

**INVESTIGATING THE USE OF RICE HUSK ASH TO IMPROVE THE DEWATERING
PERFORMANCE IN THE SLUDGE DRYING BEDS**

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S20B32/213

**A FINAL YEAR RESEARCH AND DESIGN PROJECT REPORT SUBMITTED TO THE
FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF BACHELOR OF SCIENCE IN
CIVIL AND ENVIRONMENTAL ENGINEERING OF UGANDA CHRISTIAN UNIVERSITY**

April, 2024



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ABSTRACT

Lubigi faecal and waste water treatment plant in Namugooona, Uganda adopted the non-conventional technology for treatment which possess a unique characteristic for the treatment system. In spite of the system's capacity to manage human excreta from both onsite and offsite sanitation systems, there is a high solid loading due to the incoming large volumes of wastes beyond the design capacity and an addition long drying period for the sludge thus limited sludge drying beds thus need for optimum utilization of the drying beds. The research project was investigating the use of rice husk ash to improve the dewatering performance of sludge in the sludge drying beds. Varying proportions of rice husk ash 0%, 4%, 7% and 10% of the sludge weight (30kgs) were mixed with sludge to monitor dewatering effectiveness after every seven days. The key parameters monitored were moisture content, total solids and volatile solids expressed in percentage (%) during both the dry and wet season in order to assess the effect of seasonal variation. During the wet and dry season, sludge with 0% (no Rice husk ash added) had the highest moisture content of 70.9% and 57.2% respectively, 4% dose had the lowest moisture content of 35.4% and 27.3% respectively and 10% dose had the lowest volatile solids of 21.4% and 22.3% respectively after 28days. The moisture content obtained for each season was within the recommended range of (30-40) % for sludge to be removed. Therefore, 4% dose of rice husk ash had the best dewatering performance in comparison to 0%, 7% and 10% and hence was the optimum dosage.

DECLARATION

I, **MURUNGI CHELSEA**, declare that all the content in this report is my original work, not plagiarized and has not been presented for examination to any other institute of higher learning.

MURUNGI CHELSEA

Sign:

Date:

APPROVAL

This is to certify that all the work in the report was done by **MURUNGI CHELSEA** in regards to the Final year project research at LUBIGI WASTE WATER AND FAECAL SLUDGE TREATMENT PLANT under supervision of the attached project supervisor.

Project supervisor

MR. GAVA JOB SSAZI PIUS

Signature.....

DEDICATION

My dedication goes to the fraternity of the Faculty of Engineering, Design and Technology and my beloved parents who have greatly contributed and supported to the success of my academic Journey.

ACKNOWLEDGMENT

I highly appreciate the Faculty of Engineering, Design and Technology, Department of Engineering and Environment and the administration of Uganda Christian University.

I extend my sincere gratitude to my Project Supervisor Mr. GAVA JOB SSAZI PIUS for immeasurable technical support and continuous guidance to the success of the Project.

With special thanks, I heartily appreciate my project Partner Kato Julius for the tremendous support and cooperation with the various tasks and activities carried out for the success of the research Project.

Great appreciation to National Water and Sewerage Corporation Central Laboratory who supported us as we conducted the Laboratory Tests for the Project.

Above all, I thank the almighty God for protection, guidance and the grace to successfully accomplish the research project.

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ABBREVIATIONS AND ACRONYMS

FS-Faecal sludge

TS-Total Solids

MC-Moisture Content

VS-Volatile Solids

USEPA-United States Environmental Protection Agency

ATP- Active Volatile Suspended solids

TSS-Total Suspended Solids

BOD-Biological Oxygen Demand

COD-Chemical Oxygen Demand

WSPs-Waste Stabilization Ponds

PH-Potential of Hydrogen

FWM-Faecal Waste Management

SDGs-Sustainable Development Goals

RHA-Rice Husk Ash

MAPET-Manual Pit Emptying Technology

RH-Rice Husks

MOE-Ministry of Environment

EPA- Environmental Protection Act

CFR-Code of Federal Regulation

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Over a third of the world's population use on site sanitation technologies which include pit latrines, dry toilets unsewered public ablution blocks and septic tanks. (Tayler, 2018) There is rapid urbanization growth rate due to the increasing population where the number of people living in cities is projected to increase by 50 per cent by 2045. This rapid growth rate is increasing in the low- income and low middle-income countries (Tayler, 2018). Therefore, emphasis should be put on the design of the faecal sludge treatment plant so as to accommodate the incoming sludge volume for proper operational efficiency. Appropriate facilities are needed at the treatment plant to treat the faecal sludge.

Faecal sludge is defined as solids and liquid mixture that is obtained from onsite sanitation facilities such as pit latrines and septic tanks. The quantity of faecal sludge that a plant can handle is dependent on the raw sludge characteristics and nature of flow of the faecal sludge.

Lubigi is a waste water and faecal sludge treatment plant under National water and sewerage corporation located in Namugoona, Kampala, Uganda which was commissioned in 2014 with a design capacity of 5000m³ /day of waste water and 400m³/day of faecal sludge with a supply of around 35% of the sludge collected around Kampala by cesspool emptier tanks thus operation at its maximum capacity (Taylor&Fracis, 2019).It receives around 660m³/day faecal sludge which exceeds the design capacity of the plant which is approximately 122% (KCCA, 2020).

Sludge is generated at different stages of the treatment process: sedimentation tanks separate the liquid solid slurry by settlement of the solid particles at the bottom of the tank. These solid particles are semi solid and therefore they are pumped to the drying bed for further dewatering to obtain a dry sludge cake that is easy to handle for storage.

1.2 PROBLEM STATEMENT

There is a challenge of slow dewatering process of the sludge drying beds at the Lubigi sewage and faecal sludge treatment plant for a period of 6-8 weeks which exceeds the designed drying period of 1 month (Rost, 2018). This compromises the performance efficiency of the treatment plant and coincides with the increased demand for the sludge as a fertilizer by farmers. However, the plant receives about 660m³/day faecal sludge translating into 35% of the sludge collected around Kampala thus operation at its maximum capacity (Taylor& Francis, 2019) which is already in excess of the design capacity of 400m³/day faecal sludge of approximately 122% (KCCA, 2020).

Therefore, there is need for optimum utilization of the sludge drying beds such as improving the sludge drying efficiency by reducing the sludge drying time and faecal sludge weight. By this, there will be an increased accommodation of the incoming volumes of the sludge while also being able to meet the increased demand for the sludge by the farmers.

1.3 OBJECTIVES OF THE STUDY

1.3.1 MAIN OBJECTIVE

To investigate the use of rice husk ash to improve the dewatering performance in the sludge drying beds.

1.3.2 SPECIFIC OBJECTIVE

To assess the raw sludge parameters.

To determine the chemical properties of the rice husk ash.

To determine the improvement in dewatering that can be achieved with the use of rice husk ash in the sludge drying beds.

1.4 RESEARCH QUESTIONS

What are the raw sludge parameters of the sludge in the sludge drying beds?

What is the chemical composition of the rice husk ash?

What is the improvement in dewatering that can be achieved with the use of rice husk ash in the sludge drying beds.

1.5 JUSTIFICATION

The drying beds at Lubigi Treatment plant take a period of 6-8 weeks which is beyond the design period of 4 weeks thus delayed drying of the sludge in the drying beds. This compromises the performance of the treatment plant and also coincides with the increased demand for the dried sludge by the farmers as it is used as a fertilizer. Therefore, there is need for identification of different alternatives to enhance the sludge drying process thus increased accommodation of the incoming volumes of the

sludge while also being able to meet the increased demand for the sludge by the farmers.

Rice husk ash produced after burning of rice husks under controlled temperature has a high silicon dioxide composition within the range (73.6-96) % produced in the amorphous silica state with a small percentage of carbon composition. (Singh, 2018)

The amorphous silica has a micro porous structure due to its structural arrangement thus a large surface area. The ash particles increase the surface area attributing to the dewatering process by creating a rigid lattice structure and a porous channel on the sludge. This improves permeability and aids the release of water from the sludge. (Ling Zhang, 2011) . This therefore reduce the specific resistance to filtration and the capillary time.

1.6 GEOGRAPHICAL SCOPE

The Lubigi waste water and faecal sludge treatment plant is located in Namungoona in Kampala, Uganda, near the suburbs of Kawala and Kasubi hill.



Figure 1: An Aerial View of Lubigi Treatment Plant. (NOBLE, 2021)

CHAPTER 2: LITERATURE REVIEW

2.1 HUMAN WASTES

Human waste also known as human excreta can be defined as the unwanted products of the human digestive system and metabolism including urine and faeces. These wastes therefore require proper disposal and management as part of the sanitation system so as to eradicate related illnesses such as cholera and promote sustainable development. (Wim Van Damme, 2019)

Human waste management is one of the most important health programs considered by WHO as one of the basic steps to safeguard the environment.

Human waste management involves the collection, transportation, treatment and disposal or reuse of waste by the various methods such as energy production and manure for agriculture.

Human waste management should put under consideration because of the presence of surface and ground water sources so as to ensure no contamination, bad odor, accessibility to flies and animals, cost efficiency and durability of the methods used to manage the waste. (Naughton, 2017)

A human waste management system is categorized as one site sanitation and off-site sanitation. Choice of an appropriate system for specific location is dependent on the social culture needs, the corresponding demand, affordability and the ground conditions. A criterion is used to determine the category of the human waste management system as onsite or off-site sanitation. (Naughton, 2017)

The sanitation system whose disposal facilities are contained within the occupied plot and its immediate surroundings is known as onsite sanitation system and one that

involves collection and transportation of waste away from its point of generation to a location away from its immediate locality is offsite sanitation system.

Method of waste conveyance

Dry method

This method is used for onsite sanitation systems in such a way that it does not need water as a carrier for waste. They consist a pit dug in the ground, lined with a cover slab above the hole and collects urine and faeces for a period of time. These systems include pit latrines, ventilated improved pit latrines, composting latrine. These onsite sanitation facilities use the cesspool tank to transport there wastes to the treatment plant. (Thammarat Koottatep, 2015)

Septic tanks are also categorized as onsite sanitation facilities since they store waste (septage) like latrines which is then collected and transported to the treatment facility for treatment. These however receive waste from toilets with the aid of water through a connection of pipes to the septic tank where it stored. This method is adopted for onsite sanitation system which is carried out mostly in low densely populated areas for example the individual or grouped onsite facilities in residential houses or a network of houses in intermediate location from one another. (Thammarat Koottatep, 2015)

Water borne method

This method requires water as a carrier or mode of transportation for the waste using sewer system. A sewer system is a combination of different types of sewers connected from household facilities to the wastewater treatment facility. The variation in sewer types is based on the size of the collection system and the distance to the treatment facility. This method has been adopted for offsite sanitation facilities where it is carried

out in densely populated areas for example in commercial areas where land utilization is at its optimum capacity and therefore facilities such as pit latrines are considered limiting factors to land utilization hence offsite sanitation system is preferred. (Peters, Sanitation Systems & Technologies, 2008)

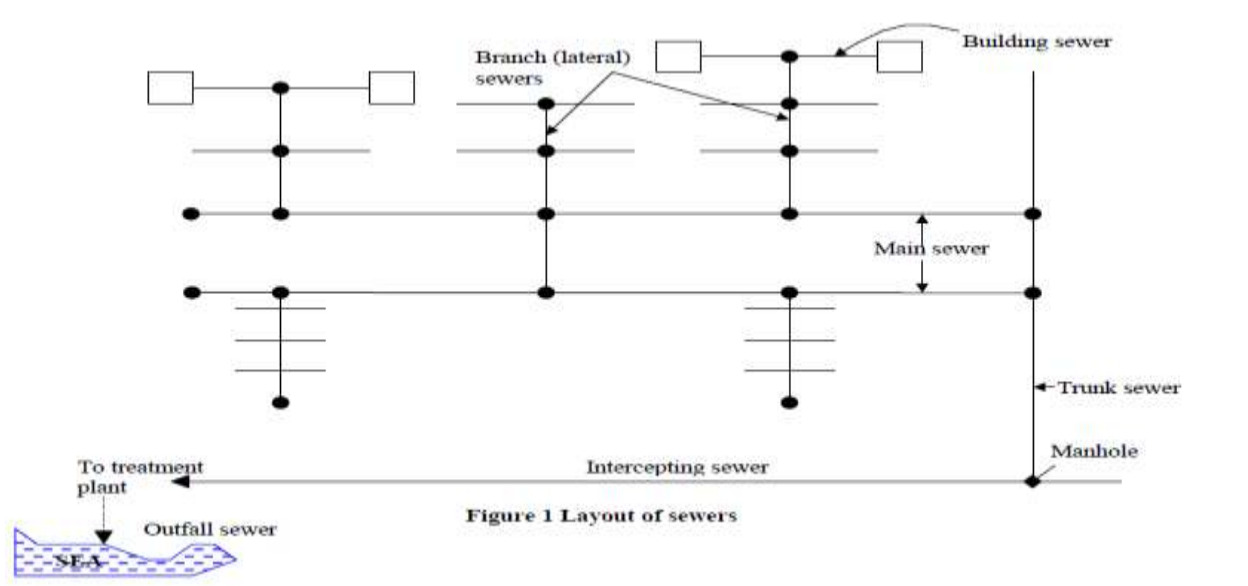


Figure 2: Waste water conveyance (J.Paul Gayer, 2020)

Terms used and their definitions in terms of human waste management.

Septage: This is raw liquid-solid material that is pumped into a cesspool tank for transportation to the treatment plant.

A cesspool tank: This is a vehicle with an enclosed container that accommodates a large quantity of the septage.

Sewage: This is also a mixture of water and excreta composed of urine and feces that is transported to the treatment plant through sewers.

Sewers: These are open channels or closed pipes that convey wastes.

2.2 WASTE WATER

Waste water which also called raw sewage is the liquid waste consisting of domestic or sanitary discharge, industrial discharge, sullage, storm water surface runoff and infiltration that is conveyed through a sewer system.

The composition of waste water is 99% water and 0.1% solids. The 0.1% contains organic matter, microorganisms and inorganic compounds. (Elias, 2017)

Domestic wastewater

This type of wastewater is as result of human household activities for example in homes and residential services and discharged from sanitary conveniences such as water closets, urinals, baths and sinks. It is further subdivided into four categories which are majorly signified by color. (Elias, 2017)

Black water

This is a combined discharge from toilets, bathrooms and bathroom sinks as well as kitchen sinks. This water contains faeces, urine, toilet paper, food wastes, fats, oils and chemicals as a result of the various cleaning agents used during cleaning process and therefore is highly contaminated thus poses high potential risk of causing diseases on poor discharge to the environment. (Elena Ficara, 2017)

Grey water

This water is termed as grey water because it does not include faeces and urine but discharged as result of other household activities such as kitchen sinks, bathrooms, bathroom sinks, washing rooms including washing machines. This water highly contains chemicals and cleaning agents such as detergents, soap, liquid soap etc. but can easily be reused on treatment since it less pathogenic. (M.ronteltap, 2014)

Yellow water

This is another term for urine thus signified by its color. This water does not include any contaminations from grey water and black water such as faeces, toilet paper and tooth paste and food stuffs.

This is normally collected from specific sanitation facilities such as urinals, urine diverting dry toilets. This urine at times is collected to be reused as it a good fertilizer since it contains low amounts of heavy metals thus less pathogenic and contains nutrients required for plant growth. (Baykal, 2019)

Brown water

This wastewater is a mixture of faeces and flush water but does not include urine during discharge. It is also as a result of separating toilets and the amount of flushing water determines the thickness of the brown water. This is further treated, dewatered and dried and then used as solid fuel or as a soil conditioner after co-composition. (Baykal, 2019)

Industrial wastewater

This is spent water discharged during industrial activities such as manufacturing, cleaning and other water related activities. The contaminants and the toxicity of the discharge are dependent on the type of industry and the chemicals used. They are mainly two types of industrial wastewater and this includes inorganic wastewater and organic wastewater.

Inorganic wastewater contains inorganic substances discharged from steel factories, electroplating plants and coal industries.

Organic wastewater contains organic industrial wastes from chemical industries that majorly use organic substances for chemical reactions such as Textile industries, tannery and leather industries, paper industries as well as pharmaceutical industries.

Table 1: Waste water pollution by industrial sector (SHI, 2017)

Sector	Pollutant
Iron and steel	BOD, COD, oil, metal, acids, phenols and cyanide
Textiles and Leather	BOD, solids, sulfates and chromium
Pulp and paper	BOD, COD, solids, Chlorinated organic compounds
Petrochemicals and refineries	BOD, COD, mineral oil, phenols and Chromium
Chemicals	COD, organic chemicals, heavy metals, SS and cyanide
Non-ferrous metals	Fluorine and SS
Microelectronics	COD and organic chemicals
Mining	SS, metals, acids and salts

Storm water

This is surface runoff that is enters sewer inlets during and after rainfall. at times, this surface runoff contains other waster such as a particles of food stuffs, car oil due to leaks during car movements and therefore collected and drained along in the sewer.

Therefore, with the above descriptions of waste water, it is evident that different treatments are required for the wastewater so as to prevent high levels of contamination that may pose hazardous to the environment. (Jason R.Vogel, 2016)

On the other hand, Lubigi wastewater and faecal treatment plant is designed to receive domestic wastewater particularly black water which deals with human excreta.

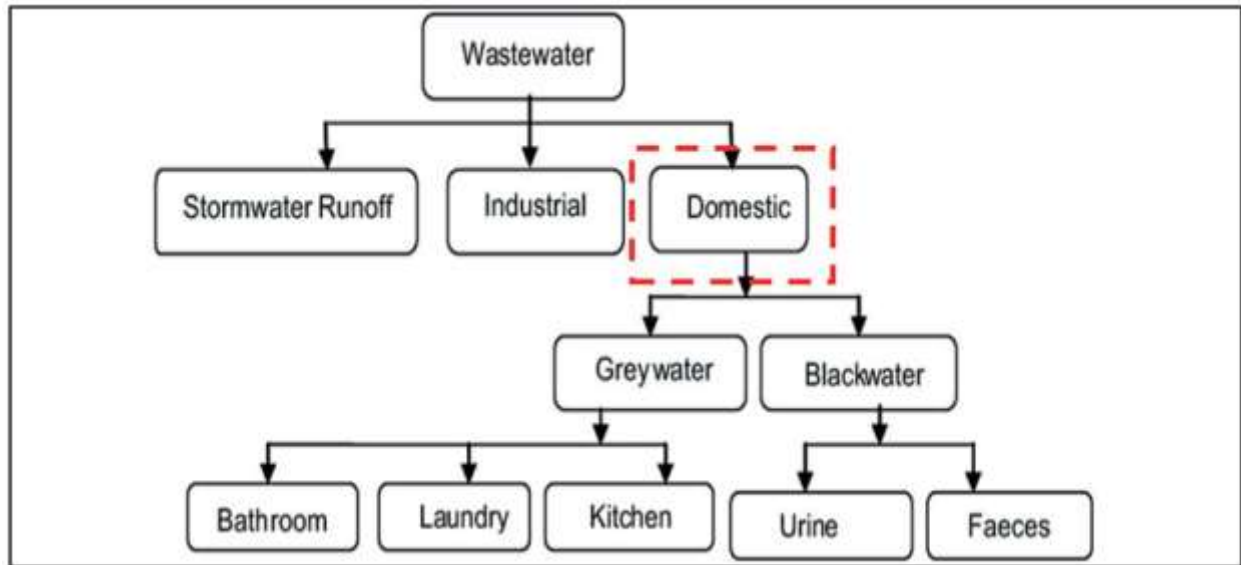


Figure 3: Types of waste water (Alaa Fahad1*, 2019)

2.3 FAECAL SLUDGE

This is a semi solid mixture collected from onsite sanitation facilities such as pit latrines, ventilated improved pit latrines, composting latrine and septic tanks. This is termed as faecal sludge because it has undergone the decomposition process which is then transported with the use of cesspool tanks to treatment plant where it under goes a series of treatment processes before disposal. (Reno, 2015) This further undergoes drying process which reduces the rate of disposal. In the dry state, it considered highly valuable (economically, environmental) in the following ways. (Shuokr Qarani Aziz a, 2022)

Dry sludge can be used as a fuel for combustion, biogas production from anaerobic digestion which aid in reduction of environmental pollution due to increased carbon dioxide concentrations as a result of deforestation.

