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DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

CIV 4100: CIVIL ENGINEERING PROJECT II

IMPACT OF SOLIDS LOADING ON THE PERFORMANCE OF THE SETTLING THICKENING TANKS AT LUBIGI FAECAL SLUDGE TREATMENT PLANT

BY

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Submitted in Partial Fulfilment of the Requirements for the Award of a Degree of Bachelor of Science in Civil Engineering

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DECLARATION

I …………………………………………… and …………………………………………hereby declare this report is our own original work which has not been leaked in any way by any third party.

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APPROVAL

This Final Year Project report has been submitted for examination purposes at Makerere University in partial fulfilment of the requirements for the award of Bachelor of Science in Civil Engineering with the approval of the following;

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LIST OF ABBREVIATIONS

APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
FS	Faecal Sludge
FSM	Faecal Sludge Management
FSTP	Faecal Sludge Treatment Plant
EAWAG	Swiss Federal Institute for Environmental Science & Technology
HLR	Hydraulic Loading Rate
KCCA	Kampala Capital City Authority
NWSC	National Water and Sewerage Corporation
SA	Surface Area
SANDEC	Dept. of Water & Sanitation in Developing Countries (EAWAG)
SLR	Solids Loading Rate
STT	Settling Thickening Tank
SVI	Sludge Volume Index
TSS	Total Suspended Solids
TS	Total Solids
UBOS	Uganda Bureau Of Statistics
WHO	World Health Organisation

ABSTRACT

Faecal sludge management is becoming increasingly important due to the increasing world population served by on-site sanitation technologies. However, there isn't adequate operational experience in managing faecal sludge due to the highly varying characteristics and high strength. This study was aimed at studying the impact of the solids loading on the performance of sedimentation tanks that are used for solids-liquid separation at Lubigi faecal sludge treatment plant. A total of 5 composite samples were obtained from the influent and effluent on a weekly basis. These samples were analysed for Total Solids and Total Suspended Solids which are the key parameters evaluated for tank performance. The volume of faecal sludge delivered to the plant on the day of sampling was also determined. The average daily flow of 856.7m^3 was considerably higher than the 400m^3 design flow for the tanks. The suspended solids removal percentage was 42%, which is lower than the 60-80% achieved by similar tanks. The results obtained suggest that the greatest factor contributing to the underperformance of the tanks is the reduced liquid retention time caused by solids build up in the tank and high flows.

CHAPTER ONE: INTRODUCTION

1. 1 Background

There has been a growing global concern over the management of faecal sludge (FS). This is because the world's population is rapidly increasing and so are the sanitation needs (Tayler, 2018). Sewer-based approaches to treatment of excreta have been used especially in Europe and North-America and were, for a long time prioritised over onsite sanitation technologies. Even though they have been largely effective, the expansion and development of functioning, conventional sewer networks is not likely to keep pace with the rapid urban expansion typical of low and middle-income countries (Strande et.al. 2014). In addition, these systems are capital intensive and depend on a reliable water supply. Therefore, they may not be affordable in these countries (Harada et.al, 2016). A large number of people in urban areas of low- and middle-income countries depend on on-site technologies and this trend is expected to grow. In Kampala 92.5% of residents are served by onsite sanitation technologies, which are either pit latrines or septic tanks (Schoebitz et.al, 2016). Therefore, management of faecal sludge from onsite sanitation technologies will continue to be of global importance for providing access to sanitation, and protecting human and environmental health.

The term faecal sludge refers to the material, largely consisting of faecal solids and urine, which accumulates at the bottom of a pit, tank, or vault (Tayler, 2018). It is raw or partially digested, a slurry or semisolid, and results from the collection, storage or treatment of combinations of excreta and blackwater, with or without greywater (Strande et.al. 2014). Faecal Sludge Management (FSM) is a relatively new field and a huge knowledge gap exists in terms of operation between wastewater treatment and Faecal Sludge Management. The technologies that were adopted for the treatment of faecal sludge in the existing plants are based on wastewater treatment yet the volumes and strength of faecal sludge and wastewater differ considerably. Moreover, where sewers and wastewater treatment plants have been constructed in low-income countries they have most frequently resulted in failures (Strande, Rontelta, & Brdjanovic, 2014).

The challenges of faecal sludge treatment as presented by Tayler (2018) include;

- High sludge accumulation rates due to high solids content. This significantly shortens the retention times to allow for desludging.

- The treatment needs of faecal sludge are above those of waste water due to the high organic strength. This creates a need for multiple treatment processes deployed in series.
- The high ammonia content may inhibit biological processes reducing the efficacy of the treatment and resulting in liquid effluent nitrogen concentrations that exceed discharge standards.
- High nutrient levels in effluent from faecal sludge treatment may be an issue, particularly for co-treatment with wastewater.

The choice on which treatment processes and technologies to adopt in order to address the above challenges largely depends on the characteristics of the material to be treated such as hydraulic, organic, and solids loadings, all of which vary from place to place (Kone & Strauss, 2004). Given this variability in sludge characteristics, it is difficult to standardize the performance of any one technology. It is therefore necessary to assess the performance of whatever technology has been chosen to determine whether they meet the treatment objectives and also to determine areas of improvement for future designs.

1. 2 Problem Statement

Due to increasing acknowledgment of the importance of faecal sludge management, several faecal sludge treatment plants (FSTPs) are currently being designed and constructed in Sub-Saharan Africa (Uganda inclusive). However, there is very limited operating experience on which to base the designs. Previous designs were based on assumptions that sometimes differ from the actual operating conditions. The result is inadequate treatment performance, or even failures of the technologies. It is therefore essential to monitor the technical aspects of FSTPs during the actual operation. Basing on the recent research findings, the design parameters for faecal sludge treatment plants are currently being documented (Tayler, 2018) and (Englund & Strande, 2019).

Solids in the faecal sludge greatly contribute to the failure of treatment plants (Tayler, 2018)**.** This is because they clog pipes and fill up treatment units thereby reducing their capacity for treating faecal sludge. Given the difficulty of estimating faecal sludge characteristics and quantities, the operations of the plant have to be adjusted to be able to deal with what is actually delivered to the plant.

Lubigi faecal sludge treatment plant was designed and constructed basing on assumptions, majorly, the performance of by then faecal sludge treatment plants in Ghana that are currently not working. The plant is said to be currently overloaded, having reached full capacity within a few months after opening (Schoebitz, Niwagaba, & Strande, 2016). Given that the design was based on assumptions, the possibility of solids overloading and therefore poor performance needs to investigated and adequate solutions provided.

1. 3 Main Objective

The main objective of the study was to evaluate the impact of the solids loading on the performance of the settling thickening tanks at Lubigi faecal sludge treatment plant.

