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

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S20B32/298

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

UGANDA CHRISTIAN UNIVERSITY
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ABSTRACT

Sludge from onsite sanitation systems is called feces, and it is not dumped into a sewer. One of the management issues in Sub-Saharan Africa's heavily crowded urban slums is Faecal sludge. The high cost of emptying, the high density of dwelling units, and the long haulage routes to the treatment plants make it expensive to collect and transport Faecal sludge from slums to treatment facilities. The slum dwellers have adopted the use of additives that are marketed under the premise of being able to reduce volume of Faecal Sludge, odor emanating from it and the flies. As per the analysis, Faecal Sludge contains over 90 % water, dewatering it presents an important step for resource recovery (Shukla, A review on generation, characterization, containment, transport and treatment of fecal sludge and septage with resource recovery-oriented sanitation, 2023). This study aimed at investigating the use of rice husks ash to improve the dewatering performance in the sludge drying beds. The Lubigi Faecal sludge and Treatment Plant was considered as our area of study. The ability of the drying beds to dewater the faecal sludge was assessed by the determination of the Moisture Content and Total Solids of the faecal sludge and these were measured in terms of percentages.

DECLARATION

I, **KATO JULIUS** hereby declare that this is my original work, and is not plagiarized and has not been submitted to any other institution for any award.

Signature: ………………………………….   Date: ……………………………….

KATO JULIUS

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APPROVAL

This is to certify that KATO JULIUS did all the work in the report 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.JOB GAVA SSAZI PIUS

Signature…………………………………….

DEDICATION

This report is dedicated to my parents, please. I have no doubt that I could not have finished this procedure without their ongoing advice and assistance. I also dedicate it to my Lecturers at the Faculty of Engineering, Design and Technology, who have greatly contributed to my ability to reach this educational milestone.

ACKNOWLEDGEMENT

Firstly, want to express my deepest thanks to my family. They have been amazing throughout my studies. They have provided financial support, offered guidance, and been a constant source of encouragement. I could not have reached this point without them, and I am incredibly grateful for everything they have done.

I would not be here without the incredible support of my project supervisor, MR.JOB GAVA SSAZI PIUS. He went beyond, offering tireless guidance, advice, and support. His dedication to my education and well-being truly touched me.

I would also like to express my special thanks to laboratory technician Mr. Abraham at NWSC Bugolobi for his guidance during the lab tests, his constant presence, and all the help he offered were invaluable to my project's development. My thanks also go to Mr. Otto Peter and Mr. Philip the Engineer at Lubigi Faecal Sludge Treatment Plant. Their assistance in acquiring my prototype for my experimental setup was a huge help, and I truly appreciate it.

Finally, I want to express my deepest gratitude to God for granting me good health throughout this project. To everyone who played a role in its success, big or small, may God bless you abundantly

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ABBREVIATIONS

FS	FEACEL SLUDGE
WWTP	WASTE WATER TREATMENT PLANT.
RA	RICE HUSK ASH.
WSPs	WATER STABILIZATION PONDS
DS	DRY SOLIDS
FSM	FAECAL SLUDGE MANAGEMENT
USEPA	UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
BOD	BIOLOGICAL OXYGEN DEMAND
COD	CHEMICAL OXYGEN DEMAND

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

Septic tanks, un-sewered public restroom blocks, pit latrines, and dry toilets are among the on-site sanitation systems used by one-third of the global population (Nasim, 2023). A 50% rise in the number of people living in cities is predicted by 2045 due to the strong urbanization growth rate caused by the growing population. According to (Shin, 2018) low-income and low-middle-income nations are experiencing an increase in this high growth rate.

Faecal sludge management (FSM) includes collecting/emptying, transporting, treating, end-use and/or disposal of FS, which make up the sanitation service chain. Emptying entails procedural and technical aspects related to the collection of FS from onsite technologies. While transportation involves hauling FS to a location where it can be treated and disposed off or harnessed for resource recovery (strande, 2014).When emptying on-site sanitation facilities, the preferred means is the use of cesspool trucks due to their level of efficiency and less exposure to the FS by workers (Zaqout, 2019). However, emptying and subsequent transportation of FS using this means is expensive because of high operational costs and the need for regular maintenance of the trucks (Semiyaga S. , 2022). In Kampala slums, the expenditure on emptying and transportation of FS is about USD 50 for 5–8 m^3 truck per trip while the median monthly income of the average user of onsite technologies in Kampala is about USD 36 per capita (Kondylis, 2017)

The National Water and Sewerage Corporation operates the Lubigi wastewater and faecal sludge treatment plant in Namugoona, Kampala, Uganda. The plant was put into service in 2014 and has a design capacity of 5000 m3 of wastewater and 400 m3 of faecal sludge per day. It is supplied with about 35% of the sludge collected in the

Kampala area by cesspool emptier tanks, allowing it to operate at maximum capacity (Niwagaba C. B., 2019).It gets more fecal waste than the facility can handle, about 660 m3/day, compared to the unit's design capacity of about 122% (Torretta, 2022). Sludge from onsite sanitation systems, such as pit latrines and septic tanks, is a mixture of solids and liquids. The properties of raw sludge and the way the sludge flows determine how much faecal sludge a facility can process.

The incoming sludge volume is be accommodated in the design of the faecal sludge treatment facility to ensure optimal operational efficiency. The treatment facility must have the proper facilities in place to distribute the feces into the designated treatment units in order to treat the feces sludge (Buckley, 2021).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 pumped to the drying bed for further dewatering to obtain a dry sludge cake that is easy to handle for storage (Kapanda, 2023).

Site visits.

Permission to carry out the study in Lubigi wastewater and feacal sludge treatment plant in Kampala city the selected case study was permitted for from National Water and Sewerage Corporation Bugolobi. Site visits were conducted for collection of FS samples that were used in this study. Different sludge drying beds within Lubigi Faecal Sludge Treatment Plant were used in this study.

The sludge drying beds used in this study were without prior use of any additives/ materials to reduce the volume of water in their contents. Rice husks ash was added to the FS samples in the laboratory to provide some level of control on the quantity added. The choice of the drying beds depended on:

a) Willingness of the Plant's administrators to participate in the study.

b) Amount of FS – the preferable choice was nearly full of FS to provide sufficiently large quantity of FS content and depth for sampling (C.B.Niwagaba, Dewaterability of faecal sludge and its implications on faecal sludge management in urban slums, 2016).

1.2 PROBLEM STATEMENT

The Lubigi sewage and faecal sludge treatment plant faces a challenge of slow dewatering of the sludge on its sludge drying beds. This occurs for a duration of over 6–8 weeks, beyond the intended drying period of one month (Ward, 2022)). As a result, solid material builds up in the sedimentation tanks, which can lead to operational issues such as pipe blockages and reduce the treatment plant's effectiveness. However, the plant receives about 660m^3/day faecal sludge translating into 35% of the sludge collected around Kampala thus operation at its maximum capacity (Christine, 2016).Which is already in excess of the design capacity of 400m^3/day faecal sludge. This is approximately 122% of FS received, way beyond and above the design capacity (KCCA, 2020).

Therefore, there is need for optimum utilization of the sludge drying beds such as improving the bed drying efficiency by reducing the sludge drying time and faecal sludge weight.

1.3 OBJECTIVES

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 objectives

1. To assess the raw sludge parameters.
2. To determine the chemical composition of the rice husk ash.
3. 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

1. What are the raw sludge parameters?
2. What is the chemical composition of the rice husk ash?
3. What is the improvement in dewatering that can be achieved with the use of rice husk ash in the sludge drying beds?

1.5 GEOGRAPHICAL SCOPE

The study took place at Lubigi Faecal Sludge Treatment Plant under NWSC located at Namungoona in Kampala.

Figure 1 : An Aerial View of Lubigi Treatment Plant (Wasswa, 2022).

1.6 EXPECTED BENEFITS

As faecal sludge is comprised mainly of water, dewatering is one of the most important treatment processes. This research will increase the understanding of the dewatering process of faecal sludge, and hence aid in developing appropriate solutions to improve the process. The study will benefit the design of efficient equipment to improve dewatering of FS especially that has been dosed with additives. It will benefit researchers and operators of FSM services.

1.7 JUSTIFICATION

National Water and Sewerage Corporation Lubigi has a treatment capacity of 400 m^3/d of FS. However, the capacity cannot keep up with the demand hence FS is also discharged for treatment at Bugolobi WWTP, which is not designed for FS treatment. There is therefore a need for alternative means for speeding up the drying process of sludge to create more space for fresh incoming sludge. The addition of rice husks ash to dewatered sludge could provide a faster means of drying the sludge (Fang, 2016).

We blended the sludge with RA because the amorphous silica, which is the major component in the RA, has a micro porous structure due to its structural arrangement. The ash particles increase the surface area attributing to the dewatering performance by creating a rigid lattice structure and a porous channel on the sludge cake. This improves permeability, which aids the release of water from the sludge. This therefore reduce the specific resistance to filtration and the capillary time (Wang L., 2016).

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

A treatment plant is a facility that breaks down waste materials like sewage or septage to create sludge cake, which is fertilizer used to increase agricultural yields, and an effluent that may be released into the environment (Shukla, 2023).

Sewage is not used to move feces; instead, it is produced on-site by sanitation technology. According to (Strande L., 2014), it is a slurry or semisolid that is either raw or partially digested. It is produced by gathering, storing, or treating mixtures of black water and excreta without the use of greywater.

2.1 Key terms and definitions

2.1.1 Wastewater

Wastewater is water that is extracted from homes, businesses, and institutions, along with any possible surface, groundwater, and storm water (Eddy, 2003). Wastewater is defined by (Awuah, 2006) as water that has waste components in it that prevent the water's natural functions from being applied.

Wastewater can be classified according to its substance and source of creation.

a) **Municipal wastewater**: Black water, which includes excreta, urine, and related muck, and grey water, which includes wastewater from the kitchen and bathrooms, make up municipal wastewater. This might or might not include a sizable amount of industrial effluent, and it might contain water from clinics and other businesses (Carraro, 2016).

Industrial wastewater: This is water that has been contaminated by industrial operations and has high concentrations of organic or inorganic substances, such as heavy metals. Microbiological pollutants are not typically present in large concentrations in industrial wastewater (Ajiboye, 2021).

b) **Storm water**: Precipitation that travels across surfaces and into receiving waters is known as storm water runoff. Storm or combined sewers are used to collect and transfer urban storm drainage. Storm sewers are exclusively used to transport storm water; mixed sewers are also used to transport sanitary waste. Storm water's composition is a reflection of both the surfaces it interacts with and the makeup of precipitation (Zoppou, 2001).

2.1.2 Sewage

The water from showers, baths, laundry, (pre-treated) industrial effluents, and storm water is referred to as sewage. Apart from what has already been said, storm water runoff—rainwater that gathers and flows from the land's surface—may combine with sewage before it is treated. It is tainted with pollutants that are either dissolved or suspended. The principal organic constituents consist of nitrogenous substances, such as protein and urea; carbohydrates, which include sugars, starches, and cellulose; and fats, oils, and greases. The primary inorganic substances include road grit from storm runoff, metallic salts, and chlorine (Everlyne, 2014).

The types of sewage include:

a) **Domestic sewage:** This is water from home or community, which includes toilets, bath, laundry, lavatory and kitchen sink waste (Okalebo, 2010). Within a day, there can be significant fluctuations in the flow rates that enter the sewerage system. The amount of water used, the time of day, and the population all have a role in this. Urine and feces can recover and recycle up to 91%, 83%, and 59% of the N, P, and K in residential wastewater, respectively, if they are collected (Kuffuor, 2010)

b) **Black water:** This is the wastewater flow from the toilets. Black water might contain besides urine and feces/excreta (together sometimes called night soil) some flush water. The mixture is termed as sewage if it ends up in a sewerage system or septage if it ends up in a septic tank.

c) **Grey water (Sullage):** This is the wastewater originating from the kitchen, bathroom and laundry (Peace, 2016). Hostels, hotels, hostels, and institutions typically produce this. It frequently ends up in the same sewage route as black water in affluent nations. Sullage typically flows on the ground and via open sewers in underdeveloped nations after being separated from other effluent
(Becky, 2016)

d) **Septage:** Sludge from private or public on-site wastewater disposal systems—mostly septic tanks—is what this is. Human excreta is flushed out using water in on-site sanitation systems that rely on it. The solid portion of the generated wastewater settles out and goes through anaerobic digestion in septic tanks. Septage is the term used to describe the liquid and settled solids that are present in septic tanks. Depending on how the facility is used, the actual amounts and components of septage can vary significantly (Shukla, 2023).

e) **Public toilet sludge:** This is the word for sludge that is collected from public restrooms that are not sewered; these sludges are typically less biochemically stabilized and have a higher consistency than septage (Strande, 2021)

f) **Faecal sludge:** This is a mixture of varying consistency sludge that builds up in untreated public restrooms, pit latrines, aqua privies, and septic tanks. The contents include additional non-faecal materials (such as kitchen grease and wastes, plastics, fabrics, and feminine towels) in varying concentrations along with settleable or settled faecal solids. Additionally, the sludge displays variable levels of biochemical stability obtained mostly by anaerobic digestion, contingent upon the surrounding temperature, duration of retention, and inhibition or augmentation resulting from the presence of other non-faecal materials (Sabok, 2018).

