

**ASSESSMENT OF MEMBRANES USED IN DRYING FAECAL SLUDGE TO
MINIMISE THE SAND TAKE-AWAY IN THE SLUDGE DRYING BEDS.**

CASE STUDY: LUBIGI PLANT

BY

NGABIRANO DENETH

(BEng. Env Eng & Mgt - KYU)

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DECLARATION

I, NGABIRANO DENETH (Reg. No. 18/U/GMEW/22154/PD), hereby declare that this submission is my work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree of the university or other institute of higher learning, except where due acknowledgement has been made in the text and reference list.

Signed:

Date:

APPROVAL

The undersigned confirms that they have read and hereby recommend for submission to Kyambogo University a dissertation entitled “*Assessment of different membranes used in faecal sludge drying to minimise the sand layer take-away in the sludge drying beds at Lubigi Faecal Sludge and Wastewater Treatment Plant*” in partial fulfilment of the requirements for the award of Master of Science in Water and Sanitation Engineering Degree of Kyambogo University.

Dr. Anne Nakagiri (Principal Supervisor)

Department of Civil & Environmental Engineering

Faculty of Engineering

Signed:

Date:

Dr. Charles Onyutha (2nd Supervisor)

Department of Civil & Environmental Engineering

Faculty of Engineering

Signed:

Date:

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DEDICATION

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LIST OF ACRONYMS

Al	Aluminium
BOD	Biochemical Oxygen Demand
ESM	Electron scanning microscope
C	Carbon
Ca	Calcium
CEDAT	College of Engineering, Design, Art, and Technology
COD	Chemical Oxygen Demand
CST	Capillary suction time
CSTW	Conventional Sewage Treatment Works
CV	Calorific Value
FS	Faecal sludge
FSDB	Faecal sludge Drying Bed
FSM	Faecal Sludge Management
FSWWTP	Faecal Sludge and Water Treatment Plant
GoU	Government of Uganda
KCCA	Kampala Capital City Authority
M	Molybdenum
MC	Moisture Content
Mg	Magnesium
N	Nitrogen

Na	Sodium
NWSC	National Water and Sewerage Corporation
O	Oxygen
OSSS	On-Site Sanitation Systems
RURA	Rwanda Utilities Regulatory Authority
SC	Sand Content
SDB	Sludge drying beds
SDB	Sludge drying beds
SDG	Sustainable Development Goal
Si	Silicon
SSP	Sewage Stabilization Ponds
STP	Sludge Treatment Plant
TS	Total Solids
TVS	Total Volatile Solids
UN	United Nations
UNDP	National Development Plan
UNEP	United Nations Environmental Programme
WHO	World Health Organization
WWAP	World Water Assessment Program

ABSTRACT

Sludge drying beds provide sludge dewatering by allowing the liquid to both drain under gravity through a permeable medium on which the sludge sits, and to evaporate under ambient conditions. Lubigi plant with 19 sludge drying beds handles faecal sludge from pit latrines and septic tanks separately for sludge dewatering. Clogging in filter beds and sand membrane material is challenging as it continues to get off with dry sludge cakes. The study's main aim was to assess different membranes used in faecal sludge drying to minimise the sand layer takeaway in the sludge drying beds at Lubigi Faecal Sludge and Wastewater Treatment Plant. This study analysed the chemical and physical characteristics of faecal sludge in the existing and unplanted drying beds at Lubigi. A pilot-scale dewatering facility was designed and constructed with four unplanted sludge drying beds (A, B, C, and D) with a one m² effective drying area. The cumulative percolate was measured following a non-uniform time interval of 5, 10, 30, 60, 180, 360, 720, and 1440 minutes. This lasted for ten days until the faecal sludge was dewatered entirely.

Five raw faecal sludge samples collected from different points of the existing and operating beds were analysed using the Makerere University laboratory. The cake samples had average weights ranging from 0.48 to 46.98% of the respective chemical elements. Carbon and oxygen had the highest weight ratios of 46.96% and 36.73%, whereas sodium had the lowest, with 0.48% in all elements, respectively. Low sodium content implies low alkaline indices in the faecal sludge, which is desirable. Additionally, moisture content (ranging from 73.68% to 75.91% by mass, mean = 74.81±1.11%), sand content (between 17.43% (89.62 g) and 19.66% (118.08 g), mean = 18.344±0.86%) and calorific value (between 2846.38 kcal/kg to 3185.46 kcal/kg. Sand (Bed A) exhibited the highest mean dewatering rates with a peak of 502 mm after 4.5 hrs, followed by pavers with 416 mm after 7.5 hrs, nylon with 384 mm in 4.5 hrs and lastly, hessian with 59mm after 20hrs. The efficiency shows that hessian, nylon and pavers were efficient ($R^2 = 0.632, 0.592, \text{ and } 0.540$), followed by sand ($R^2 = 0.491$). All membranes had a very significant correlation between dewatering time (t min) and percolate (Q ml), $p < 0.05$ based on a $> 95\%$ confidence level.

Nevertheless, nylon expedited average filtration rates at all times compared to the rest of the media. This is because its cake yielded moderate moisture, sand, and calorific values compared to the rest of the media hence optimised. Nylon filter media was optimised based on different gauge sizes of 1.0 mm (reference size) (Bed A), 0.5 mm (Bed B), and 2.00 mm (Bed C). The average dewatering times of the filter media in Beds A, B, and C were 5, 60, 180, and 360 minutes, respectively. Bed C (2.0 mm) had the highest flow rate (156.61 ml) but the lowest sand content (82.14%, 85.16%), Bed B (0.5mm) had the lowest flow rate (49.09 ml) and the highest levels of moisture content (86.91%, 90.92%) and Bed A (1.00mm) had the intermediate flowrate (83.37 ml), moisture (83.28%, 87.28%), sand (13.24%, 14.8%, and calorific value (2745.12 Kcal/kg, 2600.12 Kcal/kg). These were determined based on the size of holes in the filter media, hence recommending the 1.00 mm nylon gauge.

Keywords: Calorific value, Dewatering, Faecal Sludge, Lubigi, Moisture Content, Optimisation, Sludge Drying Beds and Sand Content.

CHAPTER ONE

1 INTRODUCTION

1.1 Background to the Study

Over 4.2 billion people rely on on-site sanitation systems (OSSS) such as pit latrines, septic tanks, and pour-flush latrines globally (Bassan et al., 2013). However, 2.7 billion people are estimated to live in areas without access to well-run sanitary services (UN-Water, 2019). According to the World Health Organization (WHO) (2017), just 7% of people have access to sewers, and only 1% of the sewage is processed. Open defecation is practised by about 19% of people, with the remaining 80% using OSSS (UNEP, 2020). More than 80% of people utilise OSSS in most emerging nations' urban regions (Kwiringira et al., 2014). By 2030, the sanitation needs of people whom onsite sanitation technologies will serve are expected to grow and surpass 5 billion (Strande et al., 2014; Lindberg and Rost, 2018; Getahun et al., 2020). Sewer-based sanitation can be replaced by on-site sanitation (OSS), which is more acceptable, economical, and simple to design, build, use, and maintain (Nakagiri et al., 2015; Nakagiri et al., 2016; Manga et al., 2016; Turyasiima et al., 2016; Gold et al., 2018; Junglen et al., 2020; Velkushanova et al., 2021).

The 2030 agenda, which was approved by the UN General Assembly in September 2015, according to Jatana & Currie (2020), set a goal for water and sanitation. Targets of SDG 6's "*access to water and sanitation for all*" goal include safe management of faecal sludge (FS) along the entire value chain, including capture, containment, emptying, transportation, treatment, and disposal/reuse. By 2030, the number of people using properly managed sanitation services, or fewer people using open defecation and more people having access to enough and equitable sanitation and hygiene, is mentioned explicitly in SDG 6.2.1. In many places, particularly in developing nations where 80 to 90% of urban wastewater is untreated

when released, the lack of wastewater treatment poses a severe health and environmental risk (UNEP, 2020).

Target 6.3 promotes reduced pollution, elimination of dumping, a significant increase in recycling and safe reuse internationally, better water quality, wastewater treatment, and both. Target 6A, which calls for expanding water and sanitation assistance to developing countries like Uganda, will support this (UN-Water, 2016; UN-Water, 2018; UN-Water, 2019).

In developing countries, faecal sludge management (FSM) using OSS facilities, which is used to promote sustainability, is receiving much attention. (Koné & Strauss, 2004; Strande *et al.*, 2014; Swaib Semiyaga *et al.*, 2017; Velkushanova *et al.*, 2021).

This is due to a shortage of space to construct new facilities once the old ones fill up (Nakagiri *et al.*, 2015; Singh *et al.*, 2017). However, currently, there is a lack of sustainable FSM, and the material accumulates in containment technologies (Schoebitz *et al.*, 2017; Rwanda Utilities Regulatory Authority (RURA), 2020). As a result, FS is not emptied, collected, and sent to the proper treatment, significantly affecting public and environmental health (Koné and Strauss, 2004; Diener *et al.*, 2014; Von Sperling, 2015).

Presently, the majority of Ugandans living in rural, peri-urban, and informal settlements (slum dwellers) lack access to even the most basic sanitation services (Katukiza *et al.*, 2012; Murungi & Pieter, 2014; WWAP, 2017; Junglen *et al.*, 2020).

More than 1.5 million people live there; about 64% of the urban area and its surroundings are residential. In informal low-income communities, which comprise 10.8% of the entire city, about 60% of the population resides (Tumwebaze *et al.*, 2013). Approximately 90% of the houses use OSSS, 9% are sewer-connected, and 1% utilise open defecation (Hawkins, Blackett & Heymans, 2014). Uganda is aiming for the "Transformation of her Society" to realize Vision 2040, according to the National Development Plan (NDP III) (2020). This is done by

addressing the strategic bottlenecks, such as providing affordable and sustainable sanitation services to the urban poor areas by providing sludge management services, hence achieving the SDGs (GoU, 2015).

Approximately 6.5% of the residential population of Kampala Capital City (Uganda) is connected to the central sewerage system, with the other 93.5% using OSSS and other FS disposal methods, including septic tanks (Ahamada et al., 2016; Swaib et al., 2017).

The critical link in the citywide FSM from household-level users to treatment for resource retrieval and safe end-use or disposal is provided by emptying, collection, and transport services (Murungi & Pieter, 2014). The city and its surroundings legally use the Bugolobi WWTP and Lubigi FSWWTP to discharge its FS for treatment (Schoebitz et al., 2017). The National Water and Sewerage Corporation (NWSC) oversees sewage stabilisation ponds, constructed wetlands, and conventional sewage treatment works are some methods utilised in Uganda to treat sewage and wastewater. The two most popular techniques for drying sludge up to between 50 and 70% in FS are sludge evaporation lagoons and sludge drying beds (SDBs) (Kayizzi, Tomusange & Paskwale, 2012; Velkushanova *et al.*, 2021).

Domestic wastewater and FS from pit latrines and septic tanks are handled separately at the Lubigi plant. Sludge is dewatered to enhance the proportion of solids in the FS. A slight decrease in the water volume in FS causes a significant drop in its volume (Manga et al., 2016). According to Kolečka *et al.* (2017), a 10% rise in dry solid sludge volume drops its initial amount by over 85%. However, the plant still needs to meet the challenges of sand membrane material used to filter the drying beds to continue to get off with dry sludge cakes. Therefore, this research assessed the different membranes used in FS drying at Lubigi to minimise the sand layer takeaway in the sludge drying beds. This was accomplished by identifying the properties of FS, evaluating the effectiveness of 3 alternative drying bed membranes, and optimising the FSDB membrane that would be used in the plant.

1.2 Statement of the Problem

Developing countries, including Uganda, must strengthen their support for water and sanitation by reducing open defecation and boosting access to appropriate and equitable sanitation and hygiene. This can be accomplished by reducing the amount of untreated wastewater by half and significantly promoting recycling and safe reuse (UN-Water, 2018).

The release of untreated liquids and solid waste pollutants in the environment causes an imbalance in the entire ecosystem that impairs the population's health and hygiene. Especially slums and emergency settlements (densely populated areas) produce large volumes of sludge in their onsite sanitation systems (IKA, 2020). Due to their low construction costs from the use of pre-existing raw materials, low water amounts required to operate, and low capacities for water-carried systems, onsite sanitation facilities are used for excreta disposal by more than 75% of the population of Kampala City and the surrounding area (Tumwebaze et al., 2013; Diener et al., 2014). Effective faecal sludge treatment is an increasing concern at the Lubigi plant. Lubigi currently handles 3800 m³/day flow for domestic wastewater and faecal sludge (Gold et al., 2015; Gold et al., 2016). The plant has 19 sludge drying bed units trapezoidal in design for the sludge treatment. Each sludge bed of 7x34 m treats about 71 m³ of sludge at a time. The units have sand (filtering membrane) on top of gravel at their bottoms to dewater the sludge (Lindberg & Rost, 2018). When the liquid infiltrates through layers, water is collected, and the remaining solid sludge in the sludge drying beds takes 4-8 weeks to dry. It is then stored for extra six months to attain the vital moisture and destroy pathogens to make it adequate for reuse (Lindberg & Rost, 2018; Velkushanova *et al.*, 2021). However, the problems of clogging in filter beds, the particle size of the sand filter and mixing ratios of sludge and septage, which lead to long dewatering time and high contaminant loads in the percolate, need to be addressed. Additionally, the plant struggles with sand layer filtering membrane loss due to its continuous peeling off when removing dry sludge cakes. This significantly shrinks the filter media

thickness over time, triggering an often replacement of the sand. This has unceasingly reduced effluent quality due to partial filtration, increased water content remaining in solid sludge and reduced quality of cakes produced as fertilisers. Additionally, the increasing sand content in the sludge cake reduces the calorific value. (Kuffour et al., 2009; Manga et al., 2016).

This research intended to identify and optimise the best-performing locally available bed membrane for use in filter beds to help increase the faecal sludge dewatering efficiency and improve the treatment of vast quantities of faecal sludge generated at Lubigi for better sanitation delivery. This study quantified the effectiveness and efficiency and proposed an alternative filter media to the current bed membrane, hence addressing the current problem.

1.3 Research Objectives

1.3.1 General or Main Objective

To assess different membranes used in faecal sludge drying to minimise the sand layer takeaway in the sludge drying beds at Lubigi Faecal Sludge and Wastewater Treatment Plant.

1.3.2 Specific Objectives

- 1) To characterise layers of faecal sludge cake from the sludge drying beds at the Lubigi faecal sludge and wastewater treatment plant.
- 2) To assess the performance of three different sludge drying beds at the Lubigi faecal sludge and wastewater treatment plant.
- 3) To optimise the best-performing bed membrane in minimising the sand layer takeaway in the sludge drying beds at Lubigi faecal sludge and wastewater treatment plant.

1.4 Research Questions

- 1) What are the characteristics of faecal sludge cake from the sludge drying beds at the Lubigi faecal sludge and wastewater treatment plant?

- 2) What is the performance of the three different sludge drying beds at the Lubigi faecal sludge and wastewater treatment plant?
- 3) What is the performance of the best-optimized FSDB membrane in minimising the sand layer takeaway in the sludge drying beds at the Lubigi faecal sludge and wastewater treatment plant?

1.5 Research Justification

During treatment, sand filters effectively remove organic matter, pathogens, nutrients, and micropollutants from grey water (Katukiza et al., 2010; Katukiza et al., 2012; Katukiza, 2013; Strande et al., 2014). The performance of faecal sludge drying beds includes; the time it takes to dewater, how effectively contaminants are removed, and the rate of solids generation, which are all impacted by the loss of sand material as a filter membrane (media thickness) (Manga et al., 2016). This problem is beginning to create worries at Lubigi Plant. The particle size of sand bed filters and their solid loading rates (Kuffour et al., 2009), the use of greenhouses or mixing FS on beds (Seck et al., 2015), the dewatering of FS using locally produced natural conditioners (Gold et al., 2016), and sand filtering thickness were some limitations that earlier studies on FS dewatering attempted to address (Swaib et al., 2017; Swaib Semiyaga, Frank, et al., 2017).

In addition, other studies have focused on the Lubigi plant, for example, the treatment of FS from pit latrines and septic tanks with lime and urea (Lindberg & Rost, 2018), the impact of filter media thickness on SDB performance (Manga et al., 2016), and the palletisation of FS (Turyasiima et al., 2016). However, little emphasis has been put on assessing different membranes other than the sand layer to address the limitations to mitigate sand loss during dry sludge (DS) removal, resulting in shrunk filter media thickness with time. Consequently, there is a reduced effluent quality due to incomplete filtration, high percolate contaminant load of sludge, and poor quality cakes produced as fertilisers (Manga et al., 2016). Therefore, this research assessed the different membranes used in FSDBs at Lubigi to minimise the sand layer

takeaway by determining characteristics of FS, assessing the performance of three different membranes, and optimising the best performing faecal sludge drying bed membrane to be adopted at the plant.

1.6 Significance of the Study

FS volumes require substantial systems for sustainable management through appropriate treatment to eliminate severe effects on the community and environmental health, thereby contributing to SDGs in Uganda. Therefore, undertaking this study has to improve understanding of the current dynamics and characteristics of FS dewatered at Lubigi Plant. It gives a detailed insight into alternative materials that can be used in SDB as efficient filter membranes. The findings established management strategy and practice to guide decision-makers on whether to change the filter media (sand) currently being used at Lubigi. The results could be translated to other faecal sludge and wastewater treatment plants constructed in Uganda.

1.7 Project Scope

1.7.1 Content scope

This research assessed the characteristics of FS in the SDBs at Lubigi FSWTP. Three different FSDB membranes at Lubigi FSTP were considered, and their performance was assessed to determine their levels of performance (dewatering) concerning treating sewage. It was based on the quantity of water (leachate) or moisture remaining in solid sludge (cake) after discharge of the effluent (treated water) from the facility through an experimental study on-site (at the Lubigi plant). Finally, of the three membranes tested, the best-performing layer membrane was optimised to establish its efficiency extents in FS treatment at the plant.

1.7.2 Geographical scope

The study was conducted at Lubigi FSWTP, located in Kawempe Division, Northern part of Kampala District- Uganda. The plant is at latitude 0.347518°N and longitude 32.546511°E along the Kampala – Northern Bypass Highway.

1.7.3 Time scope

This research was conducted for one year, from September 2021 to September 2022.

1.8 Conceptual Framework

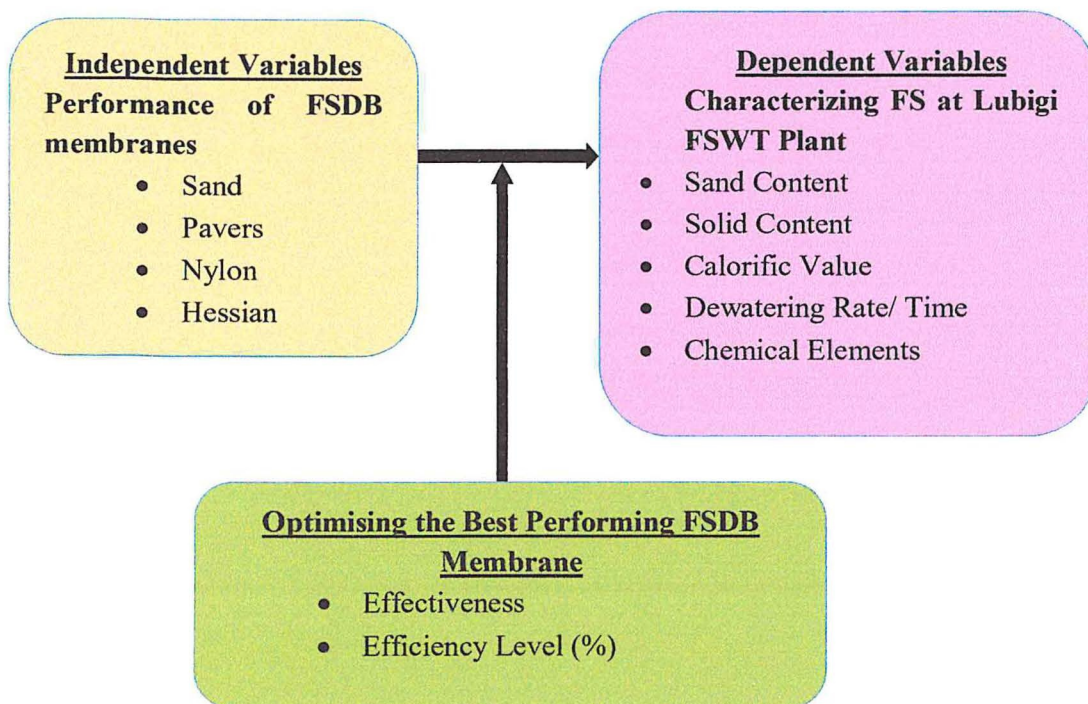


Figure 1-1: Conceptual framework of the research

1.9 Chapter Summary

Several chapters make up the thesis. There are five (05) chapters in all. Chapter One provides the study's issue statement, objectives, the significance of the research questions, and the study scope. The literature review in Chapter Two covers an overview of FSM, FS features, management tools, and the effectiveness of each. While Chapter Three provides information on the materials and procedures employed in this study. Chapter Four provides specifics on the

research findings and the discussion of outcomes. Finally, Chapter Five concludes and offers advice based on the study findings.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Faecal Sludge Management (FSM)

A safe final use or disposal of faeces is referred to as "faecal sludge management," which includes the storage, collecting, transportation, and treatment of the waste (Strande et al., 2014; Getahun et al., 2020). FS is broadly described as anything that builds up in OSSS and isn't expressly transferred through a sewer. It comprises excreta and everything else that can be put into an on-site containment system, including flush water, menstrual hygiene products, cleaning agents, grey water (bath or kitchen water, which includes fats, oils, and grease), and solid waste. FS is, therefore, highly variable, with a wide range of amounts (i.e., created and accumulated volumes) and qualities (i.e., features) (Seck et al., 2015; Getahun et al., 2020). With the rapid and exponential population expansion, urbanisation, rapid industrialisation, and changes in consumption, the output of wastewater and faeces sludge is rising (Ademiluyi & Eze, 2008; UNEP, 2020).