1. 4 Specific Objectives

- To quantify the influent to the settling thickening tanks.
- To determine the performance of the settling thickening tanks under the present solids loading.
- To determine areas of improvement and outline measures for optimizing the performance of the tanks.

1. 5 Significance

This information on operating conditions and performance of the tanks will be used to develop an empirically based understanding of faecal sludge treatment processes and in the optimization of the FSTP's operations. This work will also improve the provision of citywide treatment services for faecal sludge and hence improve public and environmental health.

CHAPTER TWO: LITERATURE REVIEW

2. 1 Intoduction

The overall objective of faecal sludge management is to ensure that the faecal material removed from on-site and decentralized sanitation facilities is dealt with in a way that protects both public health and the environment. FS treatment aims to achieve this by utilizing several processes in combination to stabilize the FS such that;

- The water content of the FS sludge is reduced making it easy to work with.
- The oxygen demand and suspended solids content of the liquid fraction that is discharged to the environment are reduced.
- Pathogens from the liquid effluent are reduced to allow its safe disposal or end use.
- Pathogen concentrations in sludge are reduced sufficiently to allow its safe end use or disposal as part of the solid waste stream.

In order to achieve the above objectives, FS is treated in stages which aim to achieve one or more of the objectives at a time. They include: reception and preliminary treatment, solids–liquid separation, liquid treatment, solids dewatering, and treatment to allow safe end use (Tayler, 2018)**.** Faecal sludge is not a uniform product and, therefore, its treatment must be specific to the characteristics of the sludge which include; solids concentration, chemical oxygen demand (COD), biochemical oxygen demand (BOD), nutrients, pathogens, and metals (Tilley, et al., 2014). These are however difficult to determine due to the variety of onsite sanitation technologies in use, such as pit latrines, public ablution blocks, septic tanks, aqua privies, and dry toilets (Kone & Strauss, 2004)**.** The problem is further compounded by the lack of standardized methodologies for the quantification or characterisation of FS (Strande et.al. 2014).

There are a number of technologies available for the treatment of FS; however, the same level of operational information is not available for all of them due to the varying degrees of implementation. Even where similar technologies have been adopted, their performance varies making it difficult to determine the factors that make a particular technology succeed or fail.

The treatment stages for faecal sludge occur in series, therefore the failure of a technology to perform adequately earlier in the series affects the performance of the subsequent technologies.

As such the solids loading on a plant greatly affects the performance of FS treatment units. The effects of solids loading on the performance of some technologies within stages of the treatment chain are further discussed below.

2.2 Reception and preliminary treatment.

Screening is a physical treatment mechanism, which removes large solid material from the influent usually with a bar screen. By removing solids in the influent, clogging in machinery and pump failures are prevented. Screening needs depend on both the FS composition and the requirements of subsequent treatment processes.

Grit and FOG removal of fresh faecal sludge may be required, depending on the nature of material to be treated and the requirements of later treatment processes. The problems of a high FOG content occur later in the treatment process. It can reduce microbial degradation due to reduced solubility in aerobic biological treatment processes, increase the scum layer in settling tanks, and reduce evaporation and percolation from drying beds (Strande et.al, 2014). Most plants deal with FOG by providing scum boards to retain scum in settling tanks before the FS proceeds to other units (Tayler, 2018). However, the best strategy for dealing with FOG is at the source by installing grease traps.

Grit chambers will be required where subsequent treatment technologies could be hindered or damaged by the presence of sand. A high grit content will increase the rate at which sludge accumulates in tanks and ponds and may also damage mechanical equipment. The rapid accumulation of sludge in these units will affect FS treatment since their performance is dependent on their storage capacity. (Heinss et.al, 1998)

Grit removal is normally provided for during preliminary treatment. Grit and sand are removed from the faecal sludge by passing the sludge through a channel where they settle, since they are too small to be removed by bar screens (Tilley, et al., 2014). Parabolic channels controlled by Parshall flumes are considered to be the best option since they are designed to maintain a roughly constant flow velocity regardless of flow, but they have not been widely used for grit removal for septage and require further investigation (Tayler, 2018). Square horizontal-flow grit chambers, a grit removal option adopted at some treatment plants, do not handle well rapid flow variations that occur as a tanker discharges, and so they are not suitable for use at faecal sludge and septage treatment facilities.

Taylor (2018) however suggests that it may be better to accept a higher rate of sludge accumulation in tanks and ponds and make no provision for grit removal because loading on FSTPs varies, which makes grit removal difficult. This will require frequent desludging of the tanks and ponds which increases the operational and storage demands increasing the likelihood that it will not happen.

2.3 Solids – liquid separation

It is possible to proceed directly from preliminary treatment to treat the whole of the FS as either liquid or sludge. Some existing treatment plants adopt this approach, utilizing either anaerobic ponds or drying beds to separate solids in conjunction with biological treatment and sludge dewatering, respectively. However, specific provision for separation of solids from liquid prior to treatment of the separated fractions will normally be advisable due to the high suspended solids concentrations in the FS, otherwise sludge build up in the ponds will occur making the solids-separation and other processes ineffective (Heinss et.al, 1998).

The main mechanisms used for solids–liquid separation are sedimentation (gravity separation), filtration, and pressure (Strande et.al, 2014). Sedimentation is employed by settling thickening tanks (STT's), filtration by planted and unplanted drying beds, while liquid-separation using pressure is employed by belt presses. Each of these mechanisms has advantages over the others in terms of cost and percentage reduction in suspended solids depending on the context of application. However, some are better at handling high solids concentrations and are less susceptible to solids loading variations than others. The approach to solids–liquid separation and the technology chosen will influence subsequent liquid treatment and solids dewatering needs depending on the solids concentrations in each part. Table 2.1 shows a comparison between different solids – liquid separation options in terms of reduction in solids content.

Table 2. 1: Comparison of main solids-liquid separation options (Taylor, 2018, p.204)

Solids-liquid separation option	**Typical solids content of separated sludge**	**Percentage reduction in liquid strength**		**Surface overflow rate**
		TSS	**BOD**	
Unplanted drying beds	At least 20% (More possible in hot dry climates and with longer retention time)	95%	70-90%	0.005-0.015
Anaerobic ponds	Typically 10%	Perhaps 80%	60% at 20°C (Performance depends on the temperature)	Typically around 0.6 depending on retention.
Belt presses	Typically 12-35% depending on type of sludge	95%		Not applicable
Gravity thickening in hooper-bottomed tanks	4-10% Typical 6%	30-60%	30-50%	Up to 30
Dakar STTs	6%	50% but depends on the length of the cycle	65-80%	12
Achimota STTs	Up to 15%	50% or more	10-20% after 4 weeks loading	0.25-0.5

In this study, emphasis is placed on Solids – liquid separation using STTs as one of those technologies that are most widely applied in low and middle income countries due to their low capital and operational costs. Their performance and operation are discussed further below.

