \frac{Q}{A}$$ $$A = \frac{\pi d^2}{4}$$ $$A = \frac{\pi(0.762m)^2}{4}$$ $$A = 0.456m^2$$ $$v = \frac{50(m^3/h)}{0.456(m^2)}$$ $$v = 109.64 \, m/h$$ The peak flow rate is for the effluent from the two discharge points, therefore for a single discharge point the velocity is 55m/h which is still beyond the recommended range, therefore	Approach velocity 5 – 15m/h	

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Parameter	Check against manual (Metcalf and Eddy 4th Edition)	Check by supervisor
as a solution, an equalization chamber has to be provided to regulate the flow into the column. Using $v_{ss} = v_{LS}\left[\frac{d_{ls}}{d_{ss}}\right]$ from Metcalf and Eddy $$30 m/h = v_{LS}(m/h)\left[\frac{1.18(mm)}{0.6(mm)}\right]$$ $$v_{ls} = 15 m/h$$ $$v_{ls} = 15 m/h$$ Where; v_{ls} is the approach velocity in the larger column v_{ss} is the approach velocity in the small-scale design. d_{ls} is the activated carbon particle size for the full scale obtained from sieve analysis d_{ss} is the activated carbon particle size used in the lab scale obtained from sieve analysis **Area (A) of effluent discharge pipe from stabilization pond** $$A = \frac{\pi d^2}{4}$$ $$A = \frac{\pi(0.3048m)^2}{4}$$ $$A = 0.0730m^2$$		

Parameter	Check against manual (Metcalf and Eddy 4th Edition)	Check by supervisor
Where d is the measured outlet pipe diameter of the effluent		
Empty Bed Contact Time for a small scale EBTC$_{SS}$ $$EBCT_{ss} = \frac{v_b}{Q_{ss}}$$ $$v_b = \frac{\pi D_{ss}^2}{4} \times H_{col}$$ $$v_b = \frac{\pi (0.01m)^2}{4} \times 0.18m$$ $$v_b = 1.1414 x 10^{-5} m^3$$ $$EBCT_{ss} = \frac{1.1414 x 10^{-5} m^3}{0.000007 (m^3/minute)}$$ $$EBCT_{ss} = 3 \text{ minutes}$$ Where, v_b is the volume of the small-scale bed Q_{ss} flow rate of the effluent through the small-scale unit D_{ss} is the diameter of the small-scale unit H_{col} is the height of the small-scale column		

Parameter	Check against manual (Metcalf and Eddy 4th Edition)	Check by supervisor
EBCT for larger scale design from Metcalf and Eddy $$EBCT_{ss} = EBCT_{ls}\left[\frac{d_{ss}}{d_{ls}}\right]^2$$ $$7.2 = EBCT_{ls}(minutes)\left[\frac{0.6mm}{1.18mm}\right]^2$$ $EBCT_{ls} = 12\ minutes$ **(OK)** **Bed volume for full-scale design** $$V_{bed} = Q \times EBCT$$ $$V_{bed} = 50m^3/h \times 0.2\ h$$ $V_{bed} = 10m^3$ **(okay)** **Area of column (a)** $= Q \div v$ $$= \frac{50(m^3/h)}{15(m/h)}$$ $$= 3.33\ m^2$$	Empty bed contact time 5-30 minutes Bed volume = 10-50 m^3	
Diameter of column D $$D = \sqrt{\frac{4A}{\pi}}$$ $$D = \sqrt{\frac{4(3.33m^2)}{\pi}}$$ $$D = 2.1m$$ Where D is the diameter of the full-scale column		
Required and bed length (L)		

Parameter	Check against manual (Metcalf and Eddy 4th Edition)	Check by supervisor
$$L = \frac{v_{Bed}}{A_{each}}$$ Bed length $= \frac{10m^3}{3.33m^2}$ Bed length $= 3m$ (OKAY)	Length = 1.8-4m	
Bulk density of the granular activated carbon (ρ_{GAC}) $$Bulk\ density = \frac{mass\ of\ activated\ carbon}{volume}$$ Mass of activated carbon = 0.042g Volume = 0.0001m³ $$Bulk\ density = \frac{0.042(g)}{0.0001(m^3)}$$ Bulk density = 420g/m³ (okay)	Bulk density 350 - 550 g/m³	
Mass of adsorbent (M) required in the large-scale column $$M = EBCT_{LS} \times Q_{LS} \times \rho_{GAC}$$ $$M = 12(minutes) \times 0.000007(m^3/minute)$$ $$\times 420(g/m^3)$$ M = 0.03528g M = 35.28kg		