2.1.3 Sludge Types

The selection of conditioning and dewatering equipment will be influenced by the specific qualities of the various types of sludge, which vary based on the intended application (Deng, 2017).

a) **Biological sludge**: This is the residue left over after wastewater is biologically treated. Varieties of microorganisms make up its composition. These microorganisms, which are primarily bacteria, combine to form bacterial flocs by synthesizing exo-polymers. With a simple decantation in the clarifier, the bacterial flocs can be easily extracted from the treated water. To maintain the health of the bacterial population in the reactor, only a portion of the excess biological sludge that has settled is carried for dewatering; the remaining fraction is circulated (Kirhan, 2021).

Their primary attributes are:

- A high percentage of volatile solids, between 70% and 80%.
- A low dry solids content: 7 g/l to 10 g/l. It is often necessary to introduce a dynamic thickening step by flotation or gravity belt.
- The dewatering ability is medium. It depends partially on the VS. The higher the VS the harder it is to extract the water from the sludge. m

b) **Primary sludge:** This comes from the settling process. It is therefore made of easily decantable suspended particles: large and/or dense particles. It has a low level of Volatile Solids content (VS around 55% to 60%) and its dewatering ability is excellent. It is also very easy to concentrate this type of sludge with a static thickening step just before dewatering (Rabah, 2019).

c) **Mixed sludge:** This is a blend of primary and biological sludges. The blending ratio is often 35% to 45% of primary sludge and 65% to 55% of biological sludge. This blending permits an easier dewatering as the intrinsic properties of this sludge are between the two types (Zonoozi, 2020).

d) **Digested sludge**: The process of digestion includes a biological stabilizing step. On biological or mixed sludge, this stabilization is carried out. It can be carried out in a variety of temperature conditions (thermophilic or mesophilic) and in either an aerobic or anaerobic environment (with or without oxygen) (Antonolle, 2015). The sludge's characteristics after this stabilization phase are as follows:

- A reduced volatile solid concentration (VS) of roughly 50%. Because of digestion, the sludge becomes mineralized.
- A decent capacity to dewater; • A dry solids content of between 20 and 40 g/l.

e) **Physical-chemical sludge**: This kind of sludge comes from treating wastewater with a combination of chemicals. The flocs created by the chemical treatment—coagulants and/or flocculants—make up its composition.

f) **Mineral sludge:** This is the sludge produced during mineral processes such as quarries or mining beneficiation processes. Their nature is essentially mineral particles of various sizes (including clays). They have a very good aptitude to settle by gravity and very high concentrations are frequently obtained (Canziani, 2019).

2.2 FAECAL SLUDGE MANAGEMENT.

On-site sanitation systems are the focus of FS management, whereas sewered sanitation is the focus of wastewater management. Treatment options for FS include co-treatment with sludges from wastewater treatment plants or separate treatment works (Strauss M., 2000)

A fecal sludge management chain is used to control feces. The chain of fecal sludge management consists of emptying, collecting, transporting, treating, and safely disposing of the waste.

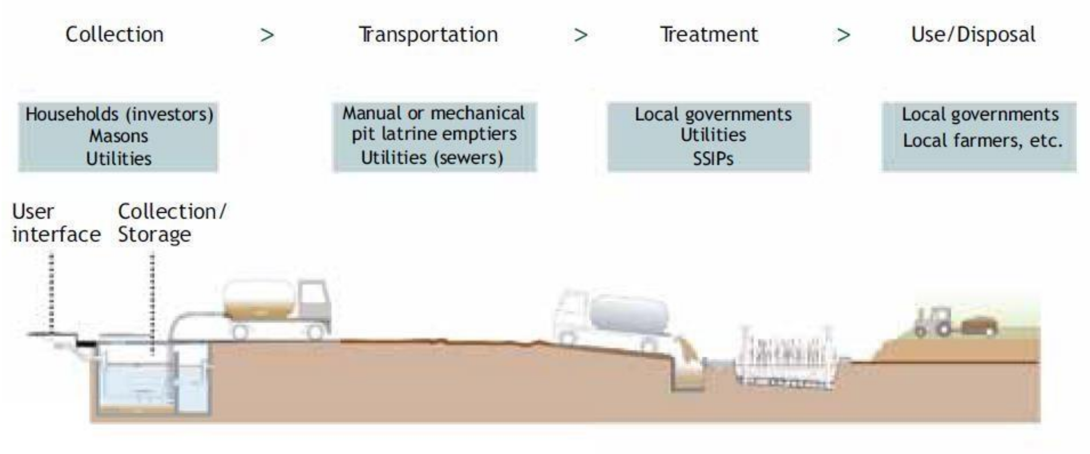

Figure 2: Sanitation and faecal sludge management service chain (strande, 2014)

2.2.1 Constituent materials and characteristics of faecal sludge

A few factors that affect the components of FS are the nutrition, way of life, habits, health, and cultural backgrounds of people who use sanitation facilities (Foxon D. S., 2012). Excreta (feces and urine) and solid and hazardous waste (disposable diapers, broken glass, chemicals, sharp metals, pads, and condoms) are among the materials that can be found in Forest Service (FS) (Foxon K., 2012). Anal cleansing material (toilet and other papers, water, rags, plastics, stones), flushing water (fresh water, grey water), and other materials can be present.

The absence of appropriate waste management systems in urban slums has frequently resulted in the disposal of solid, hazardous, and greywater wastes into on-site sanitation technologies (Katukiza, 2012). The presence of these materials alongside FS causes faster filling rates and makes pit latrine emptying dangerous and difficult. In locations where mechanized emptying is available, residual materials in FS must be manually removed, increasing emptying charges (murungi, 2014).

2.3 WASTEWATER AND FAECAL TREATMENT PROCESS AT LUBIGI FAECAL SLUDGE TREATMENT PLANT.

A treatment plant is one that is made to filter impurities out of sewage or septage in order to create sludge cake, which is fertilizer used to increase agricultural yields, and an effluent appropriate for release into the surrounding environment (Romano, 2022).

With a design, capacity of 5000 m3/day for wastewater and 400 m^3/day for faecal sludge, the Lubigi wastewater and faecal sludge treatment plant is unique in that it treats both wastewater and faecal sludge. It also has a supply of about 35% of the sludge collected around Kampala, allowing it to operate at maximum capacity (Niwagaba C. B., 2019)

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

2.3.1 PRIMARY STAGE.

Sewers gather and transmit wastewater, and cesspool tanks carry feces to the treatment facility. A sequence of treatment procedures are applied to the faecal sludge, which include sedimentation in the thickening or sedimentation tanks, grit removal in the grit chamber, and screening by screens (Lewotsky, 2021). **A. Screening.**

This involves utilizing a screen, which can be either fine or coarse depending on the size variation to remove solid materials that are included with the wastewater as well as fecal sludge.

The selection of the screen is contingent upon the makeup of the septa and the requirements of the treatment procedure (Baker, 2021). Pit latrine wastes might include hard objects like newspapers and leaves for anal cleansing, sanitary towels, shattered bottles, and medical supplies like cannulas and needles. Some of these large materials might not be able to be removed and taken to the treatment plant by the pit emptier, even though they could be separated. The pit emptier might separate these large materials, but not all of them might be taken out and carried to the treatment facility.

The plant's efficiency is impacted by the entry size of particles into the other chamber, which is determined by the distance between the bar screens. The plant's efficiency increases with decreasing spacing size and low velocity flow. Removal of trapped solids requires routine maintenance (Mert, 2018).

B. Grit removal

The grit and sand particles flow with the faecal slurry and are transferred to the channel where they are allowed to settle and eventually eliminated because they are too small to be removed by bar screens. According to (Velkushanova, 2021), the channel length and flow velocity affect the removal efficiency.

High concentrations of silt, especially from pits and septic tanks without lined walls, can be found in septage. High grit concentration speeds up the build-up of sludge in pipes, ponds, thickening tanks, and channels, causing mechanical equipment damage (Trinah, 2022).

C. 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 (Niwagaba C., 2017). 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) (Ekama, 2019). The liquid effluent from the sedimentation tank, which is taken to the anaerobic ponds, is co-treated with the wastewater at Lubigi treatment plant.

Co-treatment should be performed below an amount of 3.6% so to maintain the efficiency in the performance of treatment plant (Dangol, 2014).

Figure 3: Settling /thickening tank at Lubigi Treatment Plant (Nabaggala, 2023).

D. Anaerobic ponds.

Sewers to these deep, shallow ponds, where it is screened and the liquid effluent from the sedimentation tanks is kept, convey the wastewater. Anaerobic bacteria break down highly concentrated organic matter in the wastewater in the absence of oxygen (anaerobically), leading to biological treatment; sludge forms and settles at the bottom of the pond, influencing about 60% BOD removal; the settled sludge takes six months to de-sludge and is then transported by a dredging machine to the sludge drying beds (Ahn, 2010).

The anaerobic process in the absence of oxygen results in the formation of methane, ammonia, and carbon dioxide. The liquid effluent is kept in the ponds for four days and then moves to the facultative ponds under the secondary stage (Malik, 2020).

2.3.2 SECONDARY STAGE.

Facultative ponds

These ponds have a depth of (1-2) m and a long detention period of approximately 2-3 weeks. They are composed of both aerobic and anaerobic ponds. The aerobic zone is at the top and stimulates the growth of algae, which breaks down organic matter by consuming carbon dioxide (CO_2) and releasing oxygen (O_2), which is used by bacteria to break down organic matter (Sperling M. V., 1996). The production of algae depends on the organic load and temperature. 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 ponds that receive raw wastewater and secondary facultative ponds that receive settled wastewater from the first stage. The effluent is retained in the facultative ponds for three days (Bouwer, 2012).

2.3.3 TERTIALLY STAGE.

The facultative ponds release their effluent into the swamps, where it is allowed to self-purify by eliminating impurities prior to entering the water bodies. The use of plants in the swamps aids in this process by capturing fine particles and allowing a large percentage of the absorbed pollutants to be trapped on the sediment (Hassan, 2019).

2.3.4 WASTE WATER TREATMENT TECHNOLOGIES.

There are two categories of efficacious wastewater treatment technologies: conventional and non-conventional technological systems.

2.3.4.1 CONVENTIONAL TECHNOLOGIES.

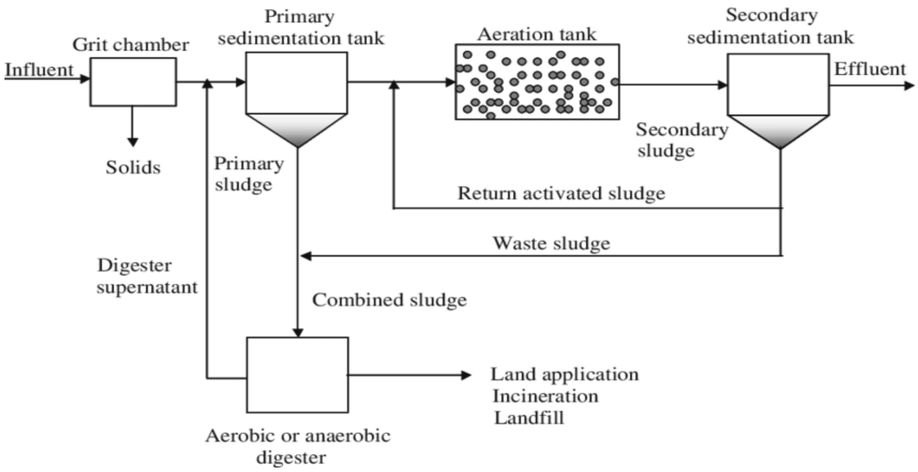

Figure 4: A diagram showing a schematic conventional sewage treatment plant (Uma, 2004).

Another name for these would be intensive technology. Because of their high-energy requirements, they are highly mechanized and depend on power and pump sources, as well as trained labor, for system processing and maintenance. Before the sludge and effluent are disposed of or used again, there are a number of steps in the treatment process (Sabri, 2020).

Preliminary treatment.

Screening and grit removal are involved here. When wastewater is discharged from the sewers, it first passes through screening before going to the grit chamber to be removed of silt.

Screening.

After wastewater has been discharged from the sewers, this is the first initial step of wastewater treatment. It involves screens that are divided into three categories based on the size of the opening: coarse screens (>50mm), medium screens (640mm), and small screens (<6mm), which are more akin to wire mesh (Jhansi, 2021).

These screens are typically made out of parallel bars arranged vertically at an angle to remove floating objects like sticks, sanitary pads, diapers, plastic bottles, and glass bottles. The size of these screens varies because of the difference in the sizes of the floating objects in such a way that course screens trap large objects and small sized objects trapped by fine screens (Christie, 2012).

Grit removal.

The discharged wastewater and faecal sludge from pit latrines and septic tanks, also known as septage, is made up of a variety of materials, including silt and sand that settles readily and floating items like paper, plastic, and clothing. Sludge from feces is taken into consideration for treatment facilities that accept wastewater and feces simultaneously, promoting co-treatment at particular treatment phases (Gantz, 1999). The fine screens readily let in silt and sand because they are too fine. Grit chambers are therefore taken into consideration to help with the removal of these particles. Elevated grit concentration accelerates the build-up of sludge in ponds, pipes, thickening tanks, and channels, causing harm to mechanical equipment such pumps (Hait, 2023).