2.3.1 Settling thickening tanks (Batch operated sedimentation tanks)

Taylor (2018) defines settling-thickening tanks (STTs) as rectangular concrete units, typically 2−3 m in depth with a floor that slopes from one end to the other**.** Faecal sludge or septage enters the tank at one end and supernatant flows out over a weir at the other end as solids settle along the length of the tank. Unlike sedimentation tanks used in wastewater treatment, STTs operate in batch mode, with each tank loaded for several days and then allowed to rest before sludge is removed. At least two settling-thickening tanks are operated alternately in parallel, in order to allow for desludging. The loading of FS, the resting period in which thickening occurs and removal of the thickened sludge and scum comprise the main phases of an operating cycle.

2.3.1.1 Operation of STT's

Settling-thickening tanks rely on three main fundamental mechanisms: settling, thickening, and flotation. Suspended solid particles that are heavier than water settle out in the bottom of the tank through gravitational sedimentation. The particles that accumulate at the bottom of the tank are further compressed through the process of thickening due to the weight of other particles pressing down on them. Floatation occurs as particles with a lower density than water are raised to the top surface of the tank to form the scum layer (Strande et.al, 2014). Due to the processes described above, four distinct zones appear in the tanks during operation namely; scum, clear water zone, separation and storage zone and the thickening zone (Heinss et.al, 1998). The volumes of the scum and thickening zones should be determined and considered in tank design, since they reduce the effective depth through which particles settle. Otherwise solids will be washed out with the supernatant if ignored.

The main FS properties that affect performance of STT's are the TSS concentration of the incoming sludge and its settleability (Englund & Strande, 2019). The sludge volume index (SVI) provides an indication of the settling ability of sludge based on the amount of suspended solids that settle out during a specified amount of time. SVI values below 100 (mL/g) are considered appropriate based on design of settling-thickening tanks for wastewater treatment plants (Heinss.et.al, 1999). Heinss et.al (1994) however point out that the SVI is affected by several factors and so it carries more validity as a relative rather as an absolute indicator for sludge settleability.

Anaerobic digestion, although not designed for, also occurs in settling-thickening tanks and contributes to the formation of the scum layer due to the generation of gasses (Heinss.et.al, 1998). This is a hindrance to the settling of partially stabilized FS since their degradation in the tank produces large amounts of gases that hinder the settling process. In addition, fresh sludges contain more bound water which is not easily removed by sedimentation (Strande.et.al, 2014).

Other factors that affect the performance of STT's are the surface and solids loading rates, tank type, solids removal mechanism, inlet design and weir placement. Current design procedure of the settling tanks is based on the assumption of uniform flow and the uniform settling particle velocity. However, circulation regions always exist in settling tanks reducing the tank's performance and decreasing its effective volume. The recirculation zones cause short-circuiting and high flow mixing problems. These can be dealt with using suitable baffle configurations to dissipate the energy of the incoming sludge. It is important to note however that the use of baffles without sufficient investigation could result in the tanks with worse performance than the ones without baffles (Tamayol, Firoozabadi, & Ahmadi, 2008). Some designs, in order to account for these challenges, oversize the settling tanks in order to cope with undesired and unpredictable system disturbances, which may be of hydraulic, biological or physio-chemical origin (Athanasia et. al, 2008). Other options for dealing with the hydraulic disturbances include; properly locating the outlet to minimise solids carry-over and ensuring that the length is longer than 30 meters and the width from 4 to 10 meters (Heinss et.al, 1994). The inlet position would also affect the size and location of the recirculation region.

The evaluation of the performance of the STT is based on the TSS concentration in the supernatant. If the TSS concentration is not suitable for the subsequent effluent treatment technology, a change in design, influent, inlet/outlet design and/or more frequent desludging might be required (Englund & Strande, 2019).

2.3.1.2 Constraints of STTs

There is lack of experience operating with FS, and lack of empirical data and results on which to base designs (Strande.et.al, 2014). For example, relationships between upflow velocity and SVI for faecal sludges have not been established. In addition, the recommendations provided on zone depths are for specific sludges and they may not be applicable elsewhere.

STTs are mainly for solids-liquid separation, not stabilisation or pathogen reduction. Therefore the end products of settling tanks cannot be discharged into water bodies or directly used in agriculture. Moreover, settled sludge still has relatively high water content and requires further dewatering while the liquid fraction remains highly concentrated in suspended solids and organics.

2.4 Liquid treatment

As noted earlier, both the strength of the material to be treated and the hydraulic loading on faecal sludge and septage treatment units can be highly variable. Technologies with a long retention time, for instance waste stabilization ponds (WSP), aerated lagoons, and constructed wetlands, will be best suited to cope with flow variations. WSP are considered to be the most important method of wastewater treatment in developing countries where sufficient land is normally available and where the temperature is most favorable for their operation. This is due to their low capital and operational costs that allow for sustainable wastewater treatment (Mara, 2004). This study therefore focuses on how the operation of the ponds is influenced by the solids loading on the plant.

2.4.1 Operation of WSPs

Mara (2004) defines waste stabilization ponds as large shallow basins enclosed by earth embankments in which raw wastewater is treated by entirely natural processes involving both algae and bacteria. There are three main types of WSP: anaerobic, facultative and maturation ponds, usually arranged in a series (Fig 2.1). Anaerobic ponds and facultative ponds are designed for BOD removal while maturation ponds are designed for faecal bacterial removal. BOD removal is achieved by the sedimentation of settleable solids and their subsequent anaerobic digestion in the resulting sludge layer.

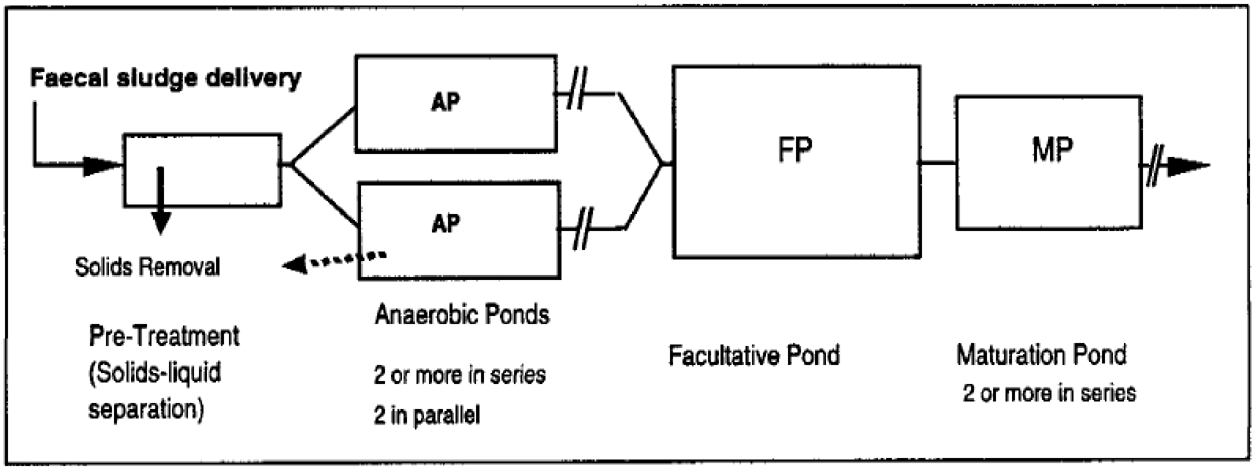

Figure 2. 1: Arrangement of different types of WSP (Heinss et.al 1998, Pg. 28)