Parameter	Check against manual (Metcalf and Eddy 4th Edition)	Check by supervisor
Specific throughput $$Specific\ throughput = \frac{V_{bed} \times t}{(EBCT_{LS} \times M)}$$ $$Specific\ throughput = \frac{10(m^3) \times 32.3(min)}{12(min) \times 0.03528(g)}$$ Where t is the hydraulic retention time in the activated carbon bed Specific throughput = 0.064m^3/g $Specific\ throughput = 64m^3/kg$ (Okay)	Specific throughput 50 - 200m^3/kg	
Carbon usage rate CUR $$CUR = \frac{1}{Specific\ throughput(m^3/kg)}$$ $$CUR = \frac{1}{64}$$ $CUR = 0.0156kg/m^3$		
Volume of effluent required V_e $V_e = \frac{M}{CUR}$ $V_e = \frac{35.28(kg)}{0.0156(kg/m^3)}$ V_e = 2262m^3		
Design of the under-drain pipes		

Parameter	Check against manual (Metcalf and Eddy 4th Edition)	Check by supervisor
The under-drain system consists of a central manifold pipe with lateral having perforations at their bottom Area of perforations = 0.2% 0f the bed area The area of the tank A = 3.33m² $Area\ of\ perforations\ =\ 0.002 \times 3.33(m^2)$ **Area of perforations = 0.0067m²** Area of the laterals = 2×area of perforations Area of laterals = 2×0.0067(m²) **Area of laterals = 0.0134m²** Area of manifold = 2×area of laterals Area of manifold = 2×0.0134(m²) **Area of manifold = 0.0268m²** Diameter of manifold = $\frac{(0.0268 \times 4)^{\frac{1}{2}}}{\pi}$ **Diameter of manifold = 0.185m** Hence 0.185cm diameter manifold pipe will be laid length wise at the bottom of the adsorption tank. The laterals run perpendicular to the manifold assuming the spacing between them is 0.15m Number of laterals = $\frac{diameter\ of\ the bed}{spacing}$	Area of the underdrain 1.5% total area of the tank	

Parameter	Check against manual (Metcalf and Eddy 4th Edition)	Check by supervisor
Number of laterals = $\frac{2.1(m)}{0.15(m)}$ Number of laterals = **14** and these should be applied on either side of the manifold		
Equalization chamber design Q = 1200m^3/day Hydraulic retention time for the equalization chamber (HRT) HRT = 5hours (pick from the manual which provides a recommended range of 4-8 hours) Q = $\frac{1200(m^3/day)}{24(h)}$ = 50m^3/h Q = 50m^3/h The manual recommends that the balancing storage is 30% of the peak average flow to facilitate the fluctuations. Q = 0.3×50(m^3/h) Q = 15m^3/h $V = Q \times HRT$ $V = 15(m^3/h) \times 5(h)$ V = 75m^3 Taking an average depth of 4m (pick from the manual)	Balancing storage 30% peak flow rate	

Parameter	Check against manual (Metcalf and Eddy 4th Edition)	Check by supervisor
$A = \dfrac{v}{depth}$ $A = \dfrac{75(m^3)}{4(m)}$ A = 19m² ok	Area of the equalization chamber 15 - 20m²	
For a rectangular equalization chamber the ratio of length to width is normally 2:1 $L = 2W \quad A = L \times W$ $2W^2(m) = 19(m^2)$ W = 3m $L = 2 \times 3(m)$ L = 6m		

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. **Determination of the physiochemical quality of the waste water effluent**

The findings done on the effluent in both the wet and dry seasons indicate that the BOD and COD concentrations from the Doko waste stabilization pond do not meet the standards set by NEMA of 50mg/l for BOD and 100mg/l for COD as the mean results of BOD_5 and COD for the dry season were 172.3mg/l and 269.7mg/l respectively and for the wet season the mean values of BOD_5 were 129.1mg/l and a COD value of 217.8mg/l and this shows that there is need to treat the waste water effluent before discharging it to the Nashibiso stream as the presence of organic matter causes adverse impacts on aquatic life through the depletion of dissolved oxygen.

2. **Determination of the reduction of BOD and COD from the waste water effluent after treatment with activated carbon**

When wood chips activated carbon was used in the treatment of the effluent, a significant reduction in BOD_5 and COD was observed and a removal efficiency of 74.5% for BOD_5 and 72.2% for COD for the dry season and a BOD_5 and COD removal efficiency of 80.3% and 82% respectively was obtained for the wet season and at these percentages the BOD_5 and COD and values reduced to acceptable limits. Therefore, the use of the wood chips activated carbon to treat the waste water effluent from the maturation pond before its discharge to the stream will help in restoring the detoriating Nashibiso stream to sustain aquatic life and also provide water for the community which is safe for use.