It is also used as a soil conditioner, faecal sludge is rich in nitrogen which can be used to produce better agricultural products.

Faecal sludge can also be a component for building material, dried faecal sludge can be added during the manufacturing of cement and bricks and in the production of clay-based materials.

Types of Faecal Sludge

Faecal sludge is categorized in a variety of states and this is influenced by factors such as the type of treatment technology adopted, the required end user product and the method of treatment.

Digested sludge

Sludge digestion is a biological process that involves the breakdown of organic matter in complex form to simpler forms. This process reduces the weight of total solids thus enhanced dewatering. This process is either carried out aerobically or anaerobically. The aerobic digestion requires the presence of oxygen and aeration conditions or contact stabilization systems as the anaerobic digestion is sensitive to temperature and PH level (acidic conditions). These processes convert to about 0.5 of the organic solids into liquids and gases in form of methane thus energy production inform of biogas. (Zhiyao Wang, 2021)

Primary sludge

This is produced during primary treatment as a by-product of the sedimentation. This involves the separation of solids from liquids in the waste water and it is highly composed of large particle suspensions. It is highly valuable in organic and biodegradable matter thus commonly used substrate in anaerobic digestion. Biological sludge: The residue that remains after wastewater undergoes biological treatment is known as biological sludge. Its constituent microorganisms are diverse thus creating bacterial flocs through the synthesis of exo-polymers. Decantation in the clarifier ensures effective removal of bacterial flocs from the treated water. The settled biological sludge is separated and the surplus circulated to maintain the health of the bacterial population within the reactor. In addition, this sludge is high in the volatile solids content about 80%. (Tereza Dokulilová¹, 2018)

Mixed sludge

A combination of primary and biological sludges is called mixed sludge. Typically, 35% to 45% of primary sludge and 65% to 55% of biological sludge are blended together. Because the inherent characteristics of this sludge fall between the two types, this blending allows for a simpler dewatering (Zonoozi, 2020).

Physical-chemical sludge: Wastewater is treated with a mixture of chemicals to create this type of sludge. Its composition is made up of the flocs produced by the chemical treatment, specifically coagulants and/or flocculants.

Mineral sludge

This is produced during mineral processes such as quarries or mining beneficiation processes. Its composition is highly influenced by the mineral particles of various sizes (including clays) and highly settleable by gravity (Canziani, 2019).

Characteristics of faecal sludge and waste water

Faecal sludge and waste water are both as a product of human excreta and therefore possess similar physical and physico-chemical characteristics in terms of content though may differ in concentrations due to the different sanitation facilities and methods of conveyance to the treatment facility.

Odor and color

The unpleasant and strong smell is as a result of decomposition of organic matter by the bacteria under anaerobic conditions. Faecal sludge is collected from pit latrines and septic tanks which provide anaerobic conditions (no oxygen) for decomposition of the organic matter.

The dark color is possessed due to the presence of organic matter and the decomposition process. However, the color may vary depending on the concentration of organic matter and the toilet cleaning products additives. (Kara L Nelson, 2016)

Nutrient content

The composition of human excreta is highly rich in nitrogen from urea and phosphorus from faeces nutrients and these are essential for plants as well as the growth and development of living organisms on application to the soil to improve its fertility. The nitrogen concentration in faecal sludge and waste water exists in form of organic nitrogen, ammonia and nitrate and this is about 0.7 %. Under the various treatment

units, anaerobic ponds hydrolyze organic nitrogen into ammonia which is further transferred to the facultative ponds where it is taken up by the algae biomass. (Roni Penn, 2018) Total phosphorous is also removed through the uptake by the algae biomass and sedimentation. In spite of their application to the soil for fertility, poor disposal causes eutrophication and contamination to the environment thus pollution. (Peters, Sanitation Systems & Technologies, 2008)

PH

The decomposition process results into the production of organic acids and therefore faecal sludge is highly acid though waste water lies within the range of acidic to neutral due to the dilution with water based on the method of conveyance. This acidic condition is favorable for the survival of microorganisms which initiate the rate of decomposition of organic matter into smaller form such as CO₂, CH₄, water vapor and these are requirements for biogas production. (Roni Penn, 2018)

Pathogens

These are microorganisms such as bacteria, viruses, protozoa and helminth which pose a high risk to human health and therefore proper treatment and disposal is required to prevent the spread of diseases. These are present in faecal sludge, untreated and partially treated waste water the faecal sludge effluent and the release into environment has detrimental impact especially for cases of reuse of produced effluent. Direct contact with polluted water or contaminated food implies contact with these pathogens which cause illnesses that are of great concern worldwide. This leads to arise in water borne diseases such as diarrhea, fever, typhoid, cholera which when not treated can lead to death. (Mihelcic, 2018)

BOD

This is the measure of dissolved oxygen that is required by bacteria and other microorganisms to breakdown the organic matter in water. This is also a measure of the amount of organic matter based on the oxygen demand by the bacteria. BOD level is based on the strength of waste water. Waste water strength is influenced by the concentration of organic matter as the higher the concentration of organic matter the stronger the waste water. The concentration of the organic matter is dependent on the water consumption. Water consumption of about 350-400l/person produces weak waste water with a BOD range (200-250mg/l) and water consumption of about 40-100l/person produces strong waste water with a BOD range (300-700mg/l). However liquid effluent from faecal sludge has a higher BOD value than waste water. This BOD also termed as BOD₅ representing after 5 days the is also influenced by a number of factors such as particle size distribution were the small sized particle and those with high solubility have a faster BOD₅ rate of reaction coefficient and the Non carbonaceous materials for example during nitrification.

Therefore, there is need for treatment so as to reduce the extremely high oxygen demand of the waste water as well as the concentration of suspended solids for environmental concerns of the recipient water source. (Tayler, 2018) The anaerobic ponds have been adopted for the removal of BOD₅ at a range of 60-85% in very short retention time and most especially in the warm climates. (Nuwagira, 2021)

Total solids

Sludge combines wastewater, faecal sludge liquid effluent and total solids. These total solid are a summation of both suspended and dissolved solids. Suspended solids are not

able to pass through the filter media and include colloidal and settleable materials and the dissolved solids pass through the filter media. (Rost, 2018). The solid particle sizes are dependent on the source of the sludge and the prior treatment. The solid content is dependent of microbial concentration. Sedimentation is a mechanism for the removal of suspended solids in the sedimentation tank and the facultative ponds. These ponds have an algae content of about 60-90% and a TSS removal efficiency of 70-80% (Nuwagira, 2021).

Particle size distribution

Particle size distribution in faecal sludge is affected by usage practices such as emptying and transportation and this could have an impact on dewatering at the treatment facility. According to (Nuwagira, 2021), small particle impact filtration and settling performance through increased clogging of the filter media such as the sand drying beds. This indicates need for elimination of these particles by conditioning which enables agglomeration of these particles into larger sizes. Mechanical dewatering is also another means adopted to remove the suspended particles by settling, however this is only applicable for waste water as it can't be adopted for faecal sludge. (Harris, 2023)

2.4 WASTE WATER TREATMENT TECHNOLOGIES

They are two types of wastewater treatment technologies that are effective for wastewater treatment, the conventional and non-conventional technology system.

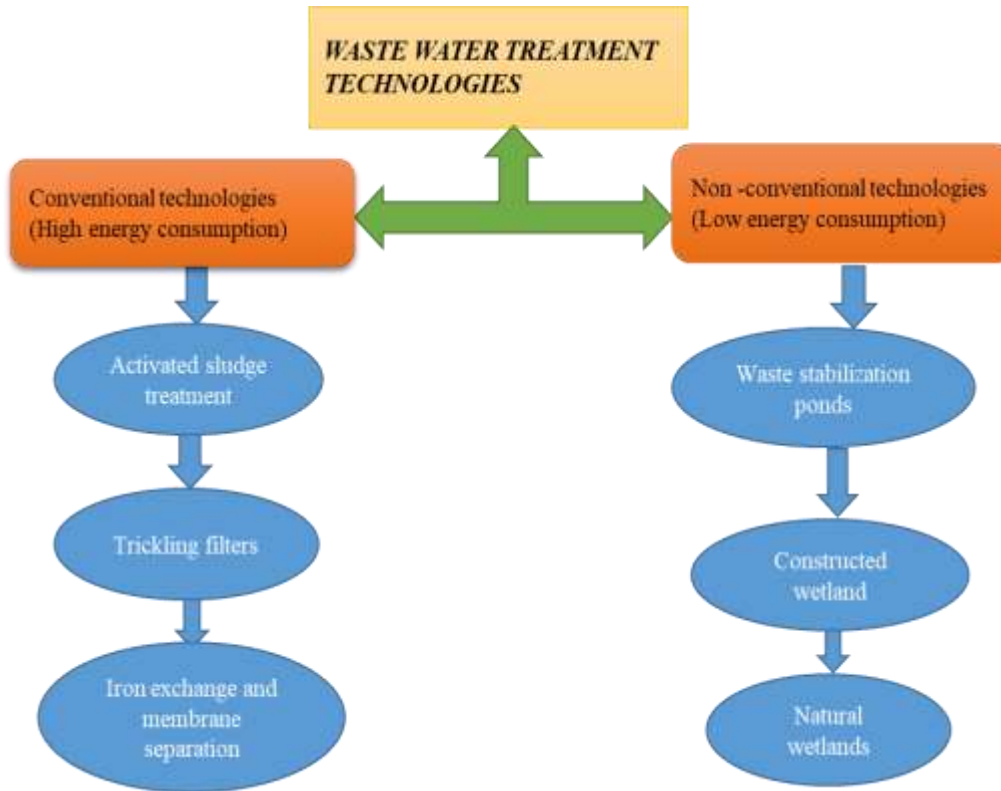


Figure 4: Waste water treatment technologies (Alaa Fahad1*, 2019)

2.4.1 CONVENTIONAL TECHNOLOGIES

These can also be called intensive technologies. They require high energy consumption and therefore highly mechanized in such a way that they require pumping and power supplies and skilled labor for processing and preservation of the system. The treatment process involves a series of stages before disposal or reuse of the effluent and the sludge.

PRELIMINARY TREATMENT

This involves Screening and Grit removal. Wastewater that is released by the sewers undergoes the Screening process and later to the grit chamber for grit removal.

Screening

This is the first preliminary stage of waste water treatment that takes place after wastewater has been released from the sewers. It involves screens categorized depending on the size of the opening, coarse screens (>50mm), medium screens (6-40mm) and fine screens more like wire mesh (<6mm) (N. R. Maddela et al. (eds.), 2021). These screens are normally an alignment of parallel bars that are placed vertically at a slight angle incline in order to remove floating objects such as sticks, sanitary pads, diapers, plastic and glass bottles. These screens differ in size because of the difference in the sizes of the floating objects in such a way that large objects are trapped by coarse screens and small sized objects trapped by fine screens.

Grit removal

Waste water and faecal sludge from pit latrines and septic tanks (septage) that is released consists of many components such as floating objects such as paper, polythene, clothes as well as sand and silt which can easily settle. Faecal sludge is considered for treatment plants that receive both faecal sludge and waste water thus encouraging co-treatment at specific stages of treatment. Sand and silt are too fine that they can easily pass through the fine screens. Due to this grit chambers are considered so as to aid in the removal of these particles. High grit concentration increases the rate of sludge accumulation in the thickening tanks, pipes, ponds and channels thus damaging the mechanical equipment such as pumps (Tayler, 2018)

Grit removal is considered for plants designed to receive a loading greater than 250m³/day and plants that use non enclosed systems such as anaerobic ponds and sludge

drying beds. The technique of grit removal is based on the principle of sedimentation due to gravitational force (N. R. Maddela et al. (eds.), 2021)

PRIMARY TREATMENT

This Stage involves a sedimentation tank for primary Settling that is carried out to reduce the percentage levels of Biochemical Oxygen Demand, suspended solids and organic matter of greater density than the waste water (N. R. Maddela et al. (eds.), 2021).

This is a physical treatment process whose technique is based on gravitational force where liquid is separated from solid particles, the solid particles present in the sewage settle down at the bottom of the tank. The liquid effluent further undergoes to other treatment units for further treatment and the accumulated solid particles form sludge which is desludged to the sludge drying beds. This process takes place twice, at primary stage (primary sedimentation) before secondary treatment and after secondary treatment (secondary sedimentation).

SECONDARY TREATMENT

This is also known as biological treatment of wastewater. This enables the removal of about 95 % of suspended Solids, Biochemical Oxygen Demand and decomposition of organic matter by microorganisms such as bacteria, algae fungi and protozoa. For balanced growth of microbes, a ratio of Biochemical Oxygen Demand (BOD), Nitrogen and phosphorous is established and these microbes feed on the unstable organic matter decomposed to solid inorganic forms. Secondary treatment process involve process such as activated sludge, trickling Filters, Rotating Biological Contactors, and Membrane bioreactors.

Activated Sludge treatment

This is the most commonly used biological treatment process. It requires a small area for operation in contrast with trickling filters. This process involves an aeration tank and a final Settling tank (sedimentation tank).

This process involves an aeration tank and a final settling tank (sedimentation tank). Liquid influent from the primary settling tank is received by the aeration tank. This contains organic matter such as food waste and faecal matter which is broken down by microorganisms. The aeration tank provides aerobic conditions for microorganisms which are favorable to encourage the micro-organism to break down the organic matter into Active Volatile Suspended solids (ATP), CO₂ and water. ATP quantifies the living microorganisms in activated sludge and this measure is to ensure that a sufficient amount enough for waste water degradation. This is also termed as synthesized new bacteria cells as a result of oxidation of the organic matter. (Alaa Fahad1*, 2019)

In this case, BOD is also obtained as it is the measure of oxygen required by microorganisms to breakdown the organic matter in the wastewater.

For a balance of micro-organisms, organic waste and oxygen O₂, some microorganisms are taken up by the sedimentation tanks where they are aggregated together to form a floc and this is known as activated sludge

The activated sludge is recycled back to the aeration tank where it serves as an inoculum and the excess sludge is discarded as either waste or co-composed to serve as a fertilizer to farmers. (Alaa Fahad1*, 2019)

The recycled activated sludge increases the number of microorganisms in comparison to the incoming waste water. However, a continuous supply of oxygen is to be maintained in the aeration tank for a favorable condition of microorganisms.

Trickling filters

This microbial slime layer has a populace of microbes such as bacteria, fungi, protozoa that is maintained by aerobic bacteria which are favorable conditions for their survival and therefore use the organic matter present in the wastewater. The Microbes present on the upper layer of the film carry out the oxidation process and this eventually increases the biofilm (Alaa Fahad1*, 2019).

The accumulation of the biofilm (slime) periodically slides off the rocks and the process is known as sloughing which is collected at the bottom of the filter along to treatment wastewater and further passed through the second sedimentation tank where it is removed by settling. Recirculation process which involves returning a portion of liquid effluent back to the trickling filters to ensure that a reasonable volume of influent is received by the filter as well as to increase the effluent organic removal and keep the biological slimes from drying out during low flow conditions. (Alaa Fahad1*, 2019)

TERTIALLY TREATMENT

This is the final treatment stage before water is discharged back to the water sources such as lakes and rivers. Effluent received from secondary treatment consists total suspended solids, total dissolved solids, organic and inorganic matter which are required to be removed before discharge. This stage however removes specific organic, inorganic matter, nutrients as well as kill pathogens with various types of treatment (N. R. Maddela et al. (eds.), 2021).

Ion exchange

This is the most appropriate technology in the effective removal of dissolved inorganic ions. Ion exchange resin is suspended in an electrolyte and since these resins possess a specific uptake capacity of the metal ions thus ion exchange process. Effluent is passed through a resin bed where these ions are attached to the resin beads due to which the loosely held solution gets released into the water. Recharge is carried out due to saturation of the resin bed thus loss of its exchange capacity. (N. R. Maddela et al. (eds.), 2021).

Membrane separation technique

This takes place under the principle of filtration (membrane filtration). Waste water flows through a semipermeable membrane and the membrane filters remove dissolved particles ranging 0.0001 to 1 μ m. this membrane also acts as a selective barrier that allows passage of certain components thus retaining other components under high pressure. (N. R. Maddela et al. (eds.), 2021).

Electrochemical techniques

This involves direct oxidation and reduction reactions by releasing chemicals that physically remove pollutants from waste water. These include electrocoagulation and electro dialysis. (N. R. Maddela et al. (eds.), 2021).

Advanced Oxidation

This process oxidizes complex waste water organic components that are non-biodegradable into simpler end products which involve generation and use of hydroxide free radicals (HO). These processes include Ozone/UV, Ozone/hydrogen peroxide (N. R. Maddela et al. (eds.), 2021).

2.4.2 NON-CONVENTIONAL TECHNOLOGIES

These can also be called extensive technologies. They require low energy consumption and therefore less mechanized in such a way that they are less sophisticated in maintenance and operation in the biological treatment process. This treatment technology is also called Decentralized Waste water Treatment System and has been highly adopted as it more economical, socially responsible and environmentally conservative. With proper planning and discharge of quantities that are in range to the design of the treatment unit, it is more effective in elimination of pathogenic organisms. (Clifford B.Fedler, 2020) However, it requires a large scale of land for the construction of the treatment units as they are more of natural means of treatment. The treatment process involves a series of stages before disposal or reuse of the effluent and the sludge.

The non-conventional technology like the conventional treatment technology undergoes the preliminary, primary, secondary or biological and the tertiary stages of treatment. (Janusz Wilas, 2016)

PRELIMINARY TREATMENT

This involves screening and grit removal which are associated with removal of materials that do not undergo decomposition such as clothes, polythene, paper, diapers, sand and silt. This eliminates materials that can't be decomposed as well as to prevent damaging of the machinery involved in the treatment process. (Clifford B.Fedler, 2020)

PRIMARY TREATMENT

This also takes place in the sedimentation tank where separation of liquids and solids occurs. The continuous accumulation of the solid particles form sludge which is

desludged to the drying beds and the liquid effluent is further taken to the waste stabilization ponds for secondary (biological) treatment. (Clifford B.Fedler, 2020)

SECONDARY TREATMENT

This like the conventional system biological treatment process of wastewater which majorly contributes to the removal of about 75% Biochemical Oxygen Demand (BOD) and high level of pathogenic removal. Waste stabilization ponds are highly adopted for this stage of treatment. Oxidation ditches are also a means of biological treatment. (Swaib Semiyagaa, 2017)

Waste Stabilization Ponds (WSPs)

These are large, shallow constructed basins that are single or aligned in a series of anaerobic, facultative and maturation (aerobic) ponds for treatment of wastewater.