Grit removal is considered for plants designed to receive a loading greater than $250m^3$/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.

The primary sedimentation tank in this stage is used to reduce the percentage levels of suspended solids, organic matter of greater density, and biochemical oxygen demand in the wastewater (James, 2023). This physical treatment method uses gravity to separate the liquid from the solid particles in the sewage. The solid particles settle at the bottom of the tank, and the liquid effluent is then sent to additional treatment units. The accumulated solid particles form sludge, which is then desludged to sludge drying beds.

. This process occurs twice, at the primary stage (primary sedimentation) prior to secondary treatment and at the secondary stage (secondary sedimentation) (Grey, 2009).

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 (Rezai, 2021).

Activation Sludge treatment.

This biological treatment method is most frequently employed. Unlike trickling filters, it only needs a tiny space to operate. An aeration tank and a final settling tank a sedimentation tank are involved in this Procedure.

An aeration tank and a final settling tank also known as a sedimentation tank are involved in this procedure. The aeration tank receives liquid influent from the main settling tank (Volcke E. , 2018). This is made up of organic material that bacteria have broken down, such as food waste and feces.

The aerobic conditions created by the aeration tank are ideal for microorganisms to break down organic matter into water, CO_2, and active volatile suspended solids

(ATP). In order to make sure there are enough living microbes in activated sludge for wastewater degradation, ATP is used to quantify the amount of bacteria present (Tian, 2017). This also known as newly produced bacterial cell arise from organic matter oxidation. Since BOD is the amount of oxygen needed by microorganisms to break down the organic stuff in the wastewater, it is also obtained in this instance.
A floc known as activated sludge is created when certain bacteria are picked up by sedimentation tanks and combined with organic waste and oxygen O_2 to maintain a balance of microorganisms (Fahad, Wastewater and its Treatment Techniques: An Ample Review, 2019).

The surplus sludge is disposed of as waste or co-composes to provide farmers with fertilizer. The activated sludge is recycled back into the aeration tank where it acts as an inoculum.

Compared to the incoming wastewater, there are more microorganisms in the recycled activated sludge. However, in order to keep the microorganisms in the aeration tank in a suitable state, a steady supply of oxygen must be maintained (Yates, 2009).

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 (Devrim, 2005).

TERTIALLY TREATMENT.

The last phase of treatment before returning water to natural sources like rivers and lakes is this one. Total dissolved solids, total suspended solids, and organic and inorganic materials are among the constituents of the wastewater obtained after secondary treatment and must be eliminated before to discharge. However, at this point, certain organic and inorganic materials, nutrients, and pathogens are eliminated using a variety of therapeutic approaches (N. R. Maddela et al. (eds.), 2021) .

The best technology for efficiently removing dissolved inorganic ions is this one. Since these resins have a particular propensity to absorb metal ions, the ion exchange process occurs when the resin is suspended in an electrolyte. The loosely held solution is released into the water after the wastewater passes over a resin bed where these ions are bonded to the resin beads. Recharge occurs as a result of the resin bed being saturated and losing its ability to exchange materials (Rezende, 2021).

Membrane separation technique.

This takes place under the principle of filtration (membrane filtration). Wastewater flows through a semipermeable membrane and the membrane filters remove dissolved particles ranging 0.0001 to 1ɥm.This membrane also acts as a selective barrier that allows passage of certain components thus retaining other components under high pressure (Strathmann, 2010).

Electrochemical techniques.

This involves chemically releasing direct oxidation and reduction processes to physically remove pollutants from wastewater. They include electrocoagulation and electrodialysis.

Advanced Oxidation.

This process oxidizes complex wastewater organic components that are no biodegradable into simpler products that involve generation and use of hydroxide free radicals (HO).These processes include Ozone/UV, Ozone/hydrogen peroxide (N. R. Maddela et al. (eds.), 2021).

2.3.4.2 NON-CONVENTIONAL TECHNOLOGIES.

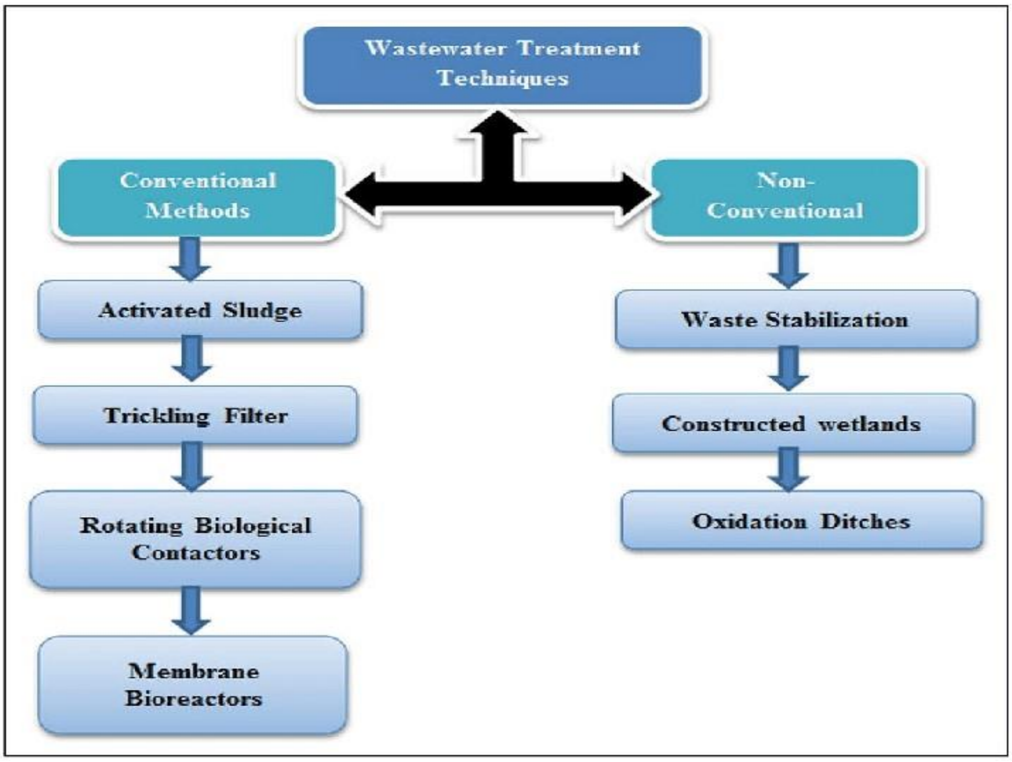

Figure 5: A diagram showing non-conventional sewage treatment plant (Saphira, 2019).

They also go by the name of comprehensive technologies. Because they use less energy, they are less mechanized and as a result, require less complicated maintenance and operation during the biological treatment process. Due to its greater affordability, social responsibility, and environmental conservancy, this treatment technology also known as the Decentralized Wastewater Treatment System has seen widespread adoption (Leo, 2022).

A larger amount of land is needed for the construction of treatment units because they are more natural means of treatment. The treatment process consists of several stages prior to the disposal or reuse of the effluent and sludge. The non-conventional technology goes through the preliminary, primary, secondary or biological, and tertially stages of treatment, just like the conventional treatment technology.

Proper planning and discharge of quantities that are in range to the design of the treatment unit makes it more effective in eliminating pathogenic organisms (March, 2013).

Preliminary treatment.

This entails screening and grit removal, which are related to the removal of materials like clothing, polythene, paper, diapers, sand, and silt that do not decompose. The goal is to remove these materials in order to prevent damage to the machinery used in the treatment process.

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 that is desludged to the drying beds and the liquid effluent is further taken to the waste stabilization ponds for secondary (biological) treatment (Camp, 2015).

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 (Saravanan, 2017).

Waste Stabilization Ponds (WSPs).

These are big, artificially made shallow basins that can be used alone or in a sequence of facultative, maturation, and anaerobic (aerobic) ponds for wastewater treatment (R.Nagesh, 2021).

These ponds are arranged in groups of three or more to guarantee efficient treatment. The anaerobic pond, facultative pond, and maturation pond are the final destinations for wastewater, with each pond having a unique treatment and size specifications (Ansari, 2009).

Anaerobic Ponds.

This is unit series of therapy is the first and is fully anaerobic and relatively deep.

With a comparatively short detention period of 1–7 days, the depth is between 2 and 5 meters. Wastewater increases the organic loading during treatment because it contains both suspended and solid organic matter (BOD) (Von, 2007).Sludge accumulates at the bottom of the pond due to the organic matter's settling and accumulation during the anaerobic stage of treatment. Anaerobic bacteria slowly break down the sludge to produce carbon dioxide (CO_2) and methane (CH_4), which removes roughly 60% of the BOD. For additional BOD reduction, the effluent is moved to the facultative ponds (Sperling V., 2007).

Facultative ponds.

The upper layer of these ponds is aerobic (has an oxygen supply), whereas the lower layer is anaerobic (has a limited oxygen supply) (Ellis, 2009). There are two different kinds of facultative ponds: the primary kind receives raw wastewater directly from the screening and grit removal process, while the secondary kind receives the anaerobic ponds' effluent. These ponds have a dentation time of 5 to 30 days and a depth of approximately 1-2 meters. Where it is distributed, the liquid effluents dissolved and tiny suspended organic matter (BOD) is oxidized by aerobic respiration (Sperling M. v., 2007). In order to maintain a balance between the production and consumption of oxygen and carbon dioxide, the population of algae must be maintained as they contribute to the oxygen supply. The pond bottom collects the settleable sediments, which the anaerobic bacteria use to continue breaking them down. Approximately 75% of the BOD is eliminated thus to the aerobic and anaerobic environments.

Maturation ponds.

These shallow ponds, which reach a depth of around one meter, serve as wastewater's last stage of treatment in waste stabilization ponds. These are fully supported with aerobic conditions in the pond, which promotes the breakdown of organic matter into carbon dioxide (CO_2) and methane (CH_4) by the bacteria (Rutegwa, 2019). Nevertheless, depending on the temperature, organic loading, and retention duration, these ponds are made to remove diseases such fecal bacteria more successfully. While organic loading causes a decrease in pathogen clearance, temperature and detention time increases lead to an increase in pathogenic removal (Pearl, 2018).

Tertially Treatment.

The process of treatment is based on the wetland vegetation in such a way that the bacteria break down the pollutants in the wastewater and nutrients are taken up by the plant roots and substrate to supplement plant growth. This is the final stage of treatment before water is discharged back to the water sources, such as lakes and rivers. The effluent is discharged into wetlands, which can either be constructed or natural wetlands (Brix, 1993).

Sometimes artificial wetlands are made with the intention of effectively removing pathogens, suspended particles, organic debris, nutrients, biochemical oxygen demand (BOD), heavy metals, and nutrients.

Compared to natural wetlands, these wetlands are thought to be more conscientious; nonetheless, it takes more understanding to build a wetland to carry out an ecological, transportation, and transformation process in treatment (Fahad, 2019).

2.3.5 Characteristics of Faecal Sludge

According to (Buckley C., 2008), faecal matter lacks distinct features and instead depends on the nutrition and overall health of the individual producing it. As such, FS features differ not only between locations but also between pits. There are several characteristics that should be investigated for characterizing the FS, according to various literature. Yet, among them, the elements that are frequently tested for the characterization of FS are: nutrients like phosphorus (P), potassium (K) and nitrogen (N), pH, total solids (TS), BOD & COD, oil & grease, and lastly grit & sand (strande, 2014).

The dewatering properties of faecal sludge differ from those of wastewater sludge due to its propensity to foam when disturbed and to resist settling and dewatering.

Dewatering faecal sludge depends on how long it has been stored on site and how old it is. It is harder to dewater fresh or raw feces sludge than it is to dewater older, more stabilized faecal sludge (Bassan, 2014). Physical, chemical, and biological aspects are among the sludge's attributes. Sludge processability and handlability can be broadly inferred from physical factors. The presence of nutrients and hazardous or toxic substances is related to chemical parameters, hence when used in agriculture, they become essential. The evaluation of the safety of use is made possible by biological parameters, which provide information on microbial activity, organic matter/pathogen presence.

a) **Concentration (g/l):** The sludge concentration, expressed in g/l, will affect the following:

The flocculants incorporation. It is more difficult to mix in a viscous flocculants solution the greater the sludge content (even at low flocculants concentrations). Using an online mixer, injecting the flocculants numerous times, diluting of the flocculants after it has been diluted, and injecting the flocculants upstream are some solutions to this issue.

The flocculants is consumed. The amount of flocculants used decreases with increasing sludge concentration.

b) **pH:** One crucial quality criterion for FS is the hydrogen-ion concentration. Typically, the hydrogen ion concentration is stated in terms of pH, which is the negative logarithm of the concentration of hydrogen ions. The concentration ranges that are acceptable for the majority of biological life are quite small and critical (usually 6–9).