3. **Design of the waste water effluent treatment unit**

This was achieved using the Metcalf and Eddy design manual, in the computations, the approach velocity to the activated carbon column was beyond the recommended range of 5-15m/h, if the velocity of the effluent was left uncontrolled, there would be distortion of the activated carbon, therefore as a result an equalization chamber is introduced to regulate the flow rate and velocity before the effluent flows into the activated carbon bed. The design was based on the results from the dry season since they were the highest and according to (Makuwa et al., 2022) who assessed the performance of activated carbon in waste water effluent treatment concludes that despite the variations in the concentration of the parameters the efficiency of the activated carbon remains the same.

5.2 Recommendations

1. **Determination of the physiochemical quality of the waste water effluent**

Recommend that an activated carbon treatment unit should be added to the existing system to act as a polishing unit to the effluent before being discharged into the Nashibiso stream.

2. **Determination of the reduction of BOD and COD from the waste water effluent**

Further research should be conducted to determine the best regeneration methods for used activated carbon, such that after it has lost its adsorption capacity it's not thrown away but can be reused again to treat the waste water effluent this helps to promote a circular economy and leads to improved sustainability and cost effectiveness.

3. **Design of the waste water treatment unit**

Regular maintenance and monitoring should be done once the system is incorporated, to monitor BOD and COD reductions whether monthly or on a weekly basis.

REFERENCES

Mopoung, S. and Dejang, N. (2021). Activated carbon preparation from eucalyptus wood chips using continuous carbonization–steam activation process in a batch intermittent rotary kiln. Scientific Reports, [online] 11(1), p.13948. doi:https://doi.org/10.1038/s41598-021-93249-x.

Dwivedi, S. and Dwivedi, N. (2022). Microalgae: A potential tool for wastewater treatment and its biotechnological applications. Elsevier eBooks, pp.121–134. doi:https://doi.org/10.1016/b978-0-12-823499-0.00003-1.

Stott, R. (2003). Fate and behavior of parasites in wastewater treatment systems. Handbook of Water and Wastewater Microbiology, pp.491–521. doi:https://doi.org/10.1016/b978-012470100-7/50032-7.

Danish, M. and Ahmad, T. (2018). A review on utilization of wood biomass as a sustainable precursor for activated carbon production and application. Renewable and Sustainable Energy Reviews, 87, pp.1–21. doi:https://doi.org/10.1016/j.rser.2018.02.003.

Chem21labs (2024) 'Solubility of Calcium Hydroxide', pp. 102–103. Available at: https://www.chem21labs.com/labfiles/UKY_GL16_MNet_Lab.pdf.

Li, J. et al. (2018) 'Analytical Approaches for Determining Chemical Oxygen Demand in Water Bodies: A Review', Critical Reviews in Analytical Chemistry, 48(1),pp.47–65Availableat:https://doi.org/10.1080/10408347.2017.1370670.

Jaya Rajan, M. and Indira Anish, C. (2022). Role of Activated Carbon in Water Treatment. Water Quality - New Perspectives [Working Title]. doi:https://doi.org/10.5772/intechopen.108349.

Mallakpour, S., Sirous, F. and Hussain, C.M. (2021). Sawdust, a versatile, inexpensive, readily available bio-waste: From mother earth to valuable materials for sustainable remediation technologies. Advances in Colloid and InterfaceScience,[online]295,p.102492doi:https://doi.org/10.1016/j.cis.2021.102492.

Bateganya, N.L., Nakalanzi, D., Babu, M. and Hein, T. (2015). Buffering municipal wastewater pollution using urban wetlands in sub-Saharan Africa: a case of Masaka municipality, Uganda. Environmental Technology, 36(17), pp.2149–2160. doi: https://doi.org/10.1080/09593330.2015.1023363. Steen, Vairavamoorthy, P. (2019). The future of water in African cities: why waste water?[online]WorldBank.Availableat:

http://documents.worldbank.org/curated/en/989631468008770979 .

Shon, H.K., Vigneswaran, S. and Snyder, S.A. (2006). Effluent Organic Matter (EfOM) in Wastewater: Constituents, Effects, and Treatment. Critical Reviews in Environmental Science and Technology, 36(4), pp.327–374. doi: https://doi.org/10.1080/10643380600580011.

Bilal, M., Wang, Z., Cui, J., Ferreira, L.F., Bharagava, R.N. and Iqbal, H.M.N. (2020). Environmental impact of lignocellulosic wastes and their effective exploitation as smart carriers – A drive towards greener and eco-friendlier biocatalytic systems. Science of The Total Environment, 722, p.137903. doi: https://doi.org/10.1016/j.scitotenv.2020.137903.

Agrawal, V.R., Vairagade, V.S. and Kedar, A.P. (2017). Activated Carbon as Adsorbent In Advance Treatment of Wastewater. IOSR Journal of Mechanical

andCiviEngineering,14(04),pp.36–40.doi:

https://doi.org/10.9790/16841404023640.

