INVESTIGATING THE DEWATERABILITY AND RESOURCE RECOVERY POTENTIAL OF DISTILLERY WASTEWATER USING SAWDUST AND CHARCOAL DUST AS CONDITIONERS

BY

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A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN WATER AND SANITATION ENGINEERING OF KYAMBOGO UNIVERSITY

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DECLARATION

I Angom Hedina, hereby declare that this submission is my own 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.

Sign:………………………………………….   Date:…………………..…………

APPROVAL

The undersigned approve that they have read and hereby recommend for submission to the Directorate of Research and Graduate Training of Kyambogo University, a dissertation entitled: Investigating the dewaterability and resource recovery potential of distillery wastewater using sawdust and charcoal dust as conditioners, in fulfilment of the requirements for the award of Master of Science in Water and Sanitation Engineering Degree of Kyambogo University.

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LIST OF ABBREVIATION

ACRONYM	**MEANING**
APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
BSc.	Bachelor of Science
COD	Chemical Oxygen Demand
CST	Capillary Suction Time
DO	Dissolved Oxygen
EC	Electrical Conductivity
FOG	Fats, Oils and Grease
K	Potassium
MC	Moisture Content
mg/l	Milligrams per Liter
mS/cm	MilliSiemens per Centimetre
N	Nitrogen
NTU	Nephelometric Turbidity Units
ORP	Oxygen Reduction Potential
P	Phosphorus
PPM	Parts per Million
pH	Potential of Hydrogen
TCU	True Colour Unit
TDS	Total Dissolved Solids
TS	Total Solids
TVS	Total Volatile Solids
UCU	Uganda Christian University
WHO	World Health Organisation
µS/cm	MicroSiemens per Centimetre

ABSTRACT

Discharge of untreated distillery wastewater has a high impact on human and environmental health. One of the critical stages in its management is dewatering. However, understanding the dewatering characteristics of distillery wastewater is a grey area as minimal research has been done on it. This research evaluated the characteristics of distillery wastewater from various sources to identify any variations, its dewatering potential, enhancement of dewatering using conditioners and its resource recovery potential. The research was undertaken using laboratory measurements and experiments to determine the wastewater characteristics and dewaterability. Dewatering performance was measured in terms of capillary suction time (CST), and turbidity of supernatant after natural and mechanical settling. The findings of this study showed that distillery wastewater characteristics were very significant in pH (3.56-6.32) p=0.017, EC (4.22-34.77mS/cm) p=0.002, COD (63,800-148,680mg/L) p=0.004 and turbidity (18,700-45,500NTU) – p=0.167. Dewatering was noted to be CST (30-5512.64s) p=0.140 and turbidity of supernatant (14,700-87,500NTU) p=0.046. Enhancing dewatering using conditioners showed CST (60.56-9047.04s) p=0.452, 0.012, 0.207 and turbidity of supernatant (4.37-93,500NTU) p=0.002, 0.013, 0.788 with better performance observed after treatment with charcoal dust. Based on the Nitrogen (31-121mg/L), Phosphorus (195-757mg/L), Potassium (4580-13449.15mg/L) and TVS/TS ratio (0.76-0.91) values, distillery wastewater showed potential for resource recovery. Distillery wastewater needs to be treated to protect human and environmental health. Strict measures should be put in place to ensure adherence to standards for discharge into the environment.

Key words:

Conditioning, dewatering, distillery wastewater, established factories/illicit distillers and resource recovery**.**

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Consumption of distilled beverages has been going on since the Middle Ages (World Health Organisation, 2014). In the past, alcohol was brewed mainly in small quantities using local methods. With the progression of time, more efficient methods of production have been adopted to meet the growing demand (World Health Organisation, 2014). As a result of this, alcohol distilling industries have contributed highly to the financial growth and advancement of many countries around the world (Kumar, Chowdhary and Shah, 2021). However, with increased production due to the use of more efficient methods of alcohol production, wastewater generation has also gone up with the increase in water usage. Alcohol distilling industries are second to paper-pulp in generating large amounts of processing wastewater that is, approximately 12-15 L per litre of ethanol manufactured (Ratna, Rastogi and Kumar, 2021). Distillery wastewater is the undesirable remaining liquid after alcohol generation (Mohana, Acharya and Madamwar, 2009). It is commonly dark brown, which can be ascribed to the presence of melanoidins, caramels and hexose alkaline reduction products (Kumar, Chowdhary and Shah, 2021). This dark brown colour is very resistant to microbial degradation and other biological treatments because melanoidins have anti-oxidant properties which are toxic to microorganisms involved in the microbial and biological treatment processes (Khot *et al.*, 2021). This requires efficient wastewater treatment solutions to minimise the risk of environmental pollution and irremediable damage.

Mechanisms used in the treatment of domestic wastewater have been utilized/adopted for the treatment of distillery wastewater to separate the liquid and solid constituents for easy disposal. Distillery sludge constitutes the solids. According to Suthar and Singh (2008), management of this sludge has become one of the emerging issues for waste managers of distillery industries because it has a high sulphate content, phenolic compounds, melanoidins, organic matter and heavy metals.

Dewatering is the process of separating the liquid and solid components of wastewater or sludge to ensure the reduction of its volume and weight for easy handling, transportation and disposal. However, like any other process, it has challenges, and these include high cost, large space requirements, low dewatering rate, and sometimes low reliability. Dewatering can be enhanced using conditioners to increase the dewatering rate and extent hence reducing sludge volume and consequently the time and space requirements. Sludge conditioning is the physical or chemical treatment of sludge to ease dewatering (IWPC, 1981). Research shows that chemical conditioners and physical conditioners namely, sawdust, rice husks, char bagasse and coal fines enhance the dewatering rate and extent of sewage sludge respectively (Semiyaga *et al.*, 2018). In this same research, (Semiyaga *et al.*, 2018) achieved an improvement in dewatering rate of faecal sludge of 15.8% and 14.3%, and dewatering extent of 35.7% and 22.9% after treatment with charcoal dust and sawdust respectively. He also reported an improvement in calorific value of faecal sludge by 49% and 42% from 11.4 MJ kg^{-1} after treatment with charcoal dust and sawdust at a dose of 50% TS.

Several distillery industries in Uganda treat the wastewater generated through their alcohol production processes. The local distillers on the other hand do not treat their wastewater; it is simply disposed of in the nearby environment. In the long run, this becomes an aesthetic nuisance and poses a threat to public and environmental health. The environmental regulation standards require industries to treat their wastewater, however, they do not cover the local distillers.

1.2 Problem Statement

Distillery wastewater is highly toxic, requiring proper treatment to match effluent disposal standards specified in the National Environment Regulations, (NEMA, 2020). As with most wastewater, proper treatment methods can be best chosen after understanding the characteristics of the wastewater. Distillery wastewater from sugarcane molasses is also known for its pungent smell and black-brown colour. Compounds liable for the black-brown colour of wastewater from distilleries are highly resistant to microbial degradation and other biological treatments. The characteristics of distillery wastewater are variant though high in concentration pH (3-4.5), TS (59,000-190,000mg/L), COD (8,000-190,000mg/L) and TVS (38,000-120,000%TS) (Khot *et al.*, 2021; Mohana, Acharya and Madamwar, 2009). However, limited research has been done to understand these characteristics to guide the proposition of treatment methods. Several distillery industries in Uganda treat the wastewater generated through their alcohol production processes because they are monitored to comply to the Occupational Safety and Health Act, 2006. However, there is point source pollution arising from illicit distillers as shown in Figure 1.1. In the long run, this becomes an aesthetic nuisance and poses a threat to public and environmental health. With the rise in alcohol consumption and local distillation to meet the demand, there is a need to explore better wastewater management strategies that will result in environmental protection. Dewatering is a significant stage for solid-liquid separation. However, most dewatering study has been done on faecal sludge (Semiyaga *et al.*, 2017); (Semiyaga *et al.*, 2018); (Ward *et al.*, 2023) and wastewater sludge (Shaw *et al.*, 2022); (Christensen *et al.*, 2015). Moreover, potential for resource recovery of solid residue from distillery wastewater for circular production is not known which could incentivise the illicit distillers to properly manage their wastes. The use of physical conditioners to improve the dewaterability potential of distillery sludge could increase the efficiency of dewatering and offset the cost of managing distillery sludge while generating a useful product (dewatered cake). This study aimed to provide a better understanding of the characteristics of distillery wastewater from various sources, its dewatering characteristics and resource recovery potential. This information is critical to inform standards, policies and management strategies.

Figure 1.1: Untreated distillery wastewater disposed at a local distillation site.

1.3 Research Objectives

1.3.1 Main Objective

To provide a better understanding of the characteristics of distillery wastewater from various sources, its dewatering and resource recovery potential.

1.3.2 Specific Objectives

a) To characterize distillery wastewater from various sources.

b) To assess the dewaterability potential of distillery wastewater.

c) To assess the impact of conditioning on dewatering of distillery wastewater.

d) To evaluate the resource recovery potential of distillery wastewater.

1.4 Research Questions

a) What are the characteristics of distillery wastewater?

b) Is distillery wastewater from a factory different from illicit sources (local distillers)?

c) What is the dewaterability potential of distillery wastewater from factory and illicit sources?

d) What is the impact of conditioning on dewatering of distillery wastewater?

e) What is the optimal conditioner dosage to attain effective dewaterability?

f) What is the resource recovery potential of distillery wastewater?

1.5 Research Justification

Managing distillery wastewater according to regulatory standards helps towards achieving United Nations Sustainable Development Goals 6 – water and sanitation, 12 – responsible production and consumption, 14 – life below water and 15 – life on land (UN DESA, 2023). Negative impacts like pollution, eutrophication, acidification, and contamination that result from improper management are avoided. In addition, there are many distillery industries in Eastern Uganda, which makes their effects on the environment noticeable. Therefore, it is crucial to ensure proper wastewater management techniques are documented ahead of encouraging distilling industries and local distillers to manage their wastes in accordance with stipulated disposal regulations for safe and sustainable disposal. In line with distillery wastewater, limited work has been done to know its characteristics and dewatering potential which further highlights the significance of this study.

Distillery sludge has high nutritional and energy values hence highlighting its resource recovery potential (energy recovery). This study aimed to investigate the dewaterability potential of distillery wastewater using physical conditioners and its value recovery potential.

1.6 Scope of the Study

The scope of the study was categorized into geographical, time and content.

1.6.1 Geographical Scope

Samples were picked from various factories and local distillers in Lugazi, Jinja and Kampala taking into consideration methods and materials used for production. These were Sugar Corporation of Uganda Limited, Lugazi (SCOUL), local distillers in Wandago, Jinja and Banda, Kampala.

1.6.2 Time Scope

The study was conducted from September 2023 to March 2024, during the master's research period.

1.6.3 Content Scope

The content scope included;

- Characterizing distillery wastewater from various sources
- Dewaterability potential (CST) of distillery wastewater.
- Impact of conditioning on dewatering of distillery wastewater
- Resource recovery potential of distillery wastewater

1.7 Conceptual Framework

A conceptual framework outlines different concepts of a study and the relationship between them hence providing a comprehensive understanding of the topic. Figure 1.2 below shows the conceptual framework for the study.

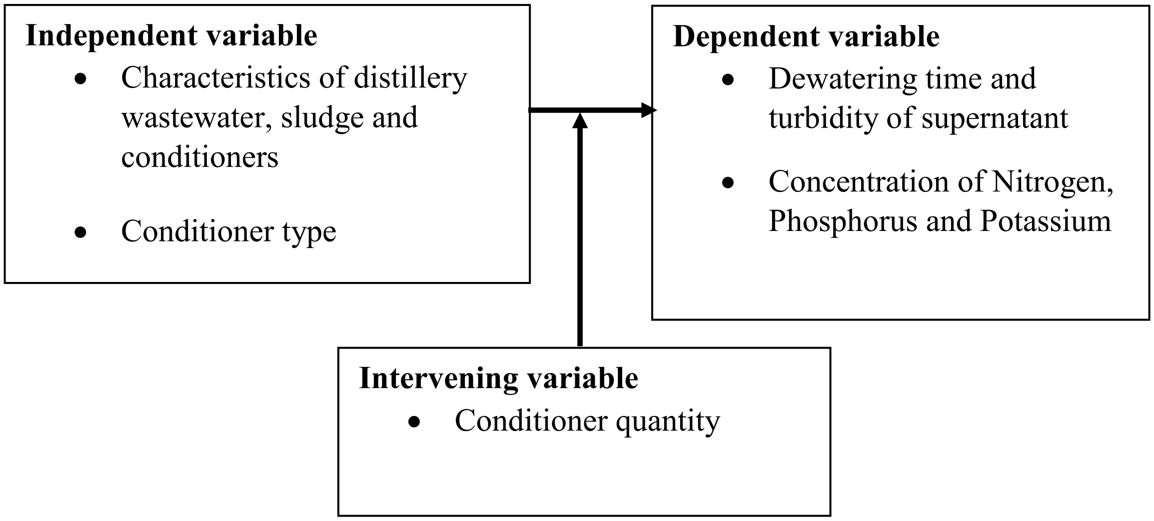


Figure 1.2: Research conceptual framework.