FSM is becoming more difficult globally, especially in developing nations' urban centres, because of inadequate FS treatment technology and infrastructure (Singh *et al.*, 2017; Swaib Semiyaga, Okureb *et al.*, 2017). These have increased the amount of FS produced and deposited in urban areas, causing cities to continue to be polluted and waste more water (Manga et al., 2016).

It is estimated that more than 2.7 billion people rely on OSS facilities for their basic sanitation needs, and by 2030, that number will rise to 5 billion (Strande et al., 2014). Only 65 to 100% of urban people in Sub-Saharan Africa are supplied by OSS methods other than sewer systems (Swaib et al., 2017). Due to the lack of dilution afforded by water-borne sewerage sanitation

infrastructure, these systems can produce significant volumes of highly concentrated FS material (Koné & Strauss, 2004; Hawkins, Blackett & Heymans, 2014).

However, difficulties such as excessive reliance on financial help for building wastewater and FSTPs, low user income generation, subpar operation and maintenance, and ineffective institutional structures limit the viability of sustainable FSM (UNEP, 2020). There are occasionally inadequate technical criteria for the building of facilities. In certain civilisations, the advantages of sustainable waste management are exclusively available to members of a particular socioeconomic class (Ahmed et al., 2019; Nikiema et al., 2020).

In Kampala City and its environment, only the Bugolobi WTP or the Lubigi FSWTP, operated by the NWSC, are authorised to accept FS for treatment (Kampala Capital City Authority (KCCA), 2018). Dewatering (or "thickening") FS is a crucial treatment goal to increase the proportion of solids in the FS since it significantly reduces volume, lowers the cost of conveying water weight, and simplifies future treatment stages (Strande et al., 2014; Seck et al., 2015). The volume of water in FS drops dramatically with a slight decrease in water volume. For instance, a 10% increase in dry sludge solids results in an almost 85 % reduction in the initial volume of sludge (Kolecka et al., 2017; Junglen et al., 2020; Septien, 2020).

2.2 Composition and Characteristics of Faecal Sludge

2.2.1 Composition of FS

The components of FS depend on, among other things: nutrition, way of life, customs, health, and cultural norms of people who use sanitary facilities (Still and Foxon, 2012; Swaib et al., 2017). FS, as defined by Lindberg and Rost (2018); Nikiema et al. (2020); UNEP (2020), is a combination of human excreta (faeces and urine), water, solid materials (anal cleansing material such as toilet and other papers, water, rags, plastics, and stones), flushing water (fresh water, grey water), and hazardous waste (disposable baby diapers, broken glass, chemicals,

sharp metals, pads, and condoms (Still and Foxon, 2012; Bassan et al., 2013; Gold et al., 2016; Turyasiima et al., 2016; Schoebitz et al., 2017; Swaib et al., 2017; Gold et al., 2018).

The constituents of FS often fall into one of three categories: solids, nutrients, or harmful microbes (Lindberg and Rost, 2018). Solids can be suspended or dissolved, and they can be either organic (volatile) or inorganic (fixed) (Bassan et al., 2013). Domestic wastewater contains phosphorus, nitrogen, and potassium nutrients from faeces and urine (Lindberg and Rost, 2018). The bacteria, viruses, protozoa, and helminths that comprise the pathogenic microorganisms covered by FS can be found in raw faeces, final effluent, and water habitats (Bassan et al., 2013). Faecal treatment failure or incompleteness can result in germs that endanger human health (Dias, Ebdon and Taylor, 2018). As a result, the consistency of FS is affected by its elements, which in turn impacts its features (Swaib et al., 2017).

2.2.2 Characteristics of FS

FS characterisation is necessary to correctly size and configure treatment processes (Junglen et al., 2020). This is because the design of treatment plants' FSM systems depends on having a thorough understanding of the FS features, but such knowledge needs to be improved (Ahmed et al., 2019). Measuring and assessing FS qualities is known as FS characterisation (Velkushanova et al., 2021). The characteristics of FS might fluctuate significantly depending on the environment and kind of facility (Strande et al., 2014). They rely on several variables, including their source, groundwater infiltration, frequency of emptying, user habits, constituent materials, and the type and location of sanitation facilities (Still and Foxon, 2012; Strande et al., 2014). For the development, design, implementation, and operation of FSM solutions, it is essential to comprehend the nature of the physical, mechanical, thermal, biological, and chemical group of features of FS (**Table 2-1**) (Strande et al., 2014). Understanding biochemical processes of degradation and nutrient cycling, monitoring treatment effectiveness and pathogen removal, calculating loadings for the design and operation of a treatment plant, choosing the

best technology for emptying sludge from on-site containments, and assessing the potential for resource recovery are some common reasons for characterising FS (Velkushanova et al., 2021). Following user practices, moisture content, and groundwater level where the system is located, Strande et al. (2014) found that the chemical and physical features of FS vary inside and between various OSSS as well as between sites (Seck et al., 2015; UNEP, 2020; Nikiema et al., 2020).

Previous studies on the characterisation of FS have mainly concentrated on agricultural use and environmental protection characteristics, such as total solids (TS), total volatile solids (TVS), nutrients, and pathogen indicators. This study will explore novel end uses for variables such as calorific value (CV), moisture or water content, and grit and sand content. This is so that FSM, which includes treatment, discharge, and end-user disposal, can promote safe public and environmental health. Dewatering, pathogen inactivation, stabilisation of organic matter and nutrients, and safe end-use or disposal are some of the objectives targeted by treatment.

Table 2-1 shows the variation in FS characteristics considered for this research within FS attributed to the abovementioned factors.

Table 2-1: Important parameters for FS characterisation at Lubigi FSWTP

Group of properties	Property analytical test	Equipment/method	Reason/ Importance
Physical and mechanical	Particle size distribution (>5mm) – Sand content	Wet sieving rig; Sieve shaker Set of sieves for dry and wet sieving.	Pit emptying equipment & mechanical process design.
	Particle size distribution (<5mm) – Sand content	Malvern particle size analyser	Pit emptying equipment & mechanical process design.
Thermal properties	Calorific value (MJ/kg)	Calorimeter	Combustion, heating potential
Chemical properties	Moisture content (%). Total dry solids (mg/L).	Oven 105 °C	Migration of pathogens. Biodegradation potential. Determining appropriate emptying methods for on-site containment technologies, loadings of technologies (mechanical behaviour) e.g., drying beds and settling-thickening tanks (mixing, drying, flowing, viscosity, combusting). Evaluating dewatering and drying performance.

(Source: Strande et al., 2014; Velkushanova et al., 2021)

2.2.2.1 Moisture or Water Content

Fractions of moisture content are crucial to properly load technologies like drying beds and settling-thickening tanks, determining appropriate emptying techniques, and assessing the

effectiveness of dewatering and drying processes (Velkushanova et al., 2021). According to Lindberg and Rost (2018), moisture in the sludge affects how long *Ascaris* eggs and larvae survive. The eggs can be viable or not, and the viable ones will eventually hatch into larvae. The best drying and dewatering techniques must be chosen based on knowledge of the moisture distribution within sludge and understanding the bond strength (boundedness) of the moisture to the solid (Getahun et al., 2020). Therefore, moisture concentration influences the solid-liquid separation and dewaterability potential, permeability, viscosity, shear thinning, mixing, and drying, as well as the biodegradability and viscosity of FS directly and indirectly (Velkushanova et al., 2021).

2.2.2.2 Sand Content

The concentration of sand in the TS of an unfiltered FS sample is known as sand content (measured as silica as an indication of soil content in FS). Sand can impact FS treatment procedures (such as dewatering), increase mechanical equipment abrasion, and impact the calibre of the finished FS treatment products (Strande et al., 2014; Velkushanova et al., 2021). According to Strande et al. (2014), sand concentrations should be considered when treating FS. With sand placed on top of the gravel, drainage is improved, and clogging is avoided since the sludge is prevented from settling in the pores of the gravel. Sand must have a specific diameter because sand with a greater diameter (1.0-1.5 mm) might cause organic matter to accumulate very quickly, raising the danger of clogging. This risk is minimised using sand with a smaller diameter (0.1-0.5 mm) (Kuffour et al., 2009).

Unlined pit latrines, cleaning and washing of vegetables and utensils, cleaning (such as sand walking into the house), and flooding are some sources of sand in FS (Junglen et al., 2020). Sand is a key design and treatment issue in locations where the FS is prevalent (Swaib et al., 2017; Velkushanova et al., 2021). Sand traps should be fitted to pipes and sinks at entry locations to lower the sand content (Kuffour et al., 2009; Strande et al., 2014). Kuffour (2010)

shows that sands for municipal anaerobic digester effluent dewatering beds should preferably have a uniformity coefficient of less than four and an effective diameter between 0.30 and 0.75 mm (Tayler, 2018). According to Kuffour et al. (2009), there is an association between the rate of clogging and the accumulation of organic debris on the sand. A bed filled with sand with bigger particle sizes is more prone to clog, necessitating replacement because organic matter accumulates more quickly on the sand with larger particles.

2.2.2.3 Calorific Value (CV)

A crucial factor in using dried sludge as a fuel source is its calorific value, which is influenced mainly by the temperature at which it is being dried. It is the finished good's physical and chemical properties (dry sludge) (Septien et al., 2020; Getahun et al., 2020).

Traditional options for sludge treatment and disposal are limited by rapid sludge formation. Anaerobic digestion, composting, and other options for sewage sludge treatment and disposal that have relatively modest conversion rates might not be practical for quick sludge processing. Therefore, it is crucial to understand the value of waste and how it might be used in other ways (IKA, 2020).

Faecal sludge's CV determines whether it may be recycled and used as biofuel. Therefore, the loss in volatile solids content in the FS can be linked to decreased calorific value. According to reports, FS has a calorific value of 17 MJ/kg solids in Kampala, Uganda, compared to the average coal calorific value of 26 MJ/kg (Muspratt et al., 2014). Similar to the range of 8.0 to 23 MJ/kg dry solids shown with bio-solids (Getahun et al., 2020). In addition, Ahmed et al. (2019) found that the CV for both dry and wet sludge ranges between 15.16 MJ/kg and 18.31 MJ/kg. Therefore, the ultimate goal of measuring the gross CV of the FS is the conversion of waste materials into reusable products that finally lead to a healthier and more hygienic environment (IKA, 2020). (Muspratt et al. (2014) assert that drying concentrates the energy in the sludge by eliminating the water and raising the calorific value, which turns the sludge into

a suitable combustible fuel (Ahmed et al., 2019). This drying can be possible through appropriate methods of dewatering, i.e., drying beds with an optimised drying bed membrane which is the aim of this research.

2.3 Sludge Drying Technology and Performance of Filtering Membranes or Media

2.3.1 Sludge Treatment Technology and Methods

There are physical (dewatering), biological (microorganism metabolism), and chemical (alkaline stabilisation) ways to treat sludge (Strande et al., 2014; Velkushanova et al., 2021). For the treatment of FS, various technological alternatives are available (more precisely, dewatering or thickening) (Velkushanova et al., 2021). At NWSC Lubigi, FS is now dried and dewatered using drying beds as the technology (Gold et al., 2015; Ziebell et al., 2016; Turyasiima et al., 2016). According to Ademiluyi & Eze (2008), the other techniques to reduce sludge volume depend on natural phenomena, such as evaporation, percolation, temperature, wind velocity, precipitation, or rainfall. These include, among others, natural sludge drying beds, lagoons, oxidation ponds, and oxidation ditches (Ademiluyi and Eze, 2008).

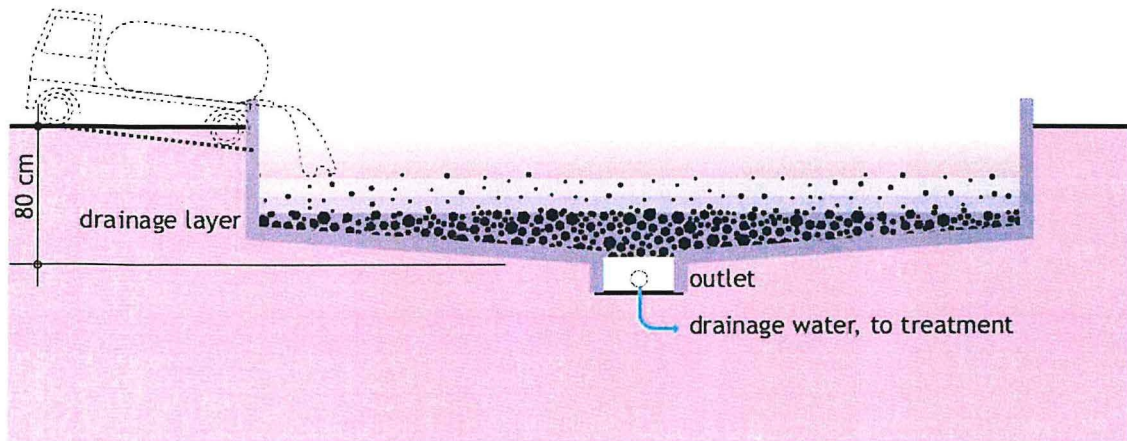
According to Strande et al. (2014) and Velkushanova et al. (2021), stabilisation, nutrition control, pathogen inactivation, and dewatering/drying are the main therapeutic goals of FS. According to the treatment's goals and place in the chain, certain FS features should be detected throughout treatment (Strande et al., 2014; Robbins and Ligon, 2015; S. Semiyaga, Okure, et al., 2017; Tayler, 2018; Narayana, 2020; Velkushanova et al., 2021).

Initial segregation, settling-thickening tanks, drying beds, leachate treatment in stabilisation ponds and co-treatment with wastewater, resource recovery, and disposal of the dewatered sludge are all components of a typical FS treatment chain (Klinger et al., 2019; Velkushanova et al., 2021). This is a crucial distinction since the dewaterability of various forms of sludge is affected by their vastly diverse features and incompatibilities (Bourgault, Shaw and Dorea,

2019; Ward et al., 2021). The amount of sludge drains down as a liquid (or leachate) varies depending on the FS characteristics and must be collected and treated before discharge (Strande et al., 2014). Since the less stabilised sludge frequently clogs filters, it must be dewatered more quickly than the more stabilised one (Ward et al., 2019).

2.3.2 Sludge Drying/Dewatering Beds (SDBs)

Sludge is frequently dewatered using an SDB, which uses filtration and evaporation (Von Sperling, 2015; Singh et al., 2017; Tayler, 2018). To efficiently receive and treat incoming sludge from primary or secondary treatment facilities, SDBs are typically located next to treatment plants (Koné and Strauss, 2004; Katukiza et al., 2010; Still and Foxon, 2012; Singh et al., 2017; Gold et al., 2018). SDBs (mostly the unplanted) have low walls, a layer of sand on top of the gravel, and an underdrain system to collect any liquid that percolates through to the beds (Ward et al., 2019). Dewatering sludge is their primary duty to separate the liquid from the particles (Tayler, 2018). Sludge drying is the primary treatment method used in many current treatment facilities. With or without preliminary screening, the arriving wet FS and septage are dumped onto SDBs to a depth of around 200-300 mm (Strande et al., 2014; S. Semiyaga, Okure, et al., 2017; Tayler, 2018; Ward et al., 2019). Figure 2 1 shows the components of the bed, which include the I support layer (bricks and coarse sand), (ii) drainage medium (fine to coarse sand followed by fine to coarse gravel), and (iii) drainage system (open or perforated pipes) (Von Sperling, 2015).



(Source: Strande et al., 2014; Von Sperling, 2015)

Figure 2-1: Schematic overview of an unplanted SDB

There are two guiding concepts for the drying process. Leachate percolates through sand and gravel as the first rule. This procedure is vital for dealing with sludge with much free water and is relatively quick, taking only a few hours to a few days. The second phase removes the bound water portion, evaporation, which usually takes days to weeks to complete (Strande et al., 2014; Manga et al., 2016; Turyasiima et al., 2016). Strande et al. (2014) found the removal of 50 to 80% by volume due to drainage and 20 to 50% due to evaporation in drying beds with FS. This range is common for sludge that contains a large quantity of free water, although more bound water causes more evaporation and less percolation.

Once the flow of percolation from the drying bed and evaporate from the surface stops, dewatering is deemed complete (Gold et al., 2018; Lindberg and Rost, 2018; Tayler, 2018). Based on a preferred time scale, the percolate volume collected from each drying bed and the total number of days needed to completely dewater the sludge are monitored and recorded, respectively (Strande et al., 2014; Tayler, 2018; Velkushanova et al., 2021). Finally, it is simple to remove the dewatered sludge from the drying beds (Ademiluyi and Eze, 2008; Seck et al., 2015; Gold et al., 2018). In some cases, the percolate is further treated in ponds though it needs a large land area (Nikiema et al., 2020). The dry sludge (dewatered) can either be removed to

a landfill or disposed of locally, sold and transported to the end users for further treatment (Muspratt et al., 2014; Manga et al., 2016; Lindberg and Rost, 2018; UNEP, 2020). It has various recycling options and can be used by farmers as a soil conditioner (Diener et al., 2014; Gold et al., 2015; Gold et al., 2016; Nikiema et al., 2020).

Due to the current development in industrialisation and urbanisation, land that may be used for drying beds is becoming increasingly difficult. Therefore, given the small sizes that may be designed due to land issues, the beds should be more efficient to accommodate the available FS (Ademiluyi and Eze, 2008).

2.3.3 Filtering Membranes or Media

Several filter media can be used in SDBs during dewatering. These include sand, pavers, nylon, and hessian (Aydilek and Edil, 2002). When building drying beds, layers of used washed sand and gravel are placed on the drainage system to prevent fine particles from clogging the bed (Strande et al., 2014). As a support, gravel layers usually are two or three layers thick and have two distinct gravel sizes. The diameter size distribution in the layers was created to prevent clogs from washing small particles into the drain. The intermediate layer comprises finer gravel with a diameter between the coarse gravel and the upper sand layer, typically 5-15 mm, and the lower layer typically contains coarser gravel with a diameter of roughly 20 to 40 mm (Strande et al., 2014; Muspratt et al., 2014). A layer of sand covers the gravel. The sand layer improves drainage and avoids clogging because it prevents sludge from settling in the gravel's pore spaces. The size of the sand is vital because larger-diameter sand (1.0-1.5 mm) can cause organic matter to accumulate relatively quickly, increasing the likelihood of blockage. Using sand with a smaller diameter (0.1-0.5 mm) lowers the risk (Kuffour et al., 2009).

Compared to drying beds, geotextiles are permeable fabrics that may be more effective at dewatering sludge (Guimarães, Urashima and Vidal, 2014; Ziebell et al., 2016). Among others,

they include nylon and hessian, which have been discovered to be efficient before loading due to effective separation (Turyasiima et al., 2016; Gold et al., 2018). However, due to their high price, their application in developing nations is restricted. They have been employed in numerous nations to dewater sludge from various sources (such as wastewater treatment and aquaculture) (Turyasiima et al., 2016; Ziebell et al., 2016). As a result, the properties of the geotextile and the FS were connected in this investigation.

Additionally, to venture into the use of paver blocks to create an eco-friendly environment under waste management has been explored in many industries. Paver blocks are used in construction in vast applications such as street roads, walking paths, and fuel stations (Velumani and Senthilkumar, 2018). Therefore, in this research, an innovative attempt has incorporated pavers in the dewatering of FS.

2.3.4 Performance Indicators of Membranes

According to Strande et al. (2014), any sludge treatment system's or technology's performance effectiveness is often assessed based on the amount of water present, the amount and type of nutrients present, as well as the degree of stabilisation and pathogen eradication of the treated sludge (Velkushanova et al., 2021). This is because meteorological and environmental factors, specifically humidity, evaporation, temperature, and precipitation, greatly influence how well the sludge drying beds perform (Manga et al., 2016). The type of membrane and type of sludge are other considerations. When low temperatures and high humidity are present during the dewatering periods, lengthy dewatering times are seen (Manga et al., 2016; Swaib et al., 2017). This research evaluated the performance of sand, pavers, nylon, and hessian SDB membranes based on dewaterability rate and extent.

2.3.4.1 Sludge Dewatering

Sludge dewatering, or solid-liquid separation, removes water from sludge for better handling and reuse. This is done by evaporating the water from the sludge or filtering it through the drying media by gravity-utilising tools like sand beds (Strande et al., 2014). The water distribution in the sludge determines the dewatering rate (Ademiluyi and Eze, 2008; Swaib et al., 2017). Therefore, the total solids (TS) concentration is typically used to gauge dewaterability. For FS treatment plants (FSTPs), TS (or dry matter) is a crucial design factor (Strande et al., 2014). By treating sludge on SDBs, it is possible to treat sludge in tropical areas to attain dry matter (DM) percentages of 20 to 35% (Koné & Strauss, 2004; Ademiluyi & Eze, 2008).

Since over 90% of FS mass is made up of water, dewatering is one of the biggest obstacles in FS treatment, which raises transport costs and impedes resource recovery. Dewatering relies on physical processes such as gravity, surface charge attractions, centrifugal force, filtration, evaporation, evapotranspiration, and pressure (Gold et al., 2015; Gold et al., 2018). The goals of sludge dewatering are to (i) lower the cost of transportation to the final disposal sites; (ii) enhance handling conditions; (iii) increase the calorific value of the sludge by removing water to prepare it for incineration; (iv) decrease the volume of the sludge for disposal in a landfill or for recovery or reuse; and (v) lower the amount of leachate that is produced when the sludge is disposed of (Wang, Shamma and Hung, 2007; Katukiza et al., 2010; Katukiza, 2013; Von Sperling, 2015). Therefore, faecal sludge (FS) dewatering is essential for adequate FS management. However, thorough knowledge of the filtering media's role in FS dewatering performance is limited.