 Shukla, S.K., Al Mushaiqri, N.R.S., Al Subhi, H.M., Yoo, K. and Al Sadeq, H. (2020). Low-cost activated carbon production from organic waste and its utilization for wastewater treatment. Applied Water Science, 10(2). doi:https://doi.org/10.1007/s13201-020-1145-z.

Yalçın, N. and Sevinç, V. (2000). Studies of the surface area and porosity of activated carbons prepared from rice husks. Carbon, 38(14), pp.1943–1945. Doi: https://doi.org/10.1016/s0008-6223(00)00029-4.

López-Cervantes, J., Sánchez-Machado, D.I., Sánchez-Duarte, R.G. and Correa-Murrieta, M.A. (2018). Study of a fixed-bed column in the adsorption of an azo dye from an aqueous medium using a chitosan–glutaraldehyde biosorbent.36(1-2),pp.215–232.

doi:https://doi.org/10.1177/0263617416688021.

Makuwa, S., Tlou, M., Fosso-Kankeu, E. and Green, E. (2022). The effects of dry versus wet season on the performance of a wastewater treatment plant in north west province, south africa. Water SA, 48(1 January). doi:https://doi.org/10.17159/wsa/2022.v48.i1.3897.

Sumangala Devi, N., Hariram, M. and Vivekanandhan, S. (2021). Modification techniques to improve the capacitive performance of biocarbon materials. *Journal of Energy Storage*, 33, p.101870. doi:https://doi.org/10.1016/j.est.2020.101870.

Rani, R., Summaiya Tasmeem, Malik, A., Garg, V.K., Singh, L. and Sanju Bala Dhull (2021). Optimization of Swiss blue dye removal by cotton boll activated

carbon: response surface methodological approach. *Toxin Reviews*, 41(1), pp.298–314. doi:https://doi.org/10.1080/15569543.2021.1873386.

Chang, H., Yuan, X.-G., Tian, H. and Zeng, A.-W. (2006). Experiment and prediction of breakthrough curves for packed bed adsorption of water vapor on cornmeal. *Chemical Engineering and Processing - Process Intensification*, 45(9), pp.747–754. doi:https://doi.org/10.1016/j.cep.2006.03.001.

Barrutia, J.M. and Echebarria, C. (2019). Comparing three theories of participation in pro-environmental, collaborative governance networks. *Journal of Environmental Management*, 240, pp.108–118. doi:https://doi.org/10.1016/j.jenvman.2019.03.103.

Alawa, B., Galodiya, M.N. and Chakma, S. (2022). Source reduction, recycling, disposal, and treatment. *Hazardous Waste Management*, pp.67–88. doi:https://doi.org/10.1016/b978-0-12-824344-2.00005-7.

APPENDICES

APPENDIX A

Figure 20: Anaerobic pond at the Doko waste stabilization pond

Figure 21: Nashibiso stream

Figure 22: the Doko waste stabilization point discharge point

Figure 23: layout of the Doko waste stabilization ponds

Figure 24: Waste water effluent sample collection

Figure 25: collected Waste water effluent samples

Figure 26: Lab analysis

Figure 27: Batch test

Figure 28: breakthrough column experiment

Figure 29: Trial runs with the wood chips activated carbon

Figure 30: performance of lab tests

Figure 31: the yellow part represents the proposed area of placing the activated carbon treatment unit

Table 12: Evaluation of the current and existing conditions of the ponds and the original design

(Mara. D, Alabaster, G; Pearson, H, et al 1992) manual for design of waste stabilization ponds.

Calculation	Check against manual	Check by supervisor
Anaerobic pond $$Lv = 300 \text{ g/m}^3/\text{d}$$ $$V = Lv/(Li \times Q)$$ $$V = (380 \times 1300)/300$$ $$V = 1647 \text{m}^3$$ **Retention time = V/Q** $$t = 1647/1300$$ $$t = 1.3 \text{ days}$$		

In the original design, the retention time for the anaerobic pond is 4days Depth of the ponds = 4m Initially a retention time of 4days was designed for the anaerobic pond (NWSC, 2021) Area of the anaerobic pond = 1647/4 Area = 412m² BOD removal at 20°C is 60% Effluent BOD from the anaerobic pond = 0.6×380 = 228mg/l This becomes the influent for the facultative pond	5 days max ok	
Depth of the ponds = 4m	2 - 5 m ok	
Facultative pond The surface loading is given by; $L_s = 350(1.107 - 0.0027)^{T-25}$ $L_s = 350(1.107 - 0.0027)^{20-25}$ $L_s = 213$ kg BOD/ha/day But; $L_s = 10L_i/A_f$ $A = 10 \times L_i \times Q/L_s$ $A = (10 \times 228 \times 1300)/213$ $A = 13,915m²$ The depth of the facultative pond is 1.5m		