These ponds are either aligned in series of three or more to ensure effective treatment where effluent flows from the anaerobic pond to the facultative pond and finally to the maturation pond where each pond has got a different treatment and design characteristics in terms of size. (A.G.Capodaglio, 2017)

Anaerobic Ponds

This is the first unit series of treatment that is relatively deep and entirely anaerobic. The depth is of 2 to 5m with a relatively short detention time of 1-7 days. Waste water constitutes of solid and suspended (BOD) organic matter thus increasing the organic loading during treatment. at the anaerobic stage of treatment, the organic matter under goes settlement and accumulation results into formation of sludge at the bottom of the pond. The sludge undergoes decomposition by anaerobic bacteria at a slow rate to form carbon dioxide (CO₂), methane (CH₄) which effects the removal of about 60%

BOD. The effluent is further transferred to the facultative ponds for further BOD removal. (A.G.Capodaglio, 2017)

Facultative ponds

These ponds consist of two layers, the top as aerobic (oxygen supply) and the lower layer anaerobic (limited oxygen supply). They are two types of facultative ponds: primary facultative pond which receive raw waste water direct from screening and grit removal, secondary facultative ponds which receive effluent from the anaerobic ponds. These ponds are about (1-2m) in depth with a detention time between 5 to 30 days. The dissolved and small suspended organic matter (BOD) in the liquid effluent is dispersed where it undergoes oxidation by aerobic respiration (Sperling, 2007). The oxygen supply is contributed by the algae thus essential to maintain its population so as to retain a balance between consumption and production of oxygen and carbon dioxide. The settleable solids are accumulated on the bottom of the pond where it further undergoes decomposition by the anaerobic bacteria. The aerobic and anaerobic conditions aid in the removal of about 75% BOD. (Sperling, 2007)

Maturation ponds

These ponds are shallow to about 1 m depth and provide the final treatment stage in waste stabilization ponds for wastewater. These are supplemented with aerobic condition entirely in the pond thus encouraging decomposition of organic matter by the bacteria into carbon dioxide CO_2 and methane CH_4 . However, these ponds are designed for more effective removal of pathogens such as faecal bacteria and this is dependent on the temperature, organic loading and the detention time. Increase in temperature and detention time increases pathogenic removal which is not the case for organic

loading whose increase results into reduction in the removal of pathogens. (Swaib Semiyagaa, 2017)

TERTIALLY TREATMENT

This is the final treatment stage before water is discharged back to the water sources such as lakes and rivers. The effluent is discharged into wetland and these wetlands can either be constructed or natural wetlands. The process of treatment is based on the wetland vegetation in such a way that the pollutants in the waste water are broken down by the bacteria and nutrients are taken up by the plant roots and substrate to supplement plant growth.

Constructed wetlands at times are designed to be efficient the removal of suspended solids, biochemical oxygen demand (BOD), organic matter, nutrients, heavy metals and pathogens.

These wetlands are considered a scrupulous in comparison to the natural wetlands however designing a wetland to carry out an ecological, transportation and transformation process in treatment is more complex in understanding (Alaa Fahad1*, 2019).

2.5 FAECAL SLUDGE MANAGEMENT.

This is a semi solid mixture collected from onsite sanitation facilities such as pit latrines, ventilated improved pit latrines, composting latrine and septic tanks.

Feacal sludge management is concerned with sanitation practices that involve the collection and transportation of Faecal sludge from the on-site sanitation systems to proper disposal facilities or for hygienic reuse as a by-product of treatment. This

specifically includes the major aspects such as FS collection, emptying, treatment and reuse/storage. (Linda Strande, 2014)

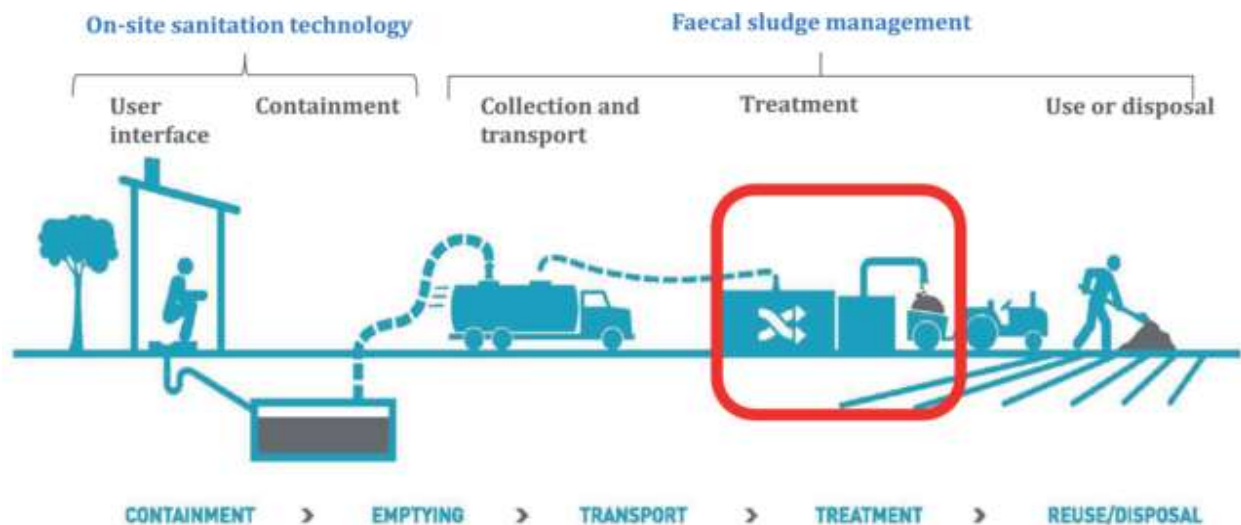


Figure 5: Key aspects of Faecal sludge management (Linda Strande, 2014)

FAECAL SLUDGE COLLECTION

Excreta (faeces and urine) is deposited in the on-site sanitation facilities such as pit latrines, composition latrines the septic tanks connected to toilets. These are points of collection for further transportation for proper disposal. However, with the influence of factors such as cultural backgrounds and absence of sanitation facilities, unhygienic practices such as open defecation are carried out a means of collection of Faecal matter impacting on human health.

FS composition is dependent on nutrition, life style, personal habits, health, and cultural backgrounds of people who use sanitation facilities (Foxon D. S., 2012). This is indicated by the presence of solid and hazardous waste such as rags, plastics, sTonnes (disposable diapers, broken glass, chemicals, sharp metals, pads, and condoms along

with the Faecal Sludge (FS) (Foxon K. , 2012). Anal cleansing materials are also part of FS composition such as toilet paper, hard paper, leaves and water.

These factors attribute to the accumulation rate of FS in the latrines thus affecting the emptying rate and cost. The presence of hazardous and solid waste poses damage to the emptying equipment thus incurring costs of repairs.

FAECAL SLUDGE EMPTYING

This is the removal of accumulated faecal sludge from onsite sanitation systems and transported to the treatment plant. This is critical in terms of contamination as improper handling of waste poses health and environmental risk. The methods of emptying mainly include manual and mechanized collection method. (Georges Mikhael, 2019)

Manual collection

This is mainly carried out in low-income communities residing in informal settlements and this is majorly categorized into cartridge containment and direct lift.

Cartridge containment

This involves the use of devices such as Uniloo which is an innovative technology designed for hygienic manual collection. This ensures safety of the users and operators by isolation from direct contact of FS. It has a capacity of about 20litres of waste where the collector regularly replaces and seals the full cartridge with an empty clean cartridge. (Georges Mikhael, 2019)

Direct lift

This involves the collection of FS from latrines or septic tanks by using long handled shovels and long handled buckets. The filled buckets are hoisted to the ground surface

and emptied into tanks fitted onto carts for further transportation thus treatment.
(Georges Mikhael, 2019)

Mechanized collection

These are either manual or automated as the mode of operation. These however are more effective in comparison to manual collection.

Manually mechanized collection

These are human powered mechanical devices used in septic tanks and pit latrines employing more effective, safe and faster means of emptying. These include Sludge Gulper, the diaphragm pump, the Nibbler, and the Manual Pit Emptying Technology (MAPET). (Benjamin Hemkendreis, 2008)

The Sludge Gulper

This is commonly adopted in low-income countries as it is a low-cost manually driven positive displacement pump that operates along the same principles as that of direct-action water pumps. It has a simple design as it can be built using locally available materials and fabrication techniques. It consists of a PVC riser pipe containing two stainless steel valves, a pump and a strainer. The pump help in lifting up the sludge through the pipe and maintained by the valves. The strainer is used to prevent entrance and blockage of the pump by biodegradable materials. (Georges Mikhael, 2019)

The performance efficiency is due to less viscous sludge with a capacity to pump at a rate of approximately 30 L/min.

Manually operated diaphragm pumps

These are simple low-cost pumps whose capacity extracts low viscosity FS containing less of the non-biodegradable materials. They consist of a rigid, disc shaped body

clamped to a flexible rubber membrane (diaphragm). The mode of operation for the pump is that the diaphragm is alternately pushed and pulled thus deformation into concave and convex shapes in the same way a rubber plunger is used to unblock a toilet. A strainer and non-returning foot valve fitted to the end of the inlet pipe prevents non-biodegradable material from entering the pump and prevents sludge backflow during operation respectively. (Georges Mikhael, 2019)

Manual Pit Emptying Technology (MAPET).

A MAPET system consists of a hand-pump that is connected to a vacuum tank mounted on a pushcart. A hose pipe is connected to the tank to suck the faecal sludge from a pit. Alteration of the hand-pump expels out air from the vacuum tank hence absorbing sludge into the tank. It has a capacity to pump sludge from a maximum depth of 3 dependent on sludge consistency. (Benjamin Hemkendreis, 2008)



Figure 6: Mapet system (Benjamin Hemkendreis, 2008)

Automated mechanized collection

These are powered by electricity and fuel systems. They can be mounted on a frame or trolley or vehicle for increased mobility in the aspect of emptying and transportation of large quantities of sludge over longer distances. This method includes equipment that are widely available such as motorized diaphragm pumps, trash pumps, gobblers, motorized pit screw auger and some types of vehicle-mounted vacuum equipment. The pumped sludge is then pumped unto conventional vacuum trucks where it is transported further for treatment. (ADHIAMBO, 2018)

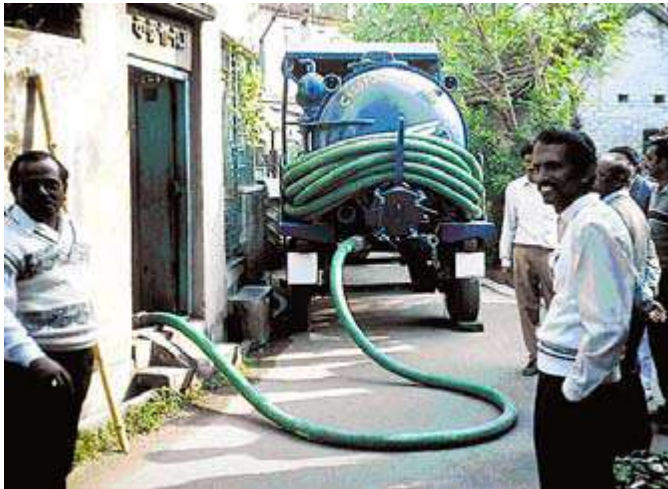


Figure 7: Vacuum trucks (Benjamin Hemkendreis, 2008)

FAECAL SLUDGE TREATMENT

This involves a series of processes undertaken to sanitize and convert untreated Faecal sludge into a byproduct that is safe for disposal or reuse with minimal impacts on public health and environment. At this stage, co-treatment of FS from onsite sanitation facilities and Wastewater through sewer systems from offsite systems is involved. (ADHIAMBO, 2018)

These processes include screening, the removal of unwanted materials such as rags, plastics and sanitary towels. Grit removal which involves the removal of grit and sand. Sedimentation process involves the solid liquid separation. Stabilization especially for undigested sludge, this takes place in the stabilization ponds such as anaerobic and facultative ponds. This is further taken to the sludge drying beds (planted or unplanted beds) for effective drying to recommended ranges before removal for disposal or reuse. The selection phase of a treatment process is dependent on factors such as FS composition, level of treatment, available resources and environmental considerations. Additionally, proper treatment is essential as it yields valuable by-products such as biogas for energy production and nutrient manure for agricultural purposes. This contributes to effective waste management practices. (Hidenori Harada, 2016)

REUSE/STORAGE

This involves the application of the treated sludge for various purposes in contrast to the FS disposal. This results into resource recovery, economic stability and environmental sustainability. (Victor Moinard, 2021)

The applications of this FS include agriculture practices where it is used as a fertilizer to improve the soil fertility and structure thus enhancing crop productivity. This is attributed to the presence of nutrient highly concentrated in nitrogen and phosphorous. Anaerobic digestion of FS involves the breakdown of organic matter into carbon dioxide (CO₂) and Methane (CH₄) thus energy production informs of Biogas which is a source of energy for cooking and electricity generation. (Victor Moinard, 2021)

The treated effluent can also be reused for irrigation purposes, ground water recharge and recycling for domestic purposes such as toilet flushing.

2.5.1 WASTE WATER AND FAECAL TREATMENT PROCESS AT LUBIGI TREATMENT PLANT.

A treatment plant is one that is designed to remove contaminants from sewage or septage so as to produce an effluent that is suitable for discharge to the surrounding environment and sludge cake that is equipped with nutrients used as a fertilizer so as to enhance agricultural yields.

Lubigi waste water and faecal sludge treatment plant is a unique treatment plant in such a way that it treats both waste water and faecal sludge with a design capacity of 5000m³/day of waste water and 400m³/day of faecal sludge with a supply of around 35% of the sludge collected around Kampala thus operation at its maximum capacity (Taylor&Fracis, 2019).It receives around 660m³/day faecal sludge which exceeds the design capacity of the plant which is approximately 122% (KCCA, 2020)

The treatment plant undergoes three treatment stages; Primary stage, Secondary stage and Tertiary stage

PRIMARY STAGE

Waste water is collected and conveyed by sewers and faecal sludge is transported by cesspool tanks to the treatment plant. The faecal sludge undergoes a series of treatment processes which include screening by screens, grit removal in the grit chamber and sedimentation in the sedimentation or thickening tanks.

Screening

This is the removal of solid materials that come along with the waste water as well as faecal sludge using a screen which is either a coarse screen or a fine screen due to their variation in sizes.

Choice of the screen is dependent on the septage composition and the treatment process requirement (Tayler, 2018). Wastes from pit latrines may contain hard items like anal cleaning such as newspapers and leaves, sanitary towels, broken bottles and medical equipment such as syringes and cannulas. The pit emptier may be able to separate these bulky materials however some may not be removed and further transported to the treatment plant.

Bar screens are used to trap the bulky solids allowing the inflow of the solid-liquids faecal mixture.

The bar screen spacing influences the entry size of the particles to the other chamber which affects the efficiency of the plant. The smaller the size of the spacing with low velocity flow, the higher the efficiency of the plant. Regular maintenance is required for removal of trapped solids (Rost, 2018)



Figure 8: Screening process at primary stage of treatment.

Grit removal

Grit and sand particles are too small to be removed by bar screens and therefore flow along with the faecal slurry and transferred to the channel where they are allowed to settle thus removed. The removal efficiency is dependent on the channel length and flow velocity (Brdjanovic, 2014).

Septage may have high concentration levels of grit particularly from pits and septic tanks without lined walls. High grit concentration increases the rate of sludge accumulation in the thickening tanks, pipes, ponds and channels thus damaging the mechanical equipment (Tayler, 2018).

Grit removal is considered for plants designed to receive a loading greater than $250\text{m}^3/\text{day}$ and plants that use non enclosed systems such as anaerobic ponds and sludge drying beds. Lubigi treatment plant is designed to receive $400\text{m}^3/\text{day}$ though due to increased population it receives $660\text{m}^3/\text{day}$ which is greater than $250\text{m}^3/\text{day}$ and uses

anaerobic ponds for treatment of waste water and sludge drying beds for drying of the sludge. (Tayler, 2018)

Sedimentation/thickening tank

These is a rectangular unit used to separate solids from the liquids in the raw solid liquid mixture. This faecal matter from the grit chamber is taken to the sedimentation tank for separation of the liquid slurry using gravitational settling method under the effect of gravity (Brdjanovic, 2014).The septage contains floating solid, fats, oil and grease which due to their densities float to form scum on the tank surface hence efficiency in removal is periodic. The settled sludge is further pumped to the sludge drying beds and liquid effluent is taken to the anaerobic ponds for further treatment. Tanks designed to standard have the capacity to remove around 80% of total suspended solids (TSS) (Brdjanovic, 2014).

The liquid effluent from the sedimentation tank which is taken to the anaerobic ponds is co-treated with the waste water at Lubigi treatment plant (Nuwagira, 2021). Co-treatment should be performed below an amount of 3.6% so to maintain the efficiency in the performance of treatment plant (Brdjanovic, 2014).



Figure 9: Sedimentation /thickening tank at Lubigi waste water Treatment Plant.

Anaerobic ponds

These are deep shallow ponds that receive waste water conveyed by sewers through which it undergoes screening and the liquid effluent from the sedimentation tanks.

They use anaerobic bacteria to breakdown organic matter (highly concentrated) in waste water in the absence of oxygen (anaerobically) thus biological treatment.

Sludge is formed and settles at the bottom of pond which influence about 60% BOD removal. The settled sludge takes a period of 6 months where it is de-sludged by a dredging machine to the sludge drying beds. The anaerobic process in the absence of oxygen result into the formation of methane, ammonia and carbon dioxide. The liquid effluent is retained in the ponds for 4 days and then proceeds to the facultative ponds under the secondary stage of treatment. (Matthew Verbyla, 2017)



Figure 10: Anaerobic ponds at secondary stage of treatment.

SECONDARY STAGE

Facultative ponds

These ponds are (1-2) m in depth with a long detention time of about 2-3 weeks and consists of both aerobic and anaerobic ponds.

The aerobic zone is on the surface (top) where it encourages algae production that consumes carbon dioxide CO_2 and releases oxygen O_2 that is used by bacteria to breakdown the organic matter. The production of algae is dependent on the organic load and temperature. (Matthew Verbyla, 2017)

The anaerobic zone is at the bottom and thus uses anaerobic bacteria to breakdown the organic matter anaerobically.

The facultative ponds are of two types: primary facultative pond which receive raw waste water and the secondary facultative pond which receive settled wastewater from the first stage.

The effluent is retained in the facultative ponds for three days and then released to the tertiary stage of treatment. (Matthew Verbyla, 2017)

TERTIALLY STAGE

The effluent from the facultative ponds is discharged to the swamps where it undergoes self-purification by removing impurities before it joins the water bodies. The effluent purification is aided by the use of plants in the swamps to capture fine particles and trap a high proportion of the absorbed pollutants attached to the sediment.

SLUDGE DRYING BEDS

Sludge drying beds are open or covered beds that use sand for filtration liquid from the faecal sludge from the sedimentation tanks and the anaerobic ponds to allow drying of the sludge. Sludge drying bed are the commonly used drying technique due to its natural ability to dewater sludge. It is mostly used due to its ease to operate, affordability in comparison to the other techniques used and the production of quality organic content used as a fertilizer.

Sludge drying beds at Lubigi treatment plant are consistent of on underlain coarse aggregate and then fine aggregates (sand) on top of which sludge is pumped on the drying beds in variation with depth.

The pumped sludge is left for a certain period of time to allow the water to percolate through the filter media on the bed as well as evaporate from the surface of the bed until the sludge is dry enough to be removed by the use of spades (Gava Job SSAZIPIUS1, 2021) Dried sludge ready for removal is identified by the formation of crack patterns on the sludge bed.

The dewatering techniques used are either mechanical or natural and these are both physical processes. The natural methods use evaporation and percolation as the main drivers of the drying process though the drying efficiency is dependent on the weather conditions, sludge nature and application depth on the drying bed (A.A. Elbaz 1, 2020).

2.6 METHODS USED FOR DRYING SLUDGE

2.6.1 NATURAL METHODS USED FOR DRYING SLUDGE.

Solar drying beds

These are oldest drying techniques which entire depend on the solar energy to achieve dewatering and drying. In a case study area, a greenhouse drier was used with solar panels as auxiliary heat sources in order to attain 90% dry sludge. However, 70% of the dry sludge was obtained thus sludge volume was reduced by approximately 40% which reduces the cost of handling, transportation and disposal or application by farmers. This system is highly efficient in cities with high radiations (KURT, 2014).