2.4 Optimisation of Performance of Filtering Membranes or Media Dewaterability

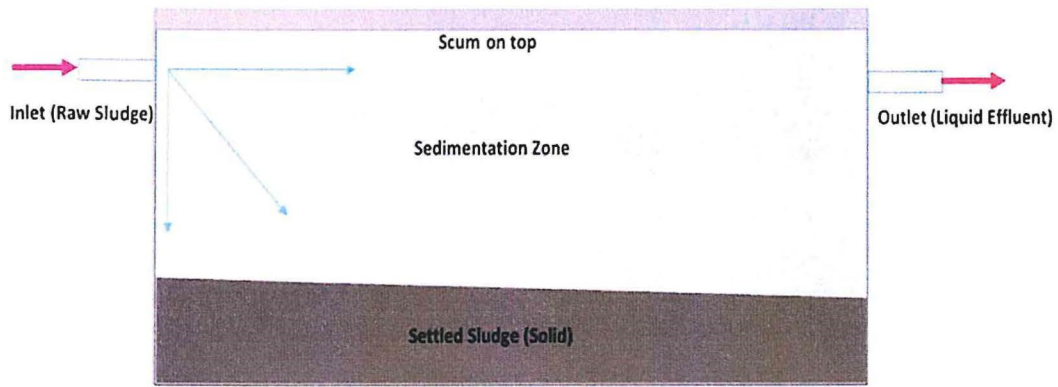
2.4.1 Dewatering Rates of FS

Dewatering is one of the most crucial elements in the treatment process; hence dewaterability is crucial for the operation of treatment plants (Ademiluyi and Eze, 2008; Seck et al., 2015;

Von Sperling, 2015; Velkushanova et al., 2021). Time spent dewatering on drying beds or geotextiles (such as capillary suction time (CST)) is one of its main metrics (Velkushanova et al., 2021). Capillary suction time (CST), a measure of dewatering, is the rate at which water is released from sludge (APHA/AWWA/WEF, 2017). It is utilised as an indicator of the effectiveness of numerous FS dewatering techniques, such as the effectiveness of geotextile and sand filtration and dewatering time on drying beds (Wang et al., 2007; S. Semiyaga, Okure, et al., 2017; Ward et al., 2019; Velkushanova et al., 2021). The amount of "bound water" remaining in the sludge cake following a dewatering procedure and the ease with which the sludge can be filtered are two factors that can be used to determine a sludge's dewaterability (Chen, Lin and Lee, 1996; Bassan et al., 2013; Gold et al., 2018). Therefore, this study quantified and compared the dewatering performance of various filtering media in SDBs built at Lubigi. This was done to suggest the optimal filter media for the plant's potential future use, should it be adopted.

2.5 Current FS Treatment and Management at Lubigi FSWTP

Both residential wastewater and FS from pit latrines and septic tanks are treated at the Lubigi FSWTP in Kampala, Uganda (Schoebitz et al., 2017; Kampala Capital City Authority (KCCA), 2018). It has a 5,400 m³/day capacity and a 3,000 m³/day present flow. Drying beds are the technology being employed for FS dewatering and drying at NWSC Lubigi (Strande et al., 2014; Turyasiima et al., 2016). For the FS treatment, there are 19 drying beds at the plant. The 7x34-meter bed can simultaneously treat almost 71,000 litres of FS (Lindberg and Rost, 2018). Wastewater and sludge are treated separately during waste handling, so the SDBs contain only pure FS (Ziebell et al., 2016; Nkurunziza et al., 2017). The primary (screening and grit removal) and secondary (sedimentation and dewatering) treatment phases are the two steps used to treat FS (Strande et al., 2014; Gold et al., 2015)



(Source: Velkushanova et al., 2021)

Figure 2-2: A schematic of the sedimentation tank where gravitational forces separate the accumulating FS.

Sedimentation at the Lubigi plant (Figure 2-2) lasts three months. Sludge builds up in the tanks during the first month and is continuously pushed to the drying beds during the next month as the beds are simultaneously loaded with fresh incoming sludge. The tank is left filled for the third month to allow the sludge to settle (Schoebitz et al., 2017; Lindberg and Rost, 2018). The retention time (period) for effluent (drained water) (Tayler, 2018) is given three days (Lindberg & Rost, 2018) before it's moved to anaerobic ponds where it is co-treated together with the wastewater (Bahri, Drechsel & Brissaud, 2008; Still & Foxon, 2012; Narayana, 2020). The settled FS is then pumped to the SDBs (Lindberg & Rost, 2018).

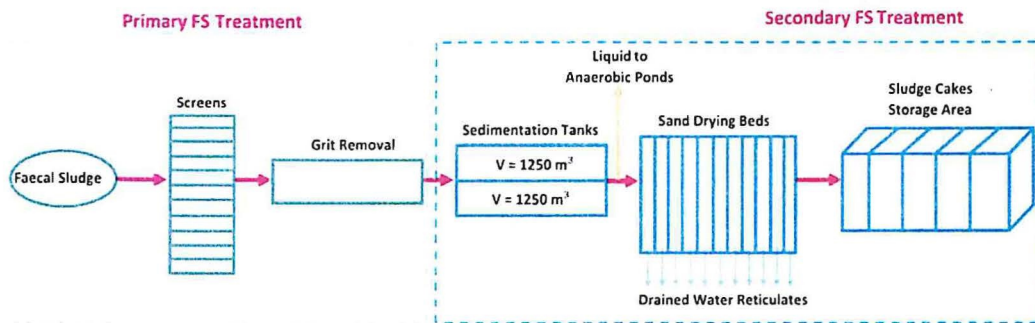


Figure 2-3: The FS treatment line at Lubigi FSWWTP in Kampala, Uganda

For now, dewatering SDBs at Lubigi treat FS physically; the major processes are evaporation and drainage, which raise the concentration of solids. The solid particles stay in the bed tanks to the filter of sand and gravel at the bottom, which allows liquid (leachate) to percolate and the drained water to be collected. However, the sand layer used as a filtering membrane at the Lubigi plant in the SDBs continues to peel off during the dry sludge cake removal process. This has significantly decreased the reduced effluent quality over time due to partial filtration with a very high percolate contaminant load of sludge as higher sand and water percentage remain in solid sludge (cakes) hence the main driver of this research.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Introduction

This chapter presents both quantitative and qualitative methods employed for the various specific objectives of the study. It contains the description of data including raw/fresh FS volumes, characteristics of FS at Lubigi Plant and historical efficiency level of SDBs Lubigi plant. It also covers the methodology for characterising layers of FS from the DBs, assessing the performance of different DB membranes through experimental set-up data analysis and processing and optimising the best-performing FSDB membrane at Lubigi STP.

3.2 Study Area

The study area is situated in Kampala, the capital of Uganda, an African nation in the east, 45 km north of the equator, at approximately 0°15N and 32°30E Kampala. The Lubigi Catchment is located in Kampala's northwest. On Kampala's northern and western suburbs, the Lubigi catchment is made up of hilly and low-lying valleys, with elevations between 1154 and 1306 m ASL and slopes between 0° and 45°. From Kisaasi to the north and extending westward, passing through Bwaise and Kawaala, before extending southward through Busega, Lubigi creates an atypical semicircle that encircles Kampala City. Along the Kampala - Northern Bypass Highway, the Lubigi Faecal Sludge Wastewater Treatment Plant is in the Lubigi Catchment at latitude 0.347518°N and longitude 32.546511°E. (Figure 3-1).

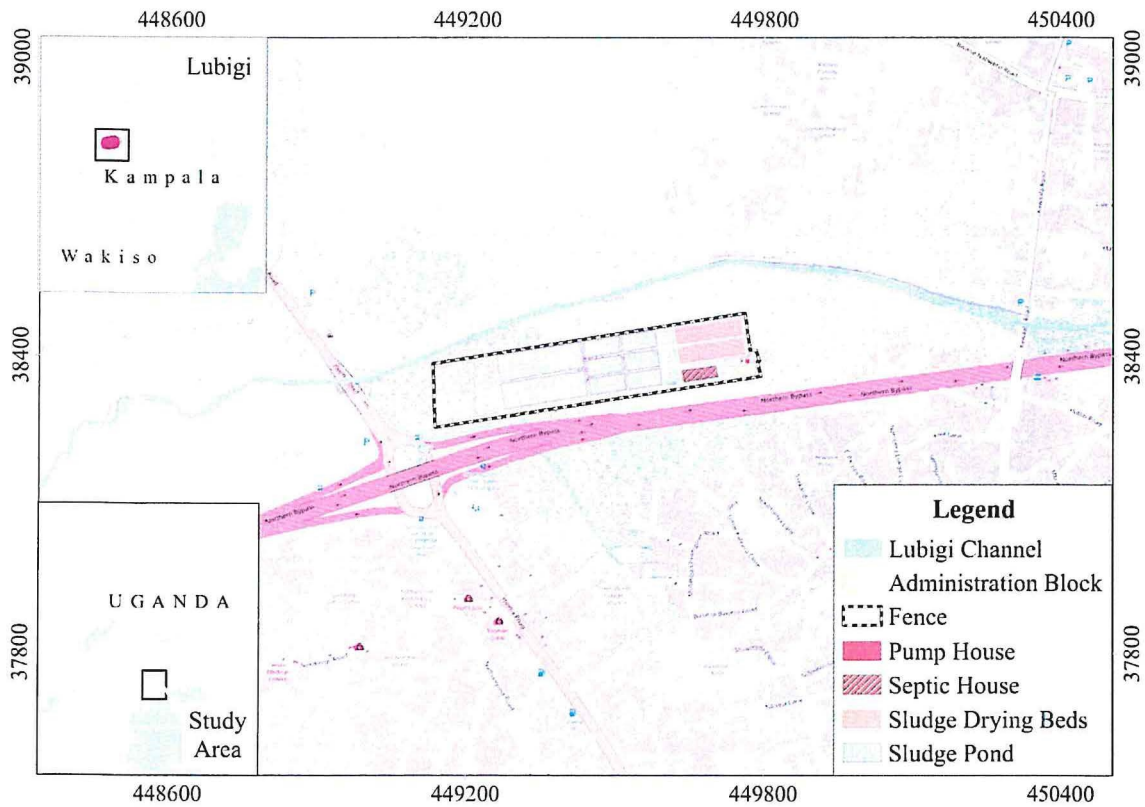
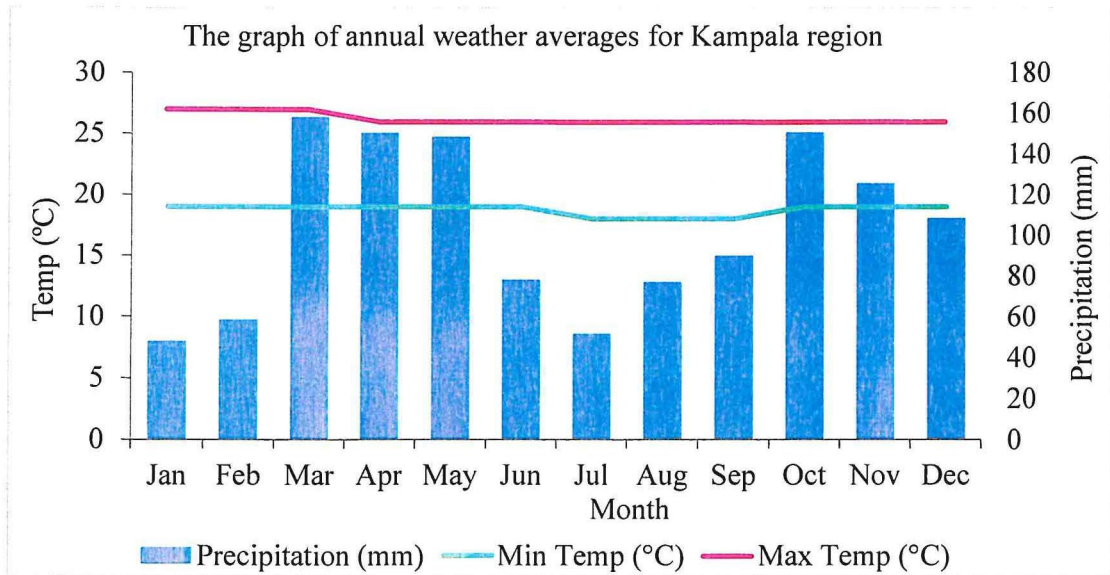


Figure 3-1: Location map of Lubigi FSWWT

3.3 Weather and Climate

The tropical climate of Kampala is marked by high average precipitation of 103.4 mm each. Due to the high evaporation rates from Lake Victoria and the consistent winds that blow through the country from east to west throughout the year, the annual rainfall totals range from 1200 mm to 1700 mm. The two wettest periods are from March to May and October to November (Figure 3-2). The region experiences highs of 27 °C, a mean temperature of 23 °C, and lows of 18 °C all year. Dew point and humidity are consistently 80% and 19°C, respectively. The pressure is 1018 bar (at 1230 m altitude), the average wind speed is 15 km/h, and the average atmospheric visibility is 11 km.



Source: Yusuf *et al.* (2021)

Figure 3-2: The annual climatic condition of the Kampala region

3.4 Data Sources and Materials

3.4.1 Data Sources

To achieve the study objectives, two types of data were used. They included primary (on-site at Lubigi) and secondary data of records from NWSC at the plant. Primary data included the: (i) dry FS cake extracted from the established sand SDBs at Lubigi that was used to characterise the layers of FS; raw/fresh FS from trucks delivering it to the plant (used in the experiment) and (iii) experimentally logged percolate (dewatering rates) data, both done on-site. Secondary data comprised historical percolate rates, characteristics of solid FS cakes from the operating sand SDBs at the plant and their efficiency levels (SDBs).

3.4.2 Materials

Table 3-1 shows the materials used in the experiment research, included

Table 3-1: Materials used in the research experiment

Material/Tool	Material/Tool
Spade	A pair of scissors
Four buckets	Masking and seal tapes
Plastic cup (0.5 ltrs)	Hacksaw
4-meter rulers (1m long) and one small transparent ruler	¼ of roofing iron nails
Three permanent makers	Manilla papers
Five pairs of gloves	Four big and small measuring cylinders
Spade	A pair of scissors

3.5 Characterization of FS Cakes from the SDBs at Lubigi FSWTP

3.5.1 Scooping Sample from the SDB

The study was conducted at Lubigi FSWTP in Greater Kampala Metropolitan Area (GKMA). A dry FS sample was collected from the existing and operating (reference) sand drying bed with the help of a plant operator using a spade on 25th February 2022. This was done to avoid deforming the sludge layers, which would have affected the typical results and getting to the bottom of the sand-filled bed. The reference drying bed is shown in Figure 3-3 (a) five weeks after filling, and in Figure 3-3 (b), dried cakes are manually removed from the SDB for resource recovery.

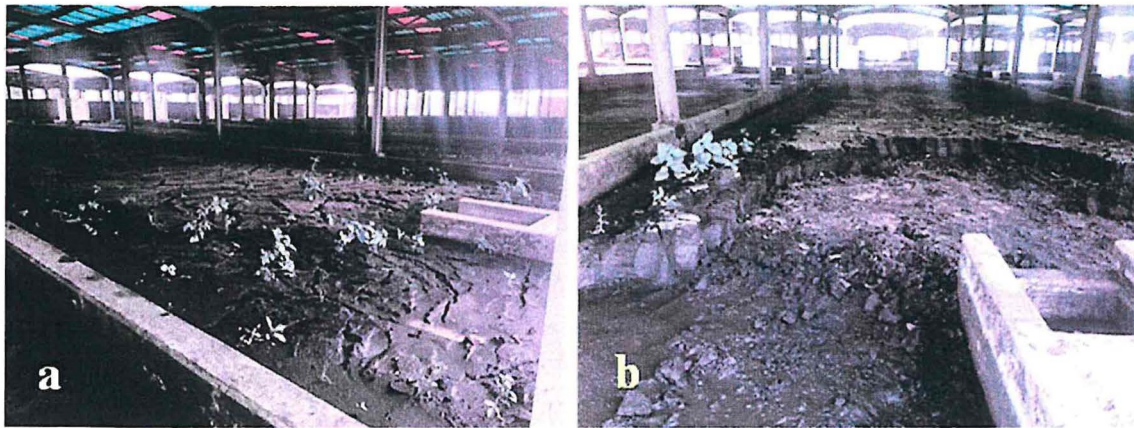


Figure 3-3: Existing (reference bed) at Lubigi Plant five weeks after filling, where a cake was scooped to characterise the sludge.

3.5.2 Characterization of the Sample

The samples from the existing FSDBs were taken to the laboratory for characterisation at the Makerere University - CEDAT laboratory. Raw FS was characterised and analysed for both chemical and physical properties. Based on the standard operating procedures created by the Pollution Research Group, the composition structure of the FS cake was identified starting with the top layer (PGR, 2015; Septien et al., 2020). These characteristics or properties potentially influence the drying bed's dewatering performance (treatment) (Strande et al., 2014; Gold et al., 2018) since they impact or influence FS treatment, design, and disposal.

Raw FS from the existing FSDBs at Lubigi FSWWTP was characterised and analysed for chemical properties, including; Carbon (C), Nitrogen (N), Oxygen (O), Sodium (Na), Magnesium (Mg), Aluminium (Al), Silicon (Si), Calcium (Ca) and Molybdenum (Mo). These were analysed by visual observation under the electronic microscope (PRESIDE-ZEISS-SmartEDX electron scanning microscope (ESM)) (Figure 3-4). This utilises the scanning electron microscopy (SEM) technology while considering the periodic table's K and L-line energy values (bands)dic table.

The ZEISS SmartEDX is a dedicated microanalysis solution for routine analytical applications that uses Energy Dispersive Spectroscopy (EDS) to collect spatially resolved elemental data from given surfaces. This allows workflow-guided solutions to improve workflow repeatability in multi-user environments. The higher transmissivity of the silicon nitride window on its X-ray detector allows for optimised detection of low-energy X-rays from light elements and 129 eV intensity peak (energy) resolution. The ESM provides a high vacuum environment in the specimen chamber to prevent the primary electron beam from being scattered. Beam scatter reduces the elemental chemistry data's spatial resolution. It raises the primary beam's acceleration energy to up to 30 kV for the best signal-to-noise ratio of the peaks in the X-ray spectrum. It uses fixed X-ray intensity values for the various X-ray energies from elemental standards along with the industry-standard ZAF correction algorithm for the interference effects of atomic number (Z or R), absorption (A), and fluorescence (F) (referred to as standardless analysis).

The entire operation procedure of the electron scanning microscope included the following:

- a) **Sample sticking:** This involved selecting a sample holder, sticking black tape onto the sample holder, sticking the sample onto the black tape and blowing off excess sample materials.
- b) **Sample coating:** This involved placing the sample in the vacuum space of the sample coater, selecting the coating material (Carbon, Chromium or Gold), fixing the coating material in the coater, closing the coater and pumping the vacuum, selecting the appropriate application and your sample and releasing the vacuum and pick the sample.
- c) **Sample holding:** included fastening the sample holder on the sample rack and place on the Scanning Electron Microscopy (SEM) stage, opening the intelligent camera, capturing and storing a live image of the sample rate, sample scanning, closing the SEM

door and pump the vacuum to 1.5×10^{-5} Torr, turning on the Gun and turning the high electron tension (EHT).

- d) **Detector selection** (in-lens, SEM2, BSD and Stem): involved selecting the detectors (any) and scanning the sample, fine-tuning the image by adjusting light, and scan speed, among others and saving the image.
- e) **Composition determination**: starting the EDX software and analysing the sample's composition, using the mapping function to determine the elemental composition, and generating the report.



Figure 3-4: ZEISS EVO Scanning Electron Microscope with high vacuum and 30 kV beam acceleration capabilities used for analysis.

3.6 Performance of Different DB Membranes at Lubigi STP

3.6.1 FS Sample Preparation

The pilot-scale dewatering facility was planned and built at the Lubigi FS treatment facility, National Water and Sewerage Corporation (NWSC). A trip of lake sand, clay bricks and three bags of cement were taken to the site (Lubigi plant) on 25th February 2022 (Figure 3-5). These were used to construct a pilot dewatering experimental setup of similar dimensional design and materials. The structure was divided into four equal compartments, i.e., 1m^2 SDB effective drying area. A plinth wall raised about one meter above the ground level served as the structure for the drying bed. The facility consisted of percolate storage containers, outlet drains,

taps/valves, metric system, percolate pipes and four unplanted SDBs of 1m² effective drying area. A transparent calibrated metre rule was fixed vertically on each bed to aid in monitoring the dewaterability rates of FS.

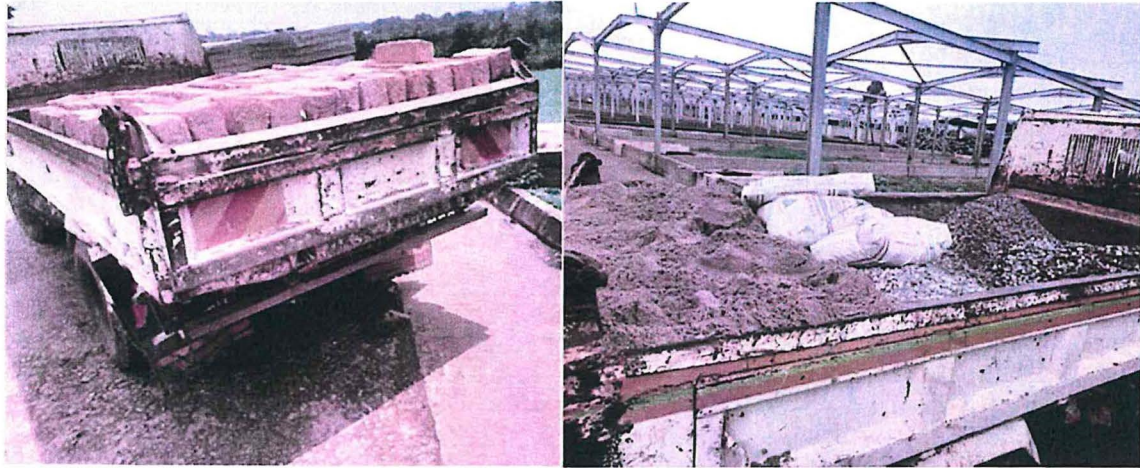


Figure 3-5: Trip of sand, bricks and clay delivered to Lubigi site

3.6.2 SDB Experiment Set-up

The constructed beds were made up of six layers, starting with a bottom base layer of coarse aggregates with an average particle size of 20 to 40 mm and thickness of 150 mm, then a middle layer of medium gravel with an average diameter of 14 to 20 mm and thickness of 75 mm, fine gravel with an average diameter of 10 to 14 mm and thickness of 75 mm, and finally fine sand with an average diameter of 6 to 10 mm and thickness of 150 mm. This was followed by a layer of very fine sand with a diameter of <6mm and a thickness of 150mm. The setup had the same design as recommended by (Wang, Shammass and Hung, 2007; Manga et al., 2016).