Detention time = V/Q = $A_f \times d$/Q t = (13915×1.5)/ 1300 t = 10.7 days approximately t = 11days In the original design, the retention time of the facultative ponds is 14days and this shows the reduction in retention time in facultative ponds by 3days	>4 days ok	
Depth of the facultative ponds = 1.5m	1 - 2 days ok	

The ponds have a volume of 40,000m³, surface area of 2.75ha, peak flow rate of 1300m³/day BOD concentration of the influent is 380mg/l (NWSC, 2025) and the design temperature is >20°C, this is recommended for areas of Eastern Africa where the temperatures go beyond 20°CThe volumetric loading rate is given as,

$L_v = L_i \times Q/V$

Where;

L_v =Volumetric organic loading rate (g/m³/d)

L_i = Influent BOD (mg O_2 /L)

Q = average influent flow rate (m³/d)

V = the required pond volume (m³)

At a temperature >20°C, the manual recommends the volumetric loading rate of 300g/m³/d. The volumetric loading is between 100 - 400g/m³/day therefore it meets the standards for design.

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Date of sampling 6th January 2025

Date of analysis 7th January 2025

Waste water effluent results

Parameter	Units	Morning Time: 8:00	Afternoon Time: 1:00	Evening Time: 5:00	Waste water Effluent discharge standards
Biochemical oxygen demand	mg/l	180.0	169.6	167.3	<50
Chemical oxygen demand	mg/l	278.7	267.3	263.2	<100
PH		8.3	8.7	8.6	5.5 - 8.5
Total suspended solids	mg/l	83.4	93.0	87.3	<100
Electrical conductivity	µS/cm	860.2	900.2	895.3	<1500

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Nashibiso Stream test results

Parameter	UNITS	Upstream	Middle stream	Down stream
Biochemical oxygen demand	mg/l	43	174	130
Chemical oxygen demand	mg/l	81.3	218.8	209.5
Total suspended solids	mg/l	35	75.7	61.7
pH		7.2	8.3	7.8
Electrical conductivity	µs/cm	114	517	490

Remarks: The results for the water samples tested were as above.
Analysed by: Wanyera Julius (QCO) &
RUHIGIRA Johnson Ngabo
KHARONO Mary Norine

NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY- BUGOLOBI
P.O BOX 7053 KAMPALA Email: waterquality@nwsc...

Student: RUHIGIRA Johnson Ngabo 521B32/043 &

KHARONO Mary Norine 521B32/111

Address: Uganda Christian University

Mukono (Uganda)

Date Sample Tested: 14ᵗʰ March , 2025.

TEST RESULTS

Sample	Activated carbon length (mm)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	pH	EC (µS/cm)
1	0	143.7	275.7	88	8.6	826.7
2	100	45.2	88.3	71	8.3	702.7
3	140	39.8	79.3	58	8.0	661.4
4	180	36.6	73.8	43	7.9	620.0
5	220	36.4	72.2	35	7.6	578.7

BATCH ADSORPTION TEST RESULTS

Parameter	Units	Activated carbon dosage (mg/l)				
		0	10	20	30	40
Biochemical oxygen demand	mg/l	143.7	115.0	58.7	38.5	31.3
Chemical oxygen demand	mg/l	265.7	165.9	84.2	45.6	35.8
pH		8.6	8.4	8.1	7.9	7.7

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BREAKTHROUGH CURVE RESULTS

Time (minutes)	Final BOD5 (mg/L)	COD (mg/L)
0	0.08	0.13
10	0.22	0.31
20	0.59	0.76
30	1.61	1.87
40	4.28	4.55
50	11.07	10.93
60	26.23	25.36
70	55.17	54.76
80	90.88	103.53
90	119.37	162.43
100	134.92	211.23
110	141.73	240.64
120	143.40	259.47
130	143.56	264.54

Remarks: The results for the water samples tested were as above.
Analysed by: Wanyera Julius (QCO) &
RUHIGIRA Johnson Ngabo
KHARONO Mary Norine

14th /03/202

Name: KHARONO MARY NORINE AND RUHIGIRA JOHNSON NGABO
Reg. No.: S21832/111 AND S21832/043
Program: BSCCE
Date: ....