It is challenging to biologically treat wastewater and FS with extremely high hydrogen ion concentrations.

c) **The organic matter content (%)**: The organic matter content is comparable to the Volatile Solids content (VS). The higher the VS, the more difficult the dewatering. The dryness achieved will be low, the mechanical properties will be low and the flocculants consumption will be high. When the VS of the sludge is high, it is recommended to add a thickening step in the process in order to achieve a better dewatering.

d) **Total Nitrogen (TN):** TN is the total amount of organic and ammonia nitrogen. Since nitrogen is an essential building block for synthesis of protein, nitrogen data will be required to evaluate the biological treatability of the sludge. Insufficient nitrogen may require the addition of nitrogen to render the waste treatable. Where algal growth in the receiving water or as part of the treatment has to be controlled (e.g. in facultative ponds), nitrogen in wastewater will have to be removed or reduced.

e) **The colloidal nature of the sludge**: This characteristic has a very important effect on the dewatering performance. The higher the colloidal nature, the more difficult it is to dewater. Four factors will affect the colloidal nature of the sludge:

- The origin of the sludge
- The freshness of the sludge: The colloidal nature of the sludge will increase with its level of fermentation (septic sludge).
- The origin of the wastewater: A dairy or brewery origin will increase the colloidal nature of the sludge.
- The sludge returns: a badly controlled return of the sludge will increase its colloidal nature.

f) **Electrical conductivity (EC):** The measured EC value is used as a surrogate measure of total dissolved solids (TDS) concentration. By measuring the electrical conductivity of treated wastewater, its salinity can be assessed. Salt content is an important parameter for agricultural wastewater reuse.

2.3.5.1 Processes occurring in the pit latrine.

Understanding the processes that take place in the pit-latrine is essential to comprehending the potential mechanisms of pit latrine additives. According to (Buckley C. , 2009), the processes can be broadly categorized as physical or biological.

Biological mechanisms

These processes are further separated into two categories: anaerobic and aerobic. The top surface of the pit experiences aerobic conditions because of a comparatively high oxygen concentration. Reduced diffusion causes the oxygen concentration to drop to extremely low levels when one descends to the lower regions of the pit, creating anaerobic conditions there (BUCKLEY, 2008)

The FS section of the pit contents is divided into four theoretical layers based on these processes, and they are as follows: 12

- Rapid aerobic degradation is the hallmark of the first category, which includes components that can be biodegraded easily. This layer is minuscule and cannot be measured in actuality.
- The top aerobic portion of the pit falls into category two. Aerobic hydrolysis of complex organic molecules to simpler compounds sets a rate restriction for the aerobic breakdown of hydrolysable organic material in this layer.
- The third layer is anaerobic due to the occlusion of oxygen by covering material. Anaerobic digestion proceeds at a significantly slower rate than in the layer above, and is controlled by the rate of anaerobic hydrolysis of complex organic molecules to simpler molecules.

- Lastly, lowest layer. In this layer, no further stabilization of organic material occurs for the remaining life of the pit contents.

a. Anaerobic Digestion processes.

Anaerobic digestion is the process by which microorganisms break down organic materials in the absence of molecules of oxygen. It mostly happens in the pit's lowest levels, which are beneath the aerobic layer. Carbon dioxide, methane, and hydrogen sulfide gases are produced during the anaerobic conversion of FS. Less solids remain undecomposed and the process proceeds very slowly. Anaerobic digestion of organic material requires four primary steps to be completed. These include the following processes: hydrolysis, acetogenesis, acidogenesis, and methanogenesis (Nwaneri, 2009).

i **Hydrolysis**

The process of anaerobic digestion begins with this. It entails converting complicated particulate materials into soluble substrates. It is a collection of extracellular enzymatic reactions in which a specific microbial population to hydrolyze complex particulate materials into smaller soluble substrates that can be broken down further produces the necessary enzymes (Frunzo, 2012).

ii **Acidogenesis.**

Acidogenesis, the second step, is the fermentation of the soluble compounds generated during the hydrolysis stage, leading to the production of simple organic compounds like lactic acid, carbon dioxide, hydrogen, ammonia, and hydrogen sulfide gas (Ken Anderson, 2003). This phase causes the organic molecules to dissolve, releasing H+ ions into the liquid phase and raising the process's acidity.

iii **Acetogenesis**

The third step, Acetogenesis is the conversion of volatile fatty acid produced from the Acidogenesis stage into the final products (acetate, carbon dioxide, and hydrogen)

iv **Methanogens:** In the final step, Methanogenesis, methane is produced from acetate or from the reduction of carbon dioxide by hydrogen using the acetotrophic and hydrogenotrophic microbes respectively (Teresa, 2013). Methane production (Haandel, Optimization of Process and Physical Design of Anaerobic and Complementary Processes, 2019).

b. Aerobic digestion processes

This primarily occurs at the pit's exterior boundary surfaces (using dissolved oxygen during hydraulic transport) and top surface (using oxygen from the vent pipe). Microorganisms and waste material, or biomass, take in oxygen and use it as energy to create new cells.

Concurrently, auto oxidation causes a chemical reduction in the microorganisms' cell mass.

2.3.5.2 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, 2015).

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 and remove sludge without damaging the under drain pipes or lose of sand (Elbaz, 2020).

Planted drying beds

Planted drying beds consist of both course 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 (Strande L., 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 (Strande L. , 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.

2.4 DEWATERING.

The initial stage of treating faecal sludge from pit latrines is dewatering. In order to facilitate better handling and reuse, sludge can be dewatered. Both generic characteristics and particular tests—the latter known as a specific technique can be used to assess dewaterability. Specific Resistance to Filtration (SRF) and Capillary Suction Time (CST) tests are the most well-known (Peng, 2011). The Specific Resistance to Filtration, which measures the resistance to filtration provided by a cake placed on the filter media with a unit dry solids weight, is the traditional metric used to assess filterability. Values between 10 and 12 m/kg or less are indicative of good industrial filterability (raw sludge generally exceed 10-14 m/kg); specific resistance can be reduced by conditioning, most commonly performed by chemicals (Canzania, 2019). By measuring resistance at different pressure, the compressibility coefficient is obtained, which provides information on the most suitable operating pressure level. The CST (Capillary Suction Time) is a simple, useful and rapid way to evaluate filterability.

According to (Semiyaga S. , 2017), the dewaterability metrics are the dewaterability extent reported as the percent cake solids and the dewaterability rate expressed in terms of capillary suction time (CST).

(i) Dewaterability rate: Measured in capillary suction time (CST), water percolates through the sludge at this speed.

(ii) The percentage of dry solids in the sludge cake is known as the dewaterability extent.

2.4.1 Factors Influencing the Dewaterability of Sewage Sludge.

Even with the same kind of dewatering equipment, treatment plants at different locations may produce very diverse dewatering outcomes. According to (Boran, 2020) there are several reasons for the disparity.

- Sort of sewage sludge conditioning; these are attributes of the sludge that are determined by the raw water and the technology used for treating wastewater and sewage sludge.
- Mechanical engineering type, namely dewatering equipment type.

2.4.2 Factors influencing dewatering characteristics

a) **Sludge particle size:** One of the primary objectives of sludge treatment is the removal of solids. Once removed, the resultant sludge must be treated and disposed of in some innocuous manner. In Africa and many developing countries, the kind of sludge that should be disposed of is the faecal sludge removed from on-site sanitation systems. In many wastewater facilities, the bottlenecks of the sludge handling system are the dewatering operation. It is also the least understood handling operation. In the case of faecal sludge (Cofie, 2006), indicated that as a result of its high variability, the design for its dewatering should be based on caseby-case study. Many factors that influence the dewatering characteristics of sludge have been reported in the literature. Among these are cellulose content, pH and particle charge, organic content, filtrate viscosity, alkalinity, solids concentration, grease content, nitrogen content and conditioning. Other factors include, type of sludge, compressibility coefficient, mechanical strength of particles, porosity, mixing, biological degradation and particle size (Ying, 2012).

b) **Clogging:** The most popular facility for individual domestic sewage treatment and disposal is a septic tank and soil absorption system. Unfortunately, the latter is often disturbed by clogging, especially in fine and loamy sands. Clogging is a wellknown phenomenon in filters (M.Spychala, 2004). The clogging layer occurs in filters, particularly with fine filtering media, during sewage (including septic tank effluent) treatment. It is unfavorable because of negative impact on hydraulic conductivity. On the other hand, a well-developed bio filter enhances the treatment efficiency of the system. There are several hypotheses explaining the clogging process. Other authors found many significant conditions and factors.

According to the literature (Tong, 2009), the main causes of clogging are:

- Mass accumulation within soil pores, particularly suspended solids from sewage,
- Precipitation and deposition of some materials, for example calcium carbonate ($CaCO_3$),
- Microorganisms growing within soil pores,
- Deposition of side products of bacterial metabolism and extracellular products of bacterial cells, particularly slimes and EPS (extracellular polymeric substances).

According to (Charles, 2009) a low C: N ratio suppressed clogging. They stated that clogging was correlated with polyuronide concentration, and therefore was a function of polysaccharide production. (Bouma, 1979) Reported that biological clogging was due to accumulation of suspended solids and biological growth in anaerobic conditions. (Kristiansen, 1981)Suggested that bacterial cells might be important in clogging by producing slime that would link soil particles together and reduce hydraulic conductivity. He stated that extracellular polymeric substances (EPS) play a very important role in the clogging process. He concluded that clogging is initiated by the deposition of suspended solids, which are linked together with soil particles by biologically produced material.

c) **Sand media characteristics:** The media characteristics of sand based treatment systems are among the most important design criteria. The primary sand media characteristics affecting filtration performance are the effective grain size and uniformity coefficient (u_o) (Ramirez, 2012). These characteristics tend to affect the retention time of liquid passing through the media and the potential for clogging.

d) **Particle size:** The larger the grain size, the faster the wastewater moves through the sand and the more the wastewater that can be filtered. However, if the grain size is too large, treatment efficiency will be reduced. (White, 1986) Observed larger breakthroughs of unoxidized matter due to short retention times and instantaneous lack of oxygen when applying relatively large hydraulic loads to filter media with coarse grain size, especially above 1mm. The ideal sand for intermittent sand filters receiving domestic wastewater is sand with an effective size between 0.3 mm and 0.5 mm (Ruhela, 2021). Clogging becomes a major concern when using sand with an effective size less than .3 mm and therefore recommended that filters using this size of sand be lightly loaded (<56.25 litres/m^2/d). The most important feature of granular media is not the grain particles but rather the pore space in the media where suspended solids are trapped, microorganisms grow, and air and water flow bringing about treatment (Brinker, 2020)

e) **Uniformity coefficient (u_o):** Uniformity coefficient is a numeric estimate of how sand is graded and is a dimensionless number. The uniformity coefficient is calculated by dividing D_{60} (the size of screen opening where 60% of a sample passes and 40% retained) by D_{10} (the effective particle size-that size of screen opening where 10% of a sample passes and 90% is retained). The larger the uniformity coefficient, the less uniform the sand. A uniformity coefficient of 4 or less is recommended for all filter media (Hamdan, 2022)

2.4.3 Sludge dewatering technologies and processes.

According to (Haandel, 2019), there are numerous dewatering techniques available. These include:

a) Natural dewatering techniques: Sludge lagoons and sludge drying beds are examples of these, which rely on evaporation and percolation.

b) Mechanical methods for dewatering that use centrifugal, vacuum suction, capillary action, and filtering. Vacuum filters, centrifuges, and pressure vessels are among the frequently utilized devices.

2.4.3.1 Natural dewatering methods.

The functioning of natural sludge dewatering is contingent upon the environmental and climatic conditions. It does not need a power source that is external. Lagoons and drying beds are two common uses for this dewatering technique (Hoadley, 2011).

a) **Drying lagoons**:

Prior to being disposed of permanently, sludge is allowed to dewater and dry for a few months to a few years. The resultant sludge may contain between 15 and 25 percent dry solid (DS). Before being fed to the lagoon, sludge is stabilized to reduce the release of odors and enhance dewaterability (Lawrence, 2014).

Design loading rate is given as; 2 – 4 per capita load/m2 /year, or 1.5 – 3 m3 sludge/m2 /year, or 10 – 20 kgDS/m2 /year. The negative effect of precipitation on sludge dry solids is strongly affected by the runoff. It is envisaged that at DS content above 10%, surface water decanting can be realized easily to increase the runoff; at DS level between 10-20% trenching at the top may improve runoff, while at DS greater than 20%, rainwater directly infiltrates into the sludge because of the occurrence of surface cracking. The drying capacity (D) of a lagoon is given by

$D = E + R + F - P$ (mm/year).

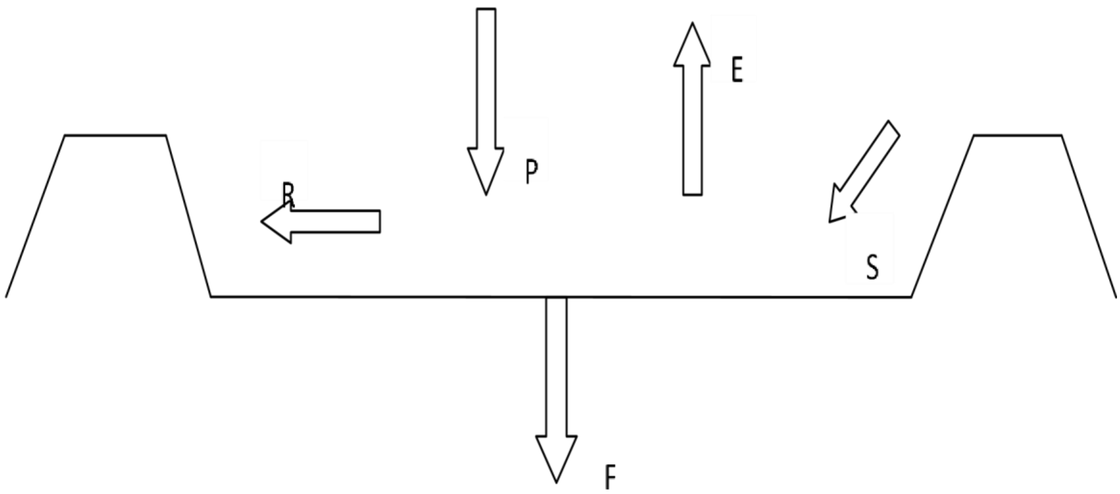

Figure 6: A sludge-drying lagoon's water balance (Musenze, 2015)

Where F, E, R, and P stand for drainage, evaporation, surface runoff, and annual precipitation rate, respectively.