Septage removed from infrequently emptied leach pits, wet pit latrines, and septic tanks will normally be uniformly well digested and the potential for further organic reduction will be lower than that for municipal wastewater. According to Taylor (2018), the two measures of the treatability of any wastewater are its volatile solids (VS) content which is normally expressed as a percentage of total solids (TS). A high VS to TS value indicates potential for further biological treatment. FS consisting exclusively of high strength sludges is not conducive to pond treatment in the same way as are lower strength sludges or wastewater. Solids separation occurs only after the sludges have become fully or almost fully digested. This requires extensive retention periods which may not be practical. Heinss et.al (1998) recommend treating high and low-strength faecal sludges separately if appreciable amounts of high strength FS are being delivered to the plant.

While prior solids–liquid separation would have reduced the solids concentration in the influent, it will still be high enough to lead to rapid sludge accumulation in tanks and ponds. Settling tank operation may also not always be optimal causing primary anaerobic ponds treating the settling tank supernatant to receive varying loads of settleable solids. A well functioning FS pond system is mainly dependent on a reliable solids separation. Solids buildup in primary ponds caused by too infrequent emptying will lead to a malfunctioning of the entire pond system. Sperling & Carlos (2005) recommend employing the following strategies for desludging;

- when the sludge layer reaches approximately 1/3 of the liquid depth

- annual removal of a certain volume, in a pre-determined month, to include the cleaning stage in a systematic way in the operational strategy of the pond.

Also if the removal is not by emptying and drying inside the pond, the whole sludge mass should not be removed, since this would lead to a total loss of the biomass, requiring the anaerobic pond to start up again.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

This section discusses the field and laboratory procedures followed during the study at Lubigi FSTP. The research was carried out between February 2020 and January 2021. The study intended to investigate the treatment performance of the settling thickening tanks during one operation cycle that was to last 12 weeks but was cut short due to the pandemic. As such only 10 samples for the inlet and outlet were collected and analysed over a 5-week period during the loading of the tank. The details are provided in the sections below.

3.2 Location of study area

Lubigi FSTP is one of two locations for legal discharge of FS and is located in Namungoona, Rubaga Division in Kampala the capital of Uganda. The Lubigi catchment area consists of Makerere, Katanga, parts of Mulago, Kalerwe, Bwaise and areas along the northern by-pass.

Kampala has a total area of 178 km^2 at an altitude of 1140 m, and a tropical climate with two rainy seasons (Schoebitz et al., 2017). It has a resident population of 1.5m (UBOS, 2016), of which 92.5% are served by on-site sanitation (Schoebitz et al., 2016). Figure 3.1 and Figure 3.2 show the location of Lubigi FSTP.

Figure 3. 1: Location of Lubigi FSTP

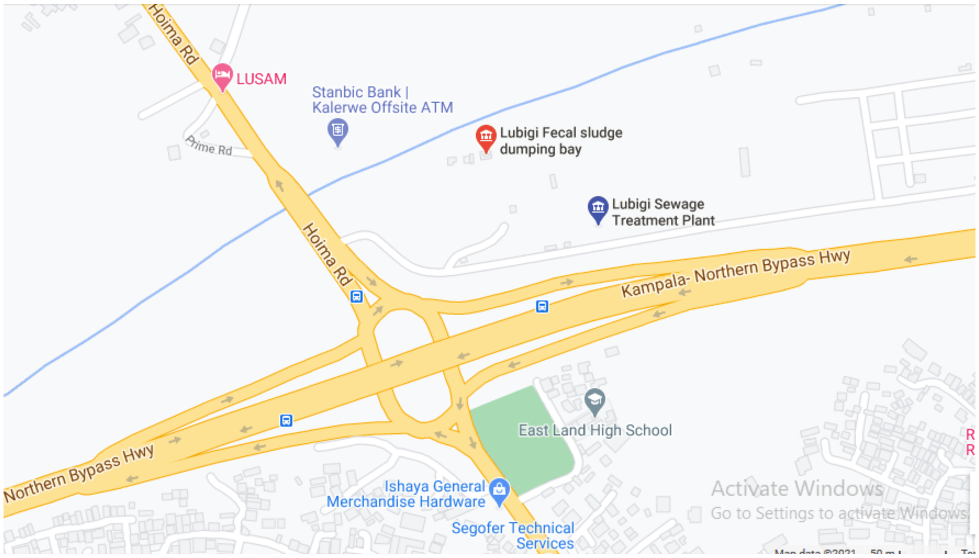

Figure 3. 2: Close-up of location of Lubigi FSTP

3.3 Treatment units at Lubigi FSTP

Lubigi Faecal Sludge treatment plant was designed to treat 5000m^3 of wastewater per day and 400m^3 of FS per day (Schoebitz et al., 2016). Faecal sludge undergoes solids-liquid separation in two parallel sedimentation tanks after preliminary treatment. The settled solid fraction is then transferred to covered unplanted drying beds for dewatering, while the liquid effluent is co-treated in waste stabilization ponds with effluent from primary wastewater treatment. The effluent of the ponds is then discharged into Lubigi wetland while the dry FS is stored and later sold to farmers (Schoebitz et al., 2016). The faecal sludge flow diagram is shown below.