CHAPTER TWO: LITERATURE REVIEW

2.1 Alcohol distillation process

Alcohol is produced through use of raw materials such as sugarcane molasses, cassava, wheat, corn and sweet sorghum among others (Bušić *et al.*, 2018). To obtain molasses, sugarcane is crushed and processed into light brown and dark brown sugar, leaving a large amount of molasses behind which is then fermented and distilled into alcohol (Fito, Tefera and Van Hulle, 2019). The other raw materials used in alcohol production are typically crushed, fermented and distilled to obtain alcohol, leaving behind wastewater. The wastewater generated from the alcohol distillation process is known as distillery wastewater.

2.2 Overview and composition of distillery wastewater

Distillery wastewater is described as extremely polluted in comparison to other industrial wastewater sources, especially those from the food and beverage industry. This wastewater is characterized (Table 2.1) by acidity, high temperature, dark brown colour (Figure 2.1), high ash content and high percentage of dissolved organic and inorganic matter with high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) (Khot *et al.*, 2021); (Ratna, Rastogi and Kumar, 2021).

Table 2.1: Research values of distillery wastewater parameters.

Parameter	**Unit**	**Value (Khot *et al.*, 2021)**	**Value (Mohana, Acharya and Madamwar, 2009)**
pH	-	4-4.5	3.0-4.5
Colour		Dark brown	
Total Solids	mg/l	100,000	110,000-190,000
Total Volatile Solids	mg/l		80,000-120,000
Total Suspended Solids	mg/l	10,000	13,000-15,000
Total Dissolved Solids	mg/l		90,000-150,000
Chemical Oxygen Demand	mg/l	8,000-120,000	110,000-190,000
Biochemical Oxygen Demand	mg/l	45,000-60,000	50,000-60,000
Alkalinity	mg/l	3,500	

Figure 2.1: The dark brown colour of factory distillery wastewater.

The high BOD and COD values are due to the presence of numerous organic compounds namely polyphenols, polysaccharides, waxes, proteins and melanoidin (Mikucka and Zielińska, 2020). The characteristics of distillery wastewater depend on the raw materials used and the alcohol production processes (Kharayat, 2012). Many distilleries use the molasses from sugar production as raw material for ethanol production. Distillery wastewater is also characterized by high levels of nutrients like nitrogen, phosphorus, potassium, and iron (Chhaya and Kumar, 2014). This makes it useful for use to improve soil fertility and increase crop yield. However, these nutrients in excess quantities lead to the eutrophication of polluted water sources. The dark-brown of distillery wastewater blocks out sunlight to aquatic flora which decreases the oxygenation of water bodies by photosynthesis (Satyawali and Balakrishnan, 2008). Distillery industries are highly water intensive and subsequently generate large volumes of wastewater. For every litre of alcohol produced, 8-15 litres of wastewater is generated (Davarnejad and Azizi, 2016).

2.3 Treatment of distillery wastewater

The treatment methods for distillery wastewater include physical, chemical, and biological methods. The choice of treatment methods depends on nature of wastewater, cost of treatment, regulatory requirements, public perception, area topography and climate (Kharayat, 2012). The physical and chemical methods are used to remove solids, oils and fats and biological methods are used to remove organic matter and nutrients. Some of the physicochemical methods include; sedimentation, coagulation-flocculation, filtration, nanofiltration, reverse osmosis, advanced oxidation, membrane technology, ozonation, ion exchange and adsorption (Ghosh Ray and Ghangrekar, 2019). Adsorption using activated carbon is effective for the removal of colour and certain organic pollutants (Satyawali and Balakrishnan, 2008). Biological methods include trickling filters, lagoons and activated sludge among others. However, these are not efficient in removing colour-causing pigments in distillery wastewater (Fito, Tefera and Van Hulle, 2019).

2.4 Dewatering and ways of dewatering

Dewatering means reducing the moisture content of wastewater/sludge (Rao, Wang and Xu, 2022). Dewatering methods are evaluated by assessing the rate at which water is expelled and the amount of water that can be removed from the wastewater/sludge.

The established ways for dewatering include mechanical dewatering, thermal drying, chemical dewatering, and electro-dewatering.

2.4.1 Mechanical dewatering

This process commonly involves filtration and compression using a mechanical force to reduce the water content of sludge (Mahmoud *et al.*, 2010). It is used as an intermediate process before thermal drying (Mahmoud *et al.*, 2013). Some of the devices used include belt presses, centrifuges and filter presses (Ashley, 2018).

2.4.2 Thermal drying

In this process, sludge is exposed to high temperatures to reduce its water content by evaporation. The sludge can be dried to 90% solids or more (Tunçal and Uslu, 2014). It is used in conjunction with mechanical dewatering. Peeters (2010) described the use of a combination of mechanical and thermal drying for handling wastewater-activated sludge. However, this method is energy-intensive and expensive (Wang *et al.*, 2025).

2.4.3 Electro-dewatering

In this process, a low direct current is applied to the sludge to enhance the removal of water from the sludge (Olivier *et al.*, 2015). According to Tuan, Mika and Pirjo (2012), electro-dewatering has advantages like inactivation of pathogens, reduction in costs of transportation of sludge and energy for treatment.

2.5 Dewatering characteristics of industrial wastewater

Wu et al. (2020) conducted a study on industry sludge samples from five different industrial waste plants in Wuhan, China namely, the food industry, Oil refinery industry, pharmaceutical industry and paint industry. It was found that only 28% of the water was removed from Oil refinery industry sludge and a minimum of 8% from food industry sludge using mechanical dewatering. Using electro-dewatering, the dewatering of industrial sludge increased significantly to >25% of the water. This indicated that electro-dewatering was more effective for industrial sludge, except for pharmaceutical industry sludge where dewatering was by only 11% of the water present.

2.6 Dewatering extent and time

Dewatering rate and extent are used as determinants of the permeability and compressibility of wastewater sludge respectively (Skinner *et al.*, 2015). Supernatant turbidity (Ward *et al.*, 2021) and per cent cake solids (Semiyaga *et al.*, 2017) have been used as metrices to quantify dewatering extent. Capillary suction time is a parameter that is widely used to determine dewatering rate (Velkushanova *et al.*, 2021).

Dewatering usually involves the formation of the sludge cake through filtration and compression of the cake through consolidation. However, these two processes are not easily separated when dewatering biological wastewater (Christensen *et al.*, 2015).

2.7 Factors affecting dewatering performance

Murthy, Novak and De Haas (1998) found that complex interactions between cations and sludge influenced the settling and dewatering properties of industrial wastewater in a manner that depended on ratios and concentrations of monovalent and divalent sludge-fed solution. An increase in divalent cations (Ca^{2+}, Mg^{2+}) improved dewatering properties by increasing floc strength. NH_4-N led to deterioration in dewatering properties (increased CST) because flocs disintegrate at high conductivity (Gold *et al.*, 2018). At high pH, dewaterability decreases due to floc disintegration and storage under anaerobic conditions lowers dewaterability (Christensen *et al.*, 2015). Gold et al. (Gold *et al.*, 2018) also reported a positive correlation between Electrical Conductivity (EC) and increased Capillary Suction Time (CST).

Sewage sludge dewatering performance is mostly affected by the following factors: sludge particle size, sludge surface charge (the greater the charge of the sludge, the more difficult to remove water), flocculent and extracellular polymer (Wu, Dai and Chai, 2020). Sludge management methods are categorized into biological, chemical, and physical. In biological methods, enzymes are used to catalyse the degradation of proteins in sludge, cut off molecular chains of macromolecular proteins and promote the disintegration of sludge flocs (Zhen, Jinxiang and Renhui, 2020). The chemical method involves the addition of a flocculant to the sludge to make the sludge particles flocculate to improve its dewatering performance (Rao, Wang and Xu, 2022). Lastly, the physical method involves changing the sludge particle size to improve its dewatering (Zhen, Jinxiang and Renhui, 2020).

2.8 Characterization of sludge dewatering

- Capillary Suction Time (CST)

CST is the time required for water to be released from sludge under capillary action (Velkushanova *et al.*, 2021). It is a common metric for measuring dewatering rate. A shorter CST time corresponds to easier sludge dewatering. Sludge dewatering performance can be calculated by obtaining the difference between the CST time before and after sludge pretreatment and expressing this as a percentage (Zhen, Jinxiang and Renhui, 2020).

Equation 2.1

$CST_{red} = ((CST_{before}-CST_{after})/CST_{after})$ x100%... (Equation 2.1)

Where CST_{red} is the CST reduction, CST_{before} and CST_{after} are the CST before and after sludge treatment respectively.

- Specific Filtration Resistance (SFR)

This assesses sludge dewatering by measuring the rate of filtration when a constant pressure difference is applied, as shown by equation 2.2 (Mowla, Tran and Allen, 2013).

Equation 2.2

$$\frac{\partial t}{\partial V} = \mu / A\Delta P(\frac{\alpha c V}{A} + Rm) \quad \text{……………………………………………… (Equation 2.2)}$$

Where;

ΔP – the applied pressure difference

V – the volume of the filtrate (∂V)

t – the filtration time (∂t)

A – the filter area

α – specific filtration resistance

c – the total solids concentration of the sludge

μ - the filtrate viscosity

Rm – the resistance of the filter medium

2.9 Enhancing distillery wastewater dewatering through physical conditioning

Various methods have been used to enhance wastewater dewatering, broadly categorised as physical and chemical conditioning. Under physical conditioning, reagents that are not chemical, thermal treatment, freezing-thawing and sonication are used to improve dewaterability. These are further discussed below:

a) Addition of porous material

These improve the structure of sludge to reduce its compressibility and improve permeability. Research shows that physical conditioners enhance the mechanical strength of faecal sludge, which allows moisture to escape easily out of the permeable sludge. In addition, physical conditioners are characterized by a low moisture content when compared to sewage sludge, and this facilitates through absorption, reduction in the moisture content of dewatered cake (Semiyaga *et al.*, 2018). Physical conditioners like char and sawdust can be cheaply obtained as unwanted materials from household activities or retail sales of charcoal and woodwork respectively. This makes them a cost-effective option for dewatering enhancement. Some of the commonly used porous materials include: rice husks, wood chips and coal fly ash among others (Wu, Dai and Chai, 2020). Use of inorganic (fly ash, hydrated lime, diatomaceous earth, cement kiln dust) and organic byproducts – as skeleton builders (Mahmood and Elliott, 2007). Sawdust and charcoal dust contain elements like silicon and aluminium that aide in flocculation. Charcoal dust can have silicon and aluminium oxide concentrations of up to 29.5% and 10.8% dry basis respectively (Arthur, Bangham and Bowring, 1948) while sawdust can have concentrations of the same up to 10.8-49% and 4.2-9.5% dry basis respectively (Demirbas, 2004; Abreu, Casaca and Costa, 2010).

b) Heat treatment

In this method of physical conditioning, sludge is heated to 60-180^{0}C in an air and watertight environment. This increases the rate of breakdown of lipids and carbohydrates and the release of proteins (Wu, Dai and Chai, 2020).

c) Freeze-thaw

This involves cyclic freezing and thawing to release the bound water contained in sludge. The challenge with this method is its high energy requirements unless natural freezing is feasible (Hu *et al.*, 2011).

d) Sonication

Low-frequency ultrasound is used to generate acoustic cavitation in sludge to improve dewaterability (Zhang, Zhang and Wang, 2007). Sonication can be enhanced through chemically conditioning sludge (Zhang and Wan, 2012). The major constraint with sonication is the hurdle to increase it to a large scale (Wu, Dai and Chai, 2020).

2.10 Enhancing distillery wastewater dewatering through chemical conditioning

In chemical conditioning, physicochemical or chemical reagents are used to alter the physicochemical features of sludge. This includes coagulation-flocculation, acid/base treatment and enzymatic treatment among others.

a) Coagulation and or flocculation

Ferric and aluminium salts are the commonly used coagulation reagents (Kweinor Tetteh and Rathilal, 2020). A study conducted to analyse the performance of ferric and aluminium salts indicated that flocs formed from the addition of the latter were larger and more compact which settled quickly (Wu, Dai and Chai, 2020). However ferric salts are cheaper, with lesser toxicity and a broad pH range of operation. The main challenge with this method is the selection of suitable conditioning chemicals in relation to the physicochemical features of the sludge (Liang *et al.*, 2023).

b) Acid or base treatment

The most commonly used reagents are NaOH (Sodium Hydroxide), $Ca(OH)_2$ (Calcium Hydroxide), and CaO (Calcium Oxide). Pretreatment of sludge using these enhances the reduction of bound water by disrupting cells of microorganisms and bio-flocs. $Ca(OH)_2$ is better for enhancing sludge dewaterability than NaOH which at low doses causes reduced sludge dewaterability (Wu, Dai and Chai, 2020).

2.11 Conditioning to improve dewatering

Conditioning is usually applied to adjust the properties of sludge in a bid to enhance dewatering. This is achieved by; coagulation-flocculation through the application of chemical conditioners, the application of physical conditioners to reduce the compressibility of sludge solids and improve its filterability and ozonation, and sonication to break up sludge to release bound water molecules (Mowla, Tran and Allen, 2013).

A commonly used option for the disposal of sludge from the treatment of wastewater from a paper-making industry is incineration (Liang *et al.*, 2023). However, the low dewaterability and dense concentration of inorganic particles in these sludges make incineration extremely challenging and costly (Zijlstra *et al.*, 2022). Sometimes polymers used to enhance dewaterability but these are quite costly (Anand, Bishoni and Soni, 2017). In some cases, fibre sludge has been used, however, because of its high organics and cellulose fibre content, it's not a perfect dewatering aid because it can be reused as a raw material (Zijlstra *et al.*, 2022).