PARTICLE SIZE DISTRIBUTION CHART

UGANDA CHRISTIAN UNIVERSITY
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FACULTY OF ENGINEERING, DESIGN, AND TECHNOLOGY
Department of Engineering and Environment

GEO-MATERIAL LABORATORY
Laboratory Test Certificate

Certificate Number: GML251J		
Sample: Bio-slurry	**Sample ID No.:**	GML/02/02/1425

Sample Description: Said to be "Wood chip char"

Party's Ref No: Nil	**Certificate Issue Date:** 5th Feb 2025

Client Name & Address: 1. Ruhigira Johnson Ngabo 2. Kharono Mary Norine **Physical Address:** Mukono **Client's Contact** Phone No.: +256 783 542511 Email: johnsonngabo5@gmail.com	Job Code: : POROSITY TEST
	Sample Received On : 7th Feb 2025
	Date of Testing : 7th Feb 2025
	Completion Date : 7th Feb 2025

Sample Condition:	Solid sample packed in a polythene bag

DETERMINATION OF POROSITY

Test	1	2	3	Average
Mass when wet Mw (kg)	0.286	0.205	0.223	0.238
Mass when dry Md (kg)	0.156	0.12	0.13	0.137
Porosity (%)	83.3	70.8	71.5	75.2

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Econi Kennedy
Laboratory Instructor

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Tom More Mwanje
Head of Department – Engineering & Environment

End of Report

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Department of Engineering and Environment

GEO-MATERIAL LABORATORY
Laboratory Test Certificate

Certificate Number: GML252J	
Sample: Bio-slurry	**Sample ID No.:** GML/02/02/1425
Sample Description: Said to be "Wood chip char"	
Party's Ref No: Nil	**Certificate Issue Date: 11th Feb 2025**

Client Name & Address:	
1. Ruhigira Johnson Ngabo 2. Kharono Mary Norine **Physical Address:** Mukono **Client's Contact** Phone No.: +256 783 542511 Email: johnsonngabo5@gmail.com	**Job Code:** : POROSITY TEST
	Sample Received On : 7th Feb 2025
	Date of Testing : 7th Feb 2025
	Completion Date : 7th Feb 2025
Sample Condition:	Solid sample packed in a polythene bag

CIVIL ANALYSIS RESULTS

The total mass of the activated carbon was **1386g**

Sieve size (mm)	Mass retained (g)	Percentage retained (%)	Cumulative percentage retained (%)	Percentage passing (%)
10	0	0	0	100
6.3	110	8.2	8.2	91.8
5.0	120	8.9	17.1	82.9
3.35	140	10.4	27.5	72.5
2.0	179	13.3	40.8	59.2
1.18	190	14.1	55.2	44.8
0.60	450	33.5	88.7	11.3
0.425	75.2	5.6	94.3	5.7
0.3	45.7	3.4	97.7	2.3
0.212	19.7	1.5	99.2	0.8
0.15	8.9	0.6	99.9	0.1
0.075	4.0	0.2	100	0.0

....
Econi Kennedy
Laboratory Instructor

....
Tom More Mwanje
Head of Department – Engineering & Environment

End of Report

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Department of Engineering and Environment

GEO-MATERIAL LABORATORY
Laboratory Test Certificate

Certificate Number: GML253J	
Sample: Bio-slurry	**Sample ID No.:** GML/02/02/1425
Sample Description: Said to be "Wood chip char"	
Party's Ref No: Nil	**Certificate Issue Date: 11th Feb 2025**
Client Name & Address: 1. Ruhigira Johnson Ngabo 2. Kharono Mary Norine **Physical Address:** Mukono **Client's Contact** Phone No.: +256 783 542511 Email: johnsonngabo5@gmail.com	**Job Code:** : POROSITY TEST
	Sample Received On : 7th Feb 2025
	Date of Testing : 7th Feb 2025
	Completion Date : 7th Feb 2025
Sample Condition:	Solid sample packed in a polythene bag