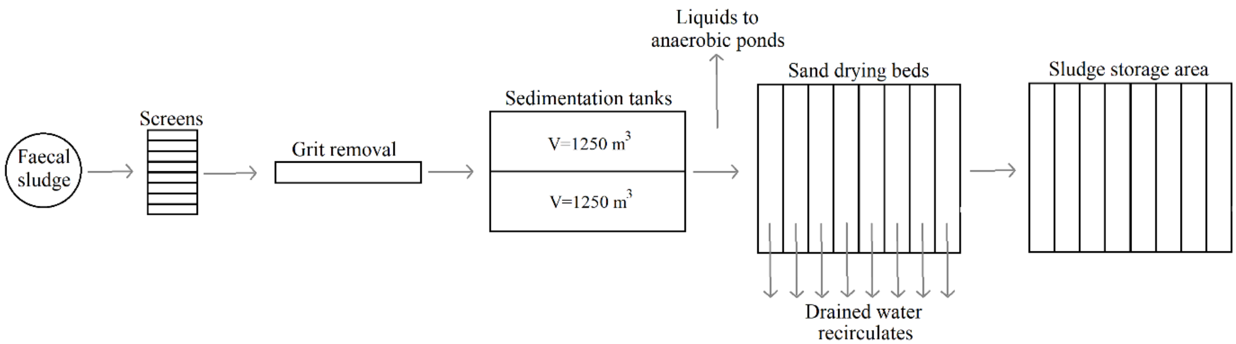

Figure 3.3: Faecal sludge flow diagram for Lubigi FSTP (Lindberg & Anna, 2018)

3.4 Quantification of faecal sludge

The volumes of trucks delivering faecal sludge to the plant were recorded against their number plates (to avoid asking for the capacities of the trucks multiple times). Estimates of the volumes of FS delivered were obtained from the truck drivers or determined using gauges at the back of the trucks (results in the appendix). The recorded volumes in this study are based on those values, and actual volumes were not measured. The total daily volumes of FS delivered to the plant were then calculated and together with the tank dimensions were used to calculate the theoretical hydraulic retention times (HRT) and the surface overflow rates (SOR) using equation 3.1 and equation 3.2 respectively (Sperling, Matthew, & Sílvia, 2020)

$$\text{HRT (hours)} = \frac{\text{tank volume}}{\text{flow}} \times 24 \qquad \text{Equation 3.1}$$

$$\text{SOR } [(\text{m}^3/\text{d})/\text{m}^2] = \frac{\text{Q}}{\text{A}} \qquad \text{Equation 3.2}$$

Where;

SOR = Surface overflow rate

Q = flow (m^3/d)

A = Surface area of the tank (m^2)

For the outlet, the volume of effluent flowing over the weir was taken to be equal to the influent volume (Sperling, Matthew, & Sílvia, 2020)**.**

Figure 3. 4: Recording FS volumes

3.5 Faecal sludge sampling strategy

Faecal sludge samples were picked between 8:00am and 4:00 pm while the trucks were delivering faecal sludge to the plant. Grab samples of about 500 mL were picked using a sampler at intervals of 15 minutes in the grit removal chamber at the valve opening to the tank being loaded and placed in a bucket over the sampling period. At the end of the day a single 500 mL composite sample was obtained after stirring and placed in a plastic container.

The same method of sampling was done at the outlet of the same tank whose influent was sampled (tank B below) where grab samples were obtained as the effluent flowed over the weir. A single 500 mL composite sample was obtained at the end of the day and placed in a plastic container.

Figure 3. 5: Picking samples of influent

All composite samples were placed in an icebox but no ice was used. These were then transported to the Public Health and Environmental Engineering Laboratory at Makerere University for analysis.

Figure 3. 6: Picking samples of effluent

The analysis was done within 24 hours from the time of sample collection. The sampling was done once a week over a 5 week period. These weekly samples were required to obtain the average solids loading in order to develop a mass balance.

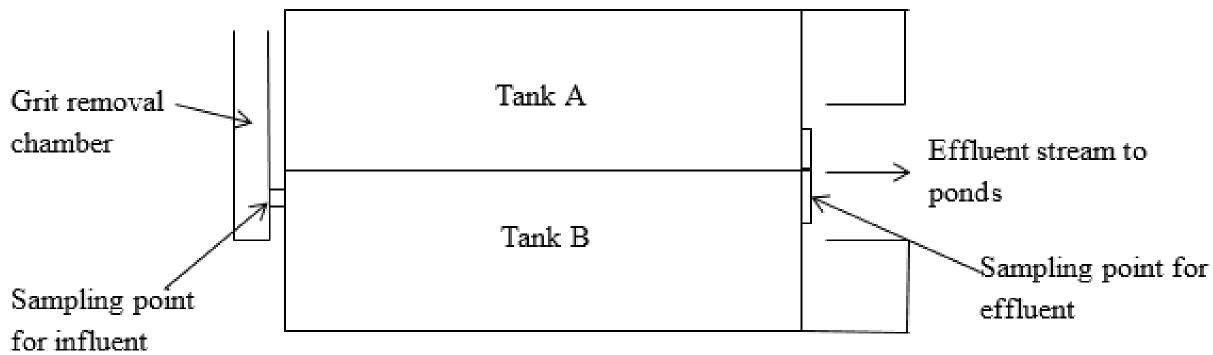

Figure 3. 7: Location of sampling points

Using the concentrations obtained from analysis of the samples and the flows, the solids loading and the solids loading rates were calculated using equation 3.3 and equation 3.4 below (Sperling et.al, 2020)

$$SL\ (kg/d) = \frac{Q\ (m^3) \times C(mg/l)}{1000} \qquad \text{Equation 3.3}$$

$$SLR\ (kg/d/m^2) = \frac{SL}{A} \qquad \text{Equation 3.4}$$

Where;

SL = solids loading

SLR = solids loading rate

Q = flow (m^3/d)

A = Surface area of the tank (m^2)

3.6 Laboratory analysis of FS samples

3.6.1 Total Solids and Total Suspended Solids

The Total Solids (TS) concentrations were determined according to standard methods as applied to examination of water and wastewater (APHA, 2017). 50 mL of well mixed composite samples was poured into clean dry empty beakers each with a capacity of 50 mL after weighing them and then placed in the oven at 105^{o}C for 24 hours**.**

The beakers were removed from the oven and then placed in a desiccator to cool. They were then weighed after cooling and the weights of the beakers with the residues were recorded. The TS concentrations were then calculated using the formula below;

$$\text{TS (mg/L)}=\left(\frac{W_A\text{-}W_B}{0.05}\right)\times 1000$$

Where;

W_A (g)=Weight of beaker with dry sample residue

W_B(g)=Weight of the same empty beaker

Total Suspended Solids (TSS) concentrations were determined gravimetrically according to standard methods as applied to examination of water and wastewater (APHA, 2017). Each composite sample was stirred and poured into a funnel placed in a flask and fitted with a filter paper to obtain a filtrate. Clean dry empty beakers each with a capacity of 50 mL were weighed and their weights recorded. 50 mL of the filtrate was poured into the beakers which were then placed in the oven at 105^{o}C for 24 hours**.**

Figure 3. 8: FS samples undergoing filtration

The beakers were removed from the oven and then placed in a desiccator to cool. They were then weighed after cooling and the weights of the beakers with the residues were recorded. The TSS concentrations were then calculated using the formula below;

$$\text{TSS (mg/L)}=\left(\frac{W_{TS}\text{-}W_{TDS}}{0.05}\right)\times 1000$$

Where;

W_{TS} (g)=Weight of beaker with dry sample residue-Weight of the same empty beaker

W_{TDS}(g)=Weight of beaker with dry filtrate residue-Weight of the same empty beaker

3.6.2 Settleability Tests and Sludge Volume Index (SVI)

The volume of settleable solids was determined volumetrically using an Imhoff cone. The composite samples were stirred and poured into Imhoff cones up to the 1-L mark and then left to settle for 45 minutes. The samples were then gently agitated near the cone sides using a rod and left to settle for another 15 minutes. The volume of settleable solids in the cone was then recorded in mL/L.