2.12 Resource recovery potential of dewatered sludge

Even though distillery wastewater is highly polluted with various contaminants, some valuable substances can still be recovered. Some of the resources that can be recovered and reused include energy, water, organic solids and nutrients (Walling *et al.*, 2022). Nutrients for example nitrogen, phosphorus and potassium are usually applied as fertilizers in agriculture to boost crop yield. Some of the main treatment processes that are used in nutrient recovery and recycling include ion exchange, adsorption, precipitation, absorption, anaerobic digestion, incineration and composting (Ahmed *et al.*, 2019). Water can be recycled after partial or complete purification. Complete purification can be achieved through reverse osmosis. Energy recovery can be done indirectly through the calorific potential of contaminants in the wastewater or directly through heat transfer (Walling *et al.*, 2022).

Table 2.2 below shows the nutrient concentration and TS/TVS ratio of different waste streams. Domestic wastewater has a comparably lower concentration of nitrogen and phosphorus than distillery wastewater. The nitrogen concentration of distillery wastewater is closer in range to that of faecal sludge and wastewater from the beverage industry. Wastewater from the beverage industry has noticeably higher potassium concentrations than distillery wastewater and all other noted waste streams.

Table 2.2: Nitrogen, phosphorus, potassium concentrations and TS/TVS ratio of different waste streams.

Sample ID	**N (mg/l)**	**P (mg/l)**	**K^+ (mg/l)**	**TS/TVS**
Distillery wastewater (mg/l)	1660-4200[1]	225-308[1]	9600-15475[1]	-
Faecal sludge	3400[2]*	450[2]	-	772.05[2]
Septage	190-300[2]	150[2]	-	240.00-479.45[2]
Beverage industry	2600[3]	4400[3]	-	-
Domestic wastewater	101.54[4]	13.09[4]	-	-

Notes: [1](Mikucka and Zielińska, 2020), [2](Katukiza et al., 2012), [3](Bhambri, Karn and Singh, 2021), [4](Khashroum, 2024)

**Total Kjeldahl Nitrogen*

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Research design and approach

This was a cross-sectional study to determine the characteristics of distillery wastewater from various sources with laboratory experiments to investigate its dewaterability potential and the impact of conditioning on dewatering.

The approach of the study was quantitative involving the collection and analysis of samples and dewatering. The results of the study were analysed statistically.

3.2 Population and sample

The target population for this research was distilleries. A total of 9 distillery wastewater samples were collected from 3 different sources (factory distillation using sugarcane molasses, local distillation using sugarcane molasses and local distillation using cassava and sorghum) representing industrial and local distilleries. The industrial wastewater samples were picked from the inlet to the treatment plant and local distillery wastewater samples from the cooling drums as shown by the images below. 11.5 litres of each distillery wastewater sample were collected from factory and local distillers in Lugazi, Jinja and Kampala. The samples were collected in clean plastic bottles and jerrycans (as shown in Figure 3.1), stored in ice-cool boxes and transported to the laboratory for analysis. Information about the raw materials used (whether sugar molasses or cassava and sorghum) and production methods were collected. In the laboratory, samples were refrigerated at 4^0C and before analysis, they were taken out of the refrigerator and allowed to attain room temperature. Distillery wastewater samples were collected and analysed from September 2023 to March 2024. Samples were analysed in the chemistry and water laboratories at Kyambogo University and the Public Health Laboratory at Makerere University.

Figure 3.1: Sample collection.

3.3 Characterization of wastewater

Homogenized samples were analysed for Fats, Oils and Grease (FOG), pH, Oxygen Reduction Potential (ORP), Turbidity, Electrical conductivity (EC), Total Dissolved Solids, Total Suspended Solids, Volatile Suspended Solids, Nitrogen, Phosphorus, Calcium, Potassium, Sulphate, Carbohydrate content, Protein Content, Dissolved Oxygen, Chemical Oxygen Demand (COD), Moisture and Ash content according to standard methods for examination of water and wastewater (APHA, AWWA and WEF, 2017). FOG was determined using the Soxhlet extraction method by extracting using petroleum ether at a quantity of 150ml per trial. pH and Oxygen Reduction Potential were determined by the electrometric method using a Consort Electrochemical Analyzer, model C6010. Turbidity was determined by the Nephelometric method using a Turbidimeter AL450T-IR by Aqua Lytic. Electrical Conductivity and Total Dissolved Solids were determined by the laboratory methods using a Mettler-Toledo AG (FE30). Total Solids and Total Volatile Solids were determined by laboratory gravimetric and ignition methods respectively. Nitrogen and phosphorus were determined using the Persulfate method. Calcium was determined using the EDTA Titrimetric method. Potassium was determined using the Potassium-Selective Electrode method. Sulphate was determined using the gravimetric method. Protein and carbohydrate contents were determined using the Macro-Kjeldahl and difference methods respectively. Dissolved oxygen was determined using the optical probe method. Chemical Oxygen Demand was determined using the Closed Reflux, colorimetric method. Moisture content was determined using the gravimetric method. Ash content was determined as the residue after analysing the Total Volatile Solids.

3.4 Preparation of conditioners

The conditioners used were sawdust and charcoal dust. These conditioners were purchased from local retailers in the Kajjansi market. They were sieved to a size less than 2.36mm for uniformity and then oven-dried at 105^0C for 24 hours (as shown in Figure 3.2). After oven drying, the conditioners were stored in plastic Ziplock bags.

Figure 3.2: Placement of the sawdust and charcoal dust to be dried in the oven.

3.5 Dewatering performance of unconditioned and conditioned wastewater

Homogenized samples were taken off into labelled 50ml falcon tubes and refrigerated at 4^0C for six days for extended/natural settling. Photos were taken of the samples on each day for a period of six days (as shown in Figure 3.3). On completion of the extended settling period, the turbidity of the supernatant was analysed using a Turbidimeter AL450T-IR according to standard methods for the examination of water and wastewater.

(a) (b) (c)

Figure 3.3: Samples during extended settling (a) factory using sugarcane molasses, (b) local using sugarcane molasses, (c) local using cassava and sorghum.

The jar test was conducted using a Stuart Flocculation Jar tester, 6-place, 230VAC, 50Hz. 500ml of each homogenized sample was measured off into the jar tester using a cylinder (as shown in Figure 3.4). Dry conditioners were measured off using an electric balance in the following proportions: 20g, 40g and 60g and added to each of the measured samples. There was a blank sample for each sample category. The same mixing speed was used for all samples, 200rpm for 2 minutes and 40rpm for 20 minutes. After the jar test, each conditioned sample was transferred to clean plastic containers for further analysis (as shown in Figure 3.5 (b)).

(a) (b)

Figure 3.4: (a) Measured samples of distillery wastewater, and (b) an ongoing jar test.

(a) (b)

Figure 3.5: (a) Observing an ongoing jar test, and (b) conditioned samples packed for further analysis.

The following observations were made during the jar test:

- Bubbles were formed at the top of the samples to which charcoal dust was added.
- Samples to which 60g of charcoal dust was added had the thickest layer of bubbles.
- Samples to which charcoal dust was added turned black (the colour of charcoal). There was a layer of charcoal at the top and at the bottom of the jar.

- Samples dosed with sawdust formed a very thin layer of sawdust at the top with most of the conditioner settling at the bottom of the jar.
- Since sawdust has a higher bulk density, the ratio of sample to conditioner for 60g conditioner dose resulted in a very pasty mixture, with very little or no supernatant.

After the jar test, the dewatering rate of the blank and conditioned samples was analysed using a Capillary Suction Timer CST-440. Equation 2.1 was used to calculate the improvement in capillary suction time (dewatering rate) after treatment with conditioners. The observation made here was that the dewatering rate was quite slow for most of the samples.

To determine the dewatering extent, samples were centrifuged using a Hettich Universal 16A (shown in Figure 3.6 (a)) at a speed of 3000rpm for 20 minutes. 15ml of distillery wastewater samples (shown in Figure 3.6 (b)) both non-conditioned and conditioned were centrifuged. The supernatant and sludge blanket heights were recorded. The turbidity of the supernatant was analysed using a Turbidimeter AL450T-IR according to standard methods for the examination of water and wastewater.

(a) (b)

Figure 3.6: (a) Centrifuge (Hettich Universal 16A), and (b) Centrifuged sample.

3.6 Resource recovery potential of distillery wastewater

To assess the resource recovery potential of the dewatered sludge, the nutrient content of the wastewater was analysed.

3.7 Quality assurance and quality control

For each category of distillery wastewater, three samples were picked. Analysis of characteristics of samples was performed in duplicate and the error obtained was extrapolated across the entire sample set. A factorial design was used to determine the conditioner proportions to evaluate their effect on the dewatering rate and extent. Eighty experiments were conducted based on a central composite design. One CST measurement was done for each sample because there were three samples for each sample category.

3.8 Data analysis and presentation

Statistical analysis was performed using Microsoft Excel and XLSTAT in Microsoft Excel. The difference in physiochemical characteristics of the distillery wastewater samples from various sources was assessed using analysis of variance (ANOVA) at a 5% significance level. Correlations were considered statistically significant at a 95% confidence level. Data is presented in tables and graphs.

3.9 Ethical considerations

Voluntary informed consent was sought from the authorities in charge of the sites where samples were collected. A letter was written to each authority explaining the objectives of the research, duration and quantity of samples needed. I received permission as shown in the letters attached in the appendices.

CHAPTER FOUR: ANALYSIS, DISCUSSION AND PRESENTATION OF RESULTS

4.1 Characteristics of distillery wastewater

Table 4.1 shows the physicochemical characteristics of the three distillery wastewater sources and literature ranges of distillery wastewater, brewery wastewater, domestic wastewater and faecal sludge. Wastewater from local distillation using cassava and sorghum had a more viscous consistency while that from factory and local distillation using sugarcane molasses was waterier. The pH of samples was between the range of 3.56-6.32 with wastewater from local distillation using sugarcane molasses at the neutral end while wastewater from factory using sugarcane molasses and local distillation using cassava and sorghum had more acidic pH. The pH values for the distillery wastewater when compared with other waste streams, 5.6-8.3 for faecal sludge (Shaw *et al.*, 2022) and 4.6-7.3 for brewery wastewater (Enitan *et al.*, 2015) are noted to be generally more acidic. The pH of samples from factory distillation using sugarcane molasses and local distillation using cassava and sorghum were within the range given in literature. According to literature, samples from local distillation using sugarcane molasses had a pH range closer to that of brewery wastewater. This could be attributed to the fact that most breweries use cassava and sorghum as some of the raw materials for beer production (Uganda_Breweries_Limited, 2023). The electrical conductivity (EC) values of samples were between the range of 4.22-34.77mS/cm. Wastewater from local distillation using cassava and sorghum had the lowest conductivity values.

Table 4.1: Physicochemical characteristics of distillery wastewater samples and literature ranges of selected wastewater sources.

Source	Sample	pH	EC (mS/cm)	DO (PPM)	ORP (mV)	MC (%)	TS (mg/l)	Turbidity (NTU)	Ash C (%)	COD (mg/l)	TVS (%TS)	FOG (%)	Ca^{2+} (mg/l)
Established factory with sugarcane molasses	F1	5.34	29.50	56.31	155.37	10.04	125.93	30,900	17.41	-	96.32	2.64	10219.89
	F1	4.53	21.43	54.89	144.39	10.03	126.49	18,700	30.06	148,680	96.43	2.45	-
	F1	4.69	20.55	55.92	133.40	10.03	125.37	21,100	29.67	114,300	95.70	2.61	-
Local with sugarcane molasses	L1	6.12	30.43	36.43	94.77	13.59	147.98	42,300	15.82	63,800	114.34	1.79	16632.30
	L1	6.07	34.77	35.98	98.77	15.69	147.68	45,500	12.03	-	113.12	1.81	15229.60
	L1	6.32	23.00	37.03	96.77	15.70	147.32	20,300	34.27	-	112.71	1.82	-
Local with cassava and sorghum	L2	4.95	7.30	2.67	138.50	5.21	102.19	45,500	2.77	-	92.71	1.83	8215.99
	L2	4.87	7.33	2.67	168.85	5.22	107.16	31,400	14.02	68,600	93.15	1.82	-
	L2	3.56	4.22	2.68	199.20	5.27	97.21	43,000	5.40	86,400	91.81	1.83	-
Literature values													
Distillery wastewater		3-4.5[1,2,4]	-	-	-	-	59,000-190,000[1,2,4]	-	-	8,000-190,000[1,2,4]	38,000-120,000[1,2,4]	-	2,300-2,500[1,2,4]
Brewery wastewater		3.55-6.0[5,6]	1.044-1.622[6]	-	-27.1 to -84.9[6]	-	1,289-12,248[6]	-	-	5,341-27,500[5,6]	1,832-4,634[6]	-	-
Domestic wastewater		-	-	-	-	-	300-1,250[3]	-	-	250-1,000[3]	140-675[3]	50-160[3]	-
Faecal sludge		7.5-7.7[7]	12.5-18.1[7]	-	-61.12 to -100.6[7]	-	51,400-177,000[7]	-	34,500-50,200[7]	65,521-132,326[7]	50,000-63,500[7]	-	-

Notes: [1](Mohana, Acharya and Madamwar, 2009); [2](Mikucka and Zielińska, 2020); [3] (Arcadio P Sincero and Gregoria A Sincero, 2003); [4](Khot *et al.*, 2021); [5](Shao *et al.*, 2008); [6](Enitan *et al.*, 2015); [7](Semiyaga *et al.*, 2017).