Paved drying beds

These beds are rectangular of about (5-15m) wide and (21-46m) long with vertical side walls though they have limited use. It also consists of a 100mm diameter pipe used to convey and drain away water. These beds are efficient with anaerobically digested sludge. They have the ability to dewater sludge by 20-30% dependent on the climatic conditions. They are mainly advantageous due to their ability to use remove sludge without damaging the under-drain pipes or lose of sand (A.A. Elbaz 1, 2020)

Planted drying beds

Planted drying beds consist of both coarse and fine aggregates (sand). Faecal sludge is loaded on the top of the bed for percolation to take place through the bed constituents

thus being drained away in the underdrain. They use sand as a filter media as a means of dewatering the sludge. They are designed based on the solid loading rates. These beds are advantageous in such a way that they also stabilize the sludge. Plants are grown on the filter bed and loaded continuously with faecal sludge (LINDA, 2019).

Unplanted drying beds

These are rectangular beds with sides high enough to accommodate the hydraulic loadings. These beds consist a splash plat to disrupt flow during loading and a ramp for solid removal. They are similar to the planted drying beds in such a way that they consist a layer of gravel and sand for filtration process. The only difference between planted and unplanted drying beds is that unplanted drying beds only dewater and dry sludge without inactivation of pathogens. (LINDA, 2019)

Note: The above beds can be covered or uncovered with iron sheets as a means to improve the dewatering performance of the drying beds.

2.6.2 MECHANICAL METHODS OF DRYING SLUDGE

Mechanical techniques have been used in waste water treatment plants are highly efficient for drying sludge and require less land unlike the sludge drying beds. However, they require reliable electricity, skilled labor to operate the machines and chemical polymers which are costly.

The mechanical presses are basically two types commonly used in lower-income countries for septage and faecal treatment, screw press and belt filter press are employed after the screening and grit removal stages. These presses separate liquids from solids by application of pressure to force the separated liquid through the filter media hence retain the dewatered sludge. The addition of a chemical conditioner

preferably a polymer is added upstream the press is required to precondition the sludge the sludge and improve the effectiveness of the dewatering performance. (Tayler, 2018)

Screw press

This is the mostly used mechanical technique used for dewatering of sludge in comparison to the other techniques such as centrifuges, belt or filter presses. The screw press has a screw enclosed by an outer screen through which sludge is conveyed. The sludge is dewatered by gravitation force where the filtrate is drained out and the solids compressed and dewatered as the screw diameter reduces towards the pipe's outlet.

This method, however requires a coagulant such as polymer for stability during the dewatering process as well as increased effectiveness. Wastes from local plants such as *Moringa Oleifera* seeds, or chiston can also be adopted as another means of dewatering of sludge. In addition, these natural materials also enhance the quality of the sludge as a fertilizer by increasing the nutrient content, calorific value and fuel potential (Alena Basamykina¹ *, 2020)

Belt filter press

This is current technique used for dewatering because of relatively low energy running costs and the simple and reliable technology. The efficiency is dependent on the dry solid content, recovered solid percentage and the lateral sludge migration on the belt. The belt filter press has a variation of zones which work together for the final product (sludge cake).

The sludge is conditioned by addition of a flocculant to it in a flocculator and this results into the formation of flocs which are comprised of free water. The flocculated sludge is then distributed evenly on the filter belt to the gravity zone.

The belt filter press consists of a pair of continuous belts that run between the rollers through which sludge is squeezed hence dewatering of sludge. This sludge has to be super flocculated for feasibility by the press and when introduced to the belts should drain out free water by gravity in the gravity zone. The solid concentration is expected to increase due to reduction in moisture content. (Daniel D. Reitz, 2018)

The semi-dewatered sludge is transferred to the wedge zone which consists of a formed wedge when the two belts come together. This sludge is subjected to gradually increasing pressure hence drainage. Continuous drainage at the compression stage indicates excess water which acts as a lubricant and promotes movement of sludge solids laterally out of the side and through the belt fabric.

The sludge solids are further transferred to the pressure zone which induces a high pressure due the decrease in diameter of the roller, the relative movement of the belts to each other and the drive torque of the machine thus a force exerted. The sludge is then discharged with a 99% solid retention. (Harris, 2023)

Centrifuges

This technique has been adopted since the 19th century for waste water treatment. It generally has got a high solid concentration though costly. (Agency, 2000) Centrifuges are used for thickening and dewatering of sludge and when it is done before digestion, it reduces the need for a tank that aids sludge digestion and dewatering process.

The working principle of a centrifuge is that it uses centrifugal force which accelerates the separation of liquids from solids. The centrifuge is a cylindrical decantor that rotates at high speed on its horizontal axis with the overflow of the clarified water and the dewatered sludge removed by the Archimedean screw. This rotation applies a centrifugal force that fastens the removal of solid particles. (Harris, 2023)

2.7 RICE HUSK ASH

Rice husk (RH) is an agricultural waste that highly generated from rice growing agricultural farmlands and milling industries. The high levels of urbanization with a population growth rate of about 3.2% in Uganda result into increase in food production to correlate with the population growth rate. Rice is one of highly consumed food type in urban areas especially by the children and teenagers who make up about 50% of Uganda's population. The large quantities of husks generated by milling industries per day have posed a great environmental impact through water and air pollution. Therefore, research has been conducted to determine the composition and physico-chemical properties of the rice husks thus reuse as raw material which becomes economically viable. It was reported that the RH which is 20% of rice grain weight is majorly composed of 50% cellulose, lignin (30%) and 20% organic compounds. (Nur Ezyan Badrul Hisham, 2018). It also consists of a significant amount of 14.8% silicon dioxide (Tatyana Germanovna Korotkova, 2016) which aid in enhancing filtration process due to the ability to absorb moisture.

Furthermore, the Rice Husk was burnt under controlled temperature to production of a waste product known as Rice Husk Ash (RHA) which resulted into an increment of more than 90% silica content (Nur Ezyan Badrul Hisham, 2018).

Under controlled burning temperatures, the volatile organic component (cellulose and lignin) are extracted with a predominant amount of silica. The silica state formed is dependent on the combustion conditions and the burning temperatures. Temperature ranges (500°C-700°C) result into amorphous silica state which is considered reactive unlike temperature range (700°C-800°C) whose state consists of nonreactive silica mineral (cristobalite and tridymite) (Singh, 2018).

2.8 QUALITY OF THE MANURE

Faecal sludge (FS) contains valuable organic matter and plant nutrients and a safe reuse possess potential benefit in the agriculture sector. However, FS is highly concentrated with pathogenic microorganisms in comparison to wastewater (Butte, 2021). Therefore, sludge treatment is crucial in the safety against serious health risks to the farmers and crop yields. These pathogenic microorganisms include viruses, bacteria, protozoa and helminth eggs that cause fatal diseases thus death and therefore need to inactivate these organisms from the sludge before application for safety of the farmers, plants and the consumers.

Bacteria

These single celled microorganisms existing in micro sizes. Under favorable conditions, they are subject to reproduce and grow. Bacteria exists in a variety of species of which most are not harmful to man (Blanca Jimenez, 2010). However, some of the bacteria species for example Escherichia Coli (E. coli) cause food poisoning due the food contamination with the bacteria a well as other bacterial infections such stomach pains.

Viruses

These are minute infectious agents that only multiply and reproduce inside the infected host cell. They are only released from excreta of an infected person independent of exhibition of symptoms. They are quite difficult to detect especially in developing countries due to the complexity and costly analytical technique (Blanca Jimenez, 2010).

Protozoa

These are single celled organisms reproduce only in the host. However, they are able to survive and remain active in the environment for a long period (months to years) depending on the environmental conditions. They are closely associated with diarrhea which is responsible for about 1.8million death per year (Blanca Jimenez, 2010).

Helminth eggs

Helminth eggs are infectious agents that are released through excreta by helminth (worms). Helminth eggs are considered more resistant compared to other pathogens due the complex layers that protect them. Temperature about 40⁰c in the periodic range (10-20) days and about 5% moisture reduction are anticipated to inactivate these pathogens. (Victor Moinard, 2021)

In conclusion, rice husk ash possesses properties (< 90% silica) attributing to dewatering of sludge thus inactivating pathogenic organisms at specific temperature conditions. Amorphous silica (SiO₂) is chemically inert and therefore does not affect the faecal sludge quality. In addition, the ash residue in the sludge also acts an organic fertiliser.

2.9 REGULATIONS, LAW AND POLICIES CONCERNING WASTEWATER AND SLUDGE MANAGEMENT.

The International water Management Institute and the United Nations Environment Programme (UNEP) expound on the current trends of faecal sludge management and the impacts of poor management practices on human, socioeconomic and environmental health in sub-Saharan and Northern Africa. This poses risk to both gender and contributes to about 115 deaths per hour resulting into excreta related diseases and economic losses. However, good sanitation practices have also been adopted in a few countries with the potential to replicate in other several African countries. Therefore, there is need to invest in sanitation systems and mechanisms to improve faecal sludge management which is essential in addressing the global sanitation crisis and achieve the Sustainable Development Goal (SDG) 2030. (A.Christodoulou, 2015)

On a global basis, about 2 billion people lack basic sanitation facilities of which 300 million people are based in Africa. Sewers connected is to only 7% with 1% treated waste. About 19% practice open defecation with 81% accessing on site sanitation systems. In 2015, United Nations introduced the Sustainable Development Goals (SDGs) 2030 as a global agenda whose focus is to ensure access to water and sanitation for all. However, there is a challenge to achieve this goal influenced by the weak policy implementation and reforms, financial instability by the government and institutions in the sanitation sector and the over dependency on public toilets. (Kayastha, 2011)

The East African Community addresses health, sanitation and environmental concerns as well as strategies for improvement such as waste water treatment but it does not enact legislation rather facilitates cooperation and harmonization of the policies. The

need for sufficient sanitation services identified by international and national development results into policy characterization in relation to Faecal Waste Management (FWM). This entails on the key aspect from collection to reuse or storage (safe disposal) in the East African Countries. (Agnes Nanyonjo, 2019) However, there is need for optimum representation of FWM in the environmental, water and sanitation policies. This is due to the absence of a ratified stand-alone sanitation and hygiene policy except for Kenya. This therefore acknowledges the non-exclusive address of the FWM chain by the policies. FWM and its chain are required to enforce implementation of equitable sanitation services. (Agnes Nanyonjo, 2019)

In Canada, the application of biosolids and other waste to agricultural land must conform to the ministry of Environment's (MOE) and Environmental Protection Act (EPA). The guide provides biosolids management options and refers to the United Environment Protection Agency (USEPA) criteria for sewage sludge treatment techniques, heavy metal limits and pathogen limits (Kearnes, 2024).

Bio solid management in accordance to, the guide for Canadian best practice also points out other unknown processes, which shows equivalency in stabilization result i.e potential treatment methods (Nadeem, 2022)

The USEPA code of Federal Regulation (CFR)-40, part 503 also allows compatible treatment processes to be considered as stabilization techniques, before approval by regulating authority.

The Waste Management Act 1996 designates the Agency as the licensing authority for significant waste management facilities, which includes landfills, taking significant

quantities of biodegradable wastes. The Act sets out the criteria, which must be followed for a waste license to be issued and retained (Goldstein, September 2008)

The water (Prevention and Control of pollution) Act of 1974 indicates restrictions of pollutant discharges to water bodies and acts as a guide to set standards and enforce water pollution rules by the central state pollution control boards with authority.

The Environment Act of 1986 which was passed in the after-effects of the Bhopal Gas Tragedy of 1984, and is an umbrella Act concerning all issues in-relation to environmental protection and provides for the audit of all facilities that require permits under hazardous waste rules, pollution and air pollution.

The Urban Sanitation Policy (NUSP) of 2008 addresses reuse of wastewater as an important factor in helping to meet the environment targets of the city (Addis, 2024).

According to the constitution of the Republic of Uganda, 1995 article XXVII of the environments, the state shall take all possible measures to prevent or minimize damage and destruction to land, air and water resources resulting from pollution or other causes and also take all practical measures to promote a good water management system at all levels (Wandhake, 2015). National Water and Sewerage Corporation, Uganda is developing a clean Development mechanism (CDM) especially focusing on the sewage treatment processes in Kampala City. As its efforts to develop a CDM project while significant are likely to address challenge of wastewater management in the country (Jonsson, 2020)

The Kampala FSM Project funded by Bill and Melinda Gates foundation aims at addressing the challenges on sanitation especially the major key aspects of fecal sludge from onsite facilities. (Godwin, 2020)

CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

This chapter entails of a series steps taken to achieve the main objective of the research project. These involve materials, Prototype setup, sample preparation and Laboratory analysis of the sludge in terms of moisture content, total solids and total volatile solids as well as the chemical composition of the rice husk ash with reference to the standard methods.

3.2 MATERIALS

Rice husk ash

The rice husk ash was produced under controlled burning of the rice husks at temperature 500⁰C to 700⁰C. The rice husks were obtained from a rice milling factory in kisoga kibanga.

Sludge

Fresh sludge samples were obtained from Lubigi wastewater and faecal treatment sludge drying beds and taken for laboratory analysis at Central Laboratory National Water and Sewerage Cooperation in Bugolobi and the results compared to the standards.

3.3 PREPARATION OF RICE HUSK ASH

The collected rice husks are cleaned in order to remove any form of unwanted debris such as stone particles.

These husks are dried under air so as to reduce the moisture content by about 10%. These husks are then placed in a furnace and burnt under controlled temperatures of 500⁰C-700⁰C for about 12 hours for cooling to ambient temperatures.

The ash is collected from the furnace, grinded to reduce the large particles and sieved through the 0.075mm sieve for uniformity in the particle size.

The ash is then collected and kept in a polythene bag that is free of any damage to prevent spillage of the ash.

Note: Every 100kgs of Rice husk produces 25kgs of Rice husk ash.

3.4 DESIGN AND SETUP OF A SLUDGE DRYING BED PROTOTYPE.

The design and setup for the prototype was based on the United States Environmental Protection Agency (USEPA) (AGENCY, 1979) which gives the basic components and operation of the sludge drying bed. The prototype is located at NWSC Lubigi waste water and faecal sludge treatment Namugooona, Uganda. The exterior bed is sized 2.20m³ volume capacity and the bed interior is sized 1m³ volume capacity and 1m² bed area and this partitioned into four sections of 0.16m³ volume capacity.

Preparation of the drying bed with the filter media layers.

The bed was constructed above the ground surface in duplication of the existing drying beds. The beds consist 4-inch perforated pipes placed bottom of all sides of the bed sections 0.3m above the ground surface at a slope of about 1cm. The base of the bed sections comprise of hardcore to a depth of 0.3m. A layer of coarse aggregates of sizing 12.5mm was placed to a depth of 0.3m above the hardcore. Sand of sizing 0.3-1.2mm in diameter was placed as a filter media to a depth of 0.15m unto which sludge was pumped to a height of 0.2m. An allowance of 0.05m was for the placement of a transparent roof which allows sunlight to penetrate through and prevent entrance of rain.

3.5 SAMPLING

3.5.1 SAMPLE COLLECTION

The sludge samples were pumped from the anaerobic ponds to the sludge drying beds. These samples were collected in containers and then taken to the sludge drying bed prototype.

3.5.2 SAMPLE PREPARATION

The sludge was mixed with varying proportions of rice husk ash based on the quantity of sludge added to the bed. These proportions were quantified in form of percentages 0%, 4%, 7% and 10% of the sludge weight added to the sludge drying bed. The weight of sludge that accommodates a depth of 0.2m in the bed is 30kg. A sludge sample was then picked from each section of a drying bed and placed in plastic bottles where it was transported for laboratory analysis. These samples were in the waste water samples fridge under a temperature of 4°C before analysis.



Figure 11: Sample preparation



Figure 12: Sample transportation

3.6 LABORATORY ANALYSIS

This involves tests that were done to determine the chemical composition of the rice husk ash, the raw sludge parameters and their periodic change. These tests are carried out as an indicator of effective dewatering of the sludge.

3.6.1 X-RAY FLUORESCENCE TECHNIQUE (XRF)

This technique is used to identify and quantify the different elements in a sample (Rice husk ash) under an X-ray Fluorescence Spectrometer.

The analysis process involves 3 elements, the X-ray source, sample and detector. The X-ray source emits X-rays to the sample which consists of many atoms. Each atom has a positively charged nucleus and negatively charged electrons. Emission of x-rays encounter acts with an atom whose electron in the nearby shell is absorbed and released out of the atom with high intensity x-rays. This leaves the atom unstable and for stability, the electron in the further shell occupies the nearby shell thus energy release in form of X-ray Fluorescence photon and this is characteristic to each element. The detector picks up the characteristic x-ray fluorescence energies of the element, identifies and quantifies them using individual wavelength.

3.6.2 GRAVIMETRIC METHOD

This method is most efficient for semi solid-to-solid sludge (al., 2017) and since the faecal sludge at the drying beds had undergone the first stage of solid liquid separation in the settlement tanks, it can be categorized as semi solid or solid sludge.

It is used to determine the moisture content and total solids of the sludge. This is obtained by the variations of moisture content before and after oven drying the sludge.

These expressions are in percentages based on the weight of the wet and dry sludge sample. (APHA, 2021)

The method obtains the faecal sludge parameters by the following;

$$\text{Total Solids (TS)} = \frac{W(c+s)_{105} - W_c}{W_s} \times 100 \quad \text{Where: } W_c = \text{crucible mass (g)}$$

$$\text{Moisture content (Mc)} = \frac{W_s - (W(c+s)_{105} - W_c)}{W_s} \times 100 \quad W_s = \text{Weight of wet sample (g)}$$

$W(c + s)_{105}$ = weight of wet sample +crucible after oven drying (g)



Figure 13: Sludge samples in the oven

3.6.3 IGNITION METHOD

This method is carried on samples for which the total solids are obtained and is used to determine the volatile solids and fixed solids in the sludge. (APHA, 2021) The volatile solids give a measure of proportion of organic content prone to volatilization and the fixed solids give a measure of inorganic and organic content (stable form). This is obtained by the variations of total solids before and after volatilization. These

expressions are in percentages based on the weight of the dry sludge sample at specified temperatures.

The dry samples are ignited at 550°C for 2 hours until constant weight is obtained. The ash retained represents the inorganic solids, while the lost weight on ignition represent volatile solids (organic matter) in the faecal sludge

$$\text{Volatile Solids (VS)} = \frac{W(c+s)_{105} - W(c+s)_{550}}{W(c+s)_{105} - W_c} \times 100 \quad \text{Where: } W_c = \text{crucible mass (g)}$$

$$W(c + s)_{105} = \text{Wet sample mass+ crucible mass before burning (g)}$$

$$W(c + s)_{550} = \text{crucible mass+ sample after burning (g)}$$



Figure 14: Muffle furnace

CHAPTER 4: RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter entails results obtained from the different tests carried out on the sludge and rice husk ash samples with the aim of achieving the main objective of the project. These tests were carried out for 2 months in account for the seasonal variation to determine the moisture content, total solids and total volatile solids as well as the chemical composition of the rice husk ash. Month 1 was the wet season and Month 2 as the dry season, because it had most of the dry spills.

4.2 CHEMICAL COMPOSITION OF THE RICE HUSK ASH

The rice husk ash is produced under controlled burning of the rice husks at temperature 500°C to 700°C so as to increase the percentage of silicon dioxide in the ash. The silicon dioxide produced at this temperature is in an amorphous state beyond which it is unreactive state. The amorphous silica in the ash has a micro porous structure due to its structural arrangement. When the ash is added to sludge, creates a rigid lattice structure and a porous channel that fastens permeability of water from the sludge. The percentage of the SiO₂ should range between (73.6-96) % for effective dewatering and from the Table 2 below, SiO₂ is 81.192% which lies within the required range.