Lastly, after preparation, the top layer of each bed was given a different filtering media/membrane. The media included sand, nylon, pavers, and the hessian before the FS layer. Sand (different layers) was used as a reference since it's the membrane currently being used on-site, considering the current grain size. Pavers were used as an alternative to sand since they don't peel off when removing dry sludge cakes. Nylon is a geotextile which does not wear out

quickly in case it is used, is porous enough and has good water absorption capacity. Hessian is also a geotextile material in the form of nets used, with tiny gaps in it and allows proper flow of filtrate from the FS.

Figure 3-6 shows the construction details of the pilot-scale FS drying beds, while Figure 3-7 shows an aerial view of the complete set-up after construction and laying of all the media. A reference bed (Bed A) was set exactly with the currently existing SDBs (same gravel and sand, i.e., layers and thickness) at the plant since it was used as a benchmark of flow rates during the experiment. To ensure homogeneity (coefficient), it was filled with sand filtering media with particles that ranged in size from 0 to 6mm (Kuffour et al., 2009; Manga et al., 2016). Bed B, C, and D were given the hessian, pavers and nylon as their top layers, respectively. A meter ruler was placed and fixed in each bed, set vertically from the top layer of each filtering media. This was used to monitor and record the drying and solid FS levels. The dimensions of each bed were 0.5m by 0.5m by 0.5m in length, width and height without the freeboard.

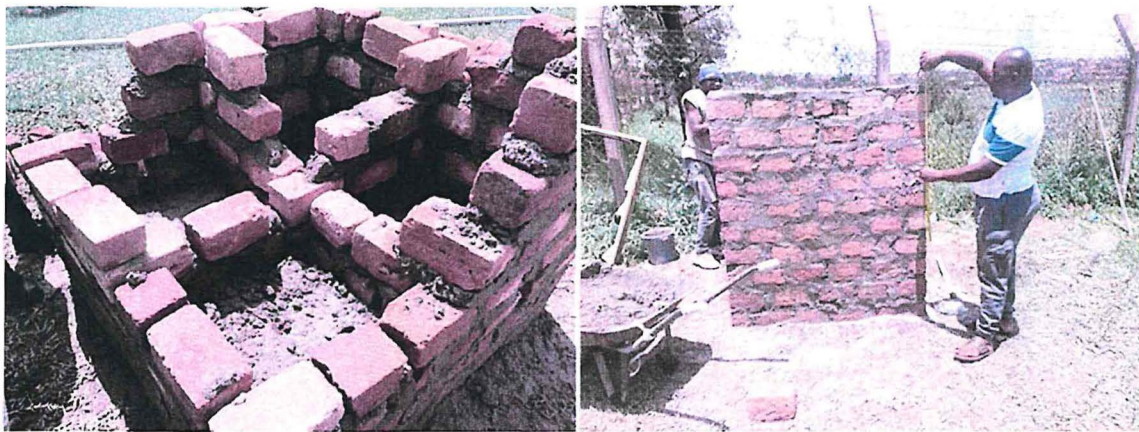


Figure 3-6: Views of the pilot-scale FS drying beds showing their construction details.

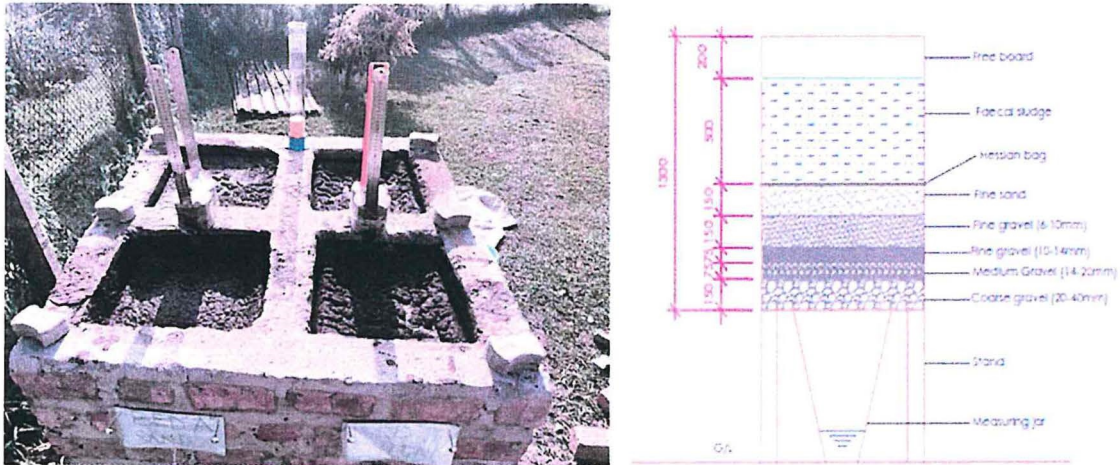


Figure 3-7: Aerial view of a complete setup of all beds loaded with FS and schematic diagram of the constructed beds

Raw and fresh FS was collected from the SDBs at Lubigi and pumped from the sedimentation tanks hours before application on FS drying beds (Figure 3-8). It was then transferred to the constructed beds using buckets to pour into them simultaneously. This was a thorough mixture in an approximate ratio of 1:2 (VIP sludge: septage). Studies such as Manga et al. (2016) conducted in Uganda and Koné et al. (2007), and Kuffour et al. (2009) in Ghana, showed that this mixing ratio resulted in good dewaterability characteristics to optimise the best-performing FSDB membrane. All SDBs were loaded and filled with FS on 5th March 2022 at the same time (10:35 am).

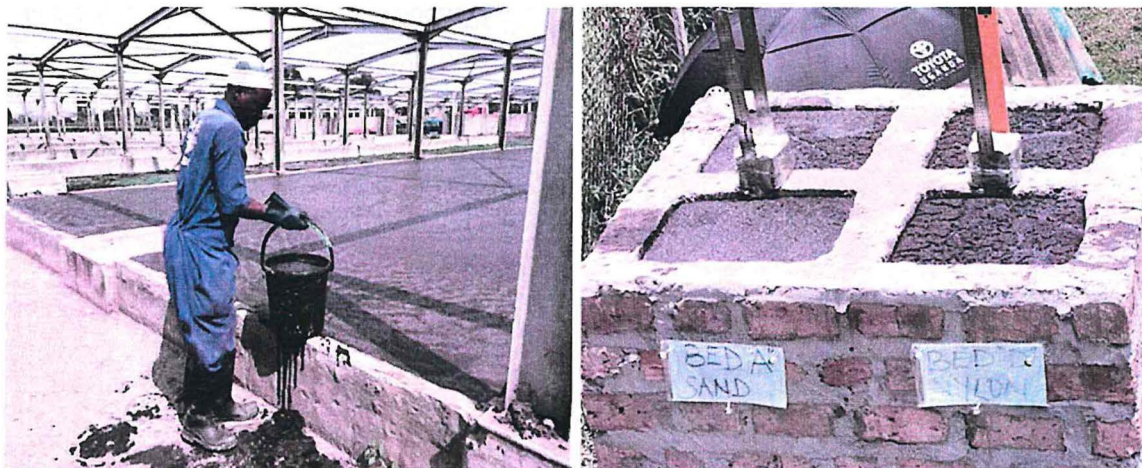


Figure 3-8: Raw and fresh FS in the SDB where a sample was scooped and taken to the experiment and an aerial view of a complete setup of all beds with FS

3.6.3 Bed (Membrane) Performance Monitoring

3.6.3.1 FS Dewatering Rates

After loading the FS, the filtrate percolated through the filter media. The dewaterability rates were manually determined using a timer and calibrated metric rules. With each bed being supervised by an individual, the observer started a timer after the first drop of effluent. Using sand, paver, nylon and hessian as the filtering membrane materials in independent boxes/facilities, the percolate volume was consistently observed and collected from each drying bed.

The cumulative percolate/effluent was measured until the complete dewatering of FS. A non-uniform time interval was used for the experiment. After five minutes, ten minutes, thirty minutes (0.5 hours), sixty minutes (one hour), three hours, six hours, and seven hours, the FS percolate rate and volumes were recorded (24 hrs). Non-uniform intervals were adopted because of lengthy measurements, i.e. as time goes on, the flow rates reduce, and more time is required to allow a needed amount to accumulate. In conclusion, the volume of solid FS still present on the FSDB filter media was also noted. After collecting the dry sludge cake, or when the flow of percolate from the drying bed stopped, and the dewatered sludge could be lifted easily from the drying beds with a spade, dewatering was deemed complete.

3.6.3.2 MS, SC and CV in the FS Cakes

Analysis was done for physical properties, including the Moisture Content (MC), Content (SC) and Calorific Value (CV). This was done on the FS cake from one of the existing FSDBs, and the four (4) experimental beds at Lubigi were determined for the remaining solid sludge cake at the end of the dewatering process. This helped to establish the prevailing conditions of already operating SDBs at the plant and to identify and determine the best-performing bed

(experiment) for further optimisation of the filtering membrane at Lubigi. Only two layers were considered for each sample, i.e. the top and bottom layers.

a) Moisture Content (MC)

An experiment used the following to obtain moisture content in the FS cake: FS from the SDB, weighing scale, 500g container and oven.

- i) The electronic balance was tarred before it was used to measure the weight. An empty, clean and dry container was weighed to obtain M_1 , and a sample of 300 g of FS was added into the container and weighed again to record the new reading (M_2 for container + FS).
- ii) The container with FS was placed in the oven and dried between 105 °C and 110 °C until it attained a constant weight. This is usually after 4 – 24 hrs.
- iii) The dry FS in the container was removed from the oven and cooled.
- iv) The dry sampler (container with contents, i.e., FS) was measured again to obtain the weight (M_3) of a container and dry FS.

The moisture content (MC) of the FS was calculated as a percentage of the dry FS weight following the equation below;

$$\text{Solid Content (SC\%)} = \left[\frac{M_3 - M_1}{M_2 - M_1} \right] \times 100 \quad (3.1)$$

$$\text{Moisture Content (MC\%)} = 100 - \text{SC} \quad (3.2)$$

$$\text{MC(\%)} = 100 - \left[\frac{(M_3 - M_1)}{(M_2 - M_1)} \times 100 \right] \quad (3.3)$$

Where:

M_1 - the weight of the container (g);

M_2 - the weight of FS + container (g); and

M_3 - the weight of dried FS + container (g)

b) Sand Content (SC)

The residue was measured regarding sand content and then expressed as a percentage of the original sample. The experiment used the following items to determine the amount of sand in the FS cake: FS from the SDB, a weighing scale, a 500 g container, and an oven.

The nylon mesh approach was employed. A nylon mesh cloth (NY20-HC) with an aperture was utilised for soil sifting. According to the International Society of Soil Science (ISSS) classification, its opening diameters are smaller than the sand fraction's upper and lower bounds (Whiting, Card and Wilson, 2011; Moritsuka et al., 2015).

- i) The weight of a pre-weighed 500 g FS sample was measured with an electric balance and then dried in an oven overnight. The dried sample was then made free of clumps by breaking them. This was measured again to obtain the final weight (W_A).
- ii) The sample was then put on a 2 mm sieve, which trapped trash and let the sand particles pass through to meet a nylon mesh cloth with a 20 m aperture. The size of sand particles ranges from 2 mm to 20 microns. The small particles in this dirtbag (made of nylon cloth) were washed away in flowing tap water until the water squeezed from the cloth turned transparent after it had been soaked in tap water for around 10 minutes. The sand was put through a wet sifting procedure. In our situation, the material was washed for 10 minutes in total.
- iii) After being washed, the coarse-particle-containing nylon mesh bag was dried in an oven for an entire night. To reduce the drying time, oven drying was employed. The sample was weighed using an electric balance the following day to determine the final weight (W_B).

iv) The weight of the sand fraction present in the initial sample was determined by comparing the weights WA and WB (before and after sifting). The amount of sand was computed based on the weight percentage of the initial sample weight.

c) Calorific Value (CV)

Raw FS cake samples were collected from SDBs to determine their calorific values. The ultimate goal of measuring the gross calorific value (GCV) of the FS is converting sludge materials into reusable products (e.g., organic manures or alternate fuels) that finally lead to a healthier and more hygienic environment. This study used an IKA calorimeter (model C 200) to determine the gross calorific value of sludge samples from SDBs at Lubigi. Sludge samples were thoroughly mixed and weighed into batches to get reproducible and reliable measurements. Most importantly, it was the first to reduce the sludge moisture level. Before examining the samples in the calorimeter, this was accomplished using a drying oven. This is because sludge is an uneven mixture of solid and liquid waste that primarily includes water and excrement along with other materials, including sand, grit, metals, rubbish, and different chemical compounds. To make the measurement process easier, the sample was, when necessary, pelletised after the drying phase.

Before starting the measurements, the IKA C 200 calorimeter was calibrated based on the manufacturer's specification, i.e., Consortium for DEWATS Dissemination (CDD) Society. Therefore, it was calibrated with C 723 benzoic acid using the operation mode 'dynamic' at 25°C. The calibration results achieved included; a CV of 2.17543 kcal/°C and a reference gross calorific value (GCV) of 6,324 kCal/kg. Subsequently, sample measurements started.



Figure 3-9: IKA calorimeter C200 for determining the gross calorific value of sludge

This was intended to single out the best-performing membrane out of the 4 to be optimised.

3.7 Optimising the Best Performing FS Drying Bed Membrane at Lubigi STP

The levels of sand content, moisture content and calorific values, together with logged percolate and solid sludge volume data, were obtained for each SDB. This was used to optimise the best-performing FSDB membrane. Comparison in the form of recorded rates, the volume of percolate, volume of the remaining solid and time it took (number of days it took the FS) to dry up in addition to the final physical properties (MC, SC and CV) was made. This was intended to single out the best-performing membrane gauge (size) through various gauge sizes and recommend it to the plant operators to solve the current issues (mainly the sand content) being faced.

3.8 Data Analysis

The findings were analysed statistically using MS Excel software to define the features of FS from the FSDBs at Lubigi. The results were presented as average values with one standard deviation (SD) of triplicate readings.

Data were analysed for dewaterability using a non-parametric test to determine the significance of variations in the mean values of each filter media configuration, with a 95% level of confidence. The significance of the correlation coefficients between the dewatering time and the amount of percolate was also examined using Spearman's rho test with a > 95% confidence

level. The statistical significance cut-off was chosen at $p = 0.05$. Concerning the percolate from reference beds, this was utilised to optimise and assess the relationship between dewatering time and the removal efficiency based on the amount of dewatered liquid from each temporally SDB of sand, pavers, nylon, and hessian membranes. The effectiveness and efficiency of correlation were described as “*Not efficient*”, “*Average*”, “*Efficient*”, and “*Most Efficient*”. Tabular and graphic presentations demonstrated how quality control was carried out by keeping the difference between the duplicates' mean values within 5%.

CHAPTER FOUR

4 RESULTS, ANALYSIS AND DISCUSSIONS

4.1 Characteristics of FS from Existing SDBs at Lubigi FSTP

a) Moisture Content (MC)

The physical properties of FS from five zones of the FSDB at Lubigi, where sludge cakes were scooped, are shown in Table 4-1 as moisture content. With a mean MC of 75.91% and a standard deviation of 1.11%, the sample cake's measured MC ranged in mass from 72.68% to 76.28%. As the liquids evaporate and the sludge dries, the MC of the sludge in the drying beds falls with time. Figure 4-1 shows that the distribution of MC in the beds is typical. Extreme I of the sample zone had the lowest moisture content (73.68%), indicating a quicker drying rate, followed by extremes III and IV (75.06% and 75.12%, respectively), the medium zone (75.28%), and the extreme II (75.91%).

Table 4-1: Moisture content of FS from SDBs at Lubigi

Sample	M ₁	M ₂	M ₃	M ₂ - M ₁	M ₃ - M ₁	MC (%)
Extreme Sample I	38.93	144.32	66.51	105.39	27.59	72.68
Extreme Sample III	39.76	161.32	68.60	121.56	28.84	75.91
Middle/Centre Sample	45.40	176.76	77.06	131.36	31.66	75.28
Extreme Sample III	45.25	187.31	80.70	142.06	35.46	75.06
Extreme Sample IV	43.03	145.05	68.38	102.03	25.36	75.12
Mean Value	42.47	162.95	72.25	120.48	29.78	74.81±1.11

W1- the weight of the container (g); W2 - weight of FS + container (g); and W3 - weight of dried FS + container (g)

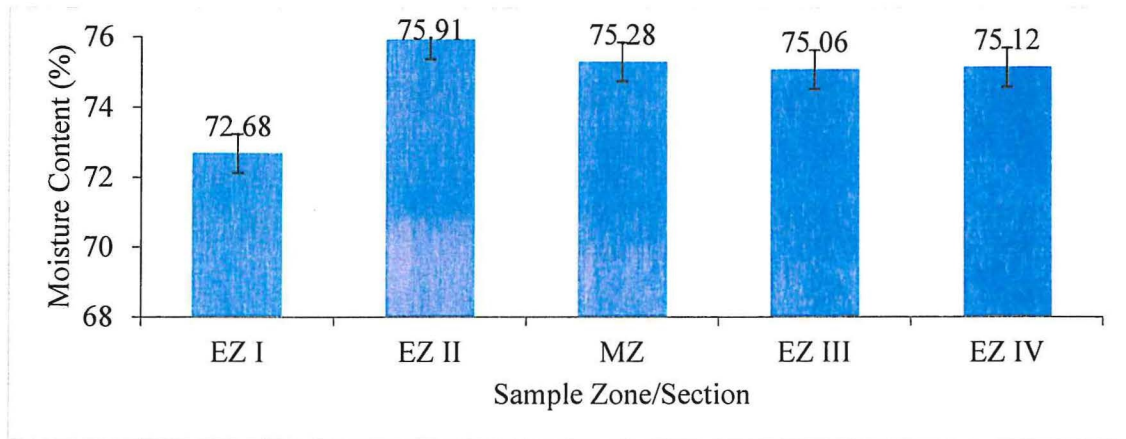


Figure 4-1: Distribution of moisture content in different FSD bed zones

The average moisture content of 75.21%, according to Tamakloe (2014) and Ahamada *et al.*(2016), is within the acceptable range. The moisture in FS can be as high as 99% (wet basis), according to Strande *et al.* (2014) and Ziebell *et al.* (2016), and dewatering can lower moisture to less than 5% dry solid (Kuffour, 2010; Naidoo *et al.*, 2019; Getahun *et al.*, 2020), which lowers the cost of handling and transport. However, the MC of the FS affects the *Ascaris* eggs and larvae's survival ability (Lindberg & Rost, 2018). Therefore, drying and dewatering concentrate the energy in the sludge by removing water and increasing the calorific value, subsequently transforming the sludge into an acceptable combustible material (Strande *et al.*, 2014) and destroying the pathogenic organisms (Stringel *et al.*, 2019; Septien *et al.*, 2020). Information on MC distribution within FS and understanding the bond strength (boundedness) of the moisture to the solid are vital for selecting optimal dewatering methods (Getahun *et al.*, 2020).

b) Sand Content (SC)

Table 4-2 shows sand content in FS from 5 zones of the FSDB at Lubigi. The measured SC in the sample cake ranged from 17.43% (89.62 g) to 19.66% (118.08 g), with a mean SC of 18.34% and a standard deviation of 0.86%. This is attributed to the source of FS, e.g., unlined pits in Kampala and areas around (S. Semiyaga, Okure, *et al.*, 2017) and the bonding of sand

and FS in the SDB during dewatering (Kuffour et al., 2009; Kuffour, 2010). SC determines and influences on dewaterability of FS in drying beds.

Table 4-2: Sand content of FS from SDBs at Lubigi

Sample	Sand Content (g)	Sand Content (%)
Extreme Sample I	89.62	17.92
Extreme Sample III	118.08	17.43
Middle/Centre Sample	87.14	18.02
Extreme Sample III	98.29	19.66
Extreme Sample IV	113.44	18.69
Mean Value	101.31	18.34±0.86

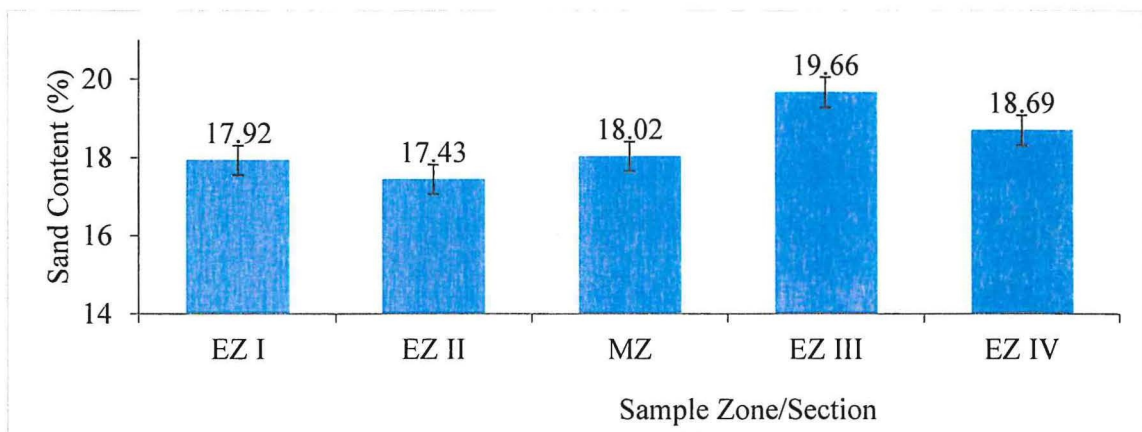


Figure 4-2: Distribution of sand content in different FSD bed zones

According to Seck et al. (2015); Gold et al. (2016, 2018), FS from line septic tanks has sand content ranging from 5-10% of TS can, 9-33% sand of FS from both lined and unlined pits in tropical regions and 45-69% sand of TS from unlined pit latrines mainly in Uganda (Velkushanova et al., 2021). The findings of this study show that SC in all zones of the SDB range between 17.43 to 19.66% in the FS. This coincides with the results of Velkushanova et al. (2021) for tropical regions like Uganda.