Using the TSS values of the samples obtained previously the SVI was calculated using the formula below;

$$\text{SVI (ml/g)} = \left(\frac{\text{settled sludge volume (mL/L)}}{\text{suspended solids (mg/L)}}\right) \times 1000$$

Figure 3. 9: Imhoff cones with samples

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This section presents results obtained from the field work and laboratory analysis of samples. The results are compared to similar studies and the identified deviations discussed.

4.2 Faecal Sludge Quantification

4.2.1 Daily Faecal Sludge flows

The results of quantification of the raw/influent FS are presented in Table 4.1. The mean daily inflow obtained over the 5 weeks is 856.7m^3 with a standard deviation of 153.8m^3. The flow for week 5 is considerably lower than the flows for the other weeks due to the road works that were going on at the time. These interfered with the delivery of FS as the trucks had to use specific routes that were longer. The mean daily flow is higher than the 660m^3/d reported by KCCA (KCCA, 2020) and considerably greater than the 400m^3 that the plant was designed to treat. In fact, the treatment plant was already operating at full capacity within a few months of opening. (Schoebitz et al., 2016). The high flow values currently recorded could be due to increasing urban population in Kampala that uses onsite sanitation systems (Schoebitz et.al, 2016) leading to rapid sludge accumulation in latrines and septic tanks hence the increased demand for desludging. The high flows can also be attributed to the increasing delivery of FS from metropolitan areas such as Mukono and Wakiso due to lack of treatment plants in those areas. It is estimated that approximately 23% of all the FS delivered to both Bugolobi and Lubigi FSTPs originates from outside Kampala (KCCA, 2020).

Table 4. 1: Results of quantification of FS

Parameter	**Units**	**WEEK 1**	**WEEK 2**	**WEEK 3**	**WEEK 4**	**WEEK 5**	**Mean ± SD**
Daily inflow	(m^3/day)	758.9	1013.1	970.5	898.7	642.4	856.7 ± 153.8
SOR	[(m^3/d)/m^2]	1.518	2.026	1.941	1.797	1.285	1.71 ± 0.31
Theoretical HRT	hours	40	30	31	33	47	36 ± 7

Notes: SOR- Surface overflow rate

Surface Area = 500m^2

The overloading of the tanks at Lubigi FSTP could be due to the poor forecasting done for the daily quantities of FS. The 2023 forecast for accumulated and collected FS was 979 and 567 m^3/d, respectively with collection rates based on records of NWSC (NWSC, 2009). It was assumed that that the amount of FS dumped at Lubigi FSTP would drop to $300m^3/d$ due to the construction of the Nalukolongo FSTP. The Nalukolongo FSTP wasn't constructed causing the Lubigi FSTP to become overloaded. Schoebitz et.al (2014) report that that there were discrepancies in the collection rates of FS that were recorded and reported by different sources. The problems of poor forecasting are exacerbated by the difficulty in estimating FS quantities due to absence of reliable data and accepted methodologies for representative quantification of FS (Schoebitz et.al, 2014).

Given the high flow values, the theoretical hydraulic retention times (HRTs) are below the design value of 75 hours. These low values affect the settling behaviour of the FS in the tank leading to poor solids removal (Strande et.al, 2014). The impact of the high flows can also be examined using the surface overflow rate (SOR) values. SOR values have a direct equivalence with the settling velocity of the particles or solids to be removed in the sedimentation tank (Sperling et.al, 2020). This means that for the tank to perform adequately, the FS particles must have settling velocities corresponding to the values in Table 4.1**.** These values exceed the design SOR of 0.8m/d (Calculated using tank dimensions), though it is below the recommended value of 12-24 $(m^3/d)/m^2$ (Sperling et.al, 2020). Strande et.al (2014) however state that the recommended value is not based on empirical experience with FS.

Results obtained from respondents in the study show that over 99.4% of the FS sludge delivered was obtained from septic tanks (Figure 4.1). Since FS from pit latrines generally have high TS and TSS values (Schoebitz et al., 2016), the management of the treatment plant restricts the source of FS delivered by vacuum trucks to be septic tanks. Only one truck delivering FS from gulpers is allowed to empty its contents at the plant. However in practice the vacuum trucks also delivered FS from pit latrines which wasn't detected or recorded by the plant staff. These deviations from the rule were not reflected in the analysis below.

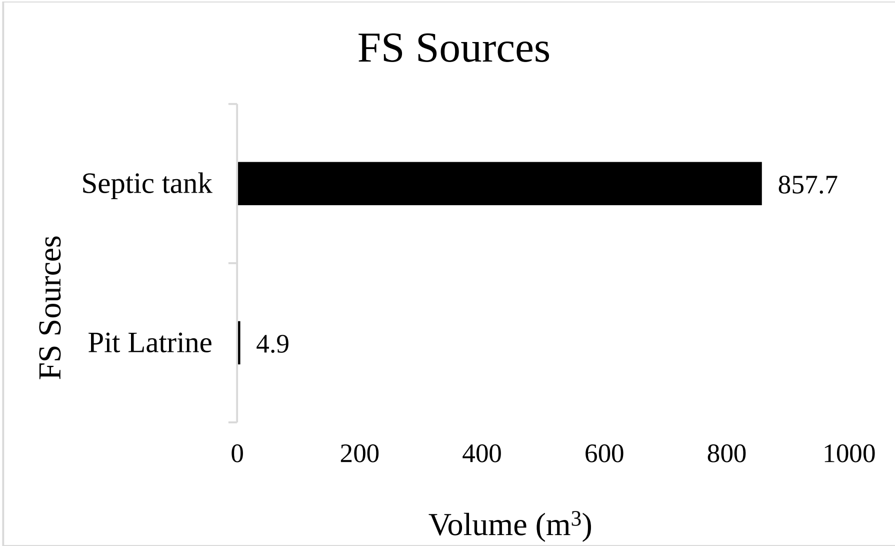

Figure 4. 1: Average daily volume of FS from each source

4.2.1 FS characteristics

The TS and TSS influent concentrations obtained are comparable to those from previous studies done on the characterization of Kampala septage (Schoebitz et al., 2016). The influent concentrations were highly variable with mean TS and TSS concentrations of 8103mg/L and 5114mg/L respectively, and standard deviations of 1883mg/L for the TS and 1993mg/L for the TSS. The TS influent concentrations are lower than the influent TS concentrations of 25900 mg/L forecasted at the design of the plant for the year 2020 (NWSC, 2009), probably because the samples analysed during the study were obtained after grit removal while the forecasts were made based on samples obtained from discharging trucks before grit removal.