Table 2: Chemical composition of rice husk ash

Rice husk ash parameter	Units	Results
Silicon dioxide	%m/m	81.192
Iron (III) oxide	%m/m	8.026
Calcium oxide	%m/m	7.049
Manganese (II) oxide	%m/m	1.919
Aluminum oxide	%m/m	0.596
Phosphorous pent oxide	%m/m	0.475
Europium (III) oxide	%m/m	0.255
Potassium (III) oxide	%m/m	0.299
Titanium (III) oxide	%m/m	0.108

4.3 CHANGE IN SLUDGE PARAMETERS

The sludge parameters such as Moisture content, total solids and volatile solids were monitored in the month of January as the wet season and February as the dry season. This was done after an interval of every 7 days for a period of 2 months (28 days each).

4.3.1 MOISTURE CONTENT

From the data analyzed, figure 15 is a representative of results in the wet season where 4% dosage of rice husk ash achieved the lowest moisture content of 35.4% compared 0%, 7% and 10% with their respective moisture content of 70.9%, 50.5% and 47.2% after a period 28days.

Figure 16 below is a representative of results in the dry season where 4% dosage of rice husk ash achieved the lowest moisture content of 27.3% compared 0%, 7% and 10% with their respective moisture content of 57.2%, 40.8% and 39.1% after a period 28days.

The sludge samples that were mixed with the rice husk ash had a better dewatering in comparison to the control sample (without ash). The moisture content of the sludge samples reduced rapidly for the 1st seven days intervals and then gradually for the 14, 21 and 28 days. However, 4% dosage of rice husk ash had a faster dewatering as indicated by the lowest moisture content of 35.4% and 27.3% for Month 1 and Month 2 respectively and therefore was selected as the optimal dose for the sludge. This indicates that increase in the proportion of rice husk ash in sludge does not necessarily result into increased dewatering of sludge. This is because with increase in ash, there is increase in agglomeration that leads to clogging of pores of the sludge thus hindering permeability of water from the sludge.

Figure 15: A graph showing reduction in moisture content with increase in days in the wet season

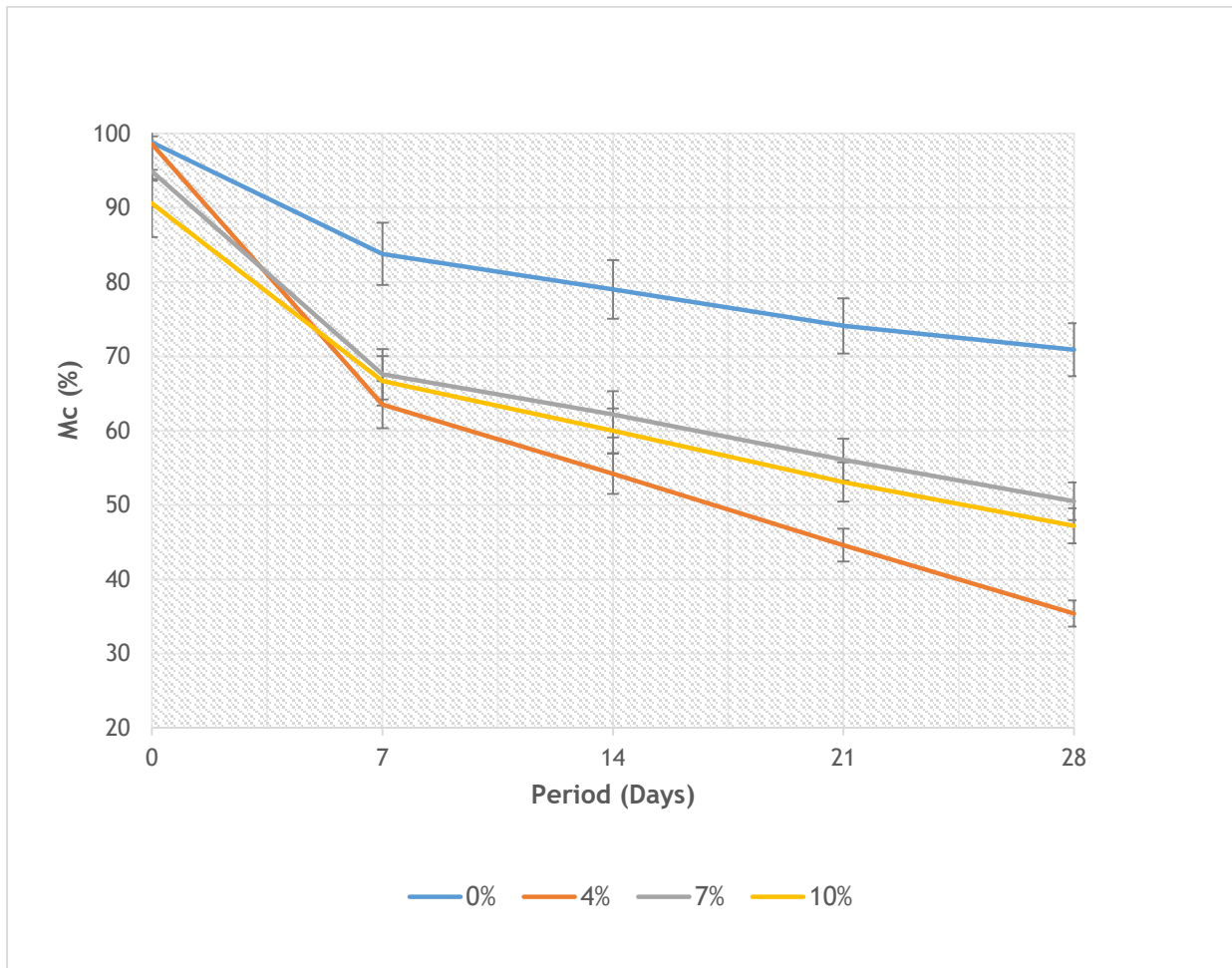
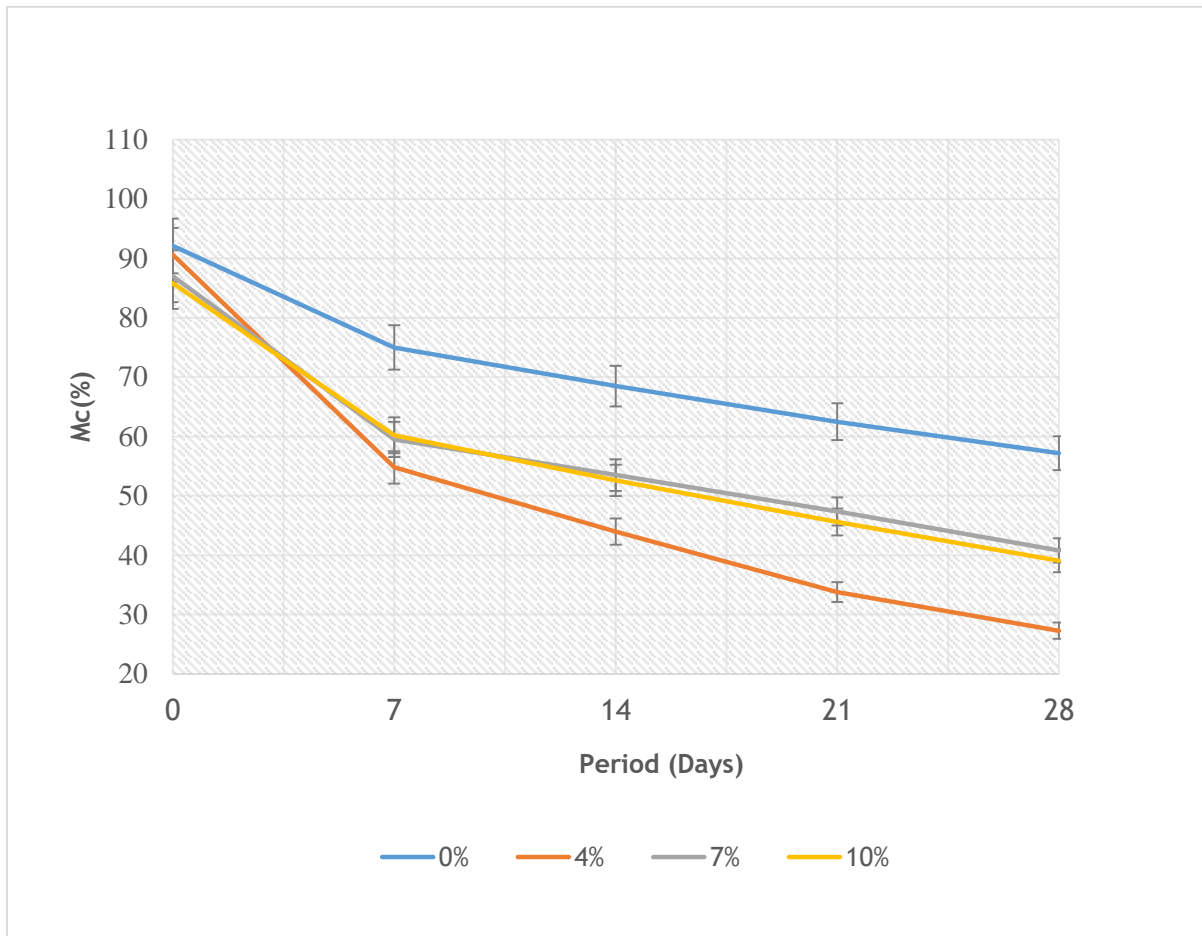


Figure 16: A graph showing reduction in moisture content with increase in days in the dry season



4.3.2 TOTAL SOLIDS

In reference to figure 17 as shown below, the presented data for the wet season indicates that 4% dosage of rice husk ash has the highest concentration of total solids of 64.6% compared to 0%, 7% and 10% with 29.1%, 49.6% and 52.8% respectively after a period 28days.

Figure 18 below presents data for the dry season, where 4% dosage of rice husk ash achieved the highest concentration of total solids of 72.7% compared to 0%, 7% and 10% with 42.8%, 59.2% and 60.9% respectively after a period 28days.

The concentration of total solids in sludge is dependent on its moisture content. Moisture content reduction leads to an increase in the quantity of total solids in sludge. Since 4% as indicated in figure 15 and 16 had the lowest moisture content, this implies that it has the highest concentration of total solids as shown in figure 17 and 18 below.

Figure 17: A graph showing increase in total solids with increase in days in the wet season

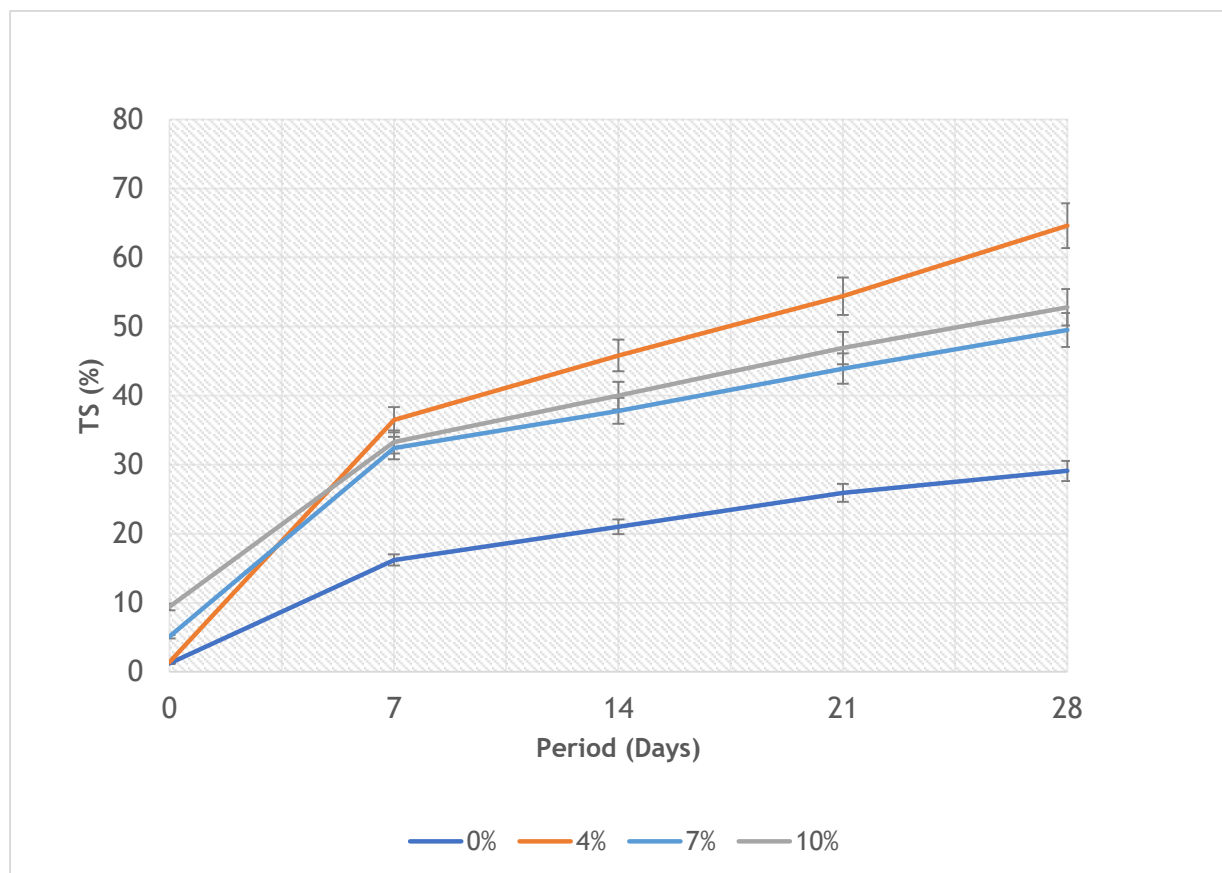
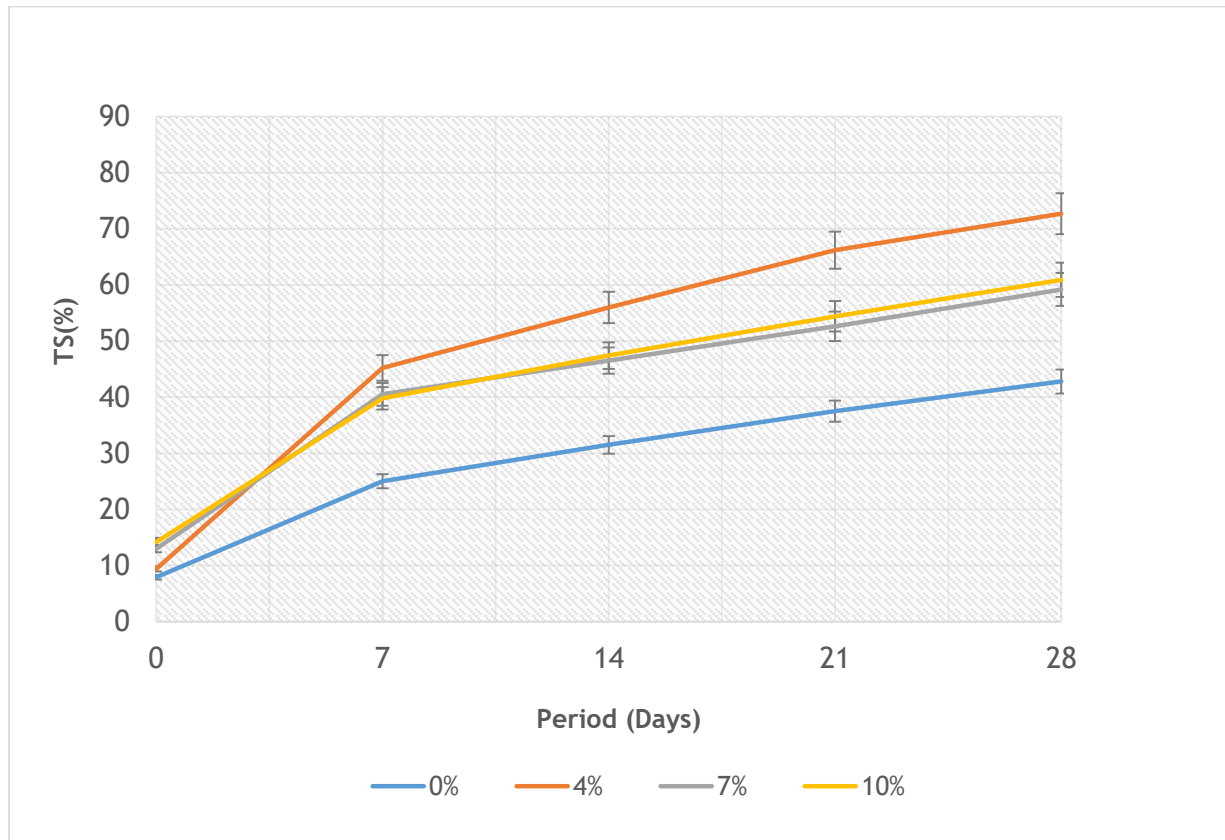


Figure 18: A graph showing increase in total solids with increase in days in the dry season



4.3.3 VOLATILE SOLIDS

From data analyzed for the wet season as represented in figure 19 below, the 10% dosage of rice husk ash achieved the lowest volatile solids of 21.4% in comparison with 0%, 4% and 7% and their respective volatile solids of 53.8%, 32.5% and 28.7% after a period 28 days.

For the dry season, results presented in figure 20 below indicates that 10% dosage of rice husk ash achieved the lowest volatile solids of 22.3% in comparison with 0%, 4% and 7% and their respective volatile solids of 51.4%, 32.4% and 25.9% after a period 28 days.

The sludge samples mixed with the rice husk ash had low percentages of volatile solids in comparison to the control sample (without ash). However, 10% dosage of rice husk ash had the lowest volatile solids. This indicates that increase in the proportion of rice husk ash reduces the amount of volatile solids. This is because with an increase of ash in sludge, an environment that has a low survival for microorganisms such as bacteria is created. This reduces the rate of microbial activity (decomposition) of organic matter proportion that is susceptible to volatilization hence a decrease in the volatile solids production.