BULK DENSITY TEST RESULTS
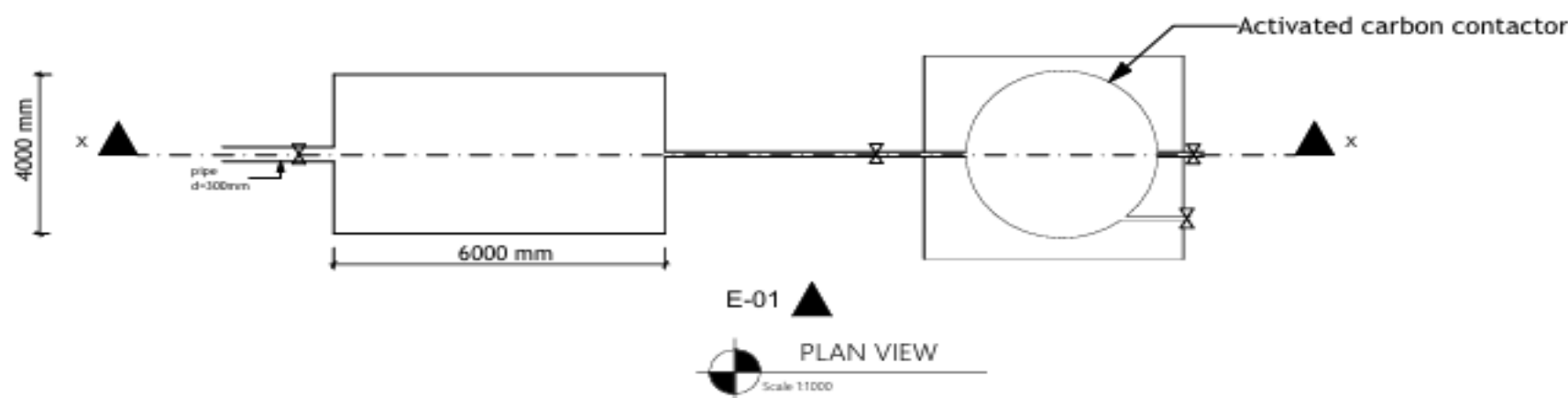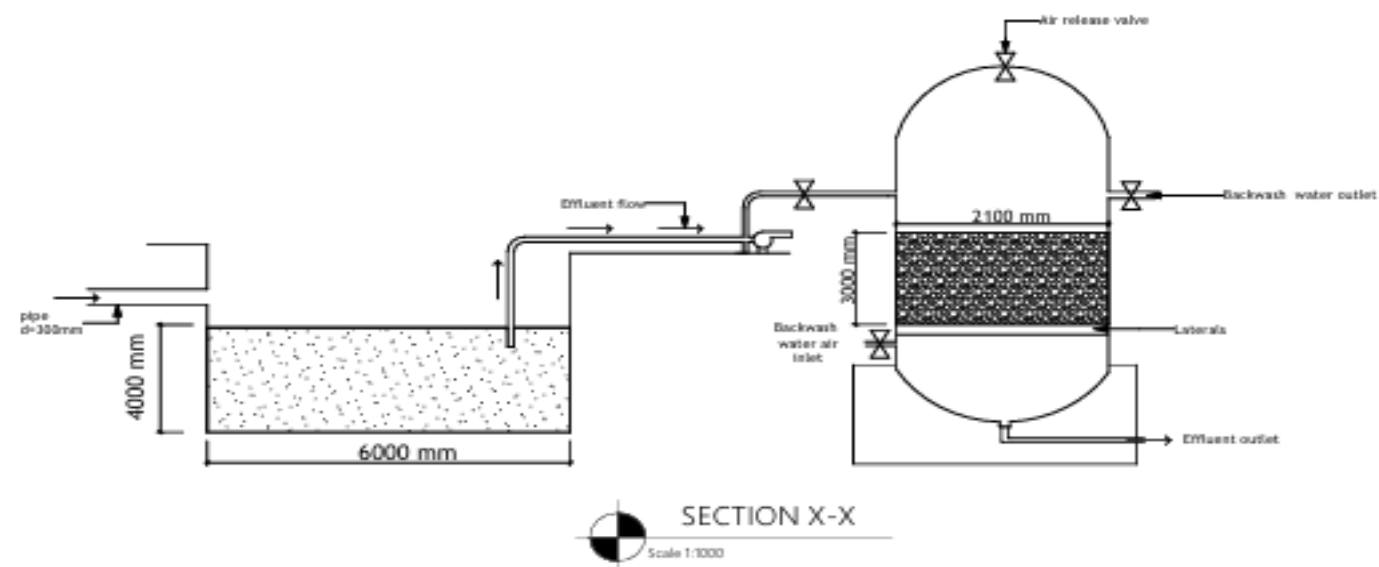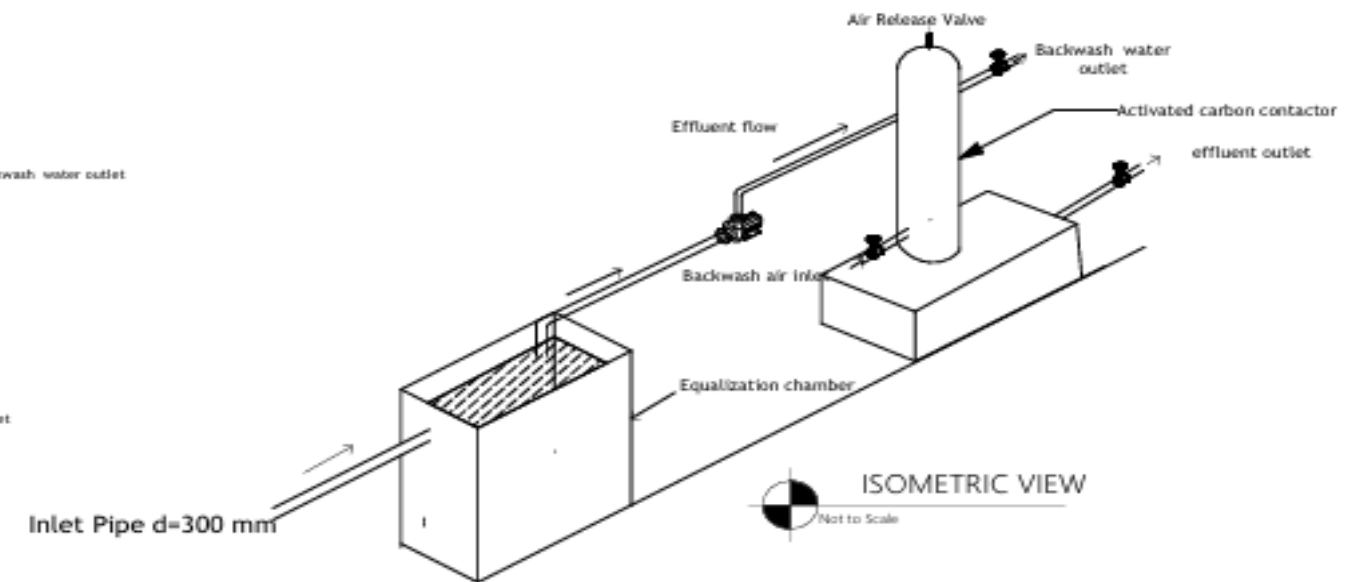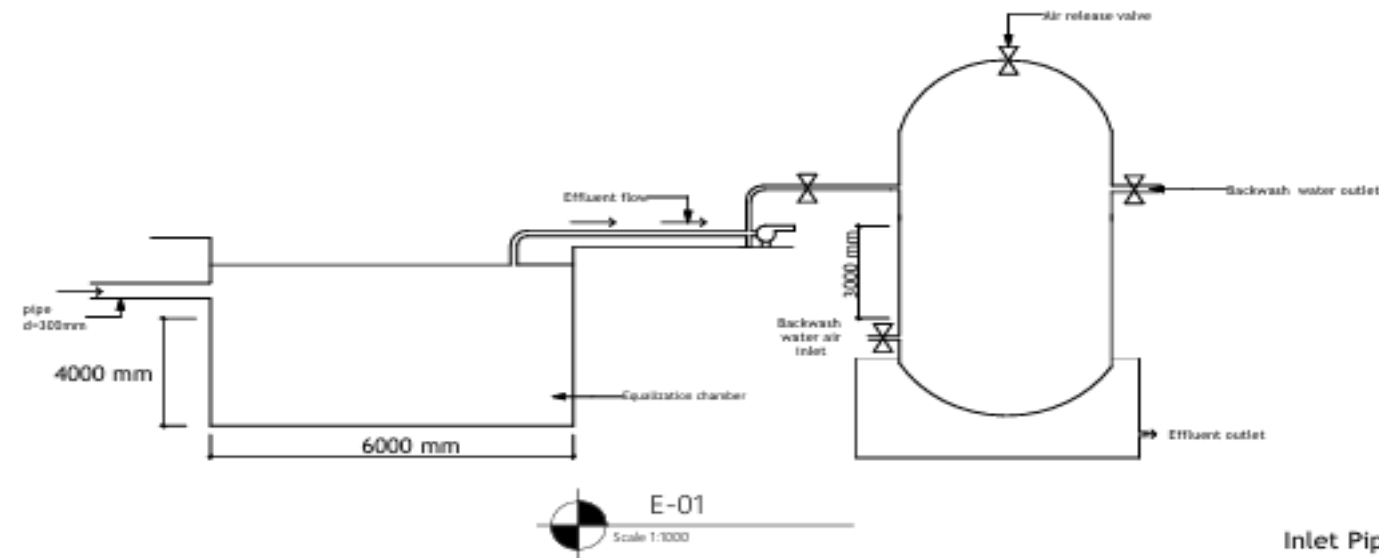Determination of bulk density of the activated carbon

Test	1	2	3	Average
Volume (m³)	0.0001	0.0001	0.0001	0.0001
Mass (kg)	0.041	0.039	0.046	0.042
Bulk density (kg/m³)	410	390	460	420

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Eddie Ojara
Laboratory Instructor

....
Tom More Mwanje
Head of Department – Engineering &
Environment

End of Report

APPENDIX C: DRAWING

E-01
Scale 1:1000

ISOMETRIC VIEW
Not to Scale

SECTION X-X
Scale 1:1000

PLAN VIEW
Scale 1:1000

DESIGN DRAWING

Drawing Title

DESIGN OF ACTIVATED CARBON TREATEMENT UNIT FOR DOKO STABILIZATION POND

Name: KHARONO MARY NORINE
Reg No: S21B32/111

Supervisor: Prof ELEANOR WOZEI

Page 1 of 1