The filling depth of a lagoon can be computed from the water balance using the formula h = (S – D) x T, where S is the sludge loading rate (in mm/year), D is the lagoon's drying capacity (in mm/year), and T is the filling duration (in years). It is reasonable to presume that sludge evaporates at a pace equivalent to open waterways. Sludge concentrations over 15% may cause DS evaporation to decrease (Chen, 2020).

Water infiltration is influenced by the properties of the soil (media), however it is typically minimal because of bottom blockage. As loading increases, infiltration decreases. While impermeable clay layers have little to no infiltration, sandy soils typically have substantial levels of infiltration. At the bottom of the lagoon, there may be an impermeable barrier composed of plastic sheet or clay to prevent groundwater pollution (Eden, 2012). Alternatively, to abstract the drainage water, drains could be built at the lagoon's bottom. Pathogens, heavy metals, and micro pollutants may be present in high concentrations in this drainage water, endangering the area's groundwater supplies. Climate factors including temperature, humidity, evaporation, and precipitation all have a significant impact on the efficiency of sludge lagoons because evaporation is the main process that removes water from sludge (Wang L. K., 2024).

b) **Sludge drying beds**:

In tropical climates with high rates of evaporation, they are most frequently utilized for small and medium-sized settlements. Drying beds are essentially shallow sand beds supported by gravel and equipped with a bottom drain. The sand bed is preserved at about 20 cm thick, and the gravel bed is maintained at about 30 cm thick (Cogger, 2020). The gravel has particles that range in size from 5.0 to 15.0 mm, while the sand has particles that are between 0.1 and 2.0 mm. Over the sand bed, sludge is often applied to a thickness of 15 to 30 cm. To make hand sludge removal easier, large drying beds are frequently separated into smaller sections. To increase the removal of sludge, a single unit might be 5–8 m wide and 15–50 m (Neyens, 2004).

Determination of dewatering rate of sludge drying beds The factors that affect the drying time which should be given consideration are: Extent of free drainage, climatic factors (evaporation rates from sludge and rainfall) and permissible moisture content of final outgoing sludge. The overall drying time can be computed using a simple mass balance of all incoming and outgoing moisture (Beer, 2014). The moisture to be evaporated per unit area is given by $q_e = (1-f_i) \times q_i + (1-f_r) \times q_r - q_d$ ....Eqn 1 Where q_e = moisture to be evaporated q_i = moisture initially present in sludge,

q_r = moisture received via rainfall, q_d = moisture remaining in final sludge f_i, r = fractions of q_i and q_r respectively that is drained from the bed, thus the $(1-f_i)$ and

(1-f_r) are the fractions remaining in sludge. The model is applicable when the evaporation dominates the drying time required.

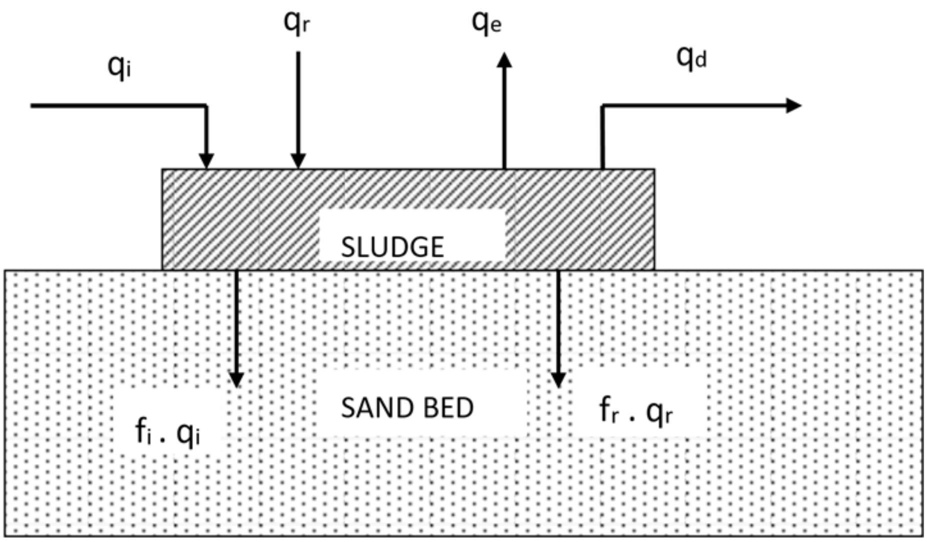

Figure 7: A model to estimate how long a sludge bed will take to dry completely (Sato, 2007)

In general, the mass/area q parameters above can be changed to volume/area, or m^3 / m^2, by just using a meter (m) or millimeters (mm) (used for rainfall data).

The formula for calculating the drying time includes a suitable reduction factor f_e to account for reduced evaporation if the rate of evaporation from the sludge surface is less than the rate found from the open pan evaporation a suitable reduction factor f_e to account for reduced evaporation is incorporated in the formula for calculation of the drying time.

From Eqn 2 below;

$$T = \frac{q_e}{f_e \times E_w} \quad \text{......r}$$

Where T is the drying time in months and E_w is the evaporation rate from free water surface (mm/month). Combining Eqns. 1 and 2, the required drying time t is given as

$$t = \frac{(1 - f_i) \times q_i + (1 - f_r) \times q_r - q_d}{f_e \times E_w} \quad \text{.....Eqn 3}$$

From equation 3, it can be understood that the overall drying time is affected by:

- The effective evaporation rate.
- The rainfall received (which is zero for covered beds).
- The permissible moisture content of the dried sludge.

The sludge characteristics that affect the f coefficients differ for different sludges based on the characteristics. Typical values for f coefficients for sludge (between 1 – 4% DS) and at drying beds of 15 -30 cm are given in Table 2.1 below.

Table 1: Characteristic f coefficients of stabilized and anaerobic digested sludge(Tomei, 2009)

Coefficient	stabilised sludge (extended aeration)	anaerobic digested sludge
f_i	0.45 – 0.65	0.8 – 0.9
f_r	0.43	0.73
f_e	0.78	0.78

According to (Ram, 2012), coefficients f_i and f_r are affected by the nature of sludge. The higher the organic matter contents of the sludge, the lower the f coefficients. Furthermore, the presence of hygroscopic fibrous materials helps moisture retention and therefore reduces the f coefficients. There is an inverse correlation between the f_i coefficient and the specific sludge resistance. The drainage fraction f_i can simply be determined by laboratory-scale sand column tests simulating the performance of a sludge drying bed (Kone, 2009).

2.3.4 Dewatering Pretreatment: Sludge Conditioning.

Particles of sewage sludge have negative surface charges, which create electrostatic repelling forces that prevent the sludge particles from sedimenting. For effective sludge dewatering, therefore, the sludge needs to be conditioned to overcome the repulsive forces. According to (Strauss, 2003) there are three main process variations:

(i) **Chemical processes:** By adding cationic charge carriers, inorganic (e.g. iron, aluminum, calcium) or organic chemicals (e.g. polymers) the sewage sludge particles are destabilized and flocs are formed. Agglomeration is achieved via flocculation and co-precipitation processes. Recently developed processes show that by applying sulfuric acid and hydrogen peroxide, dewatering is also significantly improved (Wang Y. , 2015).

(ii) **Thermal processes**: Thermal processes include both freezing and heating treatment; however, only heat treatment is employed. Waste heat is used to heat sewage sludge to approximately 40 to 50 degrees Celsius, which improves sludge dewatering, especially when raw sludge is used. Thermal disintegration processes also have a positive impact on dewatering (Mitra, 2022).

(iii) **Mechanical processes:** Adding materials that improve structure, like coal or ash, improves the dewatering properties when using mechanical procedures. When powdered activated carbon is added to the excess sludge after activated carbon is applied to wastewater treatment to remove organic trace materials, the dewaterability should improve (Bergins, 2007).

2.5 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 (Emran, 2021). 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 physiochemical 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 (Zhang, 2020). It also consists of a significant amount of 14.8% silicon dioxide 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 (Pode R., 2016).

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 (500^0C-700^0C) result into amorphous silica state, which is considered reactive unlike temperature range (700^0C-800^0C) whose state consists of nonreactive silica mineral (Patnaikun, 2021).

2.6 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 (Hiruy, 2022).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 (Scopa, 2011).

2.6.1 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 (Durán-Álvarez, 2013).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.

2.6.2 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 (Louten, 2016).

2.6.3 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).

2.6.4 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 40^0c in the periodic range (10-20) days and about 5% moisture reduction are anticipated to inactivate these pathogens (Manouana, 2020)

In conclusion, rice husk ash possesses properties (< 90percentage silica) attributing to dewatering of sludge thus inactivating pathogenic organisms at specific temperature conditions. Amorphous silica (SiO_2) is chemically inert and therefore does not affect the faecal sludge quality. In addition, the ash residue in the sludge also acts an organic fertilizer.

2.7 REGULATIONS, LAWS AND POLICIES CONCERNING WASTEWATER AND SLUDGE MANAGEMENT.

In Canada, the application of bisolids 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).

The Canadian best practice guide to biosolids management also notes that other unknown processes, which show equivalency in stabilization result, say be potential treatment methods (Nadeem, 2022)

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

The Waste Management Act1996 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 restricts discharges of pollutants to water bodies and created central state pollution control boards with authority to set standards and enforce water pollution rules.

The Environment (Protection) Act of 1986 was passed in the aftermath of the Bhopal Gas Tragedy of 1984, and is an umbrella Act on all issues related to environmental protection and provides for the audit of all facilities that require permits under pollution, air pollution and hazardous waste rules.

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). Article XXVII of the Republic of Uganda's 1995 constitution, which addresses the environment, mandates that the state take all reasonable steps to prevent or minimize harm and destruction to land, air, and water resources caused by pollution or other causes. It also requires the state to take all reasonable steps to promote an effective 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 Feacal Sludge Management (FSM) Project funded by Bill and Melinda Gates foundation aimed at addressing the challenges of sanitation especially collection, transport, safe disposal and treatment of feacal sludge from pit latrines and septic tanks (Godwin, 2020).

CHAPTER THREE: MATERIALS AND METHODOLOGY.

3.0 INTRODUCTION

This chapter presents methods, procedures, research parameters, and sources of the relevant data collection necessary for the attainment of the objectives of the study. The main function of this research is to investigate the use of rice husk ash in the stabilization of sludge.

3.1 THE GENERATION AND PREPARATION OF RISK HUSK ASH.

1. Rice husks ash

At a temperature range of 500^0C to 700^0C, rice husks were carefully burned to produce rice husk ash.

A rice milling plant located at Kisoga, Kibanga provided the rice husks

2. Faecal sludge

Fresh samples of faecal sludge were collected from the wastewater of Lubigi and the faecal treatment sludge drying beds. These samples were then sent to the Central Laboratory National Water and Sewerage Cooperation in Bugolobi for laboratory examination. The outcomes were then compared to the standards.

According to (Baruah, 2015), the general procedures for preparing rice husk ash were followed:

1. Collection and Cleaning: The rice husks were be collected, the outer layer of rice grains, which are typically obtained as byproducts from rice milling. The husks are cleaned to remove impurities, dirt, and dust.
2. Drying: Thorough drying the cleaned rice husks was done to reduce their moisture content, typically to below 10%. Drying was achieved through sun drying.

3. Combustion: The dried rice husks were burnt in a furnace at 500^0C-700^0C for about 12 hours for cooling to ambient temperatures. Complete combustion was ensured to obtain high-quality rice husk ash.

4. Collection of Ash: The ash generated after combustion was collected in dry cleaned polythene bags.

5. Milling and Grinding: Milling and grinding the ash was be done using a hammer mill to improve its properties, obtain into fine particles and uniform powder.

6. Sieving: The milled ash was passed through sieves to separate different particle sizes.

3.1.1 Design and setup of a sludge drying bed prototype.

The prototype design and setup was constructed 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 Lubigi Faecal Sludge Treatment Plant Namugoona under NWSC, Uganda

A prototype model was constructed using bricks with four chambers where one was a one control experiment chamber and the other three chambers were varied with the rice husks ash.

The bed is sized $1m^3$ volume capacity and $1m^2$ bed area and this partitioned into four section of $0.16m^3$ volume capacity.

All the chambers had a well-arranged filtering medium with hard core at bottom, coarse aggregates, fine aggregates and lake sand as the filtering medium.

Preparation of the drying bed with the filter media layers.

The bed was built as a duplicate of the current drying beds, above ground. The beds are made up of 4 inch perforated pipes that are positioned at a slope of roughly 1cm on all sides of the bed sections, 0.3 meters above the ground. Hardcore makes up the bed sections' base down to a depth of 0.3 meters.