Notes: Ash C – Ash Content, Ca^{2+} - Calcium Ions, COD – Chemical Oxygen Demand, DO – Dissolved Oxygen, EC – Electrical Conductivity,

FOG – Fats Oils and Grease, TS – Total Solids and TVS – Total Volatile Solids.

Conductivity is used to evaluate variations in dissolved mineral concentration in wastewater (APHA, AWWA and WEF, 2017). Some minerals contained in sugarcane molasses include calcium, potassium, sodium and magnesium (Jamir *et al.*, 2021). The EC values for the distillery wastewater, when compared with other waste streams, are noted to be slightly higher than 18.1mS/cm and 12.5mS/cm for faecal sludge from lined and unlined pit latrines respectively (Semiyaga et al., 2017), 1.2-11.7mS/cm for faecal sludge (Shaw et al., 2022) and 1.04-1.62mS/cm for brewery wastewater (Enitan et al., 2015). Sample dissolved oxygen values were between the range of 2.67-56.31PPM. Wastewater from local distillation with cassava and sorghum had the lowest dissolved oxygen values of 2.67-2.68PPM. The higher dissolved oxygen values for samples from factory and local distillation using sugarcane molasses could be attributed to the fact that they are disposed in the open with exposure to atmospheric oxygen. The Oxygen-Reduction Potential (ORP) of samples was between 96.77-199.20mV. Wastewater from local distillation with sugarcane molasses had lower ORP values. The ORP values of distillery wastewater were noted to be higher when compared with other waste streams like faecal sludge of -61.12mV (Semiyaga et al., 2017) and brewery wastewater of -27.1 to -84.9mV (Enitan et al., 2015). This shows some level of oxygen and that the conditions in these wastewaters are not fully anoxic.

Sample moisture content (MC) values were in the range of 5.21-15.70%. Wastewater from local distillation with cassava and sorghum had the lowest moisture content percentage. This can be attributed to its higher sludge volume compared to supernatant volume according to section 4.2 Dewatering Performance of Distillery Wastewater. The MC values of distillery wastewater when compared with other waste streams were noted to be much lower than 92.4% and 83.4% for faecal sludge from lined and unlined pit latrines respectively (Semiyaga *et al.*, 2017). The total solids (TS) values of samples were between the range of 97.21-147.98mg/l. Wastewater from local distillation with sugar molasses had the highest total solids values. The TS values of distillery wastewater, when compared with other waste streams, were noted to be much lower than 51,400mg/l and 177,000mg/l for faecal sludge from lined and unlined pit latrines respectively (Semiyaga *et al.*, 2017), 1,200-39,800mg/l for faecal sludge (Shaw *et al.*, 2022) and 1,289-12,248mg/l for brewery wastewater (Enitan *et al.*, 2015). Input into distilleries undergo dilution resulting into lower concentration of total solids compared to other waste streams. The turbidity of samples ranged from 18,700NTU in factory wastewater to 45,500NTU in wastewater from local distillation. It was noted that turbidity values for distillery wastewater are much higher when compared with faecal sludge of 140 to >10,000NTU (Shaw *et al.*, 2022). The dark-brown colour of distillery wastewater caused by melanoidins and other organic compounds increase turbidity (Kharayat, 2012). The ash content values of samples were between the range of 2.77-34.27%. Wastewater from local distillation with cassava and sorghum had the lowest ash content percentage. This means TVS is high so most of the solids can be disposed of through biodegradation. The ash content values of distillery wastewater were noted to be close to 34.5%TS for faecal sludge from lined pit latrines and slightly lower than 50.2%TS for faecal sludge from unlined pit latrines on the high range (Semiyaga *et al.*, 2017). Faecal sludge from unlined pit latrines contains higher ash content that lined pit latrines because of soil from the unlined sides that contribute to sludge makeup.

The Chemical Oxygen Demand (COD) of samples was 63,800-148,680mg/l and factory wastewater had the highest COD values corresponding to the literature values of 8,000-190,000mg/l. COD of all samples was within the range recorded in literature for distillery wastewater and faecal sludge, but quite high compared to that of brewery and domestic wastewater. High COD values indicate a high pollution load. The COD values for distillery wastewater when compared with other waste streams are noted to be much higher than 1096.41-8926.08mg/L for brewery wastewater (Enitan *et al.*, 2015), within range for faecal sludge 65,521mg/l and 132,326mg/l from lined and unlined pit latrines respectively (Semiyaga *et al.*, 2017). The total volatile solids (TVS) content of samples was in the range 91.81-114.34%TS. The TS and TVS of all samples were much lower compared to the ranges in literature for distillery wastewater 59,000 – 190,000mg/l, 38,000 – 120,000mg/l (Mohana, Acharya and Madamwar, 2009; Mikucka and Zielińska, 2020; Khot *et al.*, 2021), brewery wastewater 1,289 – 12,248mg/l, 1,832 – 4,634mg/l (Enitan *et al.*, 2015), domestic wastewater 300 - 1,250mg/l, 140 – 675mg/l (Arcadio P Sincero and Gregoria A Sincero, 2003) and faecal sludge 51,400 – 177,000mg/l, 50,000 – 63,500mg/l (Semiyaga *et al.*, 2017) respectively.

For TVS, this means the wastewaters recorded in literature have a higher biodegradable percentage than the samples analysed in this research. Wastewater from local distillation with sugar molasses had the highest total volatile solids values while TVS of wastewater from factory was slightly higher than that from local distillation with cassava and sorghum. The TVS values of distillery wastewater, when compared with other waste streams, were noted to be slightly higher than 63.5%TS and 50%TS for faecal sludge from lined and unlined pit latrines respectively (Semiyaga *et al.*, 2017), much lower than 1,832-4,634mg/l for brewery wastewater (Enitan *et al.*, 2015). The Fats, Oil and Grease (FOG) concentration in samples was in the range of 1.81-2.64%. Wastewater from local distillation had similar FOG percentages while factory wastewater had slightly higher percentages. The Ca^{2+} concentration of samples was in the range of 8215.99-16632.30mg/l. Wastewater from local distillation with cassava and sorghum had a slightly lower Ca^{2+} value. The Ca^{2+} content of samples is much higher than the range in literature for distillery wastewater.

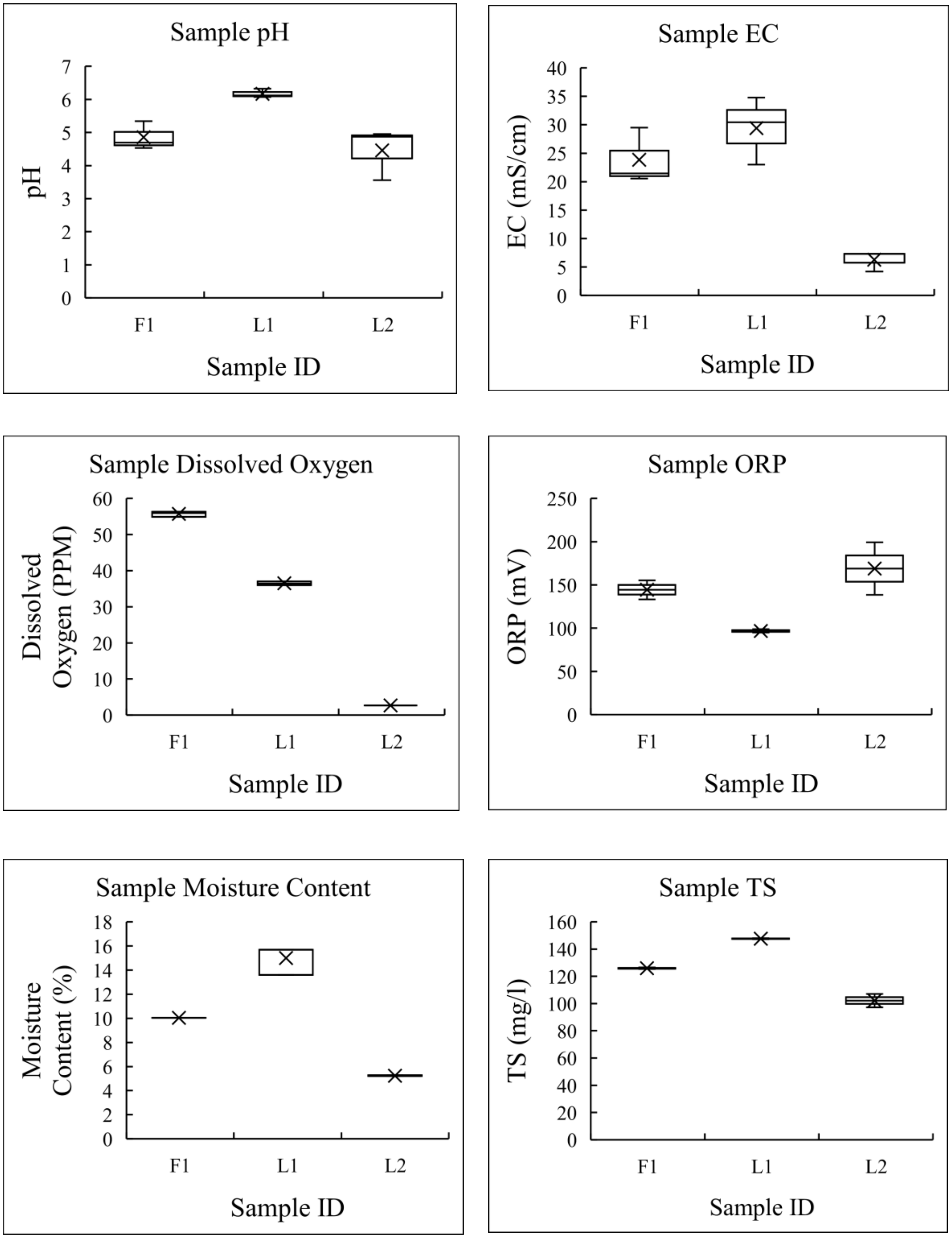
The pH of wastewater from local distillation using sugarcane molasses was within the maximum permissible limit stipulated in Table 4.2 while pH of wastewater from factory distillation using sugarcane molasses and local distillation using cassava and sorghum was outside permissible range (5.0-8.5). The electrical conductivity of samples was higher than the maximum permissible limit. The chemical oxygen demand of samples was much higher than the maximum permissible of 70mg/L. The turbidity of samples was also much higher than the maximum permissible of 300NTU. The calcium content of samples was higher than the limit provided of 100mg/L. Table 4.2 shows the national environment regulation standards for effluent discharge into water or environment.

Table 4.2: Standards for Effluent Discharge into Water and Land.

Parameter or Pollutant	**Unit**	**Maximum Permissible Limit**
Temperature increase	^0C	≤5
Odour		Not detectable
Colour	TCU	50
pH	Units	5.0-8.5
Electrical Conductivity	µS/cm	1000
Total Dissolved Solids	mg/L	750
Total Suspended Solids	mg/L	50
Biological Oxygen Demand$_5$ (Unfiltered)	mg/L	50
Chemical Oxygen Demand	mg/L	70
Total Nitrogen	mg/L	10
Total Phosphorus	mg/L	5
Sulphates	mg/L	500
Calcium	mg/L	100
Fats Oils & Grease	mg/L	10
Turbidity	NTU	300[1]