Figure 19: A graph showing reduction in volatile solids with increase in days in the wet season

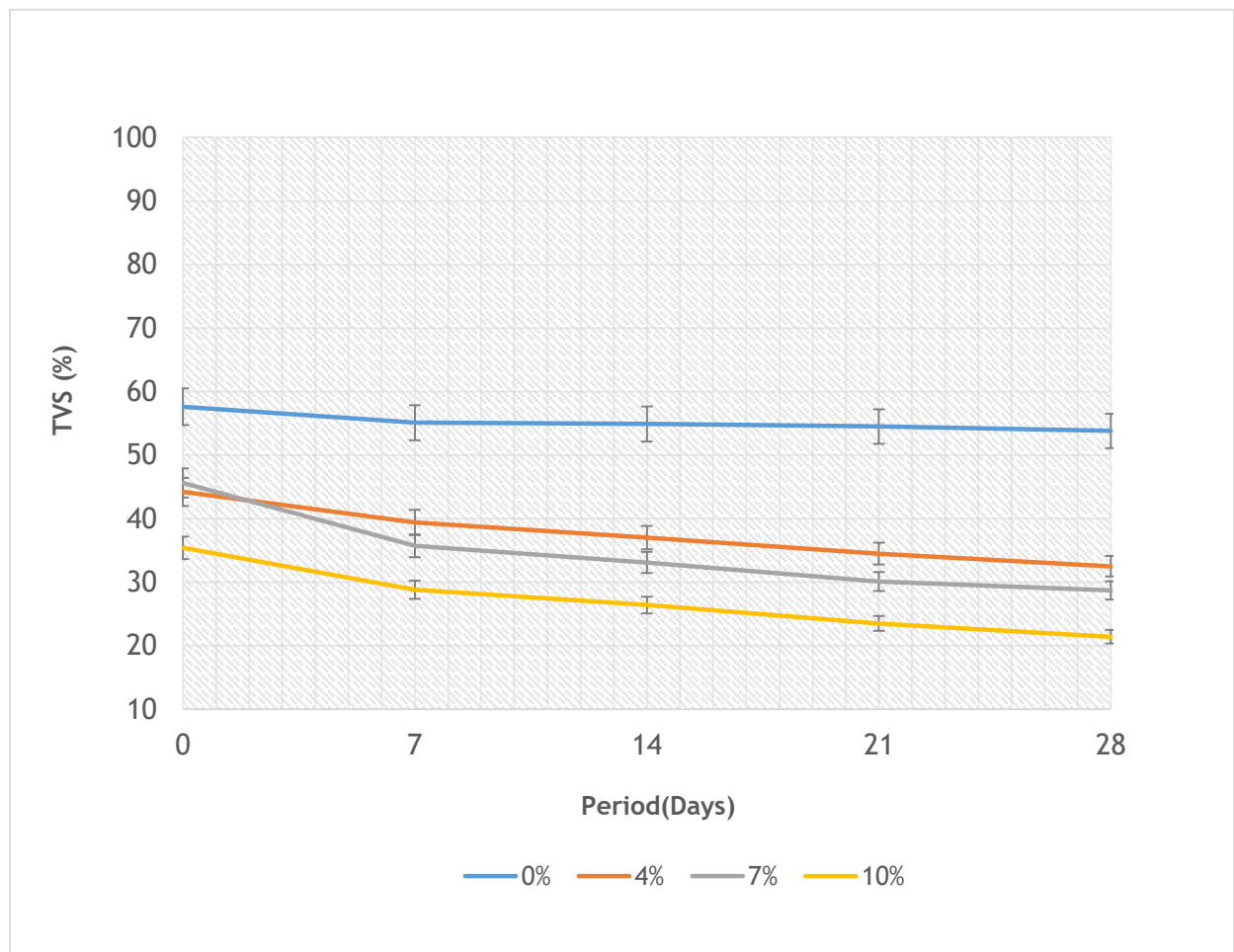
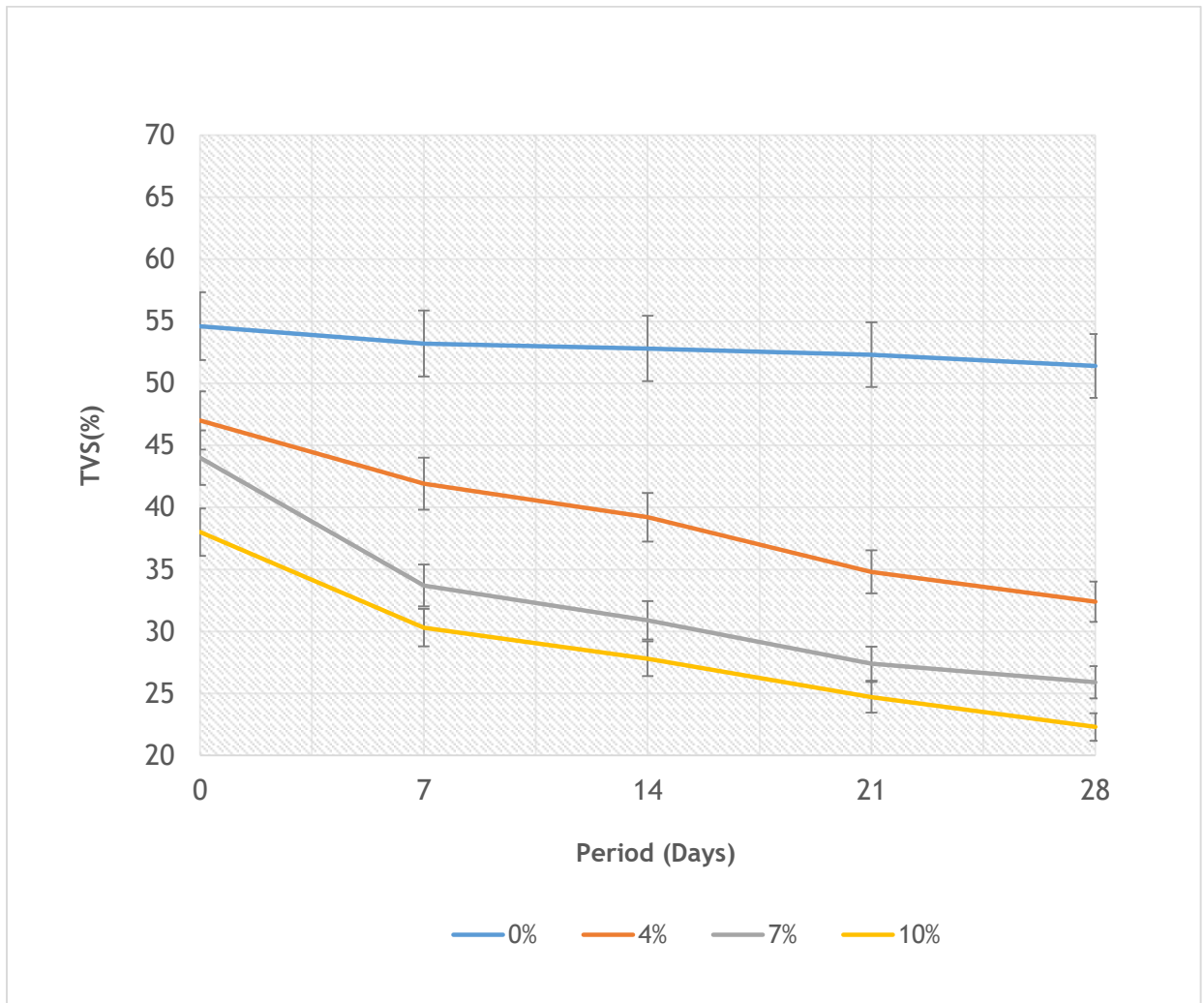


Figure 20: A graph showing reduction in volatile solids with increase in days in the dry season



4.4 DESIGN

The prototype design and setup were based on the United States Environmental Protection Agency (USEPA) (AGENCY, 1979) which gives the basic components and operation of the sludge drying bed.

GENERATED SLUDGE PER MONTH

Faecal sludge is collected from Pit Latrines and septic tanks from around Kampala by the cesspool tanks to the treatment plant. Lubigi Treatment Plant has a design capacity of 400m³/day.

Monthly capacity = (400x30) =12000m³/month

The sedimentation tank separates solids from liquids in the faecal sludge. The moisture content of the faecal sludge from the collection points (septic tank and pit latrine) has an average of 85% and 15% sludge.

Sludge per day= $\frac{15}{100} \times 400 = 60\text{m}^3/\text{day}$

Sludge produced per month= (60x30) =1800m³/month

Each sludge drying bed has a capacity =105m³

Number of drying beds at Lubigi Treatment Plant=52

Number of beds required for the sludge produced per month = $\frac{1800\text{m}^3}{105\text{m}^3}$
=17.1beds

This indicates that the Sludge drying beds are sufficient enough to accommodate the incoming volumes of sludge from the sedimentation tank if desludged on a monthly basis.

QUANTITY OF RICE HUSK ASH REQUIRED FOR THE SLUDGE DRYING BEDS

Volume of the sludge drying bed prototype= 1m^3

The sludge bed is partitioned into 4 equal sections

Volume of each section= 0.16m^3

Volume of sludge in each section= 0.032m^3

Table 3: Weight of ash added per sludge bed section

Sludge bed section	Rice husk ash sample dose (%)	Rice husk ash equivalent weight (Kgs)
1	0	0
2	4	1.2
3	7	2.1
4	10	3.0

In accordance to the results obtained for the 2 months (28 days each), 4% is the optimum dosage required since it gives lowest moisture content of 35.4% and 27.3% in Month 1 and 2 respectively that lies within the required range (30-40) % for sludge to be removed from the bed.

Weight of rice husk ash required per drying bed (V)

Volume of each drying bed= LXWXH

$$=30 \times 7 \times 0.5$$

$$=105\text{m}^3$$

Since 0.032m³ requires 1.2 kgs of ash

105m³ requires 3937.5 kgs of ash

Number of Sludge drying beds=52

Number of beds required for the sludge produced per month=17.1

Total weight of RHA required for the drying beds=3937.5x17.1

=67331.25kgs

=67.33 Tonnes

Annual weight of RHA required for the drying beds=67331.25x12

=807975kgs

=807.98Tonnes

$$\begin{aligned}\text{Number of cycles in a year} &= \frac{\text{Number of days in a year}}{\text{Number of drying days+loading days}} \\ &= \frac{365}{(28+2)}\end{aligned}$$

Number of cycles in a year=12 cycles

With the addition of rice husk ash in the sludge, there is an increase in the number of cycles due to short drying period as the sludge is dewatered at a faster rate.

QUANTITY OF RICE HUSKS NEEDED TO MEET UP WITH THE RHA REQUIRED

100kgs of Rice Husks (RH) produce 25 kgs of Rice Husk Ash (RHA)

if: 25kgs of RHA require 100kg of RH

807975kgs of RHA require 3231900kgs of RH

Therefore 3231.9 Tonnes of Rice Husks are required annually for the sludge drying beds at Lubigi Treatment plant.

AVAILABILITY OF THE RICE HUSKS IN UGANDA

Rice, which is the most important cereal crop in Uganda is commonly grown by smallholders as their source of income for household production.

Uganda has a conducive climate evidenced by the rainfall patterns in most parts of the country with a Mean annual rainfall of 1180mm/year ranging from 750-1500mm/year in the dry areas to the high rainfall areas alongside the available fertile soils. (Soonsung Hong, 2021)

Uganda produces about 350,000MT of rice annually equivalent to the import substitution of 104 million USD per year. However, this does not meet with the domestic demand thus importation to meet up with the demand. As a result, Uganda set a target to produce about 680,000MT of rice by 2020 generating an equivalent of 73 million USD worth of exportation. (Soonsung Hong, 2021)

Uganda has 3 rice production systems, the rain-fed lowland, irrigated low-lands and the upland production system which influence the area of growth of rice. These are Eastern, Northern and Mid-Western parts of Uganda influenced by the rain fed and irrigated rice systems which contribute over 90% of the national rice output majorly by the small house hold farmers. This is also substituted by the Kibimba and Doho rice scheme as well as the Olweny swamp rice irrigation project. (Soonsung Hong, 2021)

Annual production of Rice in Uganda =350000 Metric Tonnes (MT)

1 MT =1.1 Tonnes

350000MT =385000Tonnes of Rice

385000 Tonnes=385000000 kgs

1 kg of Rice constitutes 0.2 kgs of husks

385000000kg of rice constitute 77000000kgs of husks

77000000kgs of husks constitute 77000 Tonnes of husks

Lubigi Treatment Plant requires 3231.9 Tonnes of Rice Husks for the production of RHA needed for the Sludge drying beds yet 77000 Tonnes of Rice Husks are produced annually thus 4.2% demand of Rice Husks. This indicates that Rice Husks are readily available to meet up with the quantity of Rice Husk Ash required annually for the Sludge drying beds.

COST BENEFIT ANALYSIS

The Rice Husks were burnt at the United Innovation Development Center and were placed in a furnace and burnt under controlled temperatures of 500⁰C-700⁰C for about 12 hours for cooling to ambient temperatures. These conditions were provided so as to produce high silicon dioxide composition within the range of (73.6-96) %which is in amorphous silica state with a small percentage of carbon composition. (Singh, 2018).

Dry sludge that is obtained after dewatering is used by farmers as manure to support and enhance plant growth.

Annual cost of Burning, transportation and Labor of Rice Husk Ash

Burning every 1000kg cost shs15000

3231900kgs cost shs (3231.9x15000)

3231900kgs cost shs 48,478,500

Annual cost of Transport =shs 4,200,000

Annual cost of Labour=shs 16,500,000

Annual Total cost =shs (48,478,500+7,200,000+16,500,000)

Annual Total cost =shs 72,178,500

Annual benefit from the dry sludge as Manure

1 Truck of dry sludge (3x1.4x2) has a volumetric capacity of 8.4m³

1 sludge drying bed occupies 105m³

$$\text{Number of trips per bed} = \frac{105}{8.4}$$

$$= 12.5 \text{ trips}$$

1 trip of dry sludge costs shs 40000

12.5 trips cost shs (12.5x40000)

12.5 trips cost shs 500,000 per month

Annual benefit, shs (12x500, 000) =shs 6,000,000

Annual benefit from the 17.1 sludge drying beds =shs (17.1x6, 000,000)

$$\text{Annual Total benefit} = \underline{\underline{\text{shs } 102,600,000}}$$

Therefore, on assumption that the beds are desludged on a monthly basis annual cost of shs 52.678,500 is invested, an annual benefit of shs 102,600,000 will be obtained.

Note: In consideration to limiting factors to consistent drying such as weather changes and the several unroofed drying beds at the treatment plant, we considered an annual duration of about 8 months with an allowance of 4 months of inconsistent monthly desludge thus 8 cycles within a year.

Annual cost investment

Annual weight required for the drying beds=67331.25x8

$$= 538650\text{kgs}$$

$$= 538.65\text{Tonnes}$$

538650kgs of RHA require 2154600kgs of RH

Therefore 2154.6 Tonnes of RH are required annually for the sludge drying beds at Lubigi Treatment plant.

Annual cost of Burning, transportation and Labor of Rice Husk Ash

Annual cost of burning

2154600kgs cost shs (2154.6x15000)

2154600kgs cost shs 32,319,000

Annual cost of Transport =shs 4,200,000

Annual cost of Labour=shs 10,944,000

Annual Total cost =shs (32,319,500+4,800,000+10,944,000)

Annual Total cost =shs 48,063,500

Annual benefit from the dry sludge as Manure

1 Truck of dry sludge (3x1.4x2) has a volumetric capacity of 8.4m³

1 sludge drying bed occupies 105m³

Number of trips per bed = $\frac{105}{8.4}$

=12.5 trips

1 trip of dry sludge costs shs 40000

12.5 trips cost shs (12.5x40000)

12.5 trips cost shs 500,000 per month

Annual benefit, shs (8x500, 000) =shs 4,000,000

Annual benefit from the 17.1 sludge drying beds =shs (17.1x4, 000,000)

Annual Total benefit =shs 68,400,000

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The raw sludge parameters; moisture content, total solids and volatile solids were analyzed for two months during the wet and dry season at varying proportions of rice husk ash 0%, 4%, 7% and 10% of the sludge weight (30kgs). The sludge samples had initial moisture contents whose percentages reduced with increase in rice husk ash dosage, Total solids dependent on moisture content obtained per sludge sample and volatile solids whose percentages decreased with increase in rice husk ash dosage. This was influenced by the sludge characteristics and the rice husk ash dosages.

The rice husk ash had a composition of 81.192% m/m of silicon dioxide (SiO_2) with other metal oxides whose percentages for each compound are less than 10%. The percentage of the SiO_2 obtained was within the required range (73.6-96) % for effective dewatering of sludge in the sludge drying beds.

The sludge samples were monitored every seven days as a measure of dewatering effectiveness of the Faecal sludge for two months (wet and dry season).

During the wet season, sludge with 0% (no ash added) had the highest moisture content of 70.9% and 4% dose had the lowest moisture content of 35.4% after 28days. During the dry season, sludge with 0% (no ash added) had the highest moisture content of 57.2% and 4% dose had the lowest moisture content of 27.3% after 28days.

The Total solids obtained were dependent on the Moisture content in such a way that decrease in moisture content leads to an increase in Total solids. During the wet season, sludge with 0% (no ash added) had the lowest total solids of 29.1% and 4% dose had the highest total solids of 64.6% after 28days. During the dry season, sludge with 0% (no ash

added) had the lowest total solids of 42.8% and 4% dose had the highest total solids of 72.7% after 28days.

Volatile solids indicate the proportion of organic matter prone to volatilization. During the wet season, sludge with 0% (no ash added) had the highest volatile solids of 53.8% and 10% dose had the lowest volatile solids of 21.4% after 28days. During the dry season, sludge with 0% (no ash added) had the highest volatile solids of 51.4% and 10% dose had the lowest volatile solids of 22.3% after 28days.

Therefore, 4% dose of rice husk ash had the best dewatering performance in comparison to 0%, 7% and 10% which lies within the required range of (30-40) % (Getahun, 2020) and hence was the optimum dosage.

In addition, this also entails that seasonal variation contributes to the drying rate of sludge where during the dry season, there is further reduction in the moisture content of sludge compared to the wet season.

Volatile solid is a measure of the quality of the dry sludge for manure, therefore 10% which had the lowest value of volatile solids implies that the organic matter in the dry sludge retains more of the nutrients in a stable form thus most suitable for manure. This is attributed to the nutritious nature, sludge stability and the reduced risk to pathogen transmission.

5.2 RECOMMENDATION

From the research study, the addition of rice husk ash to the sludge had a comparative effect on the dewatering performance in the drying beds and the quality of manure as indicated by the moisture content and the volatile solids. However further studies should be made on the determination of Nitrogen Phosphorous Potassium (NPK) content in the sludge as it is to be used for manure by farmers.

Research should be carried out to determine the impact of the continuous rice husk ash on the volatile solids in the sludge in terms of pathogenic organisms.

Further research should also be carried out to determine impact of rice husk ash on the removal of faecal coliforms in the liquid effluent from the sludge in the sludge drying beds.