The Hardcore is covered with a layer of 12.5mm-sized particles positioned 0.3 meters below the surface. Sand with a diameter of between 0.3m- 1.2 mm was positioned as a filter medium at a depth of 0.15 meters, after which sludge was pumped to a height of 0.2 meters. A transparent roof that lets light in and keeps rain from entering was to be installed with a 0.05m allowance.

Figure 8: A designed prototype

3.2 FAECAL SLUDGE SAMPLING AND SAMPLE PREPARATION.

Sampling:

FS samples were picked from the same point in one drying bed using a bucket and taken to the prototype as shown in the figure below (C.B.Niwagaba, 2016).The parameters to be determined, time and date of sampling were recorded on a field sampling sheet.

The samples in the bucket were then transported to the prototype using a wheelbarrow.

Figure 9: collection of faecal sludge Figure 10: Mixing FS with rice husk ash

To prevent misidentification, bottles were used to select the sludge samples whose parameters needed to be examined from the prototype beds and labeled. After being kept at 4ºC in a cold box, the composite samples were shipped to NWSC laboratories in Bugolobi for examination.

Figure 11: FS samples removed from the cool box at NWSC for testing.

3.2 PREPARATION OF FS SAMPLES AND APPLICATION OF THE RICE HUSKS ASH INTO THE FS SAMPLES.

3.2.1 Sample preparation.

- The weights of the samples of FS in the bucket were determined using a weighing scale.
- The rice husks ash was added to the FS in percentages of 0, 4, 7 and 10% of the weight of the sludge and the mixture stirred vigorously to ensure a uniform mix using a rod as shown in the figure below.
- The weight of FS was 30kg implying that 0%, 4%, 7% and 10% of the weight of FS in terms of weight are 0Kkgs, 1.2kgs, 2.1kgs and 3kgs respectively of rice husks ash added.
- The four chambers of the prototype were labelled basing on the percentages of the rice husks ash added to the FS i.e. 0%, 4%, 7% and 10%. The mixed sludge was then poured in the four drying chambers of the model bed basing on the percentages of rice husks ash added.

Figure 12: **Sample preparation.**

3.4 MODEL GEOMETRY.

- Volume of the model sludge bed=1m^3
- The sludge bed is partitioned into 4 equal section
- Volume of each section=0.16m^3
- Volume of sludge in each section=0.032m^3
- Weight of the ash added per sludge bed section.

Table 2: Weight of ash added per sludge bed section

Sludge bed sections	**Sample dose of ash per weight of the sludge added (%)**	**Weight of sludge added in each section (Kgs)**
1	0	0
2	4	1.2
3	7	2.1
4	10	3.0

3.4.1 EXPERIMENTAL SETUP:

The effect of FS additives on the sludge cake solids were determined at 0,7,14, 21 and 28days for the first month. This is because at 0days the additives bond with the FS is comparatively weak (Gitonga, 2021). The characteristics of the FS were determined at 0, 7, 14, 21 and 28days.

Values of the moisture content, TS and TVS of the dewatered FS were plotted against different periods. The plots included the control and this aided in discovering the differences and in formulation of the conclusions on whether the pit latrine additives have an effect on the dewaterability on FS.

Characterization of feacal sludge.

Parameters that were considered for the characterization of FS included TS, TVS and MC.

The TS, TVS and MC were determined according to standards Method 2540G, Method 2540E (Standard Methods for Examination of Water and Waste Water).

The MC and concentration of TS were determined gravimetrically by taking the weight of an oven-dried sample at 105ºC till a constant weight (for 24hrs) as a fraction of wet sample volume.

TVS was determined by taking the weight difference between oven-dried solids and the 2-hr muffle furnace-ignited sample at 550ºC and expressed as a percentage of TS. The residue after ignition in the muffle furnace was the ash content.

3.5 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.

3.5.1 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 involved three elements, the X-ray source, sample and detector. The X-ray source emits X-rays to the sample, which consists of many atoms.

Every atom consists of electrons that are negatively charged and a positively charged nucleus. High intensity x-rays are emitted when an atom's electron in a neighboring shell is absorbed and then released out of the atom. This makes the atom unstable, and each element has its own unique way of releasing energy in the form of X-ray fluorescence photons when an electron from a neighboring shell fills that shell to stabilize the atom.

The detector picks up the characteristic x-ray fluorescence energies of the element, identifies and quantifies them using individual wavelength.

3.5.2 GRAVIMETRIC METHOD.

The faecal sludge at the drying beds has gone through the first step of solid liquid separation in the settling tanks, thus it can be classified as semi solid or solid sludge. This procedure is most effective for semi solid-to-solid sludge (Ronteltap, 2021) 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 (Ward B. , 2023)

The method obtains the faecal sludge parameters by the following;

Total Solids (TS) = $\frac{\mathrm{W(c+s)}_{105} - \mathrm{Wc}}{Ws} x100$

Moisture content (Mc) = $\frac{W_s - (\mathrm{W(c+s)}_{105} - \mathrm{Wc})}{Ws} x100$

Where: W_c = crucible mass (g)

W_s =Weight of wet sample (g)

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

3.5.3 IGNITION METHOD

This method is carried out on samples for which the total solids are obtained and is used to determine the volatile solids and fixed solids in the sludge.

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^{0}C for 2 hours until constant weight is obtained. The remaining ash represents the inorganic solids; while the weight lost on ignition represent volatile solids (organic matter) in the faecal sludge.

Volatile Solids (VS) = $\frac{W(c+s)_{105} - W(c+s)_{550}}{W(c+s)_{105} - Wc} x100$

Where: W_c =crucible mass (g)

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

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

Figure 13: Taking weight of sludge samples using a weighing scale and a muffle furnace ignited sample at 555ºC for 2hrs for TVS determination.

On the determination of the chemical composition of the rice husks ash, an XRF technique was used.

CHAPTER FOUR: RESULTS AND DISCUSSION.

4.0 INTRODUCTION

This chapter presents the findings of the study and their discussion. The experiments were conducted over a period of two months to assess the moisture content, total solids, total volatile solids, and chemical composition of rice husk ash, taking into account seasonal variations. Because it featured the majority of the dry spills, Month 2 was designated as the dry season and Month 1 as the wet season.

Table 3: Showing the chemical composition of rice husks 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

The results indicate that the silicon dioxide content of is the highest compared to other elements. This percentage composition of 81.192% follows within the recommended range of silica context in rice husk ash to serve as a good moisture absorption agent (Pode, 2016)

4.1 CHANGE IN SLUDGE PARAMETERS

The moisture content, total solids and volatile solids of the sludge were measured during the wet season in January and the dry season in February. For a duration of two months (28 days each), this was carried out at intervals of every seven days. Figure 7 below are 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.

When compared to the control sample (which lacked rice husk ash), the sludge samples that were combined with the ash demonstrated superior dewatering. For the first seven days, the sludge samples' moisture content decreased quickly; but, for the next 14, 21, and 28 days, it decreased gradually.

4.1.1 MOISTURE CONTENT

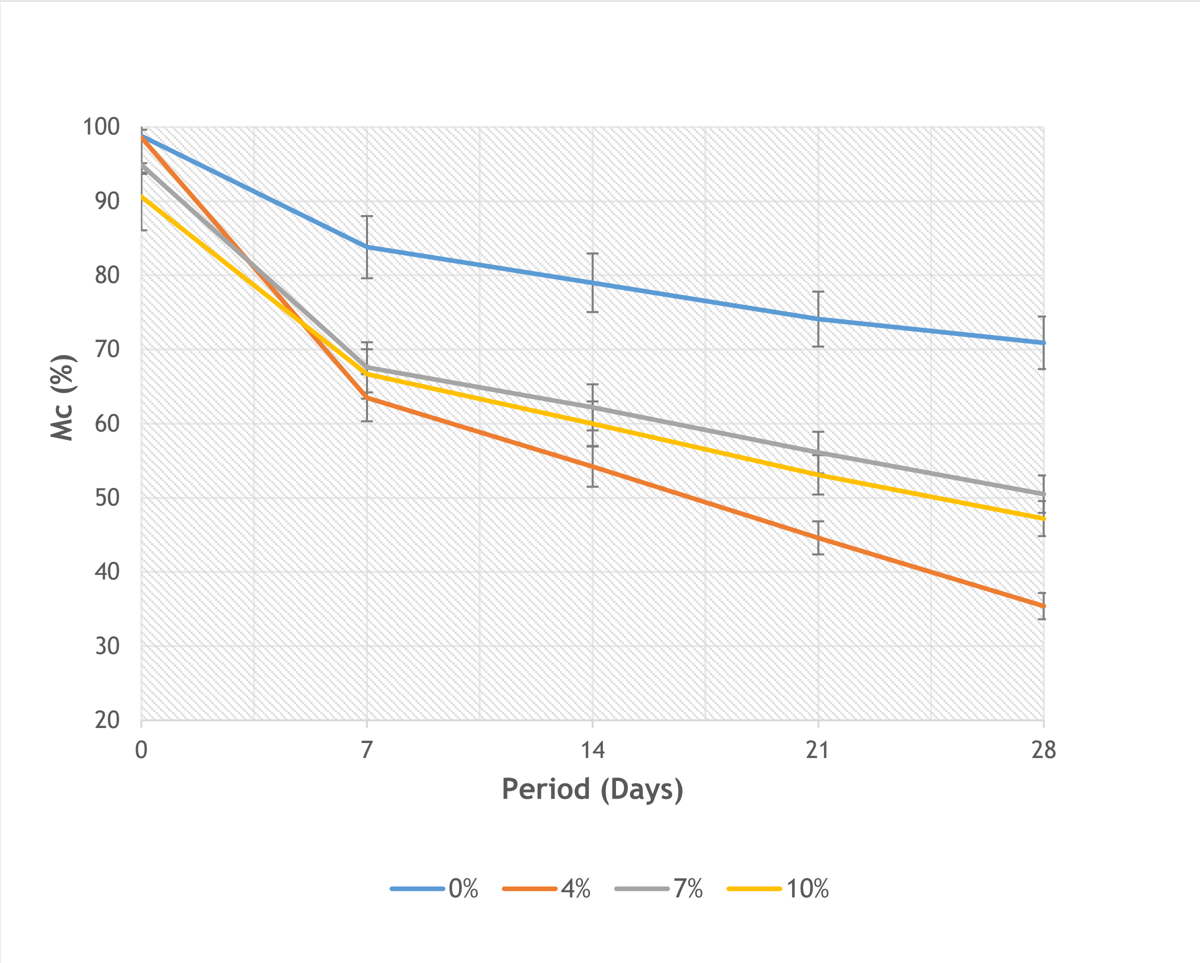

Figure 14: A graph showing variation of moisture content per dosage of rice husks ash with increase in days in the wet season.

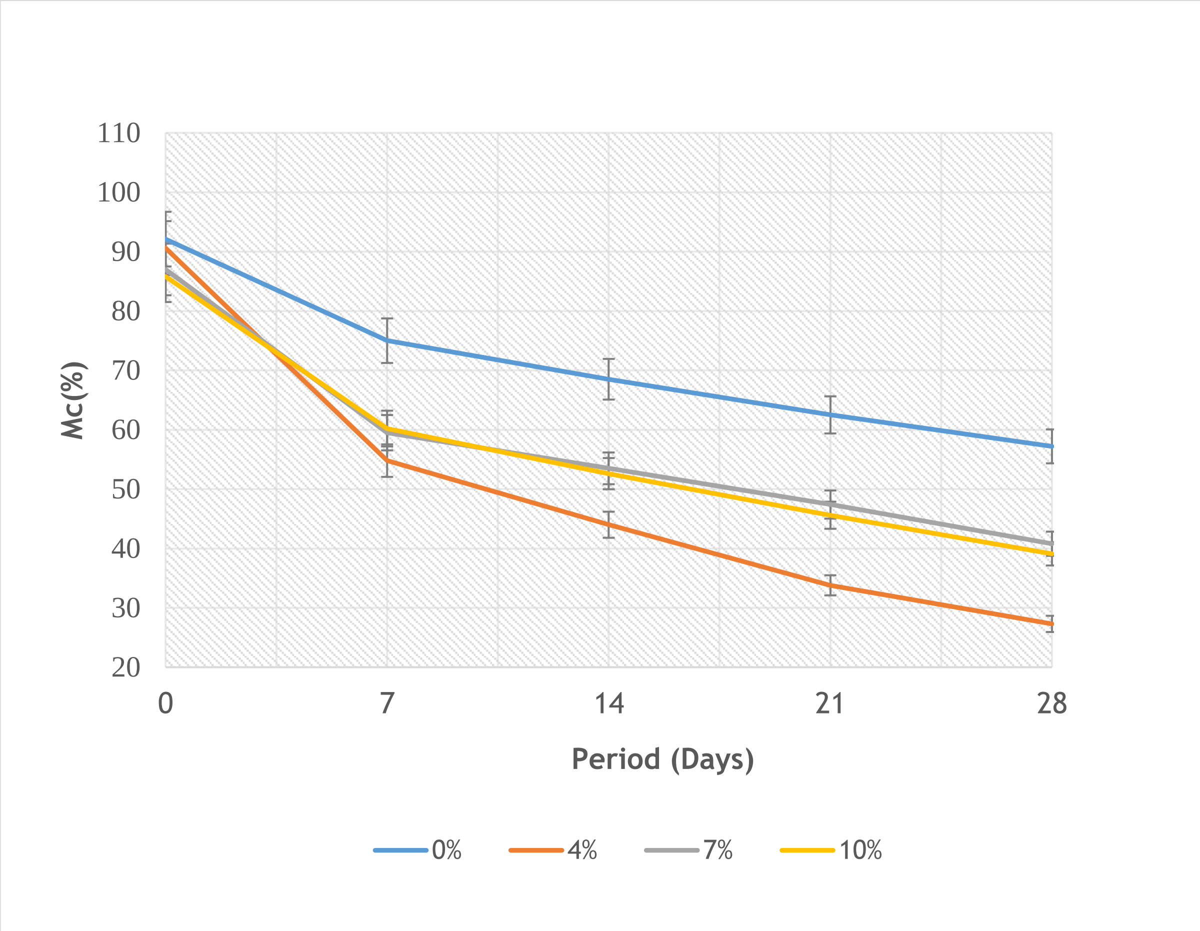

Figure 15: A graph showing variation of moisture content per dosage of rice husks ash with increase in days in the dry season.