Sand content influences FS resource recovery and final disposal as high sand concentration poses negative impacts, e.g. increased costs for disposal in landfills. (Gold et al., 2018). Strande et al. (2014) state that concentrations are essential in treating FS. Sand particle diameters are crucial as sand with a larger diameter (1.0-1.5 mm) can result in the relatively fast accumulation of organic matter, thereby increasing the risk of clogging. However, the risk can be reduced by using sand with smaller diameters (0.1- 0.5 mm) (Kuffour et al., 2009).

c) Calorific Value (CV)

According to laboratory results in Table 4-3, analysis shows that samples of FS cakes from 5 sections of an active (in use) SDB at Lubigi FS had an average calorific value (gross energy) of raw FS cakes was 3068.68 kcal/kg with an SD of 87.81 kcal/kg. The lowest and highest CVs obtained were 2946.38 kcal/kg and 3185.46 kcal/kg for the middle and extreme cake sample II, respectively. Figure 4-3 shows the distribution of calcific values in the SDB where the middle and extreme III zones/sections exhibited very low CVs of 2846.38 kcal/kg and 2875.39 kcal/kg, respectively. Extreme I, II and IV had relatively high caloric values in the SDB.

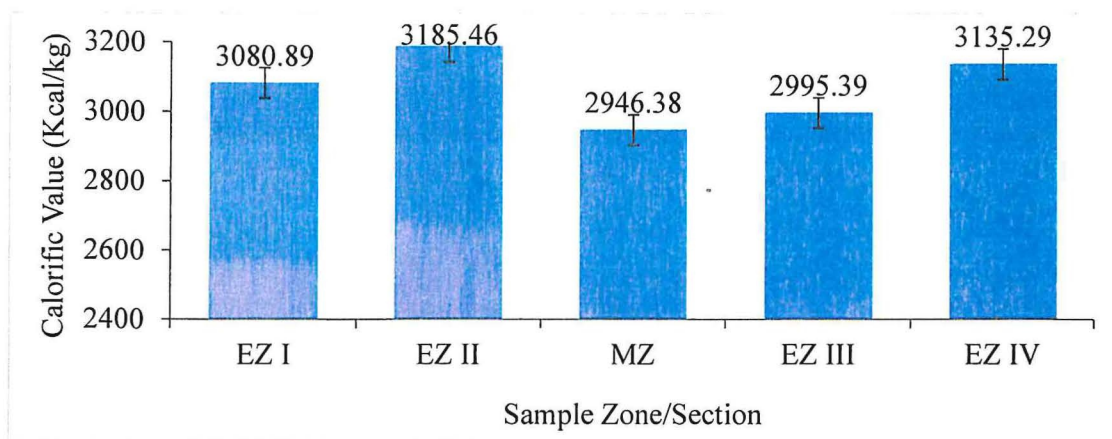


Figure 4-3: Distribution of calorific values in FS in different FSD bed zones at Lubigi

According to Strande et al. (2014), the calorific value of solid sludge typically is reported to be 17 MJ/kg (4,060 kcal/kg), compared to an average of 26 MJ/kg (6,210 kcal/kg) (Muspratt et al., 2014). This is slightly higher than the values obtained in this research, which is attributed

to the composition of the FS, biological break-down and release of carbon in the form of carbon dioxide and methane during anaerobic digestion at the Lubigi plant (Muspratt et al., 2014). Given this marvel, in the case of a large-scale system designed for harnessing embodied energy as solid fuel in Uganda, it should circumvent digestion.

The results are comparable to those of Onabanjo et al. (2016) in an experimental investigation of the combustion performance of human faeces. More still, Zuma, Velkushanova and Buckley (2015) determine the chemical and thermal properties of FS. These studies confirmed that the calorific values range between 11 MJ/kg (2,627 kcal/kg) and 18 MJ/kg (4,299 kcal/kg).

Getahun et al. (2020) obtained a CV range of 8.0 - 23 MJ/kg for dry solids observed with bio-solids, and Ahmed et al. (2019) found that the CV for both dry and wet sludge ranges between 15.16 MJ/kg and 18.31 MJ/kg. These results perfectly match the findings of the current study. However, according to Muspratt et al. (2014), proper drying must be done to concentrate the energy in the FS by removing water to increase the calorific value. Consequently, this transforms the sludge into an acceptable combustible material (Ahmed et al., 2019) at the end of the treatment process.

Table 4-3: Calorific values of FS samples from SDBs at Lubigi

Sample Description	Sample Wt.		Initial temp		Final temp		Temp rise		Fuse wire		Gross Energy		Gross Energy	Gross Energy
	(g)	(g)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	factor	Cal	(kcal/g)	(kcal)	(kcal)	(kcal/kg)
Extreme Sample I	0.98	0.99	25.85	27.10	27.11	28.31	1.26	1.21	8	12	3.16	3.00	3.08	3080.89
Extreme Sample III	1.05	1.02	28.70	28.21	30.05	29.54	1.35	1.33	10	8	3.16	3.21	3.19	3185.46
Middle/Centre Sample	1.00	1.01	26.90	28.12	28.05	29.30	1.15	1.18	12	10	2.82	2.87	2.85	2946.38
Extreme Sample III	0.98	0.99	24.70	26.10	25.88	27.23	1.18	1.13	10	8	2.95	2.81	2.88	2995.39
Extreme Sample IV	1.01	1.02	27.90	30.12	29.20	31.41	1.30	1.29	8	12	3.16	3.11	3.14	3135.29
Mean Value	1.00	1.01	26.81	27.93	28.06	29.16	1.25	1.23	9.60	10.00	3.05	3.00	3.03	3068.68

d) Chemical Elements

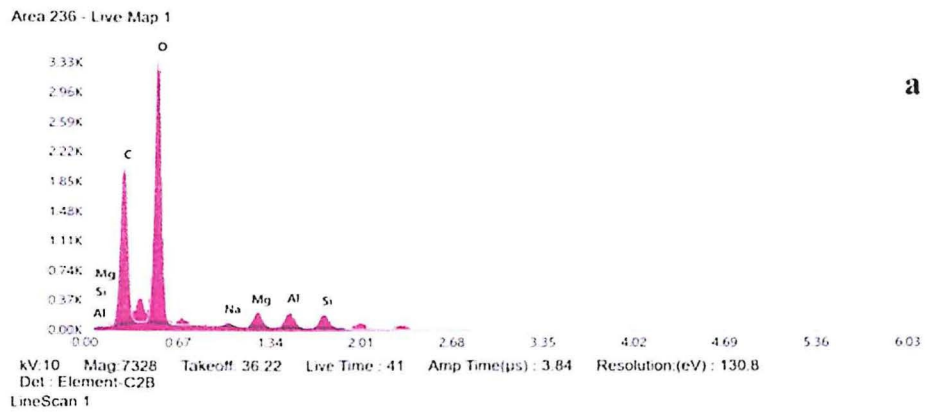
Table 4-4 shows the chemical properties of sludge cakes from the existing SDB at the Lubigi plant. The analysis revealed that all the sludge cake samples had average weights ranging between 0.48 to 46.98% of the respective chemical elements. In all samples, Carbon (C K) and Oxygen (O K) had the highest weight ratios of 46.96% and 36.73%, whereas Sodium (Na K) had the lowest with 0.48% in all elements, respectively.

Table 4-4: Smart quant chemical property results of sludge cake samples from Lubigi existing SDBs

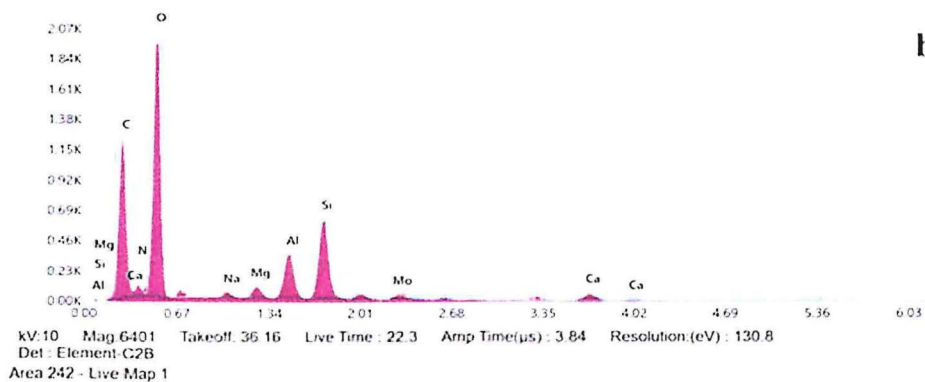
Element and band in which element was detected	Mean Value						
	Weight %	Atomic %	Error %	Net Int.	R	A	F
C K	46.98	57.61	9.14	285.00	0.9291	0.3676	1.0000
N K	3.45	3.64	27.90	16.39	0.9328	0.1548	1.0000
O K	36.73	33.75	9.62	415.44	0.9393	0.3201	1.0000
Na K	0.48	0.30	22.87	8.93	0.9509	0.6363	1.0030
Mg K	1.43	0.86	9.23	33.23	0.9545	0.7562	1.0046
Al K	2.30	1.26	7.05	61.34	0.9578	0.8335	1.0063
Si K	3.53	1.85	5.83	98.57	0.9610	0.8818	1.0060
Ca K	4.45	1.64	10.21	30.14	0.9769	0.9821	1.0208
Mo L	3.52	0.54	10.43	30.07	0.9666	0.9400	1.0039

Atomic Number (R), Absorption (A) and Fluorescence (F)

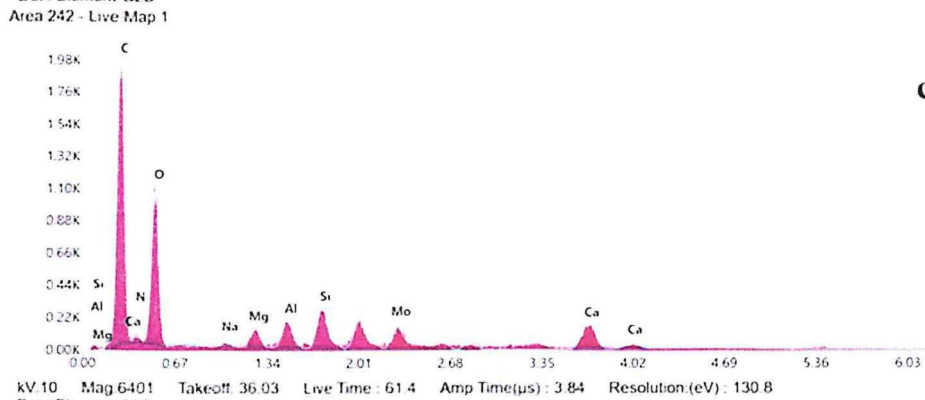
Figure 4-4 shows the bulk spectrum plot of all elements and their respective bands of where they were detected in the periodic table by the electron scanning microscope (ESM) in the laboratory, whereas Figure 4-5 shows the detailed live elemental images (maps) of sludge cake samples with are drift corrected for extreme sample I. The rest are in Annex.



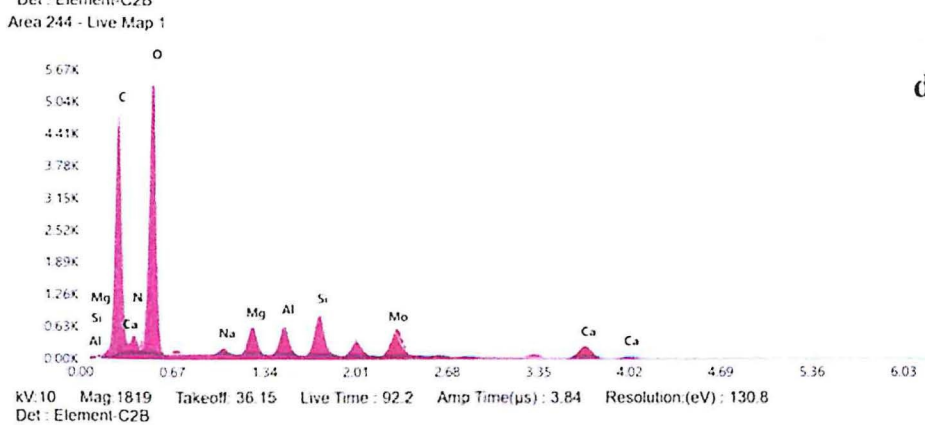
a



b



c



d

Figure 4-4: Bulk spectrum from sludge cake sample 1(a), 2(b), 3(c) and 4(c)

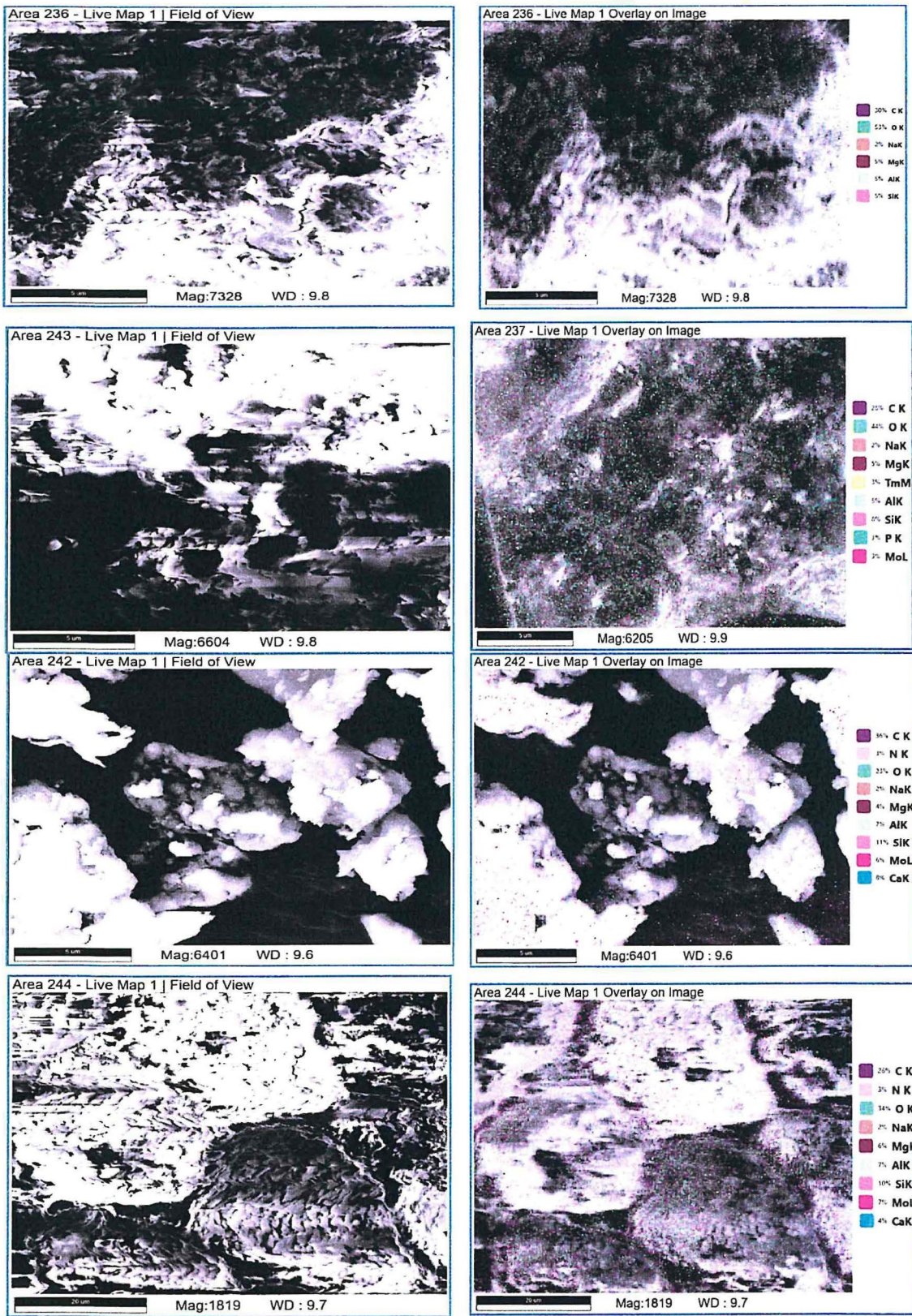


Figure 4-5: Elemental live maps (images) for chemical elements from the ESM (drift corrected)

According to Hafford et al. (2018), low Na content implies low alkaline indices in the FS, and to get value out of FS, co-firing with lower alkali content is advisable. High Carbon and oxygen contents in the FS area are beneficial since lower temperatures are required in FS pyrolysis (Ward et al., 2021). The average levels of Ca K indicate average salt concentrations. This is primarily attributable to various user behaviours at FS sources, such as restrooms (Hafford et al., 2018; Ward et al., 2021). For instance, if more males than women use these FS toilets to urinate, this would mean that a more significant portion of the urine enters containment, increasing the ratio of urine to faeces and the cation concentrations that follow from it (Ward et al., 2021). Extracellular polymeric substances (EPS), formed during biological growth and are highly charged and capable of bridging, are affected by chemical characteristics in FS (S. Semiyaga, Okure et al., 2017; Gold et al., 2018). Consequently, salts are crucial in determining the integrity of flocs and the effectiveness of dewatering (Kuffour, 2010; Velkushanova et al., 2021; Ward et al., 2021).

4.2 Performance of Different Drying Bed Membranes at Lubigi FSTP

4.2.1 Dewatering Rates of FSDB

Figure 4-6 shows the mean dewatering rates for unplanted beds with sand, hessian, paver and nylon as the filter media experimented in this research at Lubigi FSWTP. The mean dewatering times of sand, hessian, paver and nylon filtering media were 0 and 14280 minutes (10 days). Under the same weather conditions, the experimental bed filled with FS were dewatered, and the filtrate was monitored at the set intervals. Sand filter media (Bed A) exhibited the highest mean dewatering rates with a peak of 502 mm after 4.5 hrs. This was followed by pavers (Bed C), with the highest peak of 416 mm after 7.5 hrs implying a lag of 3 hrs compared to the sand bed. The nylon (Bed D) filter media expedited average filtration rates at all times compared to the rest of the media

Nevertheless, the hessian (Bed B) released the least amount of filtrate for the entire experimental period, where its highest release was only 59 mm after 20 hrs. Unpredictably, the filter media in all beds indicated a very significant change in the mean dewatering rates after a period of 3.5 hrs with a very sharp rise in amounts released, although, for the hessian, it relatively remained low. Generally, between 10.5 hrs and 4.92 days from the starting time, all the dewatering rates in all beds retarded.

According to Figure 4-7, and had the highest cumulative volume, followed by pavers, nylon and then hessian. This means sand was 18.3, 1.22 and 1.76 times in filtration faster than hessian, pavers and nylon, respectively. Therefore, pavers and nylon were the second-best performing filter media after sand. However, since the main objective of the study was to find the best filter media, the solid sludge cakes after the dewatering process were further analysed for the sand content, moisture content and calorific value, which gave a final option of the media to optimise.

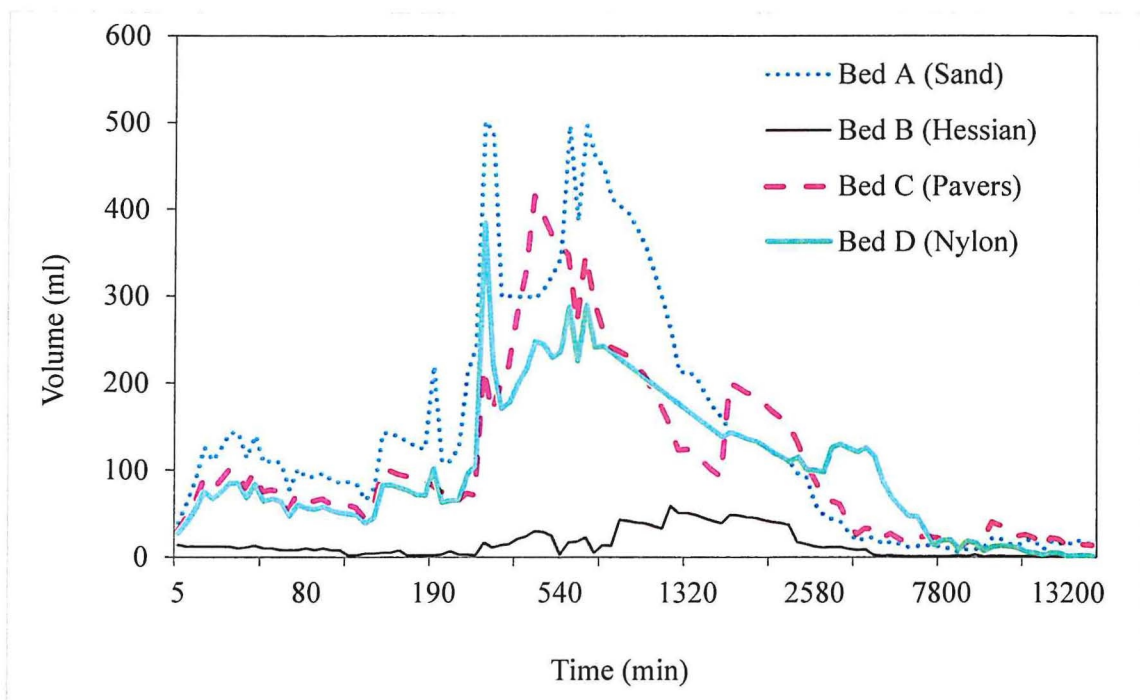


Figure 4-6: Mean dewatering rates for sand, hessian, paver and nylon filter media at Lubigi

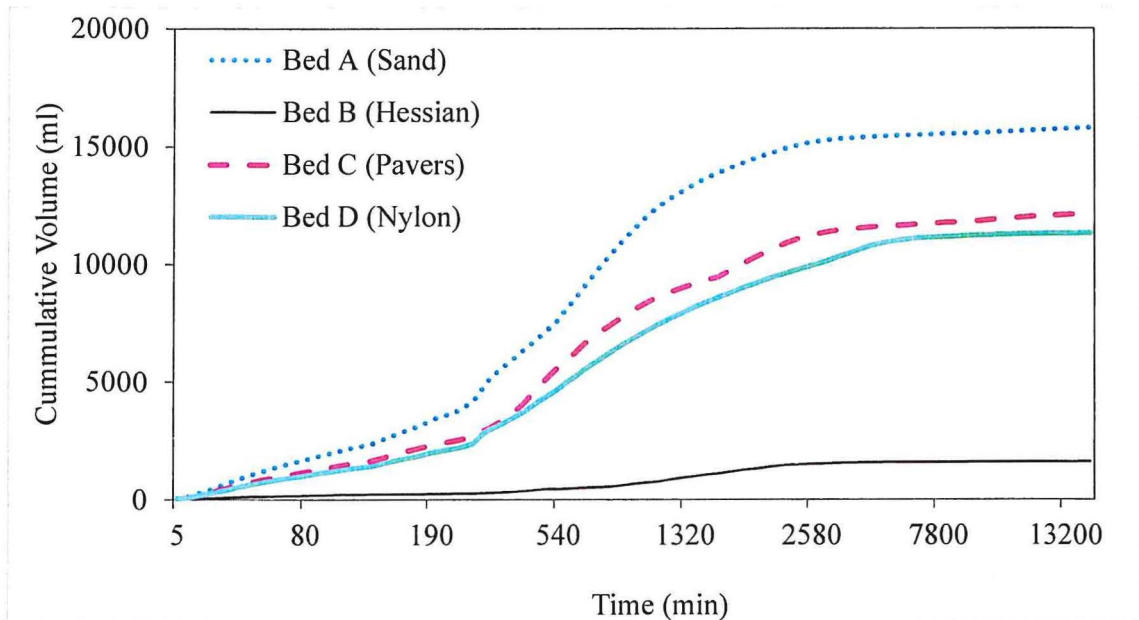


Figure 4-7: Cumulative volumes of all filter media at Lubigi

According to Table 4-4, it was found that all Hessian, Nylon and Pavers were efficient ($R^2 = 0.632, 0.592$ and 0.540), followed by Sand with $R^2 = 0.491$. Considering the Spearman's rho test used to optimise the relationship (correlation significance) between dewatering time and the removal efficiency based on the amount of dewatered liquid from each temporally SDB concerning the percolate, all membranes had a very significant correlation between dewatering time (t min) and percolate (Q ml), i.e., $p < 0.05$ based on a $> 95\%$ confidence level.