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APPENDICES

Appendix A: Figures displaying the different project activities



Figure 21: Layer of aggregates in filter media



Figure 22: Layer of hardcore in filter media



Figure 23: Taking sludge bed measurement



Figure 24: Rice husk ash sample weighing



Figure 25: Rice husk ash sample preparation



Figure 26: Pouring sludge in the sludge bed



Figure 27: Sludge depth measurement



Figure 28: Laboratory analysis of sludge samples



Figure 29: Equipment preparation



Figure 30: Oven drying of sludge samples

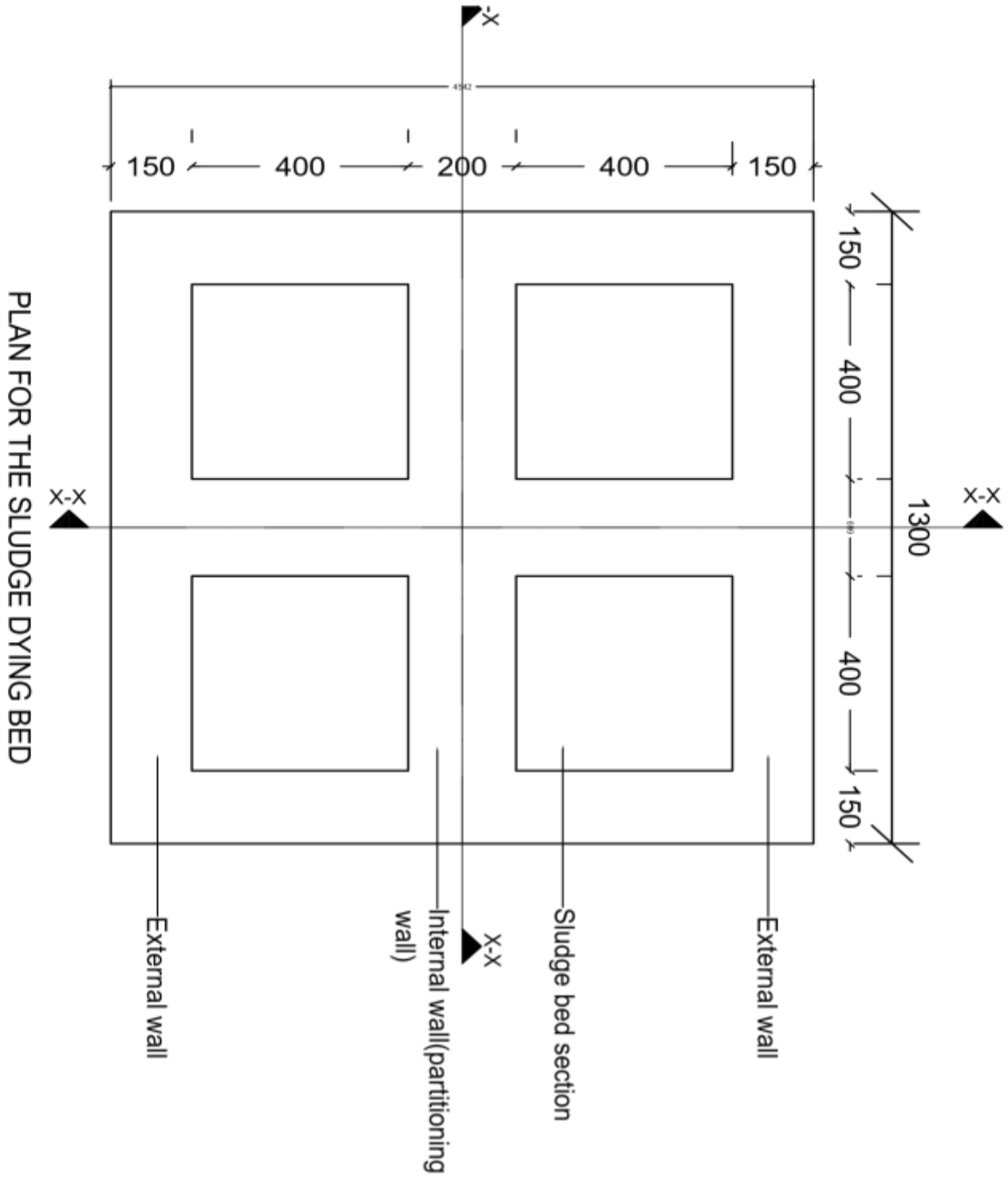


Figure 31: Running the furnace for ignition

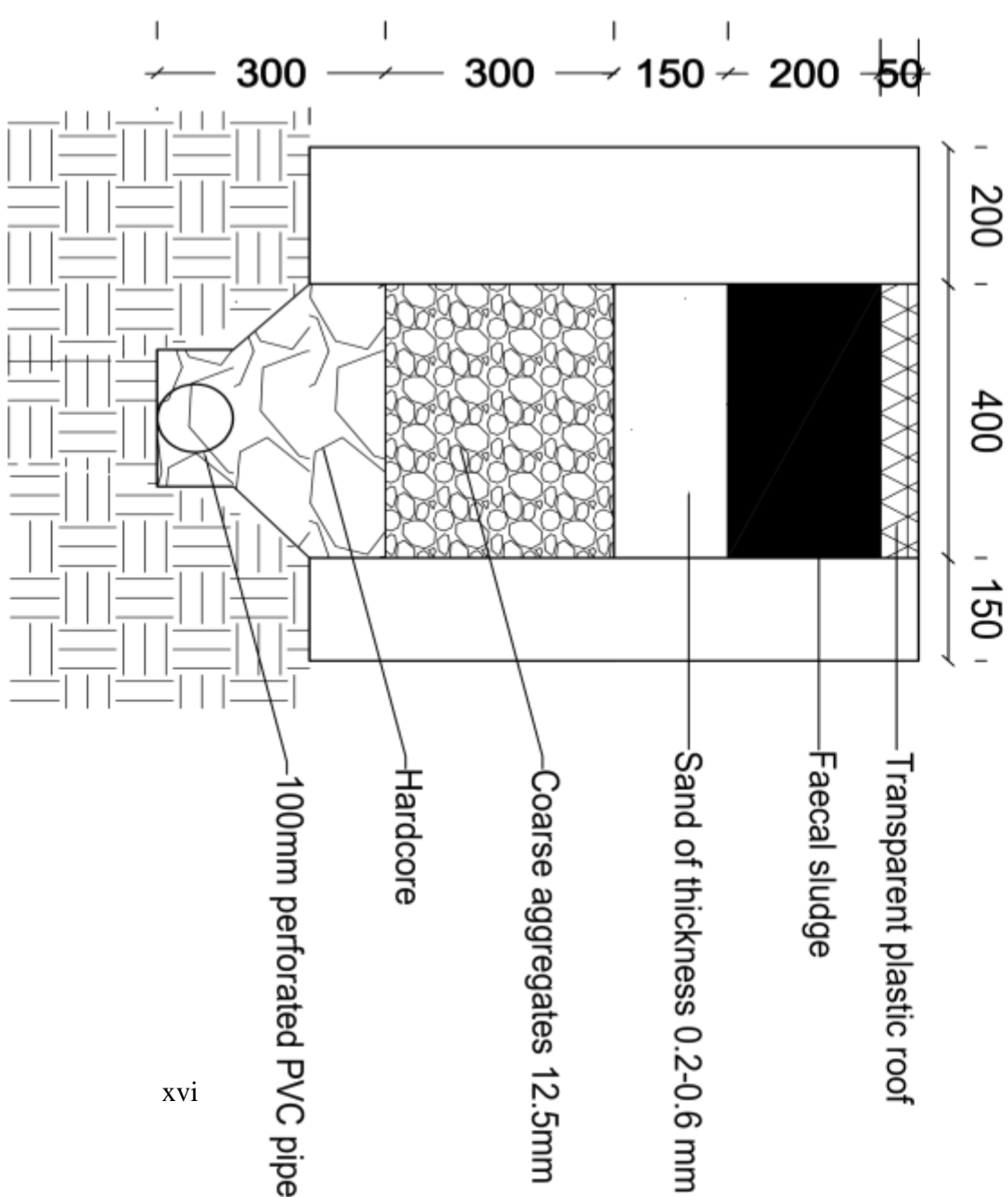


Figure 32: Sludge sample placement in furnace

Appendix B: Drawing plans for the sludge drying bed



PLAN FOR THE SLUDGE DYING BED



CROSS SECTION X-X OF THE SLUDGE DYING BED

- NOTES
1. This drawing shall be read in conjunction with all relevant documentation
 2. Do not scale from this drawing. Use only printed dimensions.
 3. All dimensions are in millimeters

PROJECT	Research and design project
TITLE	INVESTIGATING THE USE OF RICE HUSK ASH TO IMPROVE THE DEWATERING PERFORMANCE OF THE SLUDGE DRYING BEDS

DATE	12th/04/2024
BY	VARIED STATES ENVIRONMENTAL PROTECTION AGENCY (EPA)

DESIGNED BY	MURUNGI & KATO
DRAWN BY	MURUNGI & KATO

Appendix C: Laboratory results on the analysis of rice husk ash (RHA)

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MINISTRY OF INTERNAL AFFAIRS
 DIRECTORATE OF GOVERNMENT
 ANALYTICAL LABORATORY
 Plot No. 2 Lourdel Road
 Wandegaya,
 P.O. BOX 105639
 Kampala - Uganda

In any Correspondence on
 this subject please
 quote No.....**GE 027-1/2023**
30th January 2023

MR. KATO JULIUS AND MURUNGI CHELSEA
 UGANDA CHRISTIAN UNIVERSITY
 P.O BOX 4,
 MUKONO-UGANDA
 Tel: 256-786-819434

REPORT OF ANALYSIS

Description of the Samples

One sample in a white polythene bag containing Rush Husk Ash was submitted by Mr. Kato Julius, on 17th January 2024, and analysed on 22nd January 2024. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	Grey ash sample packed in a white polythene bag.	01	Sample "A" GE 027/2024

Analysis Requested

Elemental analysis

Method of Analysis

Elemental analysis was done using the XRF Method.

Results of Analysis

The above sample has been analyzed with the following results as below.

Parameter	Units	Results
		Rice Husk Ash sample GE 027/2024
Silicon dioxide	% m/m	81.192
Iron (III) Oxide	% m/m	8.026
Calcium Oxide	% m/m	7.049
Manganese (II) Oxide	% m/m	1.919
Aluminum Oxide	% m/m	0.596
Phosphorous pent oxide	% m/m	0.475
Europium (III) oxide	% m/m	0.255
Potassium Oxide	% m/m	0.299
Titanium di oxide	% m/m	0.108

Remarks

- Results relate to sample analyzed and are reported as on received basis.

Semalago Fredrick
 20/01/2024

Semalago Fredrick
 Government Analyst

Appendix D: Laboratory results on the Monthly monitoring of sludge parameters

MONTH 1 (WET SEASON) LABORATORY RESULTS

The results below were obtained after conducting the Laboratory tests during the wet season in Month 1.

They key parameters determined were: TS-Total Solids

MC-Moisture Content

VS-Volatile Solids

The sample dosage indicates the varying proportions of Rice husk ash added to the sludge. These proportions were determined dependent on the quantity of sludge (30kgs) added to the sludge bed e.g. 7% of 30kgs.

The sludge bed is partitioned into 4 sections with an equivalent sludge weight of 30kgs in each section.

Table 1: Varying proportions of Rice husk ash (%) dosage and the weight equivalent (kgs) in each bed section

Sludge bed section	Rice hush ash dose (%)	Equivalent weight(kgs)
1	0	0
2	4	1.2
3	7	2.1
4	10	3.0



**NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY - BUGOLOBI**

P.O BOX 7053 KAMPALA Email: waterquality@nWSC.co.ug

Student: MURUNGI CHELSEA & JULIUS KATO

Address: Uganda Christian University, Mukono (Uganda)

Analysis Date: 11th.01.2024

RAW SLUDGE PARAMETERS AT - 0 DAYS.

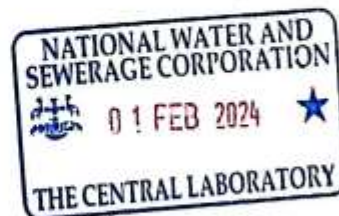
Duration: 0 days				
Parameter		Total Solids -TS (%)	Moisture Content- MC (%)	·Volatile Solids - VS (%)
Sample Dose	0%	1.2	98.8	57.6
	4%	1.4	98.6	44.2
	7%	5.1	94.9	45.6
	10%	9.4	90.6	35.4

Analysis done by: Murungi Chelsea & Julius Kato

Supervised by: Mr. Abraham Erodi (QCO-SSD)

Report Prepared By: Bayo Robert (QCO-ES)

Signature:





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

Student: MURUNGI CHELSEA & JULIUS KATO

Address: Uganda Christian University, Mukono (Uganda)

Analysis Date: 17th.01.2024

CHANGE IN PARAMETERS AFTER - 7 DAYS.

Duration: After 7 days				
	Parameter	Total Solids - TS (%)	Moisture Content - MC (%)	Volatile Solids - VS (%)
Sample Dose	0%	16.2	83.8	55.1
	4%	36.5	63.5	39.4
	7%	32.4	67.6	35.7
	10%	33.3	66.7	28.8

Analysis done by: Murungi Chelsea & Julius Kato

Supervised by: Mr. Abraham Erodi (QCO-SSD)

Report Prepared By: Bayo Robert (QCO-ES)

Signature:





**NATIONAL WATER AND SEWERAGE CORPORATION
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P.O BOX 7053 KAMPALA Email: waterquality@nWSC.co.ug

Student: MURUNGI CHELSEA & JULIUS KATO

Address: Uganda Christian University, Mukono (Uganda)

Analysis Date: 24th.01.2024

CHANGE IN SLUDGE PARAMETERS AFTER - 14 DAYS.

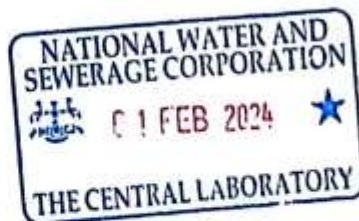
Duration: After 14 days				
	Parameter	Total Solids - TS (%)	Moisture Content- MC (%)	Volatile Solids - VS (%)
Sample Dose	0%	21	79	54.9
	4%	48.5	54.2	37
	7%	37.8	62.2	33.1
	10%	40	60	26.4

Analysis done by: Murungi Chelsea & Julius Kato

Supervised by: Mr. Abraham Erodi (QCO -SSD)

Report Prepared By: Bayo Robert - (QCO-ES)

Signature:





**NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY – BUGOLOBI**

Student: Murungi Chelsea REG. No: S20B32/213

Kato Julius REG. No: S20B32/298

Institution: Uganda Christian University, Mukono Campus

Analysis Date: 31st. Jan. 2024

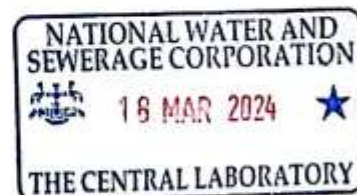
CHANGE IN SLUDGE PARAMETERS AFTER 21 DAYS

Parameter		Period: After 21 days		
		Total Solids (%)	Moisture Content (%)	Volatile Solids (%)
Sample Dose	0%	25.9	74.1	54.5
	4%	54.4	44.6	34.5
	7%	43.9	56.1	30.1
	10%	46.9	53.1	23.5

Tested by: Kato. J & Chelsea. M

**Supervised by: Abraham Erodi
(QCO SSD)**

**Issued by: Bayo Robert
(QCO External Services)**



Sign: *[Handwritten Signature]* *18/03/2024*



**NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY – BUGOLOBI**

Student: Murungi Chelsea REG. No: S20B32/213

Kato Julius REG. No: S20B32/298

Institution: Uganda Christian University, Mukono Campus

Analysis Date: 07th. Feb. 2024

CHANGE IN SLUDGE PARAMETERS AFTER 28 DAYS

Parameter		Period: After 28 days		
		Total Solids (%)	Moisture Content (%)	Volatile Solids (%)
Sample Dose	0%	29.1	70.9	53.8
	4%	64.6	35.4	32.5
	7%	49.5	50.5	28.7
	10%	52.8	47.2	21.4

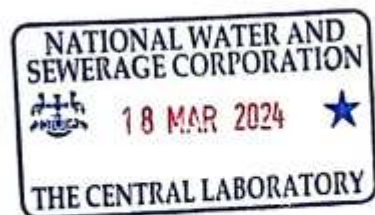
Tested by: Kato. J & Chelsea. M

Supervised by: Abraham Erodi

(QCO SSD)

Issued by: Bayo Robert

(QCO External Services)



Sign: *[Signature]* / 18/03/2024

MONTH 2 (DRY SEASON) LABORATORY RESULTS

The results below were obtained after conducting the Laboratory tests during the dry season in Month 2.

They key parameters determined were: TS-Total Solids

MC-Moisture Content

VS-Volatile Solids

The sample dosage indicates the varying proportions of Rice husk ash added to the sludge. These proportions were determined dependent on the quantity of sludge (30kgs) added to the sludge bed e.g. 4% of 30kgs.

The sludge bed is partitioned into 4 sections with an equivalent sludge weight of 30kgs in each section.

Table 2: Varying proportions of Rice husk ash (%) dosage and the weight equivalent (kgs) in each bed section

Sludge bed section	Rice hush ash dose (%)	Equivalent weight(kgs)
1	0	0
2	4	1.2
3	7	2.1
4	10	3.0



NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY – BUGOLOBI

Student: Murungi Chelsea REG. No: S20B32/213

Kato Julius REG. No: S20B32/298

Institution: Uganda Christian University, Mukono Campus

Analysis Date: 07th. Feb. 2024

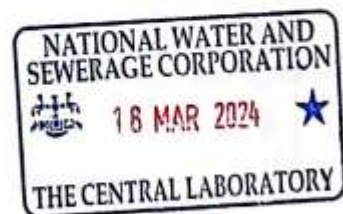
RAW SLUDGE PARAMETERS

Parameter		Initial date		
		Total Solids (%)	Moisture Content (%)	Volatile Solids (%)
Sample Dose	0%	7.9	92.1	54.6
	4%	9.4	90.4	47
	7%	13	87	44
	10%	14.2	85.8	38

Tested by: Kato. J & Chelsea. M

Supervised by: Abraham Erodi
(QCO SSD)

Issued by: Bayo Robert
(QCO External Services)



Sign:

[Handwritten Signature] 18/03/2024



NATIONAL WATER AND SEWERAGE CORPORATION
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Student: Murungi Chelsea REG. No: S20B32/213

Kato Julius REG. No: S20B32/298

Institution: Uganda Christian University, Mukono Campus

Analysis Date: 14th. Feb. 2024

CHANGE IN SLUDGE PARAMETERS AFTER 7 DAYS

Parameter		Period: After 7 days		
		Total Solids (%)	Moisture Content (%)	Volatile Solids (%)
Sample Dose	0%	25.0	75.0	53.2
	4%	45.2	54.8	41.9
	7%	40.5	59.5	33.7
	10%	39.8	60.2	30.3

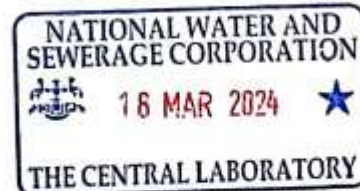
Tested by: Kato. J & Chelsea. M

Supervised by: Abraham Erodi

(QCO SSD)

Issued by: Bayo Robert

(QCO External Services)



Sign:

[Handwritten signature] 18/02/2024



NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY – BUGOLOBI

Student: Murungi Chelsea REG. No: S20B32/213

Kato Julius REG. No: S20B32/298

Institution: Uganda Christian University, Mukono Campus

Analysis Date: 21th. Feb. 2024

CHANGE IN SLUDGE PARAMETERS AFTER 14 DAYS

Parameter		Period: After 14 days		
		Total Solids (%)	Moisture Content (%)	Volatile Solids (%)
Sample Dose	0%	31.5	68.5	52.8
	4%	56	44	39.2
	7%	46.5	53.5	30.9
	10%	47.4	52.6	27.8

Tested by: Kato. J & Chelsea. M

Supervised by: Abraham Erodi

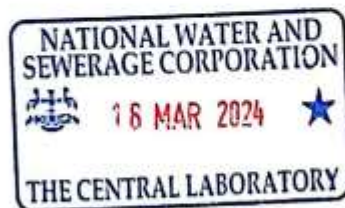
(QCO SSD)

Issued by: Bayo Robert

(QCO External Services)

Sign:

[Handwritten signature] 16/03/2024





NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY – BUGOLOBI

Student: Murungi Chelsea REG. No: S20B32/213

Kato Julius REG. No: S20B32/298

Institution: Uganda Christian University, Mukono Campus

Analysis Date: 28th. Feb. 2024

CHANGE IN SLUDGE PARAMETERS AFTER 21 DAYS

Parameter		Period: After 21 days		
		Total Solids (%)	Moisture Content (%)	Volatile Solids (%)
Sample Dose	0%	37.5	62.5	52.3
	4%	66.2	33.8	34.8
	7%	52.6	47.4	27.4
	10%	54.4	45.6	24.7

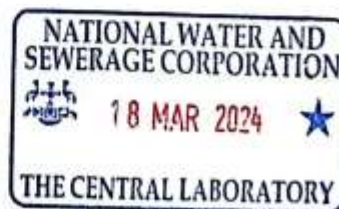
Tested by: Kato. J & Chelsea. M

Supervised by: Abraham Erodi

(QCO SSD)

Issued by: Bayo Robert

(QCO External Services)



Sign:

[Handwritten Signature] 18/03/2024



NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY – BUGOLOBI

Student: Murungi Chelsea REG. No: S20B32/213

Kato Julius REG. No: S20B32/298

Institution: Uganda Christian University, Mukono Campus

Analysis Date: 06th, Mar. 2024

CHANGE IN SLUDGE PARAMETERS AFTER 28 DAYS

Parameter		Period: After 28 days		
		Total Solids (%)	Moisture Content (%)	Volatile Solids (%)
Sample Dose	0%	42.8	57.2	51.4
	4%	72.7	27.3	32.4
	7%	59.2	40.8	25.9
	10%	60.9	39.1	22.3

Tested by: Kato, J & Chelsea, M

Supervised by: Abraham Erodi

(QCO SSD)

Issued by: Bayo Robert

(QCO External Services)



Sign:

[Handwritten Signature] 18/03/2024

8.6 CHEMICAL AND PHYSICO-CHEMICAL PROPERTIES

8.6.1 Solids and moisture content

Total solids is a term applied to the material left in a vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature. Total solids are comprised of total suspended solids (TSS), total dissolved solids (TDS), fixed solids (FS) (ash) and volatile solids (VS). Total solids are determined for all types of faecal sludge – liquid, slurry, semi-solid and solid. The same methods are used to determine TS and moisture content; the total mass of a sample before the analysis is the sum of its TS and moisture content. Sand content (measured as silica as an indicator of soil content in faecal sludge) is the concentration of sand in the TS of an unfiltered faecal sludge sample. Sand can influence faecal sludge treatment processes (e.g. dewatering), increase abrasion of mechanical equipment, and affect the quality of faecal sludge treatment end products.