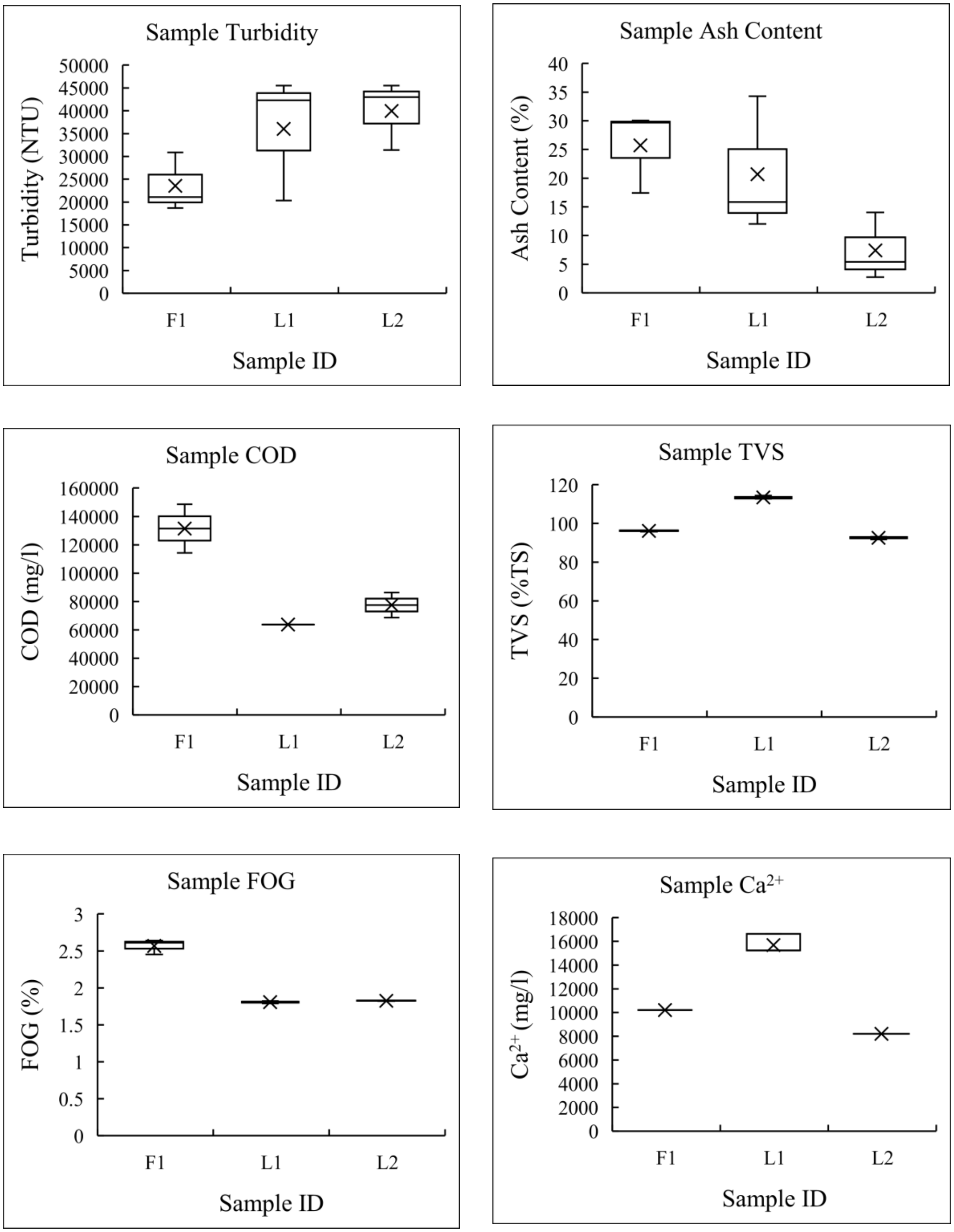
(NEMA, 2020); [1] (NER (National Environmental Regulations), 1999)

The box plots in Figures 4.1 and 4.2 show variations of physiochemical characteristic of the distillery wastewater samples. F1, L1, and L2 represent samples from factory distillation using sugarcane molasses, local distillation using sugarcane molasses, and local distillation using cassava and sorghum respectively. For the box plots, the box represents 50% of the data points, the lower and upper whiskers represent the minimum and maximum respectively, the upper, middle and lower boundaries represent the 75th, 50th and 25th percentiles respectively, and the X represents the mean.



Notes: EC – Electrical Conductivity, ID – Identification, ORP – Oxygen Reduction Potential and TS – Total Solids.

Figure 4.1: Box plots of physical characteristics, Moisture Content and TS of distillery wastewater from factory and local distillation.



Notes: Ca2+ - Calcium Ions, COD – Chemical Oxygen Demand, FOG – Fats Oils and Grease, ID – Identification and TVS – Total Volatile Solids.

Figure 4.2: Box plots of Turbidity, Ash content, COD, TVS, FOG and Ca^{2+} of distillery wastewater from factory and local distillation.

Table 4.3: Characteristics of distillery wastewater.

Parameter	Unit	Established factory	Local with sugarcane molasses	Local with cassava and sorghum	p-value
pH	-	4.85	6.17	4.46	0.017*
Electrical Conductivity	mS/cm	23.83	29.40	6.28	0.002*
Dissolved Oxygen	PPM	55.71	36.48	2.67	<0.0001*
Oxygen Reduction Potential	mV	144.39	96.77	168.85	0.017*
Moisture Content	%	10.03	14.99	5.23	<0.0001*
Total Solids	mg/l	125.93	147.66	102.19	<0.0001*
Turbidity	NTU	23566.67	36033.33	39966.67	0.167
Ash Content	%	25.71	20.71	7.40	0.075
Chemical Oxygen Demand	mg/l	131490.00	63800.00	77500.00	0.004*
Total Volatile Solids	%TS	96.15	113.39	92.56	<0.0001*
Fats Oils and Grease	%	2.57	1.81	1.83	<0.0001*
Calcium Ions	mg/l	10219.89	15930.95	8215.99	<0.0001*

Analysis of Variance (ANOVA) summarized in Table 4.3 shows that the mean pH, EC, DO, ORP, MC, TS, COD, TVS, FOG, and Ca^{2+} differ in the selected distillery wastewater sources. he pH was 4.85±0.43 for samples from factory distillation using sugarcane molasses, 6.17±0.13 for samples from local distillation using sugarcane molasses and 4.46±0.78 for samples from local distillation using cassava and sorghum. The pH of samples from local distillation using sugarcane molasses was found to be significantly higher (p=0.017) than those from factory distillation using sugarcane molasses and local distillation using cassava and sorghum. The EC was 23.83±4.93mS/cm for samples from factory distillation using sugarcane molasses, 29.4±5.95mS/cm for samples from local distillation using sugarcane molasses and 6.28±1.79mS/cm for samples from local distillation using cassava and sorghum. The EC of samples from factory and local distillation using sugarcane molasses was found to be significantly higher (p=0.002) than those from local distillation using cassava and sorghum. The DO was 55.71±0.73PPM for samples from factory distillation using sugarcane molasses, 36.48±0.53PPM for samples from local distillation using sugarcane molasses and 2.67±0.01PPM for samples from local distillation using cassava and sorghum. The DO of samples from local distillation using cassava and sorghum was found to be significantly lower ($p<0.0001$) than those from factory and local distillation using sugarcane molasses. The ORP was 144.39±10.99mV for samples from factory distillation using sugarcane molasses, 96.77±2.00mV for samples from local distillation using sugarcane molasses and 168.85±30.35mV for samples from local distillation using cassava and sorghum. The ORP of samples from local distillation using sugarcane molasses was found to be significantly lower ($p=0.017$) than those from factory distillation and local distillation using cassava and sorghum.

The MC was 10.03±0.01% for samples from factory distillation using sugarcane molasses, 14.99±1.22% for samples from local distillation using sugarcane molasses and 5.23±0.03% for samples from local distillation using cassava and sorghum. The MC of samples from local distillation using cassava and sorghum was found to be significantly lower ($p<0.0001$) than those of factory and local distillation using sugarcane molasses. The TS was 125.93±0.56mg/l for samples from factory distillation using sugarcane molasses, 147.66±0.33mg/l for samples from local distillation using sugarcane molasses and 102.19±4.98mg/l for samples from local distillation using cassava and sorghum. The TS of samples from local distillation using sugarcane molasses was found to be significantly higher ($p<0.0001$) than those of factory distillation using sugarcane molasses and local distillation using cassava and sorghum. The Turbidity was 23566.67±6463.23NTU for samples from factory distillation using sugarcane molasses, 36033.33±13719.09NTU for samples from local distillation using sugarcane molasses and 39966.67±7523.52NTU for samples from local distillation using cassava and sorghum. The Ash Content was 25.71±7.19% for samples from factory distillation using sugarcane molasses, 20.71±11.90% for samples from local distillation using sugarcane molasses and 7.40±5.89% for samples from local distillation using cassava and sorghum. There was no significant difference in mean turbidity and ash content although the values obtained were significantly different.

The COD was 131490±24310.33mg/l for samples from factory distillation using sugarcane molasses, 63800±0.00mg/l for samples from local distillation using sugarcane molasses and 77500±12586.50mg/l for samples from local distillation using cassava and sorghum. The COD of samples from factory distillation using sugarcane molasses was found to be significantly higher ($p=0.004$) than those from local distillation using sugarcane molasses and cassava and sorghum. The TVS was 96.15±0.39%TS for samples from factory distillation using sugarcane molasses, 113.39±0.85%TS for samples from local distillation using sugarcane molasses and 92.56±0.68%TS for samples from local distillation using cassava and sorghum. The TVS of samples from local distillation using sugarcane molasses was found to be significantly higher ($p<0.0001$) than those of factory distillation using sugarcane molasses and local distillation using cassava and sorghum. The FOG was 2.57±0.10% for samples from factory distillation using sugarcane molasses, 1.81±0.02% for samples from local distillation using sugarcane molasses and 1.83±0.01% for samples from local distillation using cassava and sorghum. The FOG of samples from factory distillation using sugarcane molasses was found to be significantly higher ($p<0.0001$) than those of local distillation using sugarcane molasses and cassava and sorghum. The Ca^{2+} was 10219.89±0.00mg/l for samples from factory distillation using sugarcane molasses, 15930.95±991.86mg/l for samples from local distillation using sugarcane molasses and 8215.99±0.00mg/l for samples from local distillation using cassava and sorghum. The Ca^{2+}

of samples from local distillation using sugarcane molasses was found to be significantly higher (p<0.0001) than those of factory distillation using sugarcane molasses and local distillation using cassava and sorghum.

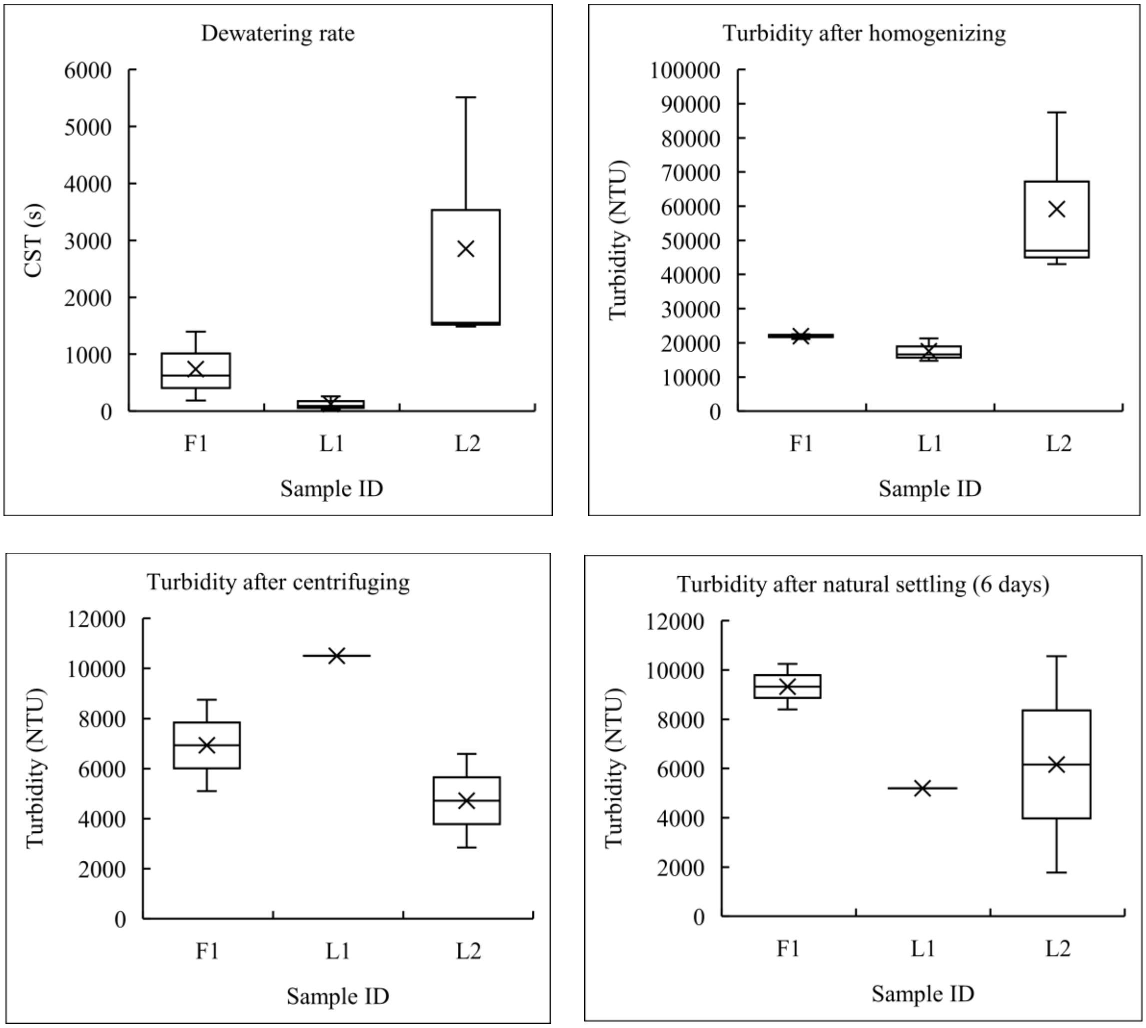
4.2 Dewatering performance of distillery wastewater

Dewatering performance was measured in terms of capillary suction time (CST), and turbidity of supernatant after natural and mechanical settling (Ward *et al.*, 2021). Figure 4.3 shows box plots of these performance indicators. The dewatering rate of samples was between the range of 30-5512.64s. There was no significant difference in the dewatering rate of samples although the values obtained were different. Wastewater from local distillation using sugarcane molasses had a higher dewatering rate (low CST values) than wastewater from factory distillation using sugarcane molasses. The dewatering rate found of samples from local distillation with cassava and sorghum was much lower than that noted in literature of 1228s and 1538s for faecal sludge from lined and unlined pit latrines respectively (Semiyaga *et al.*, 2017), and 114s, 205s and 9s for faecal sludge from households, public toilets and commercial establishments respectively (Ward *et al.*, 2023). The dewatering rate of samples from factory and local distillation with sugarcane molasses was closer to that reported in literature for faecal sludge. From the findings, it is noted that the lower dewatering rate (high CST) of samples from local distillation with cassava and sorghum with higher turbidity could be attributed to its high concentration in suspended solids.