Table 4-5: Statistical significance criterion output indices

Membrane	Multiple R	R^2	Adjusted R^2	p -value ($p < 0.05$)	Correction
Bed A (Sand)	0.700	0.491	0.486	0.0000	Average
Bed B (Hessian)	0.795	0.632	0.628	0.0000	Efficient
Bed C (Pavers)	0.740	0.547	0.543	0.0000	Efficient
Bed D (Nylon)	0.769	0.592	0.588	0.0000	Efficient

R: Pearson correlation coefficient and this is used to identify patterns in things.

R^2 : The coefficient of determination is used to identify the strength of a model.

4.2.2 MS, SC and CV in the FS Cakes

Table 4-6 shows the results of the physical characteristics of FS cakes collected from the experimental beds at the end of the dewatering process. Significant differences existed between the cakes' top and bottom layers from all beds. The dried FS from all beds had an average calorific value of 2746.47 Kcal/Kg and 2573.12 Kcal/Kg, an average sand content of 14.23% and 15.59% and an average moisture content of 86.18% and 88.44% for the top and bottom layers dry cakes at the end of the dewatering period.

Hessian had the highest levels of moisture content (MC) at 91.71% and 93.42%, followed by Nylon at 86.28% and 88.87%, Pavers at 86.12% and 87.81% and lastly, Sand (standard), which had 80.60% and 83.67% for the top and bottom layers, respectively. The sand content (SC) was very high in the Sand (reference bed) with 22.98% and 24.26%, followed by Pavers with 14.92% and 15.73%, Nylon with 13.84% and 14.01% and then hessian which had the lowest SC of 6.16% and 6.35% for the top and bottom layers, respectively. The average calorific values were high for the Hessian bed (3020.37 and 2929.76 Kcal/Kg) and low for the Sandbed (2418.12 and 2176.31 Kcal/Kg). Both the Pavers (2813.94 and 2616.96 Kcal/Kg) and Nylon (2733.46 and 2569.45 Kcal/Kg) had relatively same ranges of the CVs, though for pavers were slightly higher (Table 4-6).

Table 4-6: Mean values of physical properties of FS cakes

Bed Sampled	Average Flow Rate (ml)	MC (%)		SC (%)		CV (Kcal/Kg)	
		Top	Bottom	Top	Bottom	Top	Bottom
Paver	111.56	86.12	87.81	14.92	15.73	2813.94	2616.96
Standard (Sand)	145.08	80.60	83.67	22.98	24.26	2418.12	2176.31
Nylon (1.0 mm)	103.77	86.28	88.87	13.84	14.01	2733.46	2569.45
Hessian	14.69	91.71	93.42	6.16	6.35	3020.37	2929.76

MC - Moisture Content, SC - Sand Content and CV - Calorific Value

According to Figure 4-8, there is a strong relationship between the MC, SC and CV. The cakes from the hessian bed had the lowest sand content but the highest levels of MC and CV. The bed had the lowest flow rates recorded in the experiment (Figure 4-7). The sand bed had the highest flow rates and SC levels but the lowest MC and CV levels. This shows an opposite trend between the two physical properties (MC and CV) and SC of the dry FS cakes implying that the lower the sand content, the higher the moisture content and the calorific value, and the reverse is very true.

High sand concentration is undesirable for producing good calorific outputs since it reduces combustion performance, does not contribute to the CV (fuel potential), and must be disposed of, all of which can raise the cost of the operation (Kuffour et al., 2009; Seck et al., 2015; Septien et al., 2020). To assuage this, a filter media which yields relatively low SC and MC but with high CV was optimised and recommended to be adopted in FSTP in Uganda (Lubigi).

Therefore, Nylon was chosen as the best-performing bed, given that its FS cake yielded moderate MC, SC and CV compared to the rest. Sand (reference bed) had very high SC, which affected CV levels of CV, pavers had slightly lower MC but higher SC which affected its CV and the Hessian, which had the best results had the lowest dewatering rates and MC. It should also be noted that this bed failed to function as anticipated in the experiment. Meagre dewatering rates imply that sludge will take longer to dry at the cost of bringing new sludge to the FSTP.

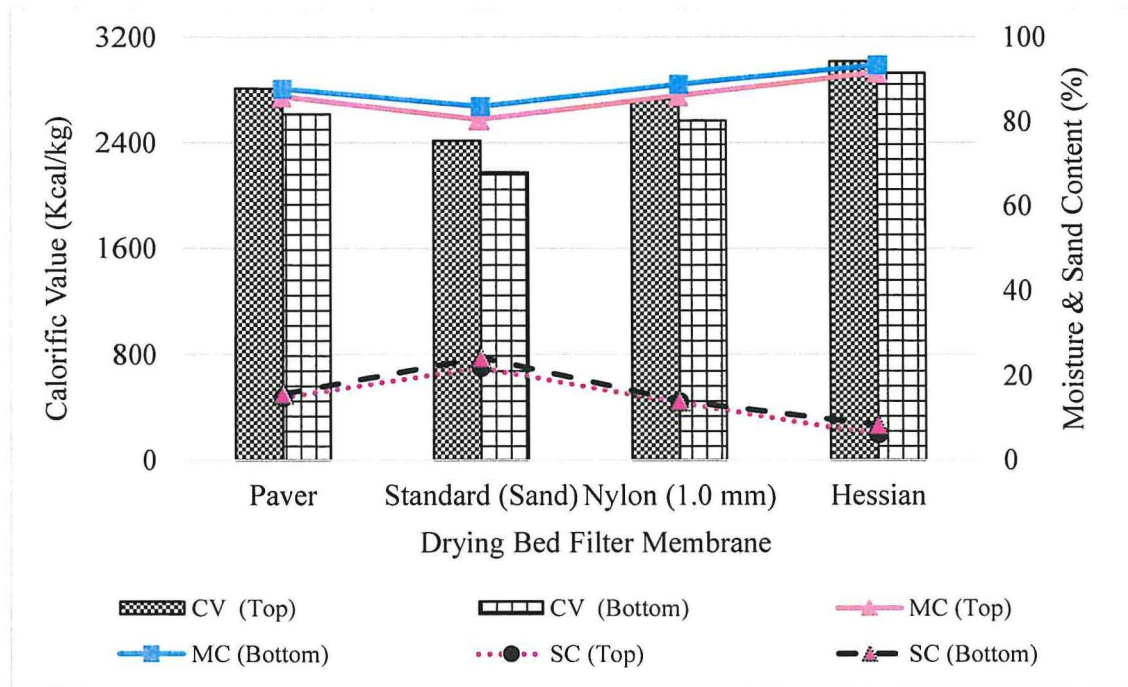


Figure 4-8: Relationship among the MC, SC and CV in FS cakes

4.3 Optimisation of FS Drying Bed Membrane at Lubigi FSTP

Nylon was singled out as the best-performing filter media (FM) and then optimised based on different gauge sizes. During optimisation, three different nylon gauges (material sizes) were used, i.e., 1.0mm (reference FM size), 0.5mm and 2.00mm. These abetted to quantify the filtrate rates, SC, MC and CV of the material at various material sizes.

Figure 4-9 shows the mean dewatering rates for unplanted beds optimised with different sizes of nylon material experimented on at Lubigi FSWTP. The average DT of the filter media (Bed A, Bed B and Bed C) was 5 min, 1hr, 3hr and 6hr, respectively. Generally, the filtration rates for the three (3) media increased slowly, from 0 to 3hrs. The flow rates, however, significantly increased between 3hrs and 16hrs, beyond which they started retarding significantly. The short dewatering times of all the filter media (10 days) might be due to comparatively high temperatures since it was a dry period. High filtration rates in Bed C (2.0mm) are due to the size of holes in the FM since the pixel size is bigger and allows more liquids to pass through

it. However, the low volumes in Bed B (0.5mm) were contrary to Bed C since the size of holes in the FM was very small. According to Figure 4-10, Bed C (2.0mm) allowed more percolation with a double ratio of about two compared to Bed A and B.

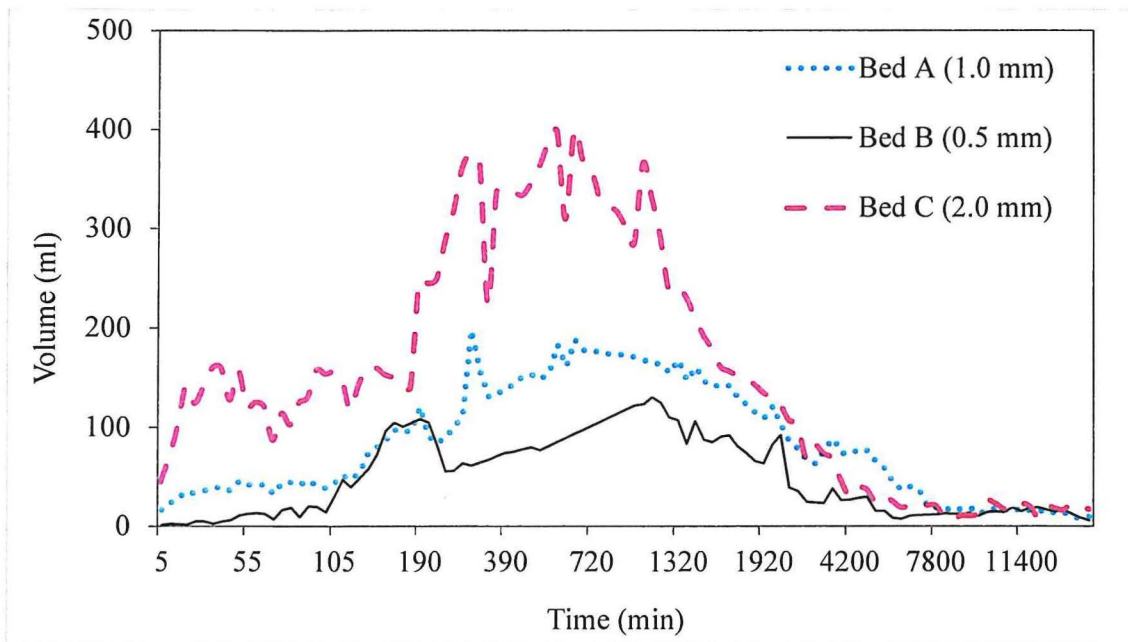


Figure 4-9: Mean dewatering rates for different sizes of nylon filter media optimised at Lubigi

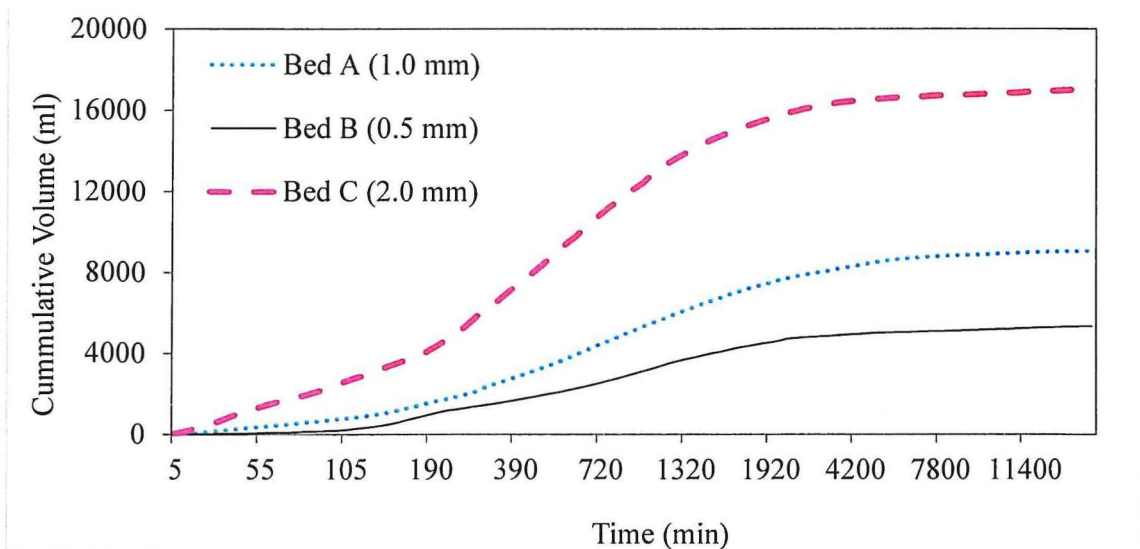


Figure 4-10: Cumulative volumes of the optimised nylon filter media sizes at Lubigi

Table 4-7 shows the results of the physical characteristics of FS cakes collected from the experimental beds after optimisation. The differences between the top and bottom layer

properties show that the 0.5mm nylon had a mean flow rate of 49.09 ml and the highest levels of MC (86.91% and 90.92%), whereas the 2.0mm had the lowest MC (82.14% and 85.16%). The low MC in the 2.0 mm bed was attributed to big holes in the materials, which allowed complete percolation of the filtrate of solid sludge than the 0.5 mm nylon material. The 1.0 mm nylon material had the average values of all properties.

The FS cake from the 2.0 mm bed had the highest SC levels (14.81% and 17.05%), followed by the FS from the 1.0 mm (13.24% and 14.8%) and then the FS from the 0.5 mm bed (6.51% and 7.03%) for the top and bottom layer. The high SC in the 2.0 mm bed was mainly due to significant gaps in the nylon, which could easily allow the sand to mix with solid sludge. The magnitude of SC influences the CV in the sludge. This is because the 0.5mm bed, which had the lowest SC, had the highest CV (3120.07 Kcal/kg and 2980.03 Kcal/kg), whereas the 2.0mm bed had the highest SC and the lowest CV (2212.1 and 2067.13 Kcal/kg) for the top and bottom layers, respectively. The 1.0 mm bed had the average CV, SC and MC.

Table 4-7: Mean values of physical properties of FS cakes after optimisation

Size (mm)	Average flow rate (ml)	MC (%)		SC (%)		CV (Kcal/kg)	
		Top	Bottom	Top	Bottom	Top	Bottom
0.5	49.09	86.91	90.92	6.51	7.03	3120.07	2980.03
1.0	83.37	83.28	87.28	13.24	14.8	2745.12	2600.12
2.0	156.61	82.14	85.16	14.81	17.05	2212.1	2067.13

Figure 4-11 shows the relationship among MC, SC and CV obtained during optimisation. Optimisation of the nylon material revealed that the 1.0 mm size is the best filter media since it performed better than other nylon sizes. The bed 2.0mm material has the advantage of faster filter rates but with high sand levels mixing with the FS cakes, while the 0.5 mm has the lowest filtering rates and high levels of clogging of the holes during filtration. Meagre dewatering

rates in the bed of 0.5mm material imply that sludge will take longer to dry at the cost of new sludge being brought to the FSTP.

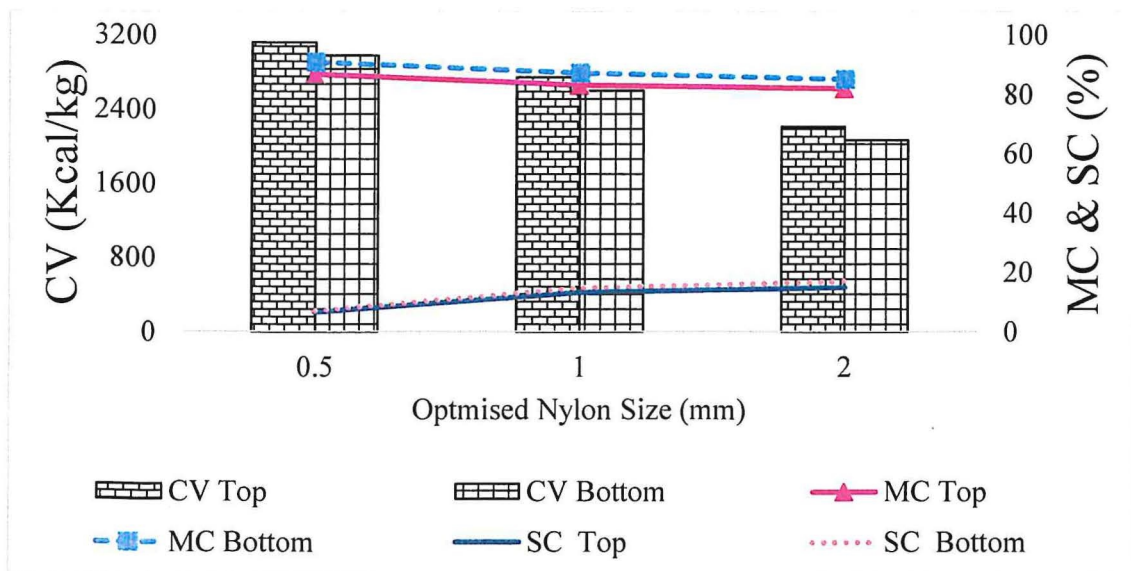


Figure 4-11: Relationship among the MC, SC and CV from the optimised nylon material beds

4.4 Implications of Findings to FSM

The volume of FS at Lubigi is substantial hence a need for substantial systems for sustainable FSM through appropriate and efficient treatment to eliminate thoughtful environmental effects. The findings of this study provide knowledge on different membranes used in FS drying to minimise the sand layer takeaway in the SDBs at Lubigi through a detailed insight into alternative materials that can be used in SDB as an efficient filter membrane, for instance, nylon. It was found out that nylon performs better in dewatering and minimizes sand take, specifically, a gauge of 1.00 mm which turned out to be the most feasible compared to the 0.5 mm and 2.00 mm.

Therefore, the findings established management strategy and practice to act as guides to decision makers on whether to change or not the filter media (sand), hence calling for the adoption of the filter media (nylon of 1.00 mm) in case of future technological advancements at the Lubigi plant to change the filter media of SDBs.

CHAPTER FIVE

5 CONCLUSION, RECOMMENDATIONS AND LIMITATIONS

5.1 Conclusions

Modest but innovative adaptations to SDBs can significantly increase the drying performance and, thus, reduce their required footprint while providing opportunities for resource recovery of treatment products. Generally, if a treatment facility is poorly maintained or managed, a lack of sustainability in its operation, maintenance, and monitoring affects treatment performance and threatens public health and the environment. This is the case with the Lubigi plant as SC in the FS cakes continues to pose issues with the quality of effluent and the solid cakes release.

5.1.1 Characteristics of FS from SDBs at Lubigi FSTP

This research found that in the existing FSDBs, the measured MC of the sample cakes ranged between 72.68% and 76.28% by mass, with a mean MC of $75.91 \pm 1.11\%$. The measured SC ranged from 17.43% (89.62 g) to 19.66% (118.08 g), with a mean SC of $18.34 \pm 0.86\%$. The average CV (gross energy) of raw FS cakes was 3068.68 ± 87.81 kcal/kg. This research did not only focus on CV, MC and SC (physical characteristics) but also the chemical properties (C, N, O, Na, Mg, Al, Si, Ca and Mo) that act as cations. These influence the floc integrity and dewatering performance in FS. From the laboratory analysis of FS cakes, in all samples, Carbon (C K) and Oxygen (O K) had the highest weight ratios of 46.96% and 36.73%, whereas Sodium (Na K) had the lowest with 0.48% at all elements, respectively.

5.1.2 Performance of Different Drying Bed Membranes at Lubigi FSTP

Like the drying kinetics, the evolution of water activity during drying also showed a different trend for the different membrane characteristics. High sand and moisture content indicate the predominance of unbound water that affects the calorific value of FS. The moisture content of the FS in the drying beds decreases with time as the liquids evaporate and the sludge dries.

Therefore, this research established the performance of different membranes through testing different filter membranes or media, including the sand (reference media), hessian, nylon and pavers in unplanted experimental beds at Lubigi. This was achieved by considering several physical characteristics such as SC, MC and CV of the final sludge cakes. CV of FS increases as the sand content further diminishes in the FS. However, it was observed that MC has less influence on CV than SC. Nylon had the average of all characteristics compared to sand and pavers with high SC and low CV. Hessian had the lowest SC and highest CV; however, the medium had the lowest dewatering rates due to clogging hence nylon qualifying as the best media since it performed better than other media. This was further optimised to choose the best gauge to recommend for future operations.