8.6.1.1 Total solids and moisture content – volumetric and gravimetric methods by oven drying³

8.6.1.1.1 Introduction

Total solids (and/or moisture content) is one of the most commonly used faecal sludge parameters, and is used for almost every design or management decision. For example, for making decisions on treatment design, settling, or emptying. A known volume (the volumetric method) and/or weight (the gravimetric method) of a thoroughly-mixed sample is evaporated to a constant weight in a crucible (porcelain or silica) or an aluminium weighing boat, in a drying oven at 103-105 °C; the remaining solids are cooled down to room temperature in a desiccator to avoid absorption of air moisture and then re-weighed. The residual material remaining in the crucible are TS, and can consist of organic and inorganic material, and dissolved, suspended or volatile matter.

³ The volumetric method is based on Method 2540B of the Standard Methods for the Examination of Water and Wastewater. The gravimetric method is based on ASTM E1756-08 Method A and on Method 2540G of the Standard Methods for the Examination of Water and Wastewater. Both methods should be cited as: Rice *et al.* (2017) as described in Velkushanova *et al.* (2021).

The gravimetric method is recommended for semi-solid and solid types of sludge, as it is often difficult to measure volumes accurately for sludge with higher TS concentrations. For more liquid types of sludge, either the gravimetric or volumetric method can be used. However, these are general recommendations, and a final decision of which method to use needs to be assessed for each application individually. Conversion between volumetric and gravimetric measurements can be done if the density is known (Chapter 2). Density of faecal sludge can easily be measured by weighing a known volume of sludge (Method 8.7.1.1). When doing such conversions, it is always recommended to measure the actual density of the specific samples, and this becomes even more important with samples at the higher range of % TS.

Solid and semi-solid sludge types can form a water-trapping crust if the initial rate of drying is too high. This can be avoided by placing the samples in the drying oven at a lower temperature, and gradually increasing the temperature of the oven until the prescribed temperature of 103-105 °C is reached.

8.6.1.1.2 Safety precautions

- General health and safety (H&S) procedures specific for conducting laboratory analysis of faecal sludge are presented in Section 8.2. Before conducting this method, it is important to be familiar with Section 8.2.3 to ensure safety measures are properly carried out.
- Appropriate personal protective equipment (PPE) should be used; specific details are covered in Section 8.2.3.1.
- Always conduct the TS analysis in a room with sufficient airflow and an exhaust system.
- Wear gloves suitable for withstanding high temperatures when placing and removing crucibles from the oven.
- Use appropriate mechanical tools, such as metal tongs, to remove crucibles and trays after drying in the oven to avoid direct contact with hot surfaces.

8.6.1.1.3 Apparatus and instruments

- Porcelain crucibles or aluminium weighing boats
- Desiccator with dry desiccant
- Drying oven
- Analytical balance with four decimal places
- Spatula
- Stainless steel tray (optional, to move crucibles in and out of the oven)
- Heat-resistant gloves
- Pencil
- Thermometer (for quality control procedure)
- Set of standard calibration weights (for quality control procedure)

8.6.1.1.4 Quality control

General information on quality assurance and quality control (QA/QC) is provided in Section 8.3. Information on standards, operating conditions and interferences that are specific to this method includes:

- The analytical balance and oven must be checked and calibrated weekly.
- Check the temperature throughout the oven area by placing a calibrated thermometer on each shelf. After 30 min, check the temperature at each level against the oven setting. Using the same method, also check for temperature differences between the front and back of the oven. Adjust the oven setting if necessary. If temperatures are uneven on the shelves, check the insulation.
- To calibrate the analytical balance, place a standard calibration weight on the balance and weigh. Adjust the balance manually if necessary. Do this with the whole range of weights from the calibration set. Make sure to include a standard weight of a mass similar to the mass of the expected sample + crucible.
- Make sure the desiccant in the desiccator is not saturated, otherwise samples can absorb water while cooling down in the desiccator. Routinely dry the desiccant in the oven at 105 °C (or at a different temperature, depending on the manufacturer's instructions), prior to the colour indicating that the desiccant is nearly saturated.
- Always keep the lid of the desiccator on and use a lubricant on the rim to ensure airtight sealing. Do not overload the desiccator.
- The volume or mass of the wet sample used should be chosen so that the drying will yield a residue

between 2.5 and 200 mg of the dried sample (in general approximately 30 mL for the volumetric method, or 10-20 g for the gravimetric method, but this will depend on the type of sludge).

- For solid, semi-solid and slurry samples: limit the sample to no more than 10-20 g faecal sludge, otherwise the sample will take too long to dry and can form a moisture-trapping crust on top. If crust formation is occurring, the samples should be placed in the oven at a lower temperature initially, gradually increasing the temperature until 103-105 °C is reached.
- For liquid samples, the volume of the sample can be higher because the TS content is much lower. The proportion of the weight of the sample to the weight of the porcelain or aluminium crucible should be also taken into account, so that weight differences in the sample can be measured accurately.
- Make sure that the samples are fully cooled in a desiccator to ambient temperature prior to weighing.
- Sludges that contain highly mineralised water with a significant concentration of calcium, magnesium, chloride and sulphate can be hygroscopic and require prolonged drying, complete desiccation and rapid re-weighing.
- Exclude larger, inconsistent or floating particles from the sample if it is determined that their inclusion can affect the final result (e.g. hair, stones, glass, and maggots).
- Disperse visible floating oil and grease with a blender or stainless steel mixing rod before withdrawing a sample portion for analysis.

8.6.1.1.5 Sample preservation

Samples should be analysed as soon as possible. If samples cannot be analysed immediately, they should be stored in a refrigerator at 4 °C for no longer than 7 days and, if TSS or VSS analysis is conducted, no longer than 48 hours. Before starting analysis, let the samples return to ambient temperature. Do not freeze the samples.

8.6.1.1.6 Sample preparation

- Uniformly mix all the samples using a stainless steel rod (or other appropriate tool) in order to have thoroughly mixed representative samples. If

desired, samples can also be blended (see Section 8.4.2).

- Measure out an appropriate sample volume/mass (indicatively 30 mL for the volumetric method, or 10-20 g for the gravimetric method) which will yield a residue between 2.5 and 200 mg of dried sample, by using a volume measuring cylinder or analytical balance. With very dilute faecal sludge samples, a pipette can be used. For other sludge types, clogging of the pipette will occur, and therefore using a graduated cylinder to measure volume is recommended.

8.6.1.1.7 Analysis protocol

Preparation of equipment

- Pre-heat the oven to 103-105 °C.
- If analysing multiple samples or replicates at the same time, number the bottom of the crucible with a pencil and record in a laboratory notebook which sample and replicate is in which number crucible to distinguish between crucibles. If using aluminium weighing boats, the replicates can also be marked by scratching the number on the weighing boat with a sharp item.
- Place the clean crucible in the oven at a temperature of 103-105 °C for 1 hr prior to use (to remove any moisture). After drying, place the crucible in the desiccator and allow it to cool down to room temperature. Keep the crucible in the desiccator until the next step.
- Note: if measuring volatile solids after the TS, prepare the crucible in a furnace at 550 °C for 15 min prior to use to remove any potential residual organic material from previous measurements. Only porcelain crucibles should be used (see Method 8.6.1.2).

Procedure

- Remove the crucible from the desiccator and weigh it using the analytical balance. Record the weight of the dry, empty crucible (W_1).
 - For the gravimetric method (semi-solid to solid sludge):
 - Weigh out 10-20 g mass of the sample to the weighed crucible using a spatula.
 - Record the wet mass + mass of the crucible (W_2).

- For the volumetric method (liquid to slurry sludge):

- Measure 30 mL of the sample volume using a measuring cylinder and record the exact volume of the sample (V_{sample}).

- Transfer to the weighed crucible. Rinse the cylinder with small volumes of distilled water to dislodge heavy particles. Make sure that all the particles are transferred to the crucible. Add the washings to the crucible but note, calculations must be based on the sample volume and exclude the volume of the washings.

- Oven-dry the sample at 103-105 °C for at least 24 hr or until a constant weight is achieved (which could take longer). To do this, cool and weigh the sample as described below, place the sample back in the drying oven for 1 hr and cool and weigh again. Repeat the steps of drying, cooling and weighing until a constant weight is obtained, or until the weight change is less than 0.5 mg, or 4% of the previous measurement. The length of drying time needs to be evaluated for each specific type of sample, and revisited periodically.
- Take the sample out of the oven and place it in the desiccator to reach room temperature.
- Weigh the dry mass of sample + crucible using an analytical balance and record the weight (W_3).

8.6.1.1.8 Calculation

Liquid and slurry samples (volumetric method):

Total Solids in wet sample (mg/L) =

$$\frac{(W_3 \text{ (g)} - W_1 \text{ (g)}) \times 1,000,000}{V_{\text{sample}} \text{ (mL)}}$$

Total Solids in wet sample (g/L) =

$$\frac{(W_3 \text{ (g)} - W_1 \text{ (g)}) \times 1,000}{V_{\text{sample}} \text{ (mL)}}$$

Semi-solid and solid samples (gravimetric method):

Total Solids in wet sample (g/g) =

$$\frac{(W_3 \text{ (g)} - W_1 \text{ (g)})}{(W_2 \text{ (g)} - W_1 \text{ (g)})}$$

Moisture content in wet sample (g/g) =

$$\frac{(W_2 \text{ (g)} - W_3 \text{ (g)})}{(W_2 \text{ (g)} - W_1 \text{ (g)})}$$

Moisture content (%) =

$$\frac{(W_2 \text{ (g)} - W_3 \text{ (g)})}{(W_2 \text{ (g)} - W_1 \text{ (g)})} \times 100(\%)$$

Where:

W_1 = Crucible mass (g)

W_2 = Wet sample mass + crucible mass before drying (g)

W_3 = Dry sample mass + crucible mass after drying (g)

V_{sample} = Volume of sample used (mL)

For an explanation of the conversion of these units into %TS, refer to Chapter 2, Section 2.2.

8.6.1.1.9 Data set example

Described in Engund *et al.* (2019) and Strande *et al.* (2018) are the collection of 60 faecal sludge samples in Hanoi, Vietnam, and 180 samples in Kampala, Uganda. Solids analysis for TS, TSS, VS, VSS, and fixed solids were carried out and reported as concentrations. The complete raw data set is available using the link below⁴.

A faecal sludge sample was collected from a ventilated improved pit latrine in Durban, South Africa. It was analysed gravimetrically in six replicates using Method 8.6.1.1. The average COD (g/g wet sample) was 0.23. The results for TS and moisture content are presented in Table 8.4 (source: unpublished data UKZN PRG).

Table 8.4 Mass of samples before and after the analysis and analysis results for the gravimetric method.

Sample no.	Crucible mass (g) (W_1)	Sample mass (g)	Sample + crucible (g) (W_2)	Residue + crucible mass after drying (g) (W_3)	Moisture (g/g wet sample)	Total solids (g/g wet sample)
1-a	64.7232	19.9688	84.6920	69.4310	0.7642	0.2358
1-b	48.0356	20.0035	68.0391	52.7174	0.7660	0.2340
1-c	38.6685	20.0007	58.6692	43.2768	0.7696	0.2304
1-d	36.5180	20.0119	56.5299	41.2682	0.7626	0.2374
1-e	41.1442	20.0934	61.2376	45.8654	0.7650	0.2350
1-f	34.8260	20.0226	54.8486	39.5203	0.7655	0.2345
Average					0.7655	0.2345
SD					0.0023	0.0023

8.6.1.2 Volatile and fixed solids – ignition method⁵

8.6.1.2.1 Introduction

The dry sample residue from Method 8.6.1.1 is ignited at 550 °C for 30 min or until constant weight. The remaining ash represents the fixed (inorganic) solids, while the weight lost on ignition represents the volatile solids (organic matter) in faecal sludge. For more details, see Chapter 2.

8.6.1.2.2 Safety precautions

- General health and safety (H&S) procedures specific for conducting laboratory analysis of faecal sludge are presented in Section 8.2. Before conducting this method, it is important to be familiar with Section 8.2.3 to ensure safety measures are properly carried out.

⁴ <https://doi.org/10.25678/0000t>.

⁵ This method follows Method 2540E of the Standard Methods for the Examination of Water and Wastewater, and should be cited as: Rice *et al.*, (2017)

- Appropriate personal protective equipment (PPE) should be used; specific details are covered in Section 8.2.3.1.
- Always conduct the volatile solids analysis in a room with sufficient airflow and preferably with an exhaust system.
- Never remove crucibles or trays by directly touching objects in the furnace, even if heat resistant gloves are worn. Use appropriate metal tools (such as stainless steel tongs) to place and remove crucibles and trays from the furnace to avoid direct contact with hot surfaces. Always wear heat-resistant gloves suitable for withstanding high temperatures.

8.6.1.2.3 Apparatus and Instruments

- Porcelain crucibles
- Desiccator with dry desiccant
- Muffle furnace that can reach temperatures of 550 °C
- Analytical balance with four decimal places
- Stainless steel tray (optional, to move crucibles in and out of the furnace)
- Stainless steel tongs (to move crucibles in and out of the furnace)
- Heat-resistant gloves
- Pencil

8.6.1.2.4 Quality control

General information on quality assurance and quality control (QA/QC) is provided in Section 8.3. Information on standards, operating conditions and interferences that are specific to this method includes:

- The analytical balance and furnace must be checked and calibrated weekly.
- Check the temperature throughout the furnace area by placing a calibrated thermocouple on each shelf or reading the temperature with a laser thermometer.
- After 30 min, check the temperature at each level against the furnace setting. Using the same method, also check for temperature differences between the front and back of the furnace. Adjust the furnace setting if necessary. If temperatures are uneven on the shelves, check the insulation.
- To calibrate the analytical balance, place a standard calibration weight on the balance and

weigh. Adjust the balance manually if necessary. Make sure to use a standard weight of a mass similar to the mass of the expected sample + crucible.

- Limit the sample to no more than 200 mg of residue after ignition at 550 °C (initial faecal sludge mass before TS analysis 10-20 g).
- Sludges that contain highly mineralised water with a significant concentration of calcium, magnesium, chloride and sulphate can be hygroscopic and require prolonged drying, proper desiccation and rapid re-weighing.

8.6.1.2.5 Sample preservation

Samples should be analysed as soon as possible. If samples cannot be analysed immediately, they should be stored in a refrigerator at 4 °C for no longer than 7 days and, if TSS or VSS analysis is conducted, no longer than 48 hours. Before starting the analysis, let the samples return to room temperature (20 °C). Do not freeze the samples.

8.6.1.2.6 Sample preparation

Dry the samples to constant weight to remove moisture content, following Method 8.6.1.1.

8.6.1.2.7 Analysis protocol

Preparation of equipment

- Pre-heat the furnace to 550 °C temperature before inserting the sample.
- Before conducting TS analysis (Method 8.6.1.1), position clean, dry crucibles in the furnace at 550 °C for 1 hr to remove any potential organic matter.

Procedure

- Ignite the residue from the TS in a muffle furnace at a temperature of 550 °C for 20 min. Note: for some solid and semi-solid faecal sludge samples, 20 min might not be enough, as they might need more time to combust all the volatile matter. For each type of sludge, check that constant weight is achieved after 20 min. To do this, cool and weigh the sample as described below, place the sample back in the furnace for 10 min and cool and weigh again. Repeat the steps of drying, cooling and weighing until a constant weight is obtained, or until weight change is less than 4% of the previous

measurement. The length of combustion time needs to be evaluated for each specific type of sample, and revisited periodically.

- Transfer the crucibles to the stainless tray and let them cool partially until cool enough to transfer to a desiccator.
- Transfer to the desiccator for final cooling. Do not overload the desiccator.
- Weigh the crucible on the analytical balance as soon as it has cooled to ambient temperature and record the weight (W_4).

8.6.1.2.8 Calculation

Liquid and slurry samples (volumetric method):

Volatile solids in wet sample (g/L) =

$$\frac{(W_3 \text{ (g)} - W_4 \text{ (g)}) \times 1,000}{V_{\text{sample}} \text{ (mL)}}$$

Fixed solids in wet sample (g/L) =

$$\frac{(W_4 \text{ (g)} - W_1 \text{ (g)}) \times 1,000}{V_{\text{sample}} \text{ (mL)}}$$

Where:

W_1 = Crucible mass (g)

W_2 = Crucible mass + wet sample mass (g)

W_3 = Crucible mass + sample after drying (g)

W_4 = Crucible mass + sample after incinerating (g)

$(W_3 - W_1)$ = Sample mass after drying (g)

$(W_4 - W_1)$ = Sample mass after incinerating (g)

V_{sample} = Sample volume used (mL)

Slurry, semi-solid and solid samples (gravimetric method):

Volatile solids in wet sample (g/g) =

$$\frac{(W_3 \text{ (g)} - W_4 \text{ (g)})}{(W_2 \text{ (g)} - W_1 \text{ (g)})}$$

Volatile solids in dry sample (g/g) =

$$\frac{(W_3 \text{ (g)} - W_4 \text{ (g)})}{(W_3 \text{ (g)} - W_1 \text{ (g)})}$$

Volatile solids (%TS) =

$$\frac{(W_3 \text{ (g)} - W_4 \text{ (g)})}{(W_3 \text{ (g)} - W_1 \text{ (g)})} = \frac{\text{VS} \left(\frac{\text{g}}{\text{g}}\right)}{\text{TS} \left(\frac{\text{g}}{\text{g}}\right)} \times 100 (\%)$$

Fixed solids in wet sample (g/g) =

$$\frac{(W_4 \text{ (g)} - W_1 \text{ (g)})}{(W_2 \text{ (g)} - W_1 \text{ (g)})}$$

Fixed solids in dry sample (g/g) =

$$\frac{(W_4 \text{ (g)} - W_1 \text{ (g)})}{(W_3 \text{ (g)} - W_1 \text{ (g)})}$$

Fixed solids (%TS) =

$$\frac{(W_4 \text{ (g)} - W_1 \text{ (g)})}{(W_3 \text{ (g)} - W_1 \text{ (g)})} = \frac{\text{Fixed solids} \left(\frac{\text{g}}{\text{g}}\right)}{\text{TS} \left(\frac{\text{g}}{\text{g}}\right)} \times 100 (\%)$$

Note: for values of W_1 to W_3 and how to calculate them, see Method 8.6.1.1.

8.6.1.2.9 Data set example

A faecal sludge sample was collected from a ventilated improved pit latrine in Durban, South Africa. It was analysed in six replicates using Method 8.6.1.2. The average initial samples mass was 5 g dry weight - the same dry samples from Section 8.6.1.1.9 were used for ignition. The average VS (g/g dry sample) was 0.56. The results for VS and fixed solids are presented in Table 8.5 (source: UKZN PRG).

Table 8.5 Mass of samples before and after the analysis for the ignition method.

Sample no.	Volatile solids (g/g dry sample)	Fixed solids (g/g wet sample)	Fixed solids (g/g dry sample)
1-a	0.5574	0.1044	0.4426
1-b	0.5673	0.1013	0.4327
1-c	0.5896	0.0946	0.4104
1-d	0.5499	0.1069	0.4501
1-e	0.5571	0.1041	0.4429
1-f	0.5599	0.1032	0.4401
Average	0.5635	0.1024	0.4365
SD	0.0140	0.0042	0.0140