The turbidity of the sample supernatant after homogenizing was between the range of 14,700-87,500NTU. The difference in turbidity of samples was significant (P=0.046). Wastewater from local distillation using cassava and sorghum had much higher turbidity results of up to 87,500NTU. In comparison, wastewater from local distillation with sugar molasses had lower turbidity results, as low as 14,700NTU. The turbidity of samples from local distillation using sugarcane molasses decreased by over 50% after homogenizing while samples from factory distillation using sugarcane molasses had only a 7% decrease.

The turbidity of samples after centrifuging was between the range of 2,850-10,500NTU. Wastewater from local distillation with sugarcane molasses had higher turbidity results while that from local distillation with cassava and sorghum had lower turbidity results. In comparing the turbidity reduction from the original (before centrifuging), wastewater from factory and local distillation using sugarcane molasses was found to have a similar reduction of 71% while wastewater from local distillation using cassava and sorghum had an 88% reduction. This indicates an improvement in the turbidity of samples when mechanical settling (centrifuging) is applied.

The turbidity of samples after natural settling was between the range of 1,770-10,560NTU. Wastewater from local distillation with cassava and sorghum had the lowest and highest turbidity results. Wastewater from factory distillation using sugarcane molasses had only a 60% reduction in turbidity from the original (before natural settling) while wastewater from local distillation using sugarcane molasses and cassava and sorghum had over 85% reduction. General analysis of the turbidity results indicated an improvement in the turbidity of the samples from the jar test after mechanical dewatering (centrifuging).

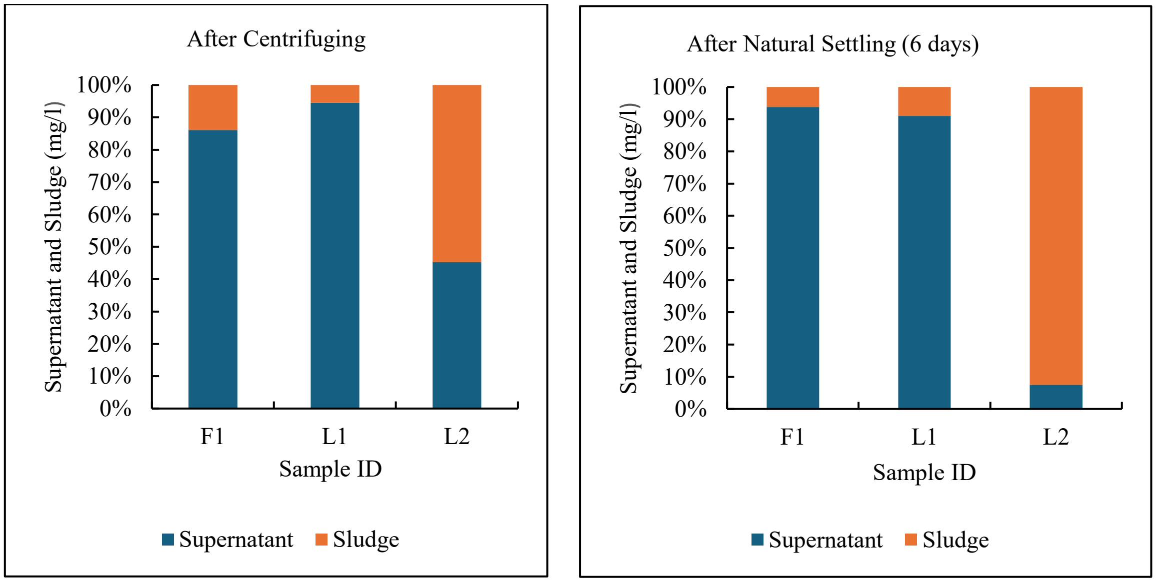


Notes: CST – Capillary Suction Time, ID – Identification, s – Seconds and NTU – Nephelometric Turbidity Units.

Figure 4.3: Box plots of dewatering characteristics of distillery wastewater samples from factory and local distillations.

F1 represents samples from factory distillation using sugarcane molasses, L1 represents samples from local distillation using sugarcane molasses and L2 represents samples from local distillation using cassava and sorghum respectively.

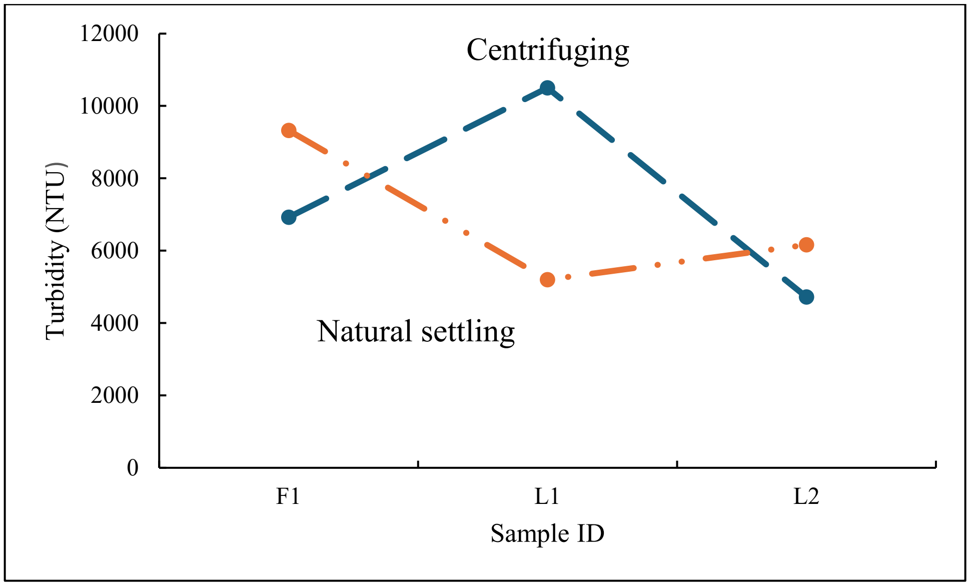
Figure 4.4 shows variation in supernatant and sludge volumes in samples after centrifuging and natural settling. Analysis of supernatant and sludge quantities after centrifuging and natural settling indicated that the wastewater from factory and local distillation using sugarcane molasses had higher supernatant quantities with lower sludge quantities. Wastewater from local distillation using cassava and sorghum had lower supernatant quantities with higher sludge quantities. The supernatant and sludge quantities in wastewater from factory and local distillation using sugarcane molasses after centrifuging was similar to the quantities after natural settling. Wastewater from local distillation using cassava and sorghum had about 45% supernatant and 55% sludge after centrifuging. The samples from location distillation using cassava and sorghum had better supernatant and sludge separation in natural settling with 8% and 92% respectively.



Notes: ID – Identification, mg/l – Milligrams per Liter.

Figure 4.4: Staked bar plots showing variation in supernatant and sludge volume.

Figure 4.5 shows variation in supernatant turbidity of samples after centrifuging and natural settling. The supernatant turbidity of samples from local distillation using sugarcane molasses was lower in natural settling (5200NTU) compared to centrifuging (10500NTU). Wastewater from factory distillation using sugarcane molasses and local distillation using cassava and sorghum had better supernatant turbidity after centrifuging compared to natural settling.



Notes: ID – Identification and NTU – Nephelometric Turbidity Units.

Figure 4.5: Variation in supernatant turbidity after centrifuging and after natural settling.

4.3 Impact of conditioning on dewaterability

This section analyses the use of conditioners to enhance the dewatering efficiency of distillery wastewater. The dewatering performance of conditioned wastewater samples was determined in terms of capillary suction time (dewatering rate) and turbidity of the supernatant after conditioning.

Figure 4.6 shows conditioner effect on the dewatering rate of samples. The dewatering rate after application of sawdust to samples from factory distillation using sugarcane molasses was 114.48s for 20g, 81.52s for 40g and 8497.43s for 60g. The dewatering rate was 1295.28s for 20g, 340.40s for 40g and 5048.05s for 60g of sawdust in samples from local distillation using sugarcane molasses. The dewatering rate was 856.96s for 20g, 9047.04s for 40g and 1613.44s for 60g of sawdust in samples from local distillation using cassava and sorghum.

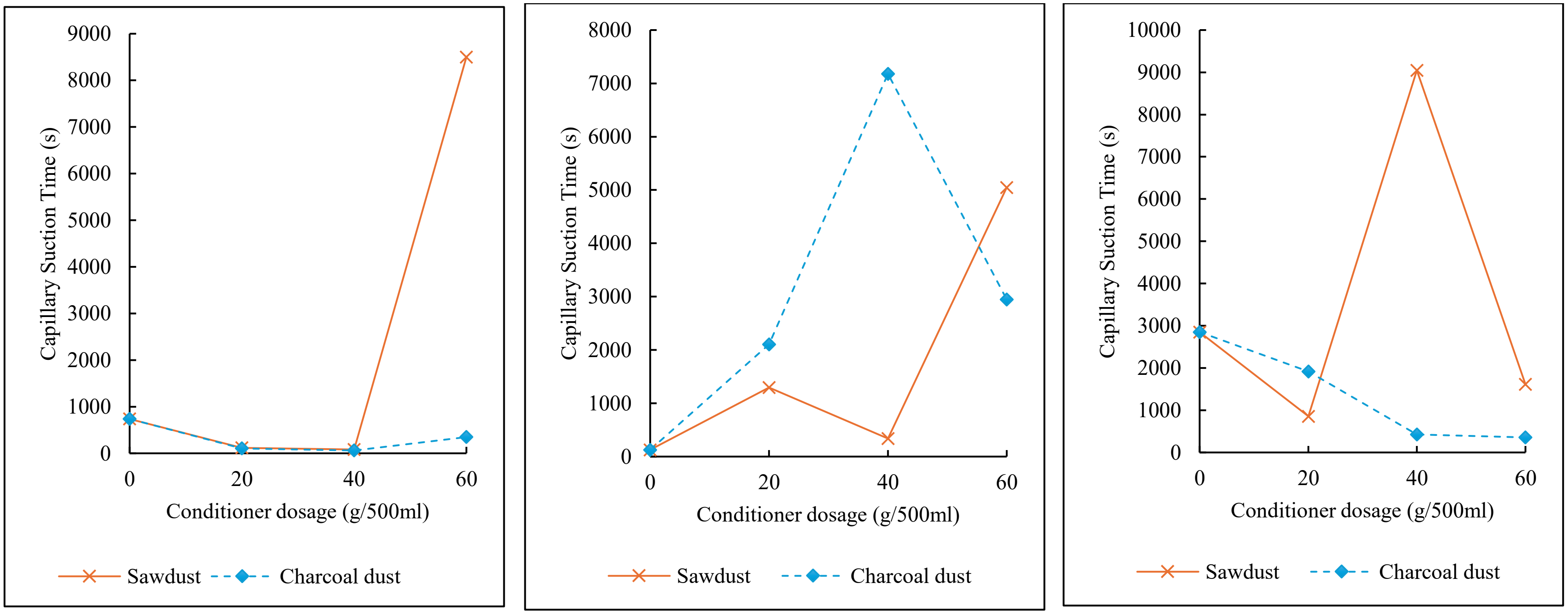
The dewatering rate after application of charcoal dust to samples from factory distillation using sugarcane molasses was 106.29s for 20g, 60.56s for 40g and 348.79s for 60g. The dewatering rate was 2103.44s for 20g, 7178.82s for 40g and 2947.08s for 60g of charcoal dust in samples from local distillation using sugarcane molasses. The dewatering rate was 1914.92s for 20g, 428.17s for 40g and 356.09s for 60g of charcoal dust in samples from local distillation using cassava and sorghum.

Generally, both conditioners performed well based on dewatering rate improvement of 72% with sawdust and 73% with charcoal dust. The conditioners performed best in the samples from factory distillation with sugarcane molasses with 87% and 77% improvement in dewatering rate after the application of sawdust and charcoal dust respectively. The samples from local distillation with cassava and sorghum had 57% and 68% improvement in dewatering rate after applying sawdust and charcoal dust respectively. The conditioners had the lowest performance in the samples from local distillation with sugarcane molasses with only a 25% improvement in dewatering rate after conditioning with sawdust. Improvement in dewatering rate was not observed in samples from local distillation with sugarcane molasses after conditioning with charcoal dust.

Based on the improvement in dewatering rate, the best conditioner performance for factory samples was observed at 89% for 40g Sawdust and 92% for 40g Charcoal dust. And best conditioner performance for samples from local distillation with cassava and sorghum was observed at 70% for 20g Sawdust and 88% for 60g Charcoal dust.

In a study by (Ahereza, 2024), the performance of sawdust and charcoal dust was compared with that of moringa, Iron (III) Chloride and ALUM on the wastewater samples above. The application of moringa, ALUM and Iron (III) Chloride to samples from local distillation with cassava and sorghum resulted in a 90%, 74% and 94% improvement in dewatering rate respectively which was slightly better than the performance of sawdust and charcoal for the same sample category. The application of Iron (III) Chloride to samples from factory distillation with sugarcane molasses resulted in a 76% improvement in dewatering rate. This result was close to that of sawdust and charcoal dust for the same sample category.