4.1.2 TOTAL SOLIDS

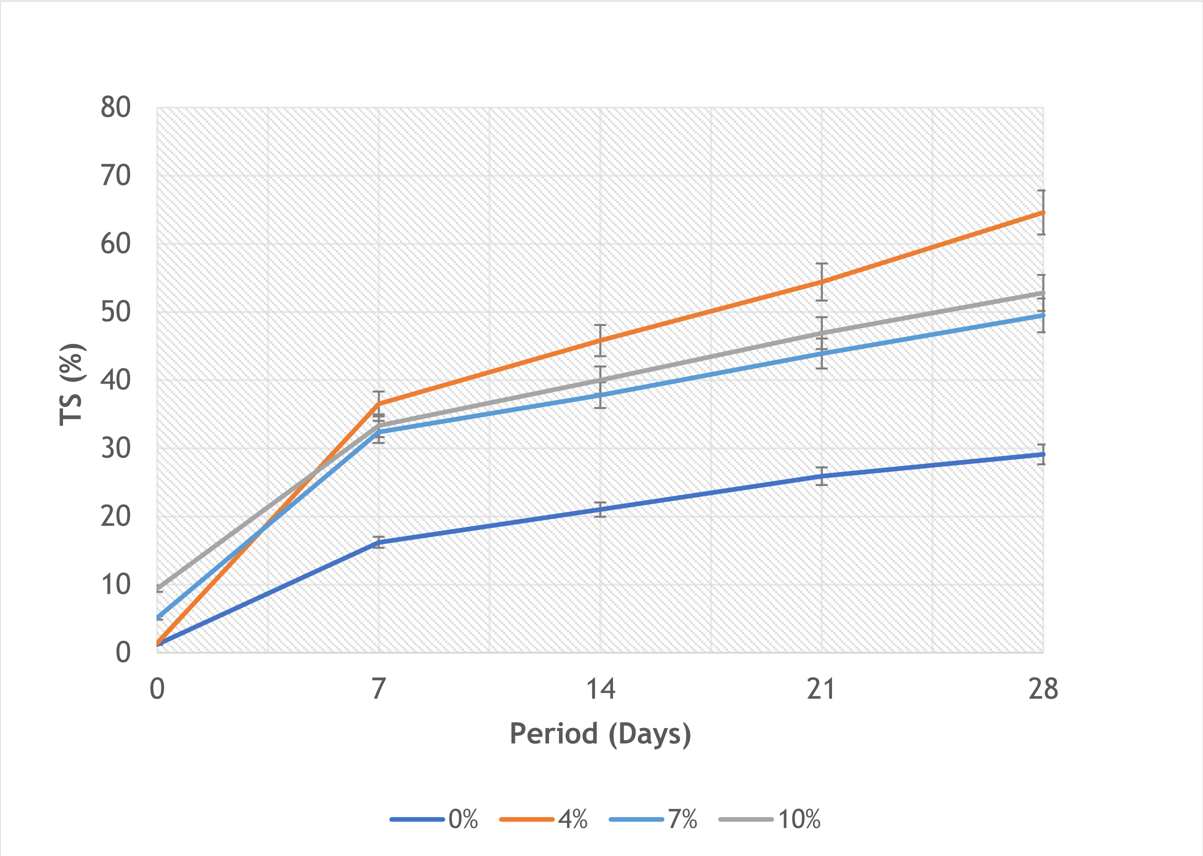

Figure 16: A graph showing increase in total solids with increase in days in the wet season.

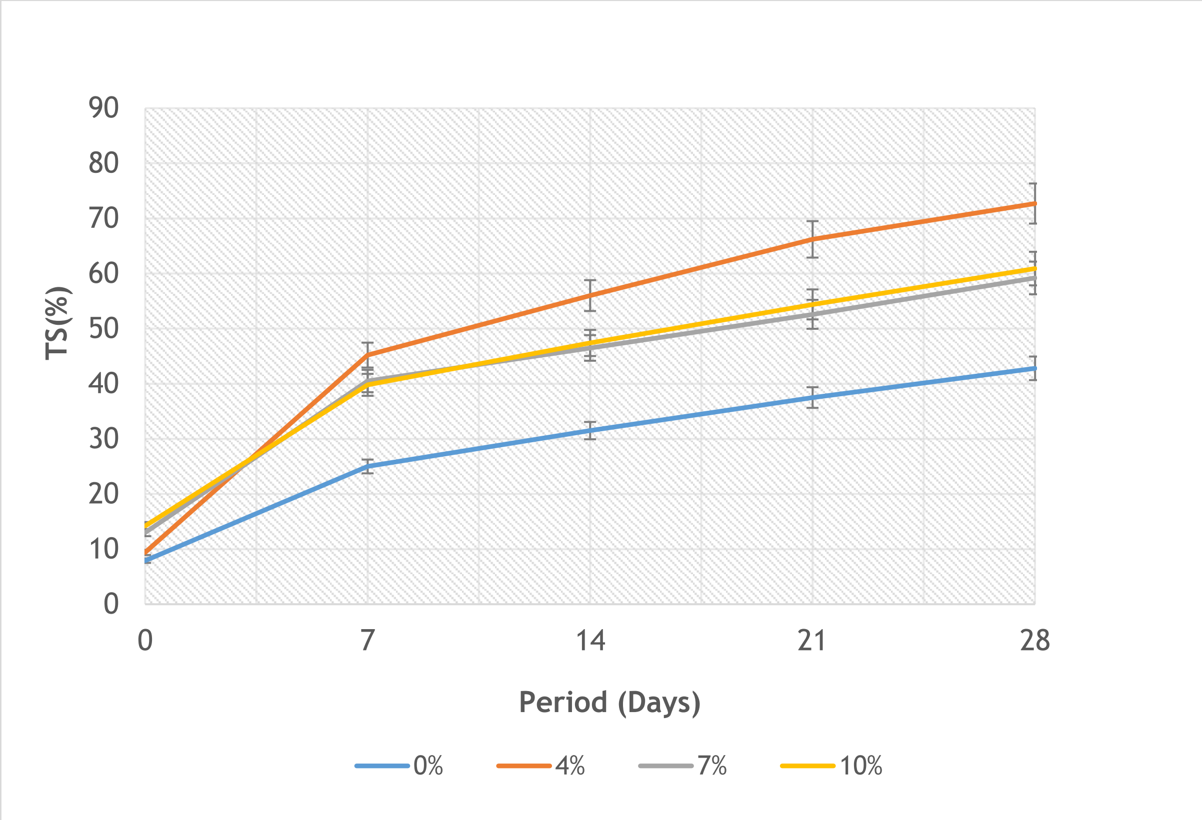

Figure 17: A graph showing increase in total solids with increase in days in the dry season

Figure 16 below illustrate the statistics reported for the rainy season. After 28 days, the 4% dosage of rice husk ash has the highest concentration of total solids at 64.6%, compared to 0%, 7%, and 10% at 29.1%, 49.6%, and 52.8% respectively.

The statistics during the dry season are shown in Figure 17, where a dosage of 4% rice husk ash produced the maximum concentration of total solids at 72.7%, compared to 42.8%, 59.2%, and 60.9% for dosages of 0%, 7%, and 10% after a 28-day period.

Sludge's moisture content affects the amount of total solids it contains. The amount of total solids in sludge increases when the moisture content decreases.

Given that 4% had the lowest moisture content, as shown in Figures 14, and 15, it follows that it has the largest concentration of total solids, as demonstrated in Figures 16 and 17 below.

4.1.3 VOLATILE SOLIDS

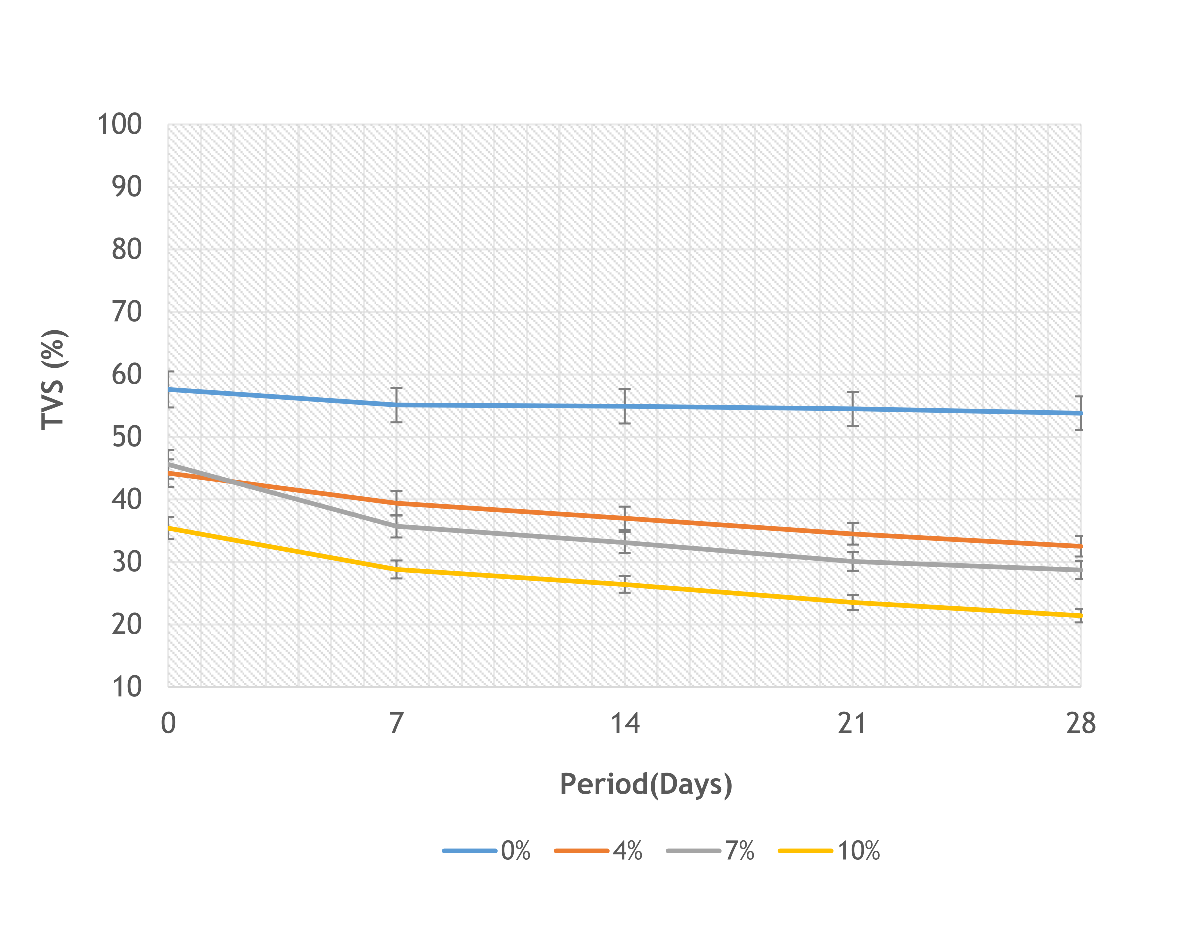

Figure 18: **A** graph showing reduction in volatile solids with increase in days in the wet season