In comparison to the design effluent TSS value of 4000-5000 mg/L for the tanks (NWSC, 2009, p. 148), the mean effluent concentration of 2924 mg/L obtained during the study is within the design range. This implies that the solids loading onto the anaerobic ponds was appropriate.

Figure 4.2 and Figure 4.3 show an increasing trend for TS and TSS values for the inlet during the first 3 weeks while TS and TSS values for the outlet show a decreasing trend during the same period. It was expected that the higher TS concentrations in the influent would lead to hindered settling and hence higher effluent TS values (Heinss et.al, 1998).

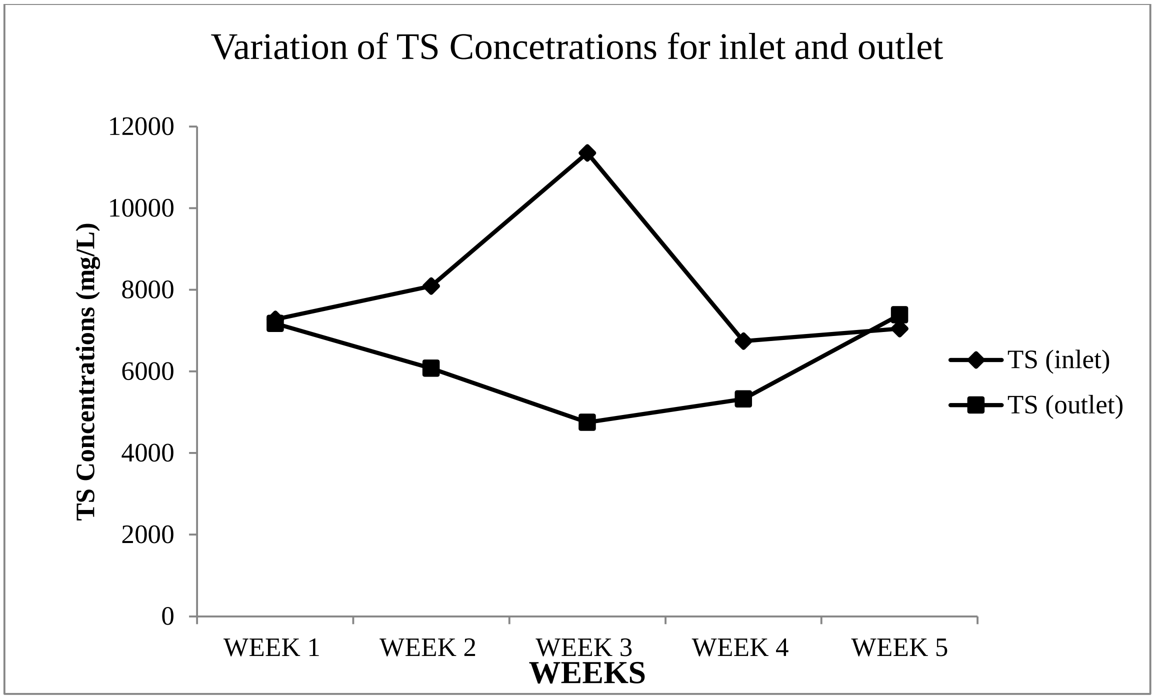

Figure 4. 2: Variation of TS concentrations

However, the TS and TSS values for the outlet increased for week 4 and 5 even though the influent values decreased, implying decreased solids removal in the tank.

From Figure 4.3 and Table 4**.**1, the effluent TSS and the theoretical HRT had an inverse relationship in the first three weeks i.e. as the HRT decreased, the effluent TSS increased. This was to be expected since the increasing FS volumes reduce the residence time of the FS in the tank leading to high TSS concentrations in the effluent due to reduced settling (Sperling et.al, 2020).

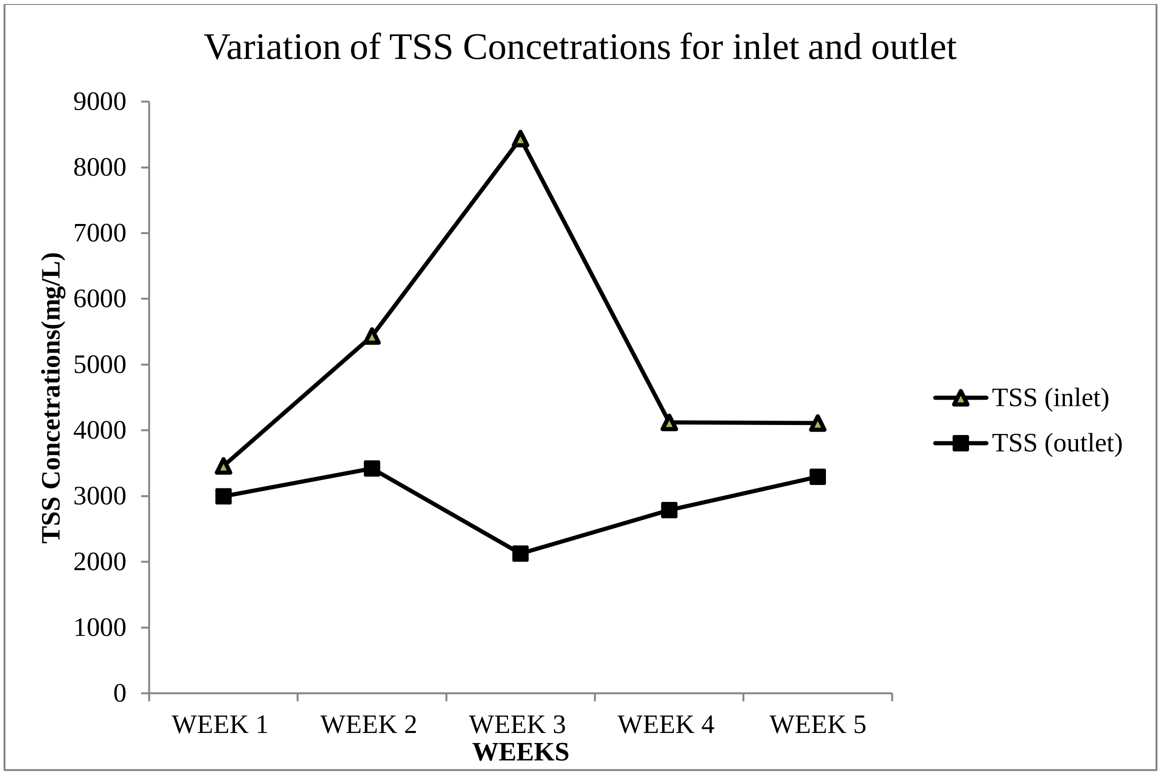

Figure 4. 3: Variation of TSS concentrations

However, the effluent TSS increased with a higher HRT for week 4 and 5, which would mean that the actual HRT varied greatly from the theoretical values calculated due to solids build up in the tank. The higher than expected effluent values could also be attributed shock loading that occurs as the trucks are emptying FS. It was observed that as the trucks were desludging, the screens would get clogged by solid waste and required manual cleaning. The trucks were stopped from emptying for some minutes while cleaning was going on. Afterwards, the large volumes of FS caused the grit chamber to be filled to capacity and FS to enter the tank at high velocities. This process probably led to short circuiting in the tank causing particles that had already settled to resurface.