At a 5% significance level using the Analysis of Variance (ANOVA) test in XLSTAT, the dewatering rate of samples from local distillation using sugarcane molasses was found to be significantly different (p=0.012) after conditioning. There was no significant difference in the dewatering rate of factory samples (p=0.452), and samples from local distillation with cassava and sorghum (p=0.207) after conditioning although the values obtained were different.



(a) (b) (c)

Figure 4.6: Plots showing effects of conditioner dosage on the capillary suction time (dewatering rate) of distillery wastewater (a) samples from factory distillation using sugarcane molasses, (b) samples from local distillation using sugarcane molasses, and (c) samples from local distillation using cassava and sorghum.

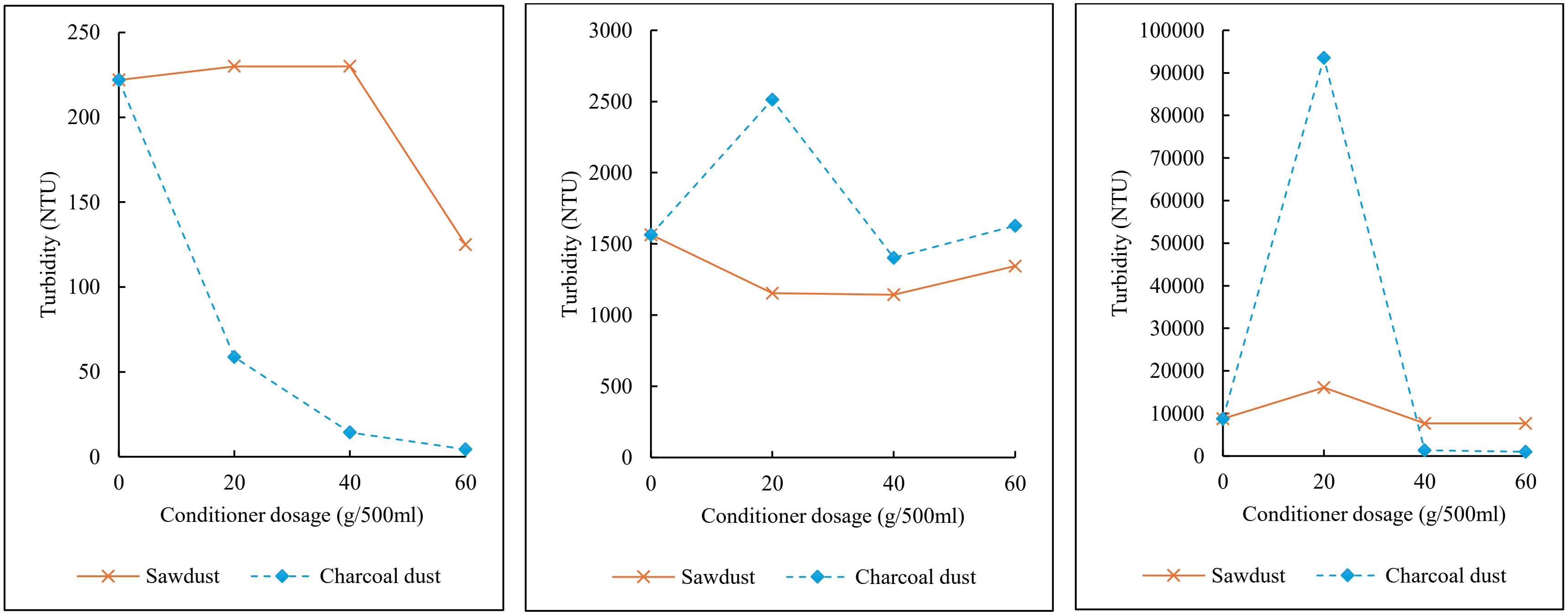
Figure 4.7 shows conditioner effect on supernatant turbidity. The turbidity of supernatant after application of sawdust to samples from factory distillation using sugarcane molasses was 230NTU for 20g, 230NTU for 40g and 125NTU for 60g. The turbidity of supernatant was 1155NTU for 20g, 1143NTU for 40g and 1345NTU for 60g of sawdust in samples from local distillation using sugarcane molasses.

The turbidity of supernatant was 16100NTU for 20g, 7670NTU for 40g and 7670NTU for 60g of sawdust in samples from local distillation using cassava and sorghum.

The turbidity of supernatant after application of charcoal dust to samples from factory distillation using sugarcane molasses was 58.8NTU for 20g, 14.4NTU for 40g and 4.37NTU for 60g. The turbidity of supernatant was 2513NTU for 20g, 1403NTU for 40g and 1627NTU for 60g of charcoal dust in samples from local distillation using sugarcane molasses. The turbidity of supernatant was 93500NTU for 20g, 1360NTU for 40g and 997NTU for 60g of charcoal dust in samples from local distillation using cassava and sorghum.

Generally, the best-performing conditioner according to the improvement in supernatant turbidity after conditioning was charcoal dust (72%). Sawdust had a performance that was below average of 26%. The conditioners performed best in the samples from factory distillation with sugarcane molasses with an overall average improvement in turbidity of 66%. In addition, after conditioning with sawdust and charcoal dust, the turbidity of the samples from factory distillation with sugarcane molasses was in the range of 4.37-230NTU which is below the Uganda effluent discharge standards of 300NTU, implying improved supernatant turbidity after the application of conditioners. This was followed by the samples from local distillation with sugarcane molasses with an overall average turbidity improvement of 43%.

In a study by (Ahereza, 2024), the performance of sawdust and charcoal dust was compared with that of moringa, Iron (III) Chloride and ALUM on the wastewater samples above. The application of moringa, ALUM and Iron (III) Chloride to the wastewater samples resulted in an average improvement in turbidity of 33%, 29% and 19% respectively. Sawdust and charcoal performed better in terms of improvement in turbidity of samples.



(a) (b) (c)

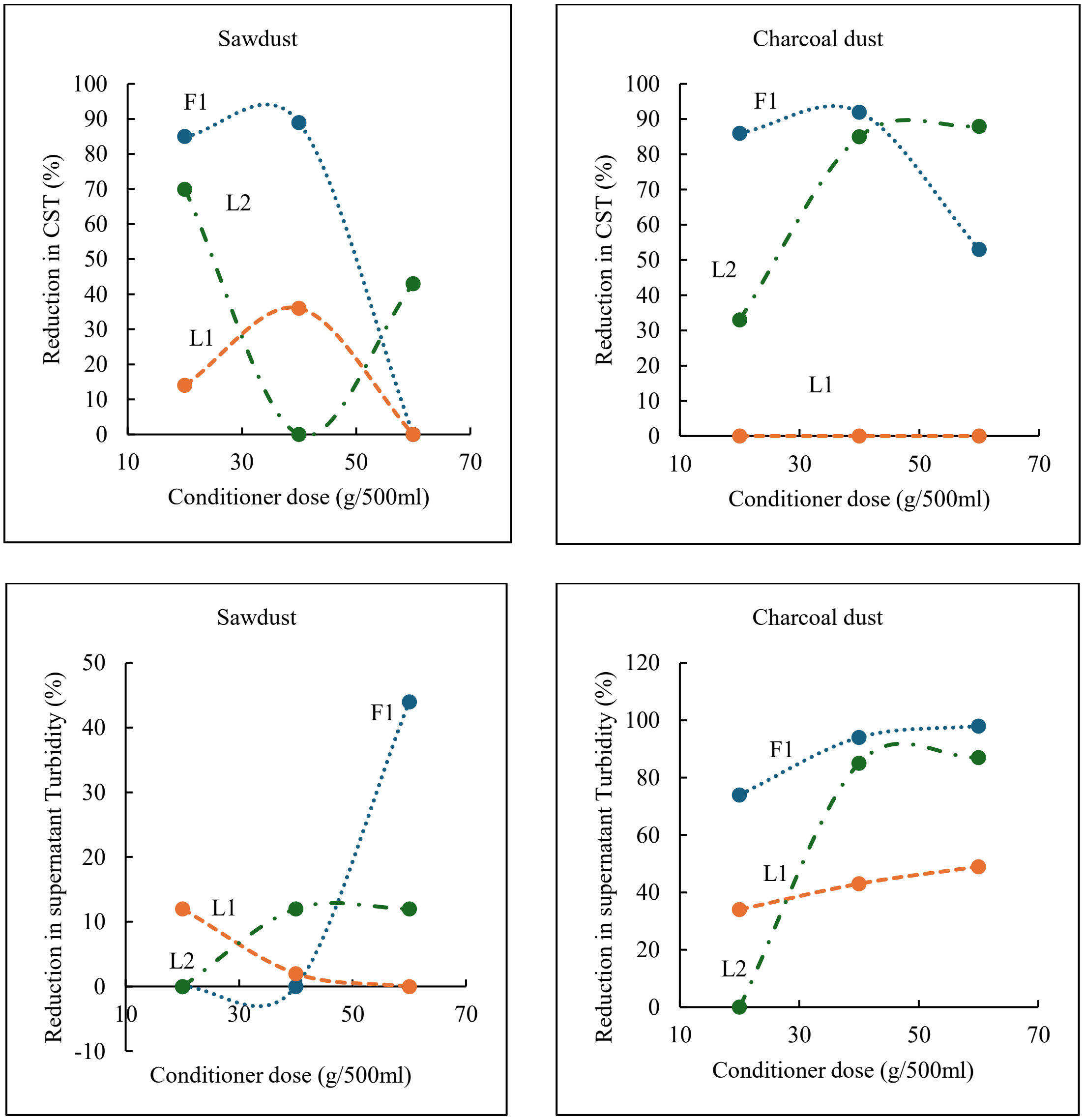
Figure 4.7: Plots showing effects of conditioner dosage on the supernatant turbidity of distillery wastewater (a) samples from factory distillation using sugarcane molasses, (b) samples from local distillation using sugarcane molasses, and (c) samples from local distillation using cassava and sorghum.

At a 5% significance level using the Analysis of Variance (ANOVA) test in XLSTAT, the turbidity of supernatant after conditioning of factory samples (p=0.002), and samples from local distillation with sugarcane molasses (p=0.024) was found to be significantly different. There was no significant difference (p=0.788) in the turbidity of supernatant after conditioning of samples from local distillation with cassava and sorghum although the values obtained were different.

4.4 Optimal conditioner and dosage

According to (Velkushanova *et al.*, 2021), an optimal conditioner dose is the lowest dose that achieves >75% improvement in CST. Figure 4.8 shows results of jar test results after conditioning samples with sawdust and charcoal dust. In the samples from factory distillation with sugarcane molasses, both sawdust and charcoal dust at doses of 20g and 40g resulted in CST improvement greater than 75%. However, charcoal dust at 40g performed best with a CST improvement of 92%. The samples from local distillation with sugarcane molasses did not have CST improvement percentages greater than 75% for both sawdust and charcoal dust. Samples from local distillation with cassava and sorghum had CST improvement percentages greater than 75% in charcoal dust at 40g (85%) and 60g (88%) doses. With the results above, it is reasonable to propose charcoal dust as the optimal conditioner and 40g as the optimal dose because of its performance in both sample categories.

The results of supernatant turbidity improvement were also analysed. There was no improvement greater than 75% for sawdust in all sample categories. In samples from local distillation using sugarcane molasses, there was also no improvement greater than 75% after treatment with charcoal dust. Samples from factory distillation using sugarcane molasses had supernatant turbidity improvement greater than 75% at 40g (94%) and 60g (98%) charcoal dust doses. Samples from local distillation using cassava and sorghum had supernatant turbidity improvement greater than 75% at 40g (85%) and 60g (87%) charcoal dust doses. It is also reasonable to propose charcoal dust as the optimal conditional and 40g as the optimal dose for wastewater from factory distillation using sugarcane molasses and local distillation using cassava and sorghum.