5.1.3 Optimisation of FS Drying Bed Membranes at Lubigi FSTP

Further optimisation of the nylon filter media was done using three different nylon gauges. These included the standard (reference) gauge of 1.0 mm, a decrease of 0.50 mm and an increase of 1.00mm. The research found that the 1.0 mm gauge is the best filter media since it performed better than other sizes of nylon. The bed 2.0mm material has the advantage of faster filter rates but with high sand levels mixing with the FS cakes, while the 0.5 mm has the lowest filtering rates and high levels of clogging of the holes during filtration. Therefore, the 1.00 mm nylon gauge is recommended for future technological advancements at Lubigi FSTP in case there is a need to change the filter media of the plant beds.

5.2 Recommendations

5.2.1 Faecal Sludge Management

The advantages of FSM must be weighed against the corresponding higher operational and capital expenses. With future studies, for instance, on replacing filter media and a more thorough understanding of the impact of hydraulic (dewatering) and solid loading rates, this

required footprint might theoretically be further attained. Given that FS has a CV that is comparable to that of other widely used biofuels, technological advances that reduce the amount of sand in the final residues increase treatment potential while also enabling the use of FS as a fuel, a source of income to help defray treatment costs and an improvement to sustainable sanitation services.

5.2.2 Future research

Given that this study considered dewatering rates and volumes (quantity) and chemical and physical properties of FS for different filter media, it is recommended that future research analyse and quantifies the water quality of filtrate (percolate) from the FS using these filter media.

5.3 Limitations

This study assessed different membranes used in FS drying to minimise the sand layer takeaway in the SDBs at Lubigi FSWTP. However, other factors such as climatic conditions, FS source and handling, among others, were not considered.

Failure of Bed B (Hessian) in the middle of the experiment affected the final results of this study.

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ANNEX

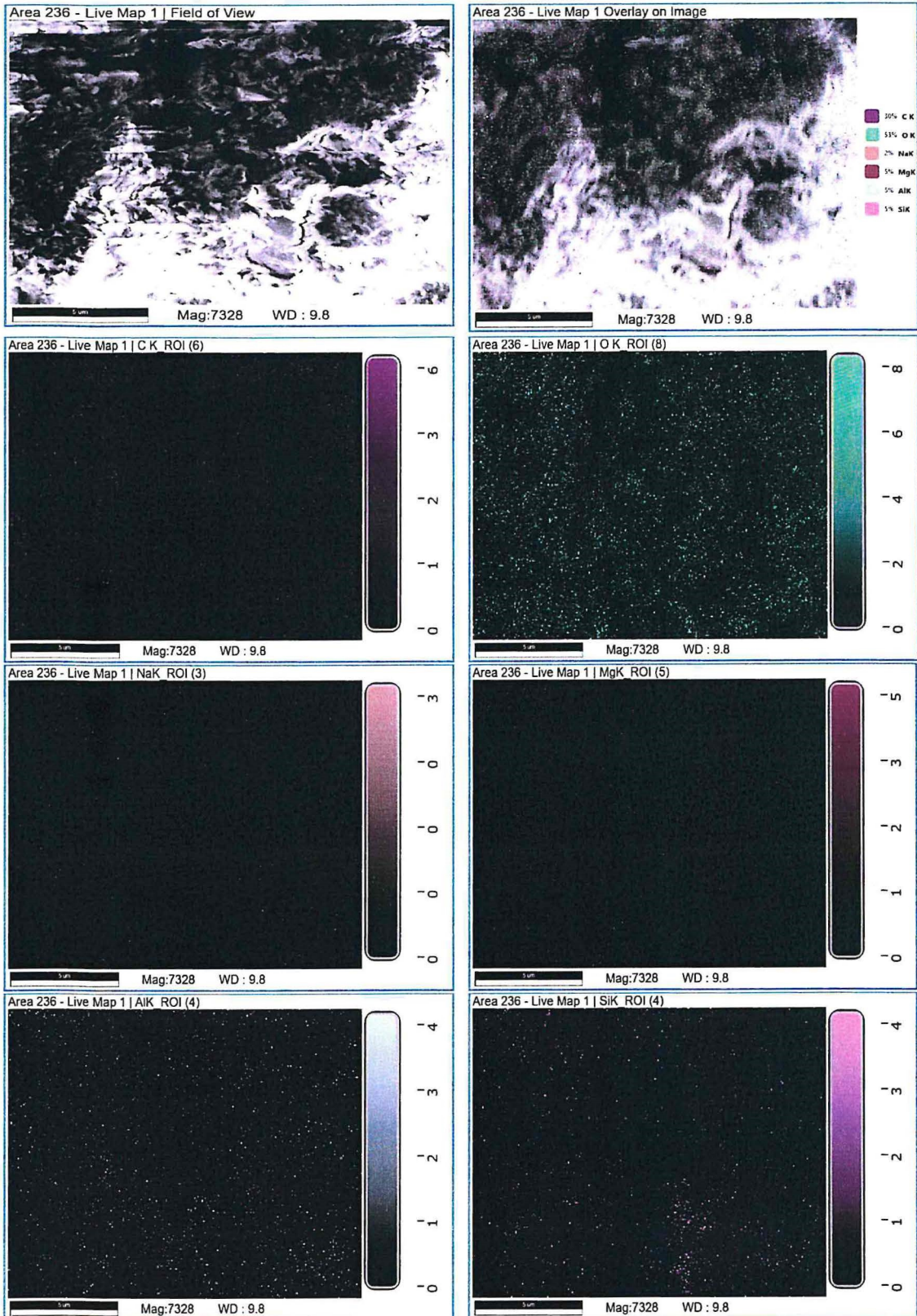
Analysis of Chemical Properties in the Laboratory

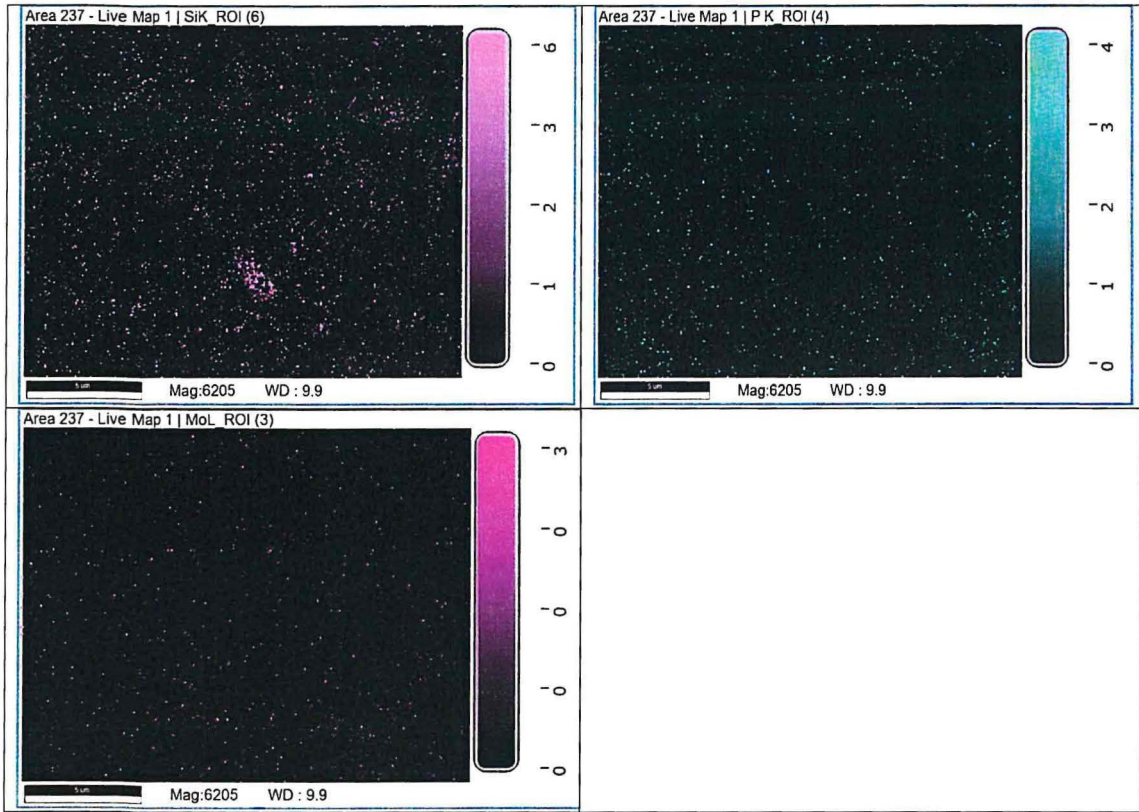
Element	Weight %	Atomic %	Error %	Net Int.	R	A	F
Sludge Sample 1							
C K	39.6	47.99	9.04	322.37	0.9352	0.3686	1
N K	-	-	-	-	-	-	-
O K	52.08	47.37	8.47	553.21	0.9448	0.406	1
Na K	0.72	0.45	24.13	8.5	0.9556	0.6232	1.0026
Mg K	2.36	1.41	8.44	37.82	0.9589	0.7457	1.0035
Al K	2.59	1.4	7.87	40.4	0.9619	0.8222	1.0041
Si K	2.65	1.37	7.2	40.11	0.9649	0.8732	1.0036
Ca K	-	-	-	-	-	-	-
Mo L	-	-	-	-	-	-	-
Sludge Sample 2							
C K	44.15	54.28	9.84	321.14	0.9306	0.3351	1
N K	3.68	3.88	19.81	22.97	0.9362	0.1743	1
O K	37.93	35	9.49	601.39	0.9407	0.3254	1
Na K	0.47	0.3	24.38	13.79	0.9521	0.6399	1.0033
Mg K	0.75	0.45	12.71	29.83	0.9556	0.7593	1.0056
Al K	3.28	1.8	6.32	128.37	0.9589	0.8391	1.0073
Si K	6.24	3.28	5.12	236.45	0.962	0.8822	1.0047
Ca K	2.17	0.8	16.68	24.78	0.9784	0.9831	1.0225
Mo L	1.33	0.21	21.16	17.25	0.9686	0.9331	1.0029
Sludge Sample 3							
C K	57.84	70.91	8.94	197.46	0.9243	0.3925	1
N K	1.71	1.79	49.39	3.09	0.9303	0.1262	1
O K	22.32	20.54	11.08	110.18	0.9351	0.2527	1
Na K	0.28	0.18	28.71	3.34	0.9473	0.6498	1.0031
Mg K	1.08	0.65	8.89	17.4	0.9511	0.767	1.005
Al K	1.68	0.92	7.93	26.51	0.9546	0.8424	1.0073
Si K	2.69	1.41	6.04	41.51	0.9579	0.89	1.0085

Ca K	7.88	2.89	6.53	35.89	0.9758	0.9821	1.0185
Mo L	4.51	0.69	4.73	23.8	0.9651	0.945	1.0053
Sludge Sample 4							
C K	46.32	57.26	8.73	299.02	0.9261	0.3743	1
N K	4.95	5.25	14.49	23.1	0.932	0.1639	1
O K	34.59	32.1	9.43	396.96	0.9367	0.2963	1
Na K	0.44	0.28	14.25	10.09	0.9487	0.6324	1.0029
Mg K	1.53	0.93	6.86	47.87	0.9524	0.7529	1.0043
Al K	1.63	0.9	6.08	50.08	0.9558	0.8304	1.0063
Si K	2.52	1.33	4.97	76.22	0.9591	0.8819	1.0072
Ca K	3.29	1.22	7.42	29.74	0.9765	0.9812	1.0215
Mo L	4.73	0.73	5.41	49.16	0.9661	0.9418	1.0034
Sludge Sample 5							
C K	46.32	57.26	8.73	299.02	0.9261	0.3743	1.0000
N K	4.95	5.25	14.49	23.10	0.9320	0.1639	1.0000
O K	34.59	32.10	9.43	396.96	0.9367	0.2963	1.0000
Na K	0.44	0.28	14.25	10.09	0.9487	0.6324	1.0029
Mg K	1.53	0.93	6.86	47.87	0.9524	0.7529	1.0043
Al K	1.63	0.90	6.08	50.08	0.9558	0.8304	1.0063
Si K	2.52	1.33	4.97	76.22	0.9591	0.8819	1.0072
Ca K	3.29	1.22	7.42	29.74	0.9765	0.9812	1.0215
Mo L	4.73	0.73	5.41	49.16	0.9661	0.9418	1.0034

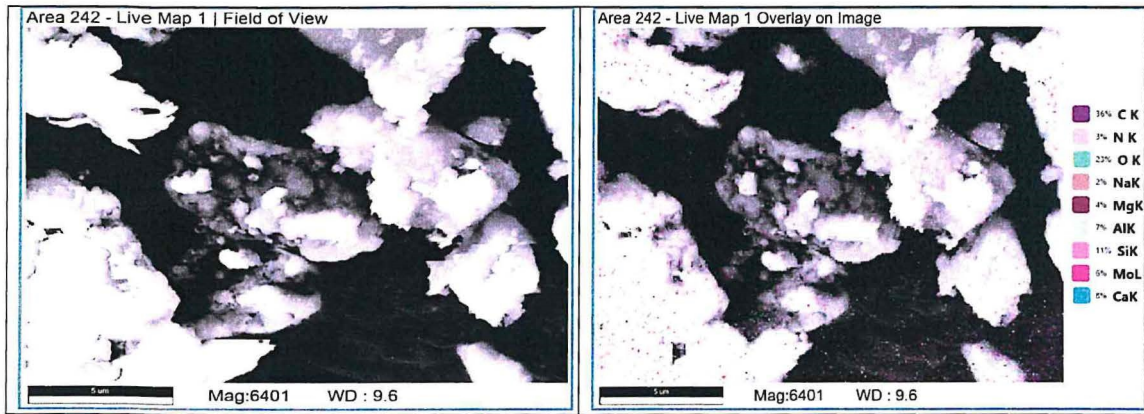
Elemental live maps (Images) for chemical elements from the ESM (Drift corrected)