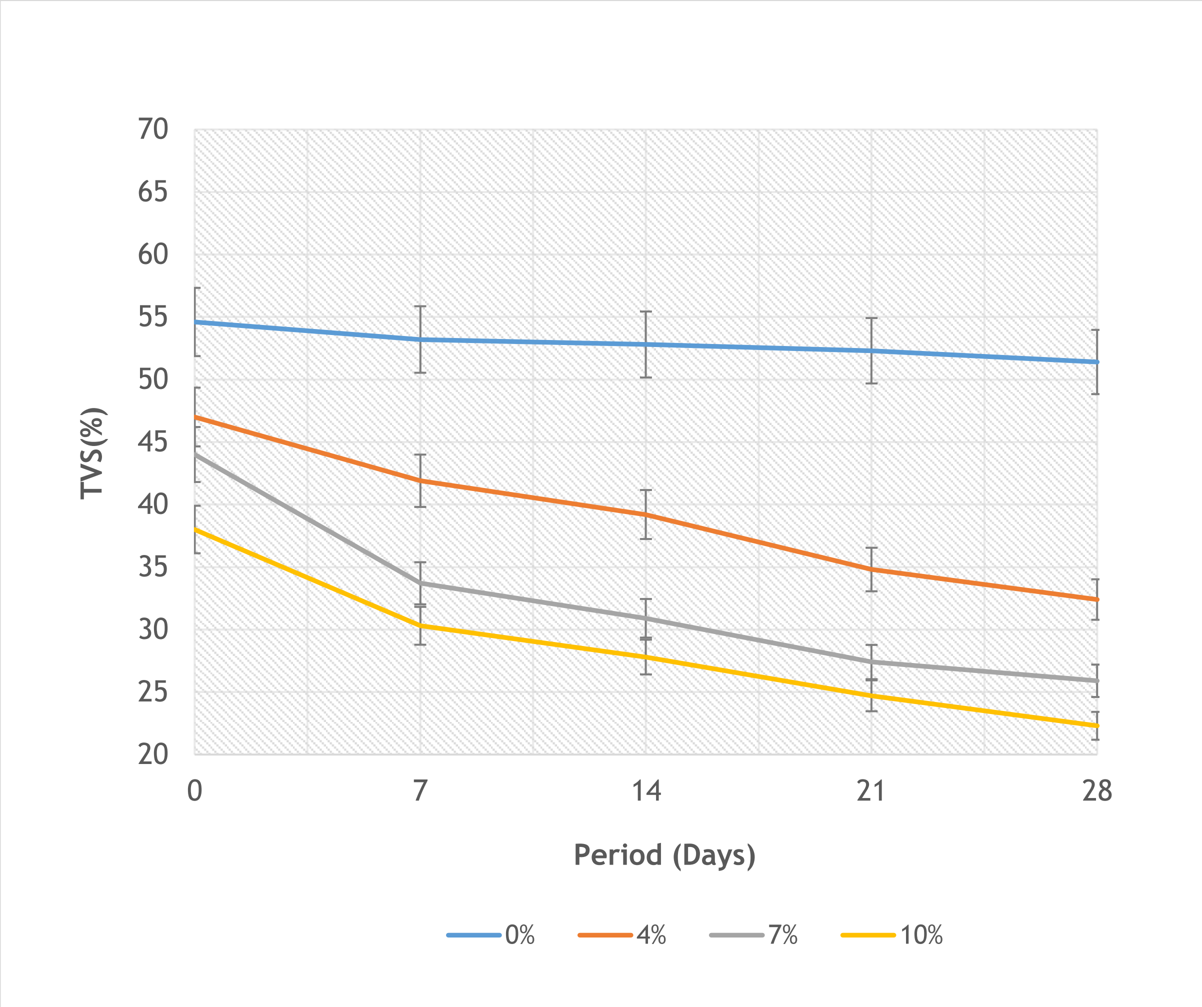

Figure 19: A graph showing reduction in volatile solids with increase in days in the dry season

The 10% dosage of rice husk ash produced the lowest volatile solids of 21.4% after 28 days, compared to 0%, 4%, and 7% and their corresponding volatile solids of 53.8%, 32.5%, and 28.7% based on data examined for the wet season, as shown in Figure 18 below.

During the dry season, the results shown in Figure 19 below show that a 10% dosage of rice husk ash produced the lowest volatile solids of 22.3% after 28 days, compared to 0%, 4%, and 7% and their corresponding volatile solids of 51.4%,

32.4%, and 25.9%.

Compared to the control sample (which did not contain any ash), the sludge samples that were combined with the rice husk ash had lower percentages of volatile solids. The lowest volatile solids were found with a 10% dosage of rice husk ash. This suggests that a rise in the percentage of rice husk ash lowers the concentration of volatile substances. This is because sludge that contains more ash creates an environment in which microorganisms, such bacteria, have a low chance of surviving. This lowers the rate at which organic matter that is vulnerable to volatilization is being broken down by microorganisms, which in turn lowers the amount of volatile solids produced.

4.2 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.

4.2.1 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 400m^3/day.

Monthly capacity = (400x30) =12000m^3/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= $\frac{15}{100}$x400=60m^3/day

Sludge produced per month= (60x30) =1800m^3/month

Each sludge drying bed has a capacity =105m^3

Number of drying beds at Lubigi Treatment Plant=52

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

=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.

4.2.2 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 4: 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

=30X7X0.5

=105m^3

Since 0.032m^3 requires 1.2 kgs of ash

105m^3 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

Number of cycles in a year = $\frac{\text{Number of days in a year}}{\text{Number of drying days+loading days}}$

$= \frac{365}{(28+2)}$

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.

4.2.3 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.

4.2.4 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 is 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.

4.2.5 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 500^0C-700^0C 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 8.4m^3

1 sludge drying bed occupies 105m^3

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

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

Annual Total benefit =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

=538650kgs

=538.65Tonnes

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 =<u>shs 48,063,500</u>

Annual benefit from the dry sludge as Manure

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

1 sludge drying bed occupies 105m^3

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 =<u>shs 68,400,000</u>

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS.

5.0 INTRODUCTION.

This chapter presents the conclusions drawn from the findings of the study and the recommendations with regard to the effect of the rice husks ash on improving the dewatering performance in the sludge drying beds at Lubigi.

5.1 CONCLUSIONS

1) The 4% RHA addition of the weight of sludge gives the best dewatering performance thus taken to be the optimal dosage as per the results obtained.

2) The Silicon dioxide content gave the highest percentage existence in the RHA as it gave a composition of 81.192% as per the literature reviewed.

3) The higher percentage additions of rice husks ash i.e. 7%, 10% have a relatively low effect on the dewatering in the sludge drying beds compared to the 4% of the RHA addition in the drying beds.

5.2 Challenges encountered

The leaking shelter roofs for the covered sludge drying beds were a problem during the rainy season.

Lack of a proper mixing tool of RHA with the sludge to obtain a homogeneous mixture.

5.3 RECOMMENDATIONS

From the study, I recommend the use of 4% RHA addition as it has comparatively high effects on the dewatering performance in the drying beds giving a moisture content of 35.4%, which is in the minimum recommended range of 3040% for dry sludge to be used as manure (Getahun, 2020).

Further studies should be made on the determination of NPK content in the sludge if it has to be used as manure.

Furthermore, in order to create safer manure that can be applied to all soil types, we advise conducting further research on how to bring an alkaline sludge cake stabilized with RHA down to a neutral pH.

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APPENDICES

Appendix 1: Pictures showing the project implementation and laboratory tests.

Figure 20: Freshly pumped sludge

Figure 21: Sample preparation

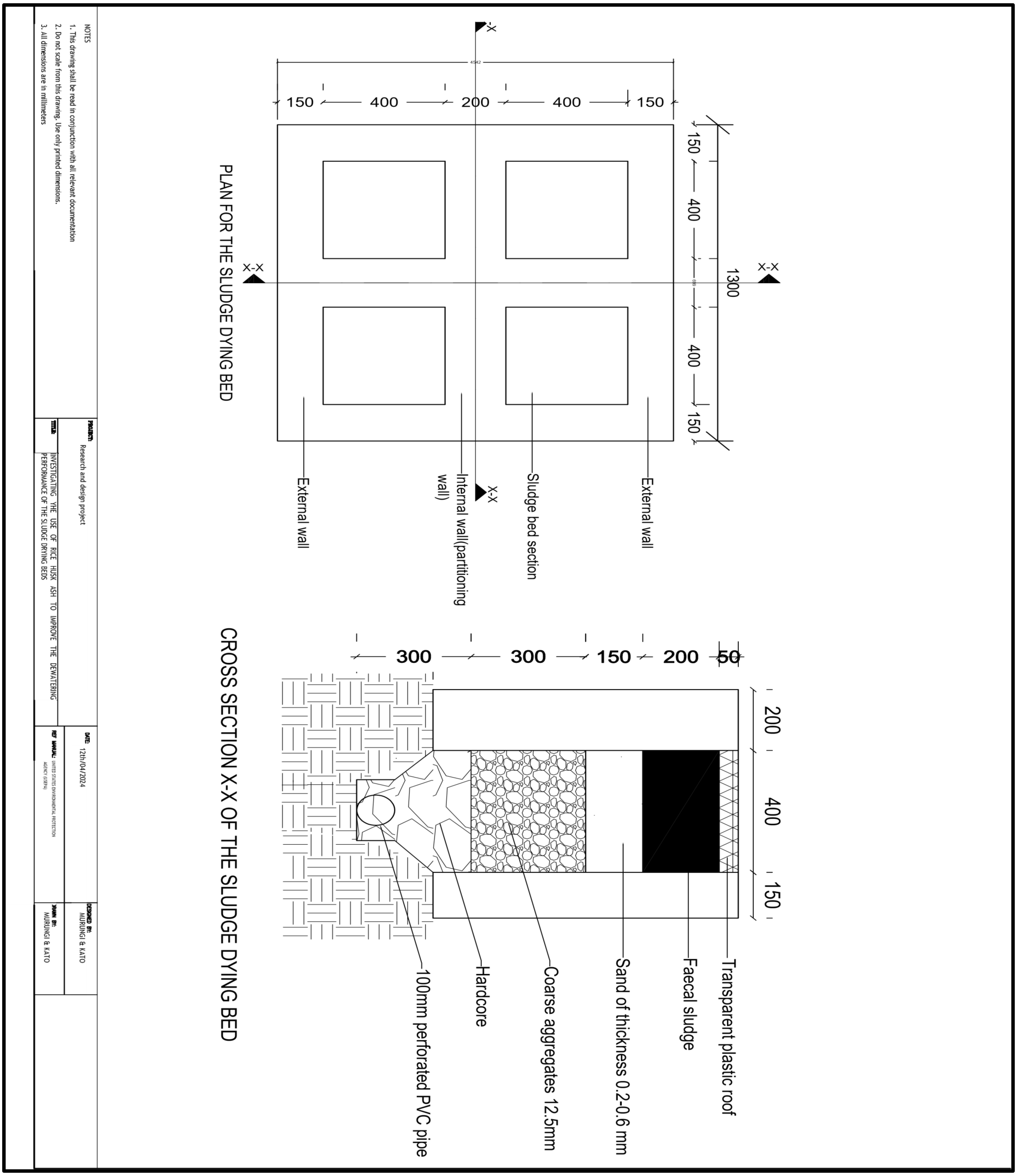
Figure 22: Picking sludge from the drying beds.

Figure 23: Pouring sludge in the prototype.

Figure 24: Placing samples in muffle furnace. Figure 25: Setting the muffle furnace at 550^0C

Figure 26: Weighing the faecal sludge samples Figure 27: Placing sludge samples in an Oven

Appendix 2: Drawing plans for the sludge drying bed



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

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30th January 2023

MR. KATO JULIUS AND MURUNGI CHELSEA
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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

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

30/01/2024

Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Appendix 3: Pictures showing the results for the sludge parameters monitoring in wet and dry seasons

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 monitored were Total Solids (TS), Moisture Content (MC), Volatile Solids (VS).

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 four sections with an equivalent sludge weight of 30kgs in each section.

Table 11**: Varying proportions of Rice husk ash (percentage) dosage and the weight equivalent (kgs) in each bed section**

Sludge bed section	**Rice hush ash dose per the weight of sludge added (%)**	**Equivalent weights of sludge(kgs)**
1	0	0
2	4	1.2
3	7	2.1
4	10	3.0

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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: ....

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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: ....

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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
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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)

NATIONAL WATER AND SEWERAGE CORPORATION
18 MAR 2024
THE CENTRAL LABORATORY

Sign: 18/03/2024

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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)

NATIONAL WATER AND SEWERAGE CORPORATION
18 MAR 2024
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MONTH 2 (DRY SEASON) LABORATORY RESULTS

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

The key parameters monitored were Total Solids (TS), Moisture Content (MC), and Volatile Solids (VS).

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 four sections with an equivalent sludge weight of 30kgs in each section.

Table 12: Varying proportions of Rice husk ash (percentage) dosage and the weight equivalent (kgs) in each bed section

Sludge bed section	**Rice hush ash dose per the weight of sludge added (%)**	**Equivalent weights of sludge(kgs)**
1	0	0
2	4	1.2
3	7	2.1
4	10	3.0

NATIONAL WATER AND SEWERAGE CORPORATION

CENTRAL LABORATORY – BUGOLOBI

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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

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CENTRAL LABORATORY – BUGOLOBI

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

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Issued by: Bayo Robert

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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)

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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

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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)

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18 MAR 2024
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ANNEX

TEST PROCEDURES

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 drying[3]

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.

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.

[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).

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) =

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

Total Solids in wet sample (g/L) =

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

Semi-solid and solid samples (gravimetric method):

Total Solids in wet sample (g/g) =

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

Moisture content in wet sample (g/g) =

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

Moisture content (%) =

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

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 below[4].

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 method[5]

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/10.25678/0000tt.

[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) =

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

Fixed solids in wet sample (g/L) =

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

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) =

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

Volatile solids in dry sample (g/g) =

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

Volatile solids (%TS) =

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

Fixed solids in wet sample (g/g) =

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

Fixed solids in dry sample (g/g) =

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

Fixed solids (%TS) =

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

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