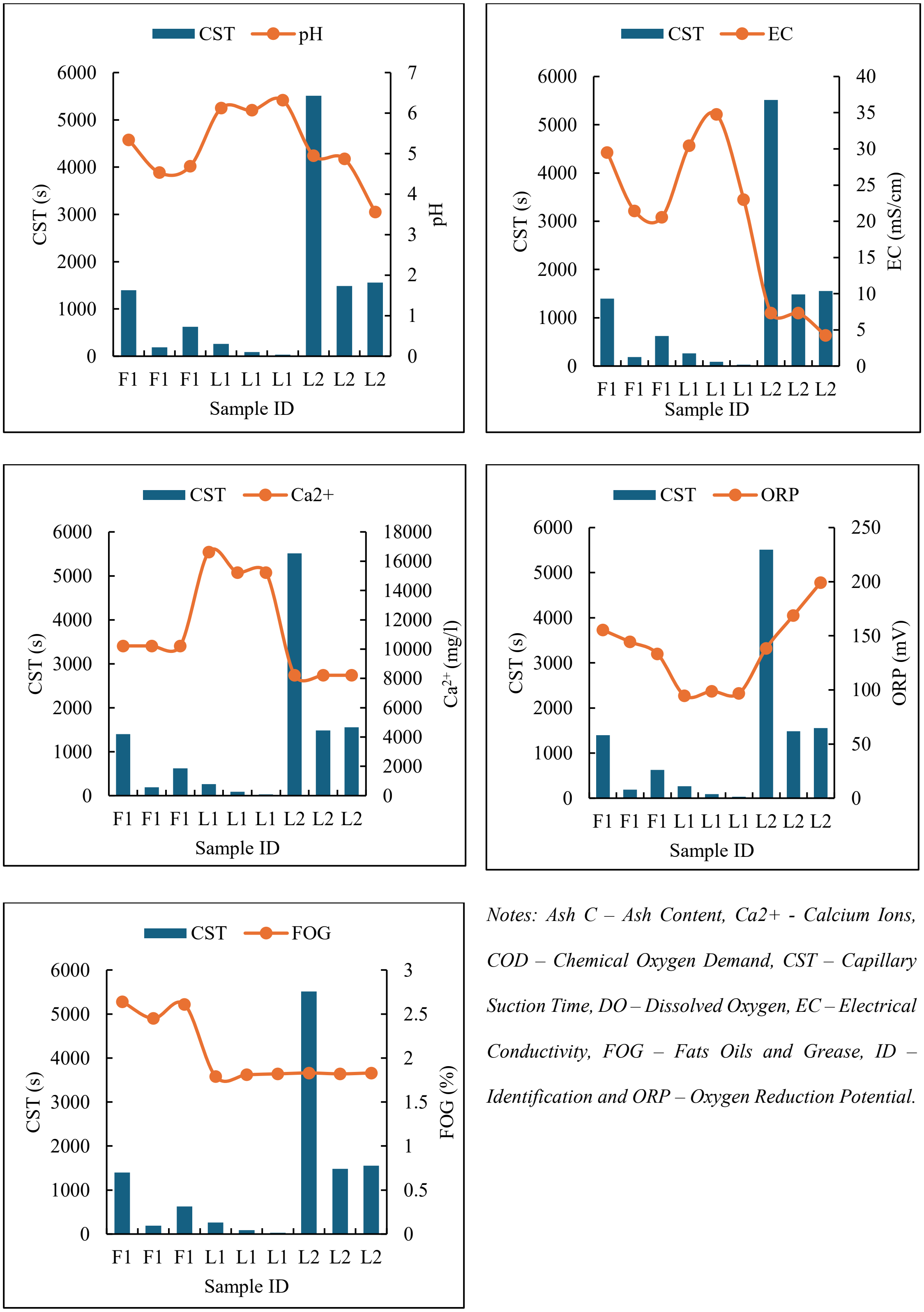


Note: CST – Capillary Suction Time.

Figure 4.8: Results of Jar tests with Sawdust and Charcoal dust.

4.5 Parameters affecting dewatering performance

According to Ward et al. (2021), some correlations have been made between the physicochemical characteristics of sludge and settling and dewatering performance. Plots of CST versus pH, EC, Ca^{2+}, ORP, and FOG are shown in Figure 4.9. CST was found to be lower at low pH for the samples most especially those from factory distillation with sugarcane molasses (F1). Low CST was also found to correlate with low EC for the samples from factory distillation with sugarcane molasses (F1). There were some variations in the behaviour of samples from local distillation with sugarcane molasses and cassava and sorghum where at a lower CST, EC was slightly higher. A clear correlation was not made between CST and Ca^{2+} because the values of Ca^{2+} for each sample were very similar. In the analysis of the relationship between CST and ORP, a correlation was found in the samples from local distillation with cassava and sorghum where at lower CST, ORP was slightly higher. A similar observation was made in the samples from local distillation with sugarcane molasses. In the analysis of the relationship between CST and FOG, a slight decrease in FOG was seen to correlate with low CST for the samples from factory distillation with sugarcane molasses. A similar observation was made in the samples from local distillation with cassava and sorghum. In the samples from local distillation with sugarcane molasses, a slight increase in FOG was seen to correlate with low CST.



Notes: Ash C – Ash Content, Ca2+ - Calcium Ions, COD – Chemical Oxygen Demand, CST – Capillary Suction Time, DO – Dissolved Oxygen, EC – Electrical Conductivity, FOG – Fats Oils and Grease, ID – Identification and ORP – Oxygen Reduction Potential.

Figure 4.9: Relationship between CST and the physicochemical characteristics of distillery wastewater.

4.6 Resource recovery potential of distillery wastewater

The samples' nutrient content and TS to TVS ratio were analysed to indicate resource recovery potential (as shown in Table 4.4). F1, L1 and L2 represent wastewater from factory distillation using sugarcane molasses, wastewater from local distillation using sugarcane molasses and wastewater from local distillation using cassava and sorghum respectively. L1 was found to have higher nitrogen and phosphorus concentrations than the other two wastewater categories. L2 was found to have the lowest concentration of nitrogen and phosphorus. F1 and L2 had the highest concentration of potassium and L1 had the lowest concentration. The TS/TVS ratio of the three wastewater categories was quite similar with a slight variation in L2. It was found that the nitrogen concentration in F1 and L1 was close to the of domestic wastewater recorded in literature. The low concentration of nitrogen in analysed distillery wastewater samples compared to literature values makes them not suitable for resource recovery of nitrogen. There was a noticeable variation in the phosphorus concentration of the wastewater categories and that found in literature for faecal sludge, septage, wastewater from beverage industries and domestic wastewater. The potassium concentration of F1 and L2 was found to be within the range for distillery wastewater recorded in literature. In a study by (Ranasinghe *et al.*, 2016), the average nitrogen, phosphorus and potassium concentrations of human urine were 3070±1.15mg/L, 20±0.004mg/L and 1700±0.2mg/L respectively. All distillery wastewater samples were found to have lower nitrogen concentrations but higher phosphorus and potassium concentrations than those of human urine reported by (Ranasinghe *et al.*, 2016). Phosphorus and potassium are critical raw materials which can be recovered. The TS/TVS ratio of F1, L1 and L2 was noticeably lower than that of faecal sludge. This indicates that the analysed wastewater samples can easily degrade. The TVS/TS ratio shows a higher potential for biogas recovery in L2.

Table 4.4: Nitrogen, phosphorus, potassium concentrations, and TS/TVS ratio of different waste streams.

Sample ID	N (mg/L)	P (mg/L)	K^+ (mg/L)	TS/TVS
F1	95	595	10690.35	1.31
F1	94	586	10920.25	1.31
L1	119	744	4712.95	1.29
L1	121	757	4580.00	1.31
L2	33	204	13219.25	1.13
L2	31	195	13449.15	1.06
Literature				
Distillery wastewater (mg/L)	1660-4200[1]	225-308[1]	9600-15475[1]	
Faecal sludge	3400[2]*	450[2]	-	772.05[2]
Septage	190-300[2]	150[2]	-	240.00-479.45[2]
Beverage industry	2600[3]	4400[3]	-	-
Domestic wastewater	101.54[4]	13.09[4]	-	-

*Notes: [1](Mikucka and Zielińska, 2020), [2](Katukiza et al., 2012), [3](Bhambri, Karn and Singh, 2021), [4](Khashroum, 2024), *Total Kjeldahl Nitrogen, N – Nitrogen, P – Phosphorus, K^+ - Potassium, TS – Total Solids, TVS – Total Volatile Solids.*

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Specific objective 1: Characterizing distillery wastewater from various sources

In general, the characteristics of distillery wastewater range from pH (3.56-6.32), EC (4.22-34.77mS/cm), COD (63,800-148,680mg/L) and turbidity (18,700-45,500NTU). Most parameters were higher than the National Environment Management Authority maximum permissible limits. The pH was more acidic and there was a broad range of variation in the EC, COD and turbidity of samples from various sources. At a 5% significance level using the Analysis of Variance (ANOVA) test in XLSTAT, the mean pH, EC, COD, ORP, TS, TVS, FOG, Ca^{2+}, DO and MC were found to be significantly different in the selected distillery wastewater sources. There was no significant difference in mean turbidity and ash content although the values obtained were different. The characteristics of distillery wastewater were also found to be dependent on the raw materials used in alcohol distillation.

Specific objective 2: Assessing the dewaterability potential of distillery wastewater

Dewatering performance was measured in terms of capillary suction time (CST), and turbidity of supernatant after natural and mechanical settling. The CST ranged from 30-5512.64s and turbidity of supernatant from 14,700-87,500NTU. Generally, there was a variation in the dewatering behaviour of the three distillery wastewater categories. The findings showed that raw materials used in alcohol distillation influence the dewatering potential of distillery wastewater. Wastewater from local distillation with cassava and sorghum had significantly slower dewatering rates (high CST) while that from local distillation with sugar molasses had faster dewatering rates (low CST). Wastewater from local distillation with cassava and sorghum had significantly higher turbidity results after homogenizing of up to 87,500NTU. In comparison, wastewater from local distillation with sugar molasses had lower turbidity results, as low as 14,700NTU after homogenizing. Wastewater from local distillation with sugar molasses had higher turbidity results while that from local distillation with cassava and sorghum had lower turbidity results after centrifuging. General analysis of the turbidity results indicated an improvement in the turbidity of the samples after mechanical dewatering (centrifuging).

Wastewater from local distillation using cassava and sorghum had much better supernatant and sludge separation after natural settling compared to centrifuging. The supernatant and sludge quantities in wastewater from factory and local distillation using sugarcane molasses after centrifuging was similar to the quantities after natural settling.

Specific objective 3: Assessing the impact of conditioning on dewatering of distillery wastewater

The physical conditioners used in the study were sawdust and charcoal dust. Dewatering performance was measured in terms of capillary suction time (CST), and turbidity of supernatant after conditioning. The application of conditioners resulted in better dewatering rate of samples from factory distillation with sugarcane molasses of 87% (for sawdust) and 77% (for charcoal dust). There was an improvement in dewatering rate of samples from local distillation using cassava and sorghum after conditioning, 57% (sawdust) and 68% (charcoal dust). Least dewatering rate improvement was observed in samples from local distillation using sugarcane molasses of 25% for sawdust and none for charcoal dust. Better supernatant turbidity was obtained after application of charcoal dust (72% improvement) and below average performance (26% improvement) after application of sawdust. After conditioning with sawdust and charcoal dust, the turbidity of the samples from factory distillation with sugarcane molasses was in the range of 4.37-230NTU which is below the Uganda effluent discharge standards of 300NTU, implying improved supernatant turbidity after the application of conditioners.

Specific objective 4: Assessing the resource recovery potential of distillery wastewater

Resource recovery potential was assessed in terms of nitrogen, phosphorus, potassium content and TVS/TS ratio. The ranges were Nitrogen (31-121mg/L), Phosphorus (195-757mg/L), Potassium (4580-13449.15mg/L) and TVS/TS ratio (0.76-0.91) Samples from local distillation using sugarcane molasses had the highest phosphorus concentrations while samples from factory distillation using sugarcane molasses and local distillation using cassava and sorghum had the higher potassium concentrations. All samples had lower nitrogen concentrations compared to values for distillery wastewater recorded in literature. Samples from local distillation using cassava and sorghum had a higher TVS/TS ratio (0.89-0.91) indicating a high potential for biogas recovery.

5.2 Recommendations

5.2.1 General

The findings showed that the concentration of parameters that characterize distillery wastewater were above recommended discharge limits and should be treated before discharge into the environment. Based on the characteristics of distillery wastewater, technologies for treatment of domestic wastewater can apply. Based on analysis of the dewatering potential of the selected distillery wastewater samples, dewatering is possible and natural and mechanical settling methods can be applied. However, treatment using physical or chemical conditioners could provide better results. Supernatant from dewatering needs further treatment.

Application of conditioners can improve dewatering rate and clarity of supernatant obtained. Charcoal dust performed very well in improving the dewatering rate and supernatant turbidity of wastewater from factory distillation using sugarcane molasses and local distillation using cassava and sorghum. Therefore, it is recommended as a suitable conditioner for improvement of dewatering for these wastewaters at an optimal dose of 40g/0.5L.

All wastewater categories had very low nitrogen concentration when compared with values recorded in literature for distillery wastewater, faecal sludge and beverage industry wastewater. Therefore, resource recovery can be limited to phosphorus and potassium. The TVS/TS ratio were on the high end of the range (0.5-0.8); therefore, it has a potential for biogas recovery.

5.2.2 Policy

Policy documents should be revised or updated to capture distillery wastewater. More constrained guidelines need to be put in place to ensure that both factory and local distillers treat their wastewater before discharge into the environment. A lot of point source pollution arises from local distillers that simply discharge untreated distillery wastewater into the environment. Similar standards on effluent discharge that are applied to factories can be used to regulate the activities of illicit distillers. Stakeholder engagement is crucial to ensure adherence to the set standards.

5.2.3 Further research

The following are areas for further research;

a) Investigate dewatering performance over set time intervals, visually analysing the turbidity of the supernatant (clear, cloudy, and turbid).

b) Investigate morphology and how it affects dewatering.

c) In-depth study of resource recovery potential of distillery wastewater before and after applying conditioners. Analyse sludge volume and calorific value

d) Investigate the biogas recovery potential of distillery wastewater from distillation using cassava and sorghum given the TVS/TS ratio (0.89-0.94).

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APPENDICES

Appendix I: Plagiarism Test Results

Appendix II: Introduction Letter

Appendix III: Letters of Consent

Appendix IV: Laboratory Test Results

RESULTS OF ANALYSIS OF DISTILLERY WASTE WATER SAMPLES AT MAKERERE UNIVERSITY PUBLIC HEALTH LABORATORY