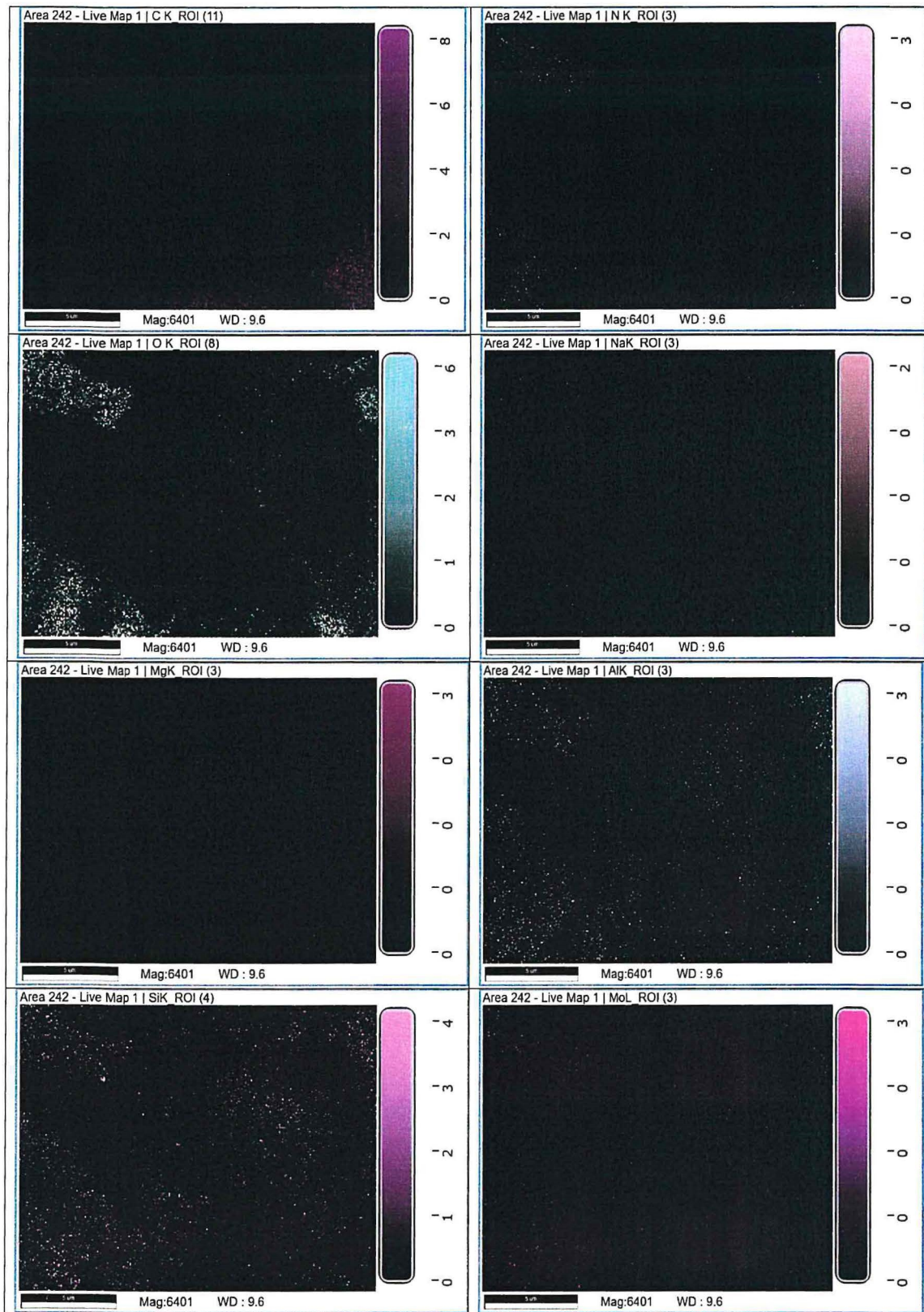
a) Sludge Cake Sample 1

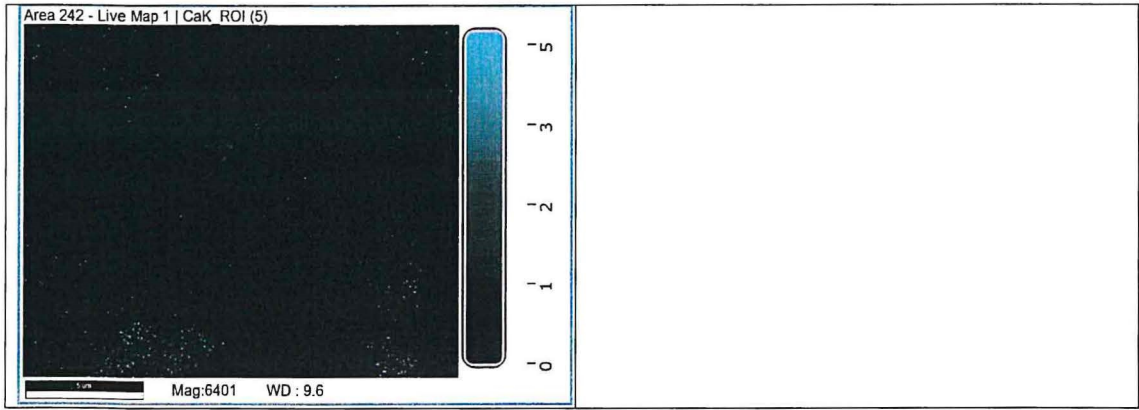




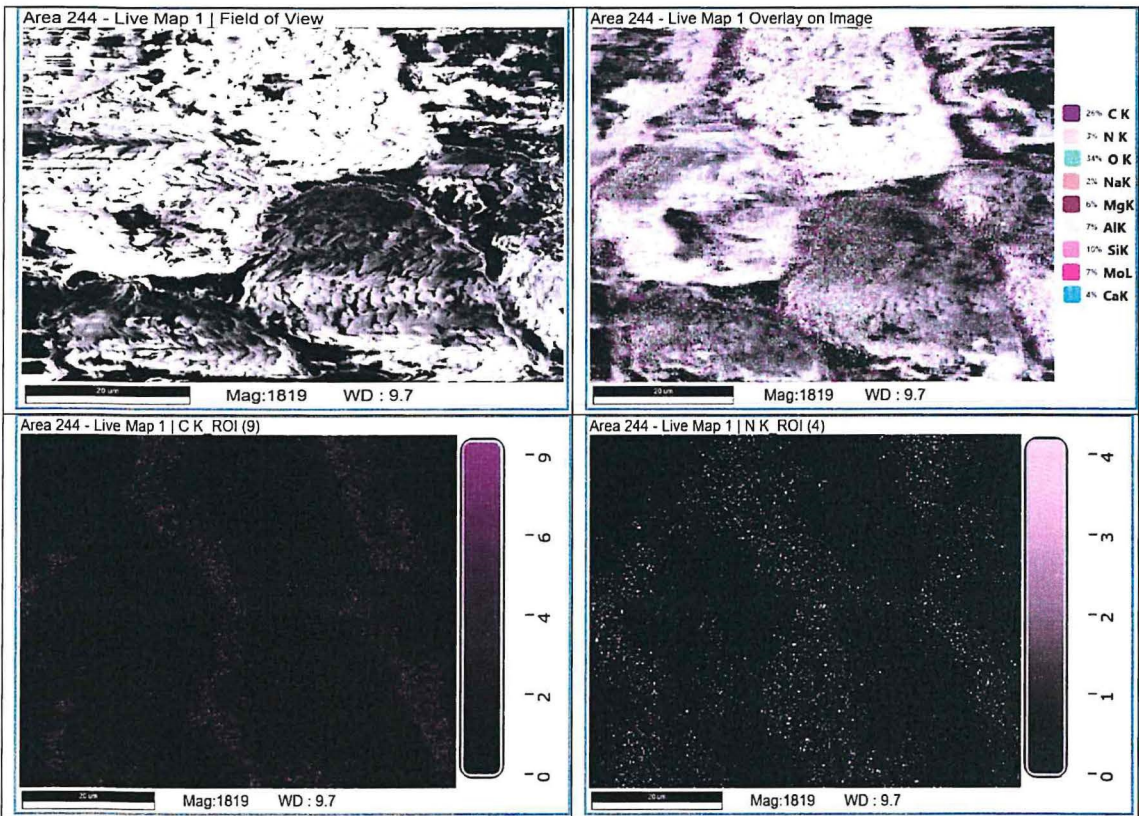
c) Sludge Cake Sample 3

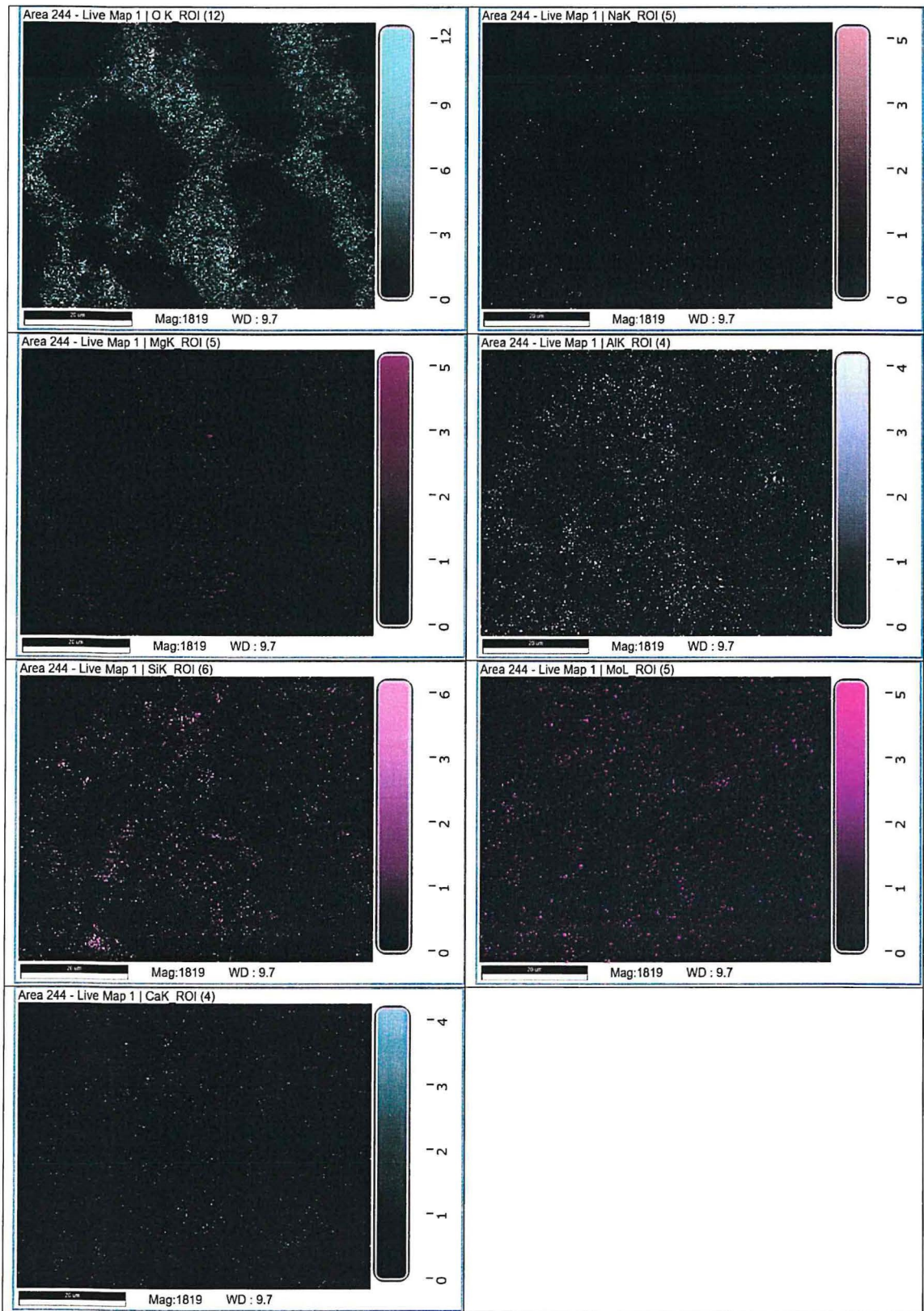




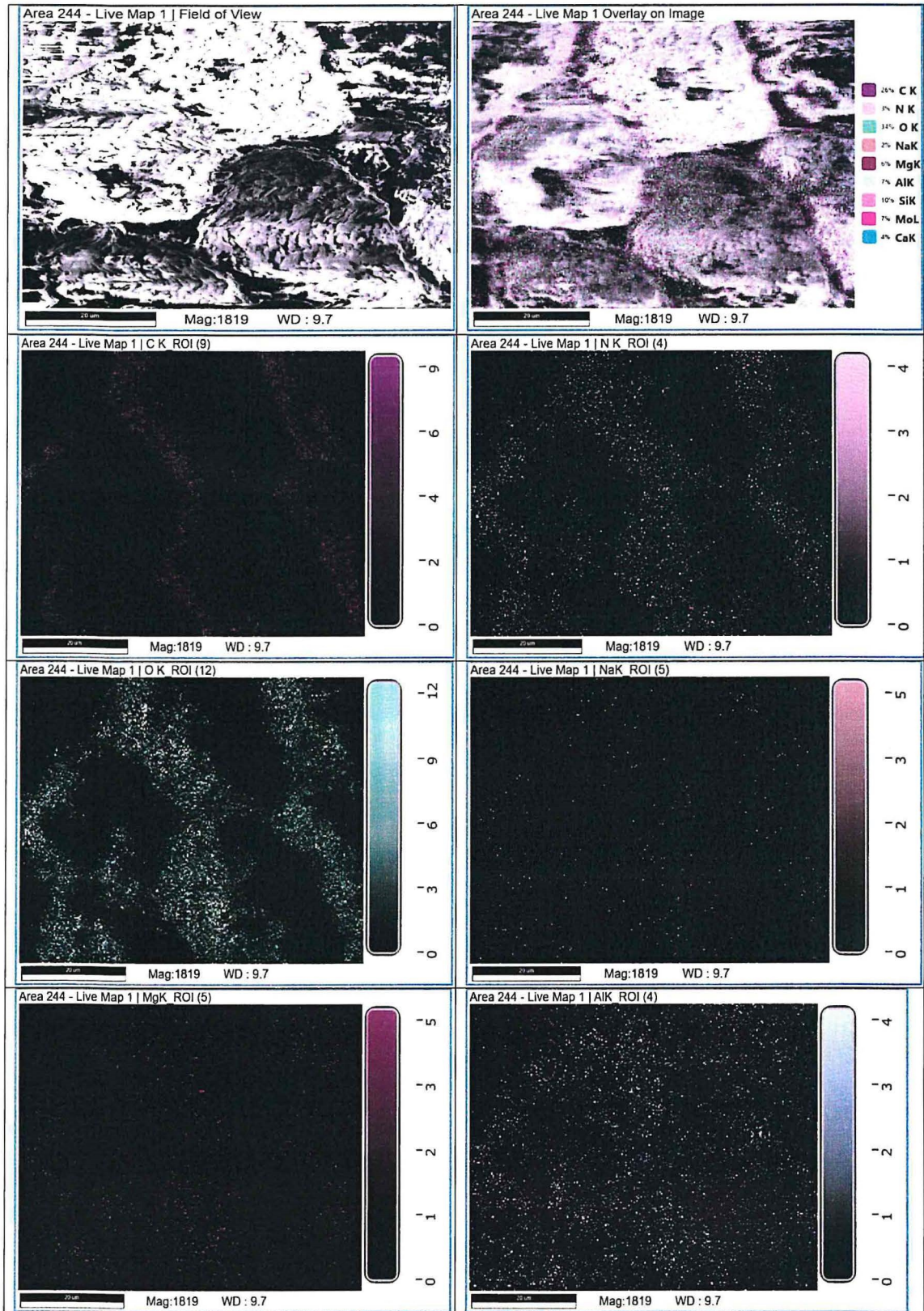


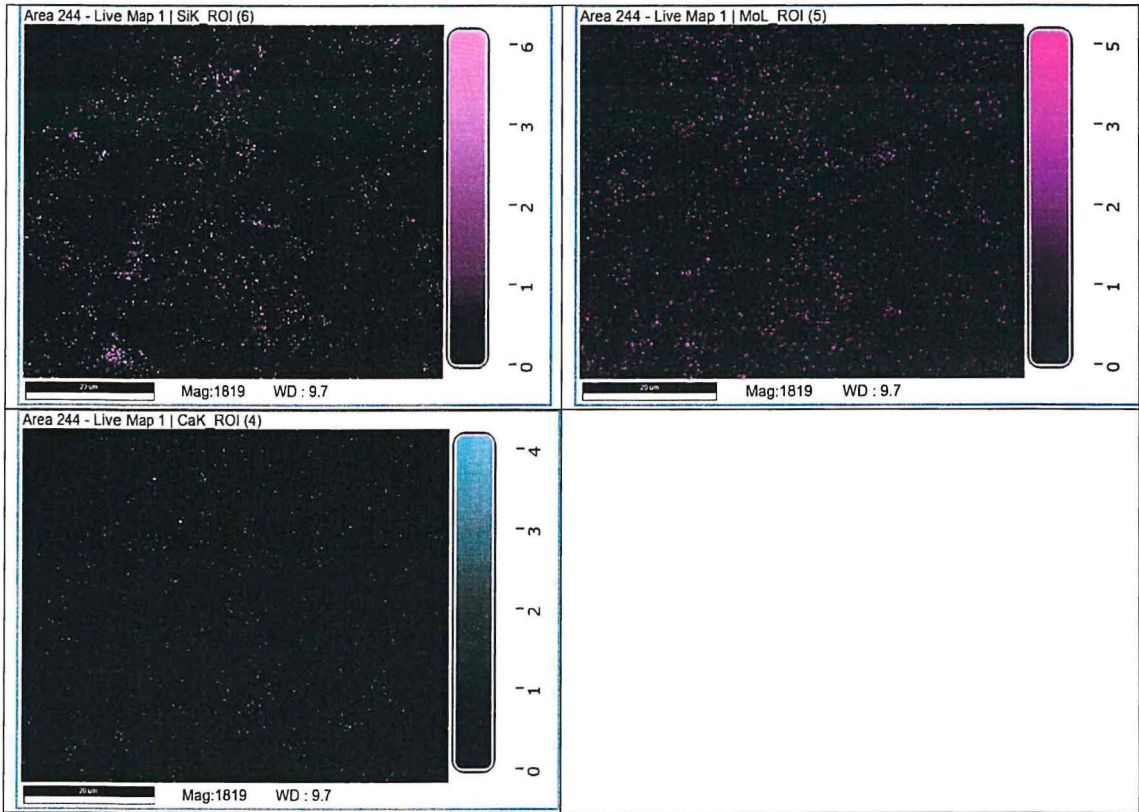
d) Sludge Cake Sample 4





e) Sludge Cake Sample 5





f) Analysis of Chemical Properties in the Laboratory (Descriptive Statistics)

<i>MC (%)</i>	
Mean	75.20801839
Standard Error	0.364975471
Median	75.16552189
Standard Deviation	0.894003673
Sample Variance	0.799242567
Kurtosis	1.438478615
Skewness	-0.852894776
Range	2.597456158
Minimum	73.67790657
Maximum	76.27536273
Sum	451.2481103
Count	6
Confidence Level (95.0%)	0.938199316

<i>Sand Content (%)</i>	
Mean	18.344
Standard Error	0.385468546
Median	18.02

Standard Deviation	0.861933872
Sample Variance	0.74293
Kurtosis	0.50375281
Skewness	0.941373392
Range	2.23
Minimum	17.43
Maximum	19.66
Sum	91.72
Count	5
Confidence Level (95.0%)	1.070232258

g) Regression Analysis

Sand

<i>Regression Statistics</i>	
Multiple R	0.700490649
R Square	0.490687149
Adjusted R Square	0.485927216
Standard Error	4290.284564
Observations	109

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	1.9E+09	1.9E+09	103.087	2.29333E-17
Residual	107	1.97E+09	18406542		
Total	108	3.87E+09			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	6355.016077	510.1074	12.45819	1.49E-22	5343.787685	7366.244	5343.788	7366.244
Time (min)	1.01254911	0.099727	10.15318	2.29E-17	0.814851314	1.210247	0.814851	1.210247

Hessian

<i>Regression Statistics</i>	
Multiple R	0.79483018
R Square	0.631755016
Adjusted R Square	0.628313474
Standard Error	374.9293019

Observations 109

ANOVA

	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	25804438	25804438	183.5674	5.91544E-25
Residual	107	15041202	140572		
Total	108	40845640			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	476.7479698	44.57844	10.69459	1.36E-18	388.3764062	565.1195	388.3764	565.1195
Time (min)	0.118079712	0.008715	13.54871	5.92E-25	0.10080284	0.135357	0.100803	0.135357

Pavers

Regression Statistics

Multiple R	0.739792316
R Square	0.547292671
Adjusted R Square	0.543061762
Standard Error	3062.257592
Observations	109

ANOVA

	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	1.21E+09	1.21E+09	129.3558	3.98221E-20
Residual	107	1E+09	9377422		
Total	108	2.22E+09			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
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Intercept	4416.400973	364.0971	12.12973	8.01E-22	3694.62092	5138.181	3694.621	5138.181
Time (min)	0.809585548	0.071182	11.37347	3.98E-20	0.668475659	0.950695	0.668476	0.950695

Nylon

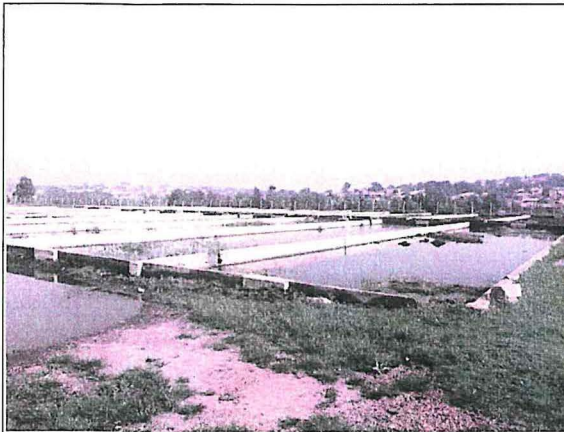
<i>Regression Statistics</i>	
Multiple R	0.769327379
R Square	0.591864616
Adjusted R Square	0.588050267
Standard Error	2707.629295
Observations	109

ANOVA

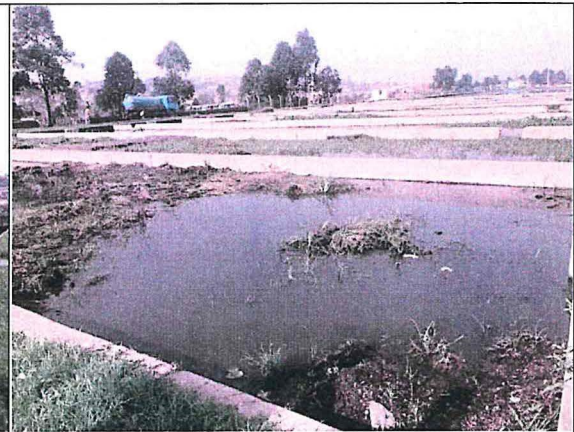
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	1.14E+09	1.14E+09	155.1679	1.49776E-22
Residual	107	7.84E+08	7331256		
Total	108	1.92E+09			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	3850.020005	321.9324	11.95909	1.93E-21	3211.826529	4488.213	3211.827	4488.213
Time (min)	0.784003934	0.062939	12.45664	1.5E-22	0.65923544	0.908772	0.659235	0.908772

h) Photos



Sludge lagoon



Sludge lagoon



Sludge Drying Beds



Sludge cakes being removed



Materials for the set-up of the site



Experimental set-up construction



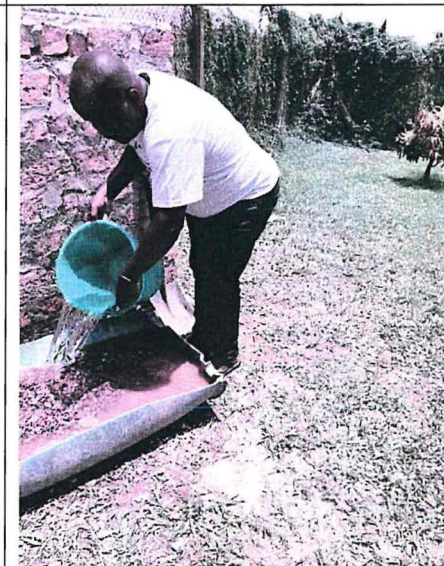
Ceiling the inside of the set-up



Measuring the specified height of the setup



Percolate pipe drilled with holes.



Washing the aggregates to use in the beds



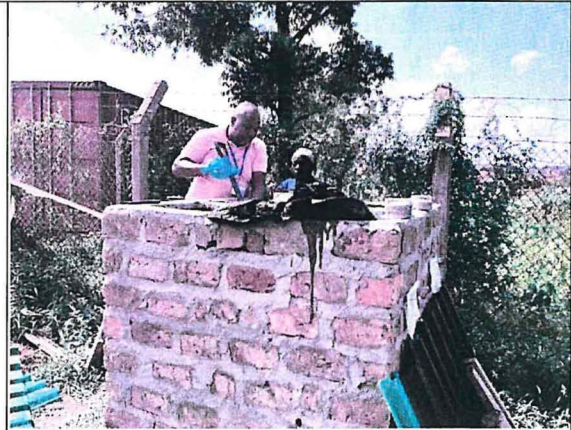
Calibrating the metre rule used



Metre-rule inserted in the bed



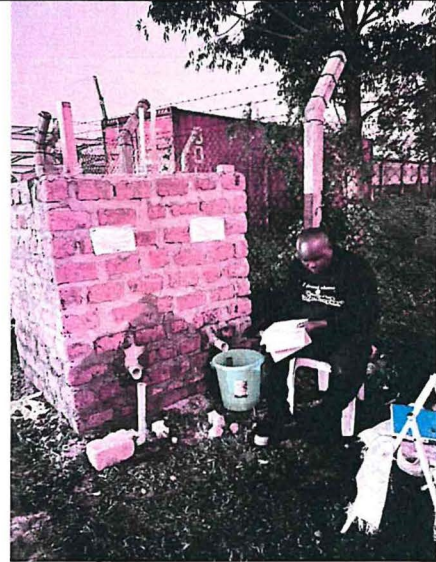
Beds A, B, C and D with calibrated rule



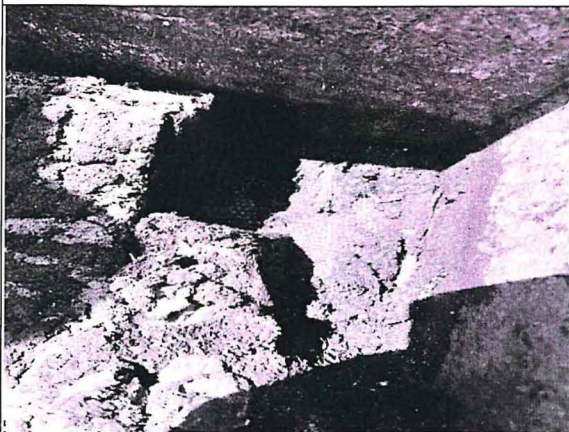
Checking the level of solid FS



Shrinking solid sludge during dewatering



Recording dewatering/flow rates



Scooping the solid sludge cake from the Beds



Nylon bed

i) Laboratory Analysis Results

MAKERERE

P.O. Box 7062 Kampala, Uganda

<http://www.sci.mak.ac.ug>

<http://www.science.ac.ug>



UNIVERSITY

Tel: +256-414-540765

Fax: +256-414-532780

Email: pmb@cns.mak.ac.ug

**COLLEGE OF NATURAL SCIENCES
DEPARTMENT OF PLANT SCIENCES, MICROBIOLOGY AND BIOTECHNOLOGY**

10th February, 2022

RESEARCH TEST RESULT

Student Name: NGABIRANO DENETH

Reg. No: 18 UGMEW/22154/PD

Key

MC	Moisture Content
SC	Sand Content
CV	Calorific Value
F	Extreme Sample I
H	Extreme Sample III
G	Middle Centre Sample
J	Extreme Sample III
I	Extreme Sample IV

Moisture Content

Sample	MC (%)	SC (%)	CV (kcal/kg)
F	72.68	17.92	3080.89
H	75.91	17.43	3185.46
G	75.28	18.02	2946.38
J	75.06	19.66	2995.39
I	75.12	18.69	3135.29
Mean Value	74.81	18.34	3068.68

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P.O. Box 7062 Kampala, Uganda

<http://www.sci.mak.ac.ug>

<http://www.science.ac.ug>



UNIVERSITY

Tel: +256-414-540765

Fax: +256-414-532780

Email: pmb@cns.mak.ac.ug

**COLLEGE OF NATURAL SCIENCES
DEPARTMENT OF PLANT SCIENCES, MICROBIOLOGY AND BIOTECHNOLOGY**

7th April, 2022

RESEARCH TEST RESULT

Student Name: NGABIRANO DENETH

Reg. No: 18/U/GMEW/22154/PD

Key

CV	Calorific Value
SC	Sand Content
MC	Moisture Content

Results

Bed Sampled	MC (%)		SC (%)		CV (Kcal/Kg)	
	Top	Bottom	Top	Bottom	Top	Bottom
Bed A (Sand) - Standard	80.60	83.67	22.98	24.26	2418.12	2176.31
Bed B (Hessian)	91.71	93.42	6.16	6.35	3020.37	2929.76
Bed C (Pavers)	86.12	87.81	14.92	15.73	2813.94	2616.96
Bed D (Nylon)	86.28	88.87	13.84	14.01	2733.46	2569.45

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P.O. Box 7062 Kampala, Uganda

<http://www.sci.mak.ac.ug>

<http://www.science.ac.ug>



UNIVERSITY

Tel: +256-414-540765

Fax: +256-414-532780

Email: pmb@ens.mak.ac.ug

**COLLEGE OF NATURAL SCIENCES
DEPARTMENT OF PLANT SCIENCES, MICROBIOLOGY AND BIOTECHNOLOGY**

6th June, 2022

RESEARCH TEST RESULT

Student Name: NGABIRANO DENETH

Reg. No: 18/U/GMEW/22154/PD

Key

CV	Calorific Value
SC	Sand Content
MC	Moisture Content

Results

Bed and Nylon Size (mm)	MC (%)		SC (%)		CV (Kcal/kg)	
	Top	Bottom	Top	Bottom	Top	Bottom
Bed A (1.00mm)	83.28	87.28	13.24	14.8	2745.12	2600.12
Bed B (0.50 mm)	86.91	90.92	6.51	7.03	3120.07	2980.03
Bed C (2.00 mm)	82.14	85.16	14.81	17.05	2212.1	2067.13