4.3 Settling Thickening Tank Performance

4.3.1 Operation

The two STT's at Lubigi FSTP have a capacity of 1250m^3 each, are batch-operated and loaded by vacuum trucks at the deep end of the tank. Solids settle along the length of the tank while effluent flows out over a weir at the other end into the following anaerobic pond. Each tank measures 50m in length, 10m in width and 2.5m in height (Figure 4.4 and Figure 4.5)

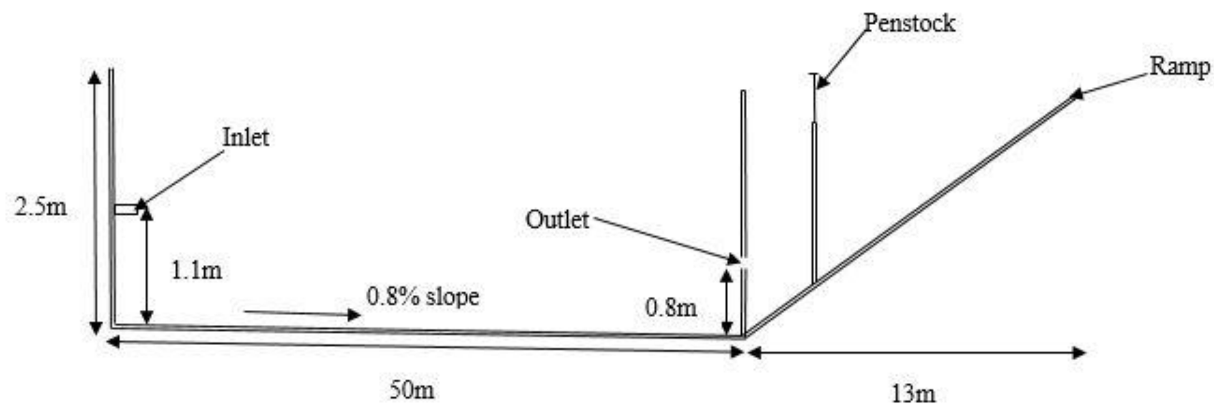

Figure 4. 4: Schematic showing side view of the STTs at Lubigi

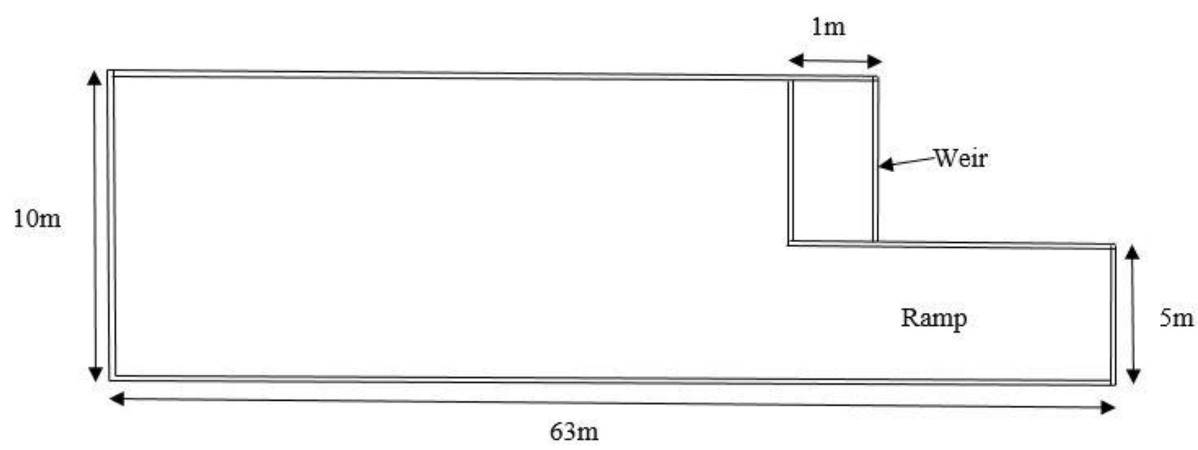

Figure 4. 5: Schematic showing plan of the STT

At an average daily flow of 856.7 m^3/d, the 1250m^3 tank is filled within two days and works from then on as sludge accumulator. The tanks were designed to operate in parallel with each operating cycle lasting about 8 weeks with 4 weeks loading followed by 4 weeks resting (NWSC, 2009). However, during the study period, it was found that the tanks were loaded for more than 6 months. The settled sludge in liquid phase was removed from the tanks by pumping to the dying beds at irregular intervals (when the inlet was blocked by sludge or when the scum level passed the top of the tank). This was done to reduce the amount of sludge to be removed mechanically and the frequency of mechanical desludging requirement. At the end of the operating cycle, the tanks which can be accessed by a ramp, are emptied by front-end-loaders which transfer the remaining hard fraction of sludge and scum onto drying beds.

4.3.2 Performance in terms of solids removal

The percent removal of TS and TSS was 24.2% and 42.8% respectively. The results of TSS removal efficiency in this study are below the expected values of 60-80% for FS with SVI values below 100 (Strande et.al, 2014). The TSS removal percentage is also lower than the 57% obtained from the studies of the Achimota tanks (Tayler, 2018).

The low percentage could be attributed to high initial solids loading of FS as shown in Table 4.2 and the short Hydraulic Retention Time (HRT) recorded during the processes (Table 4.1). This does not allow enough time for the suspended solids to settle out leading to reduced solids removal. The HRT is further shortened when the settled and thickened sludge layers gradually expand in volume during tank operation which increasingly reduces the sedimentation area necessary to absorb the settled solids. As a result, solids are carried into the effluent at an increasing rate (Strande et.al, 2014). In addition to sludge build-up within the tank, the occurrence of dead zones within the tank due to uneven inflow distribution or uneven outflow collection at the inlet and outlet zones occurs (Figure 4.6), most especially for rectangular tanks where the inlet opening is at the center such as those at Lubigi FSTP.

The design solids loading for the plant was 10560 (kg TS/d) while the projection for the year 2020 was 10360 (kg TS/d) (NWSC, 2009, p. 140). These values are higher than the average solids loading of 7065.3 (kg TS/d) calculated for the tanks at Lubigi FSTP. This means that in comparison to the design values, the tanks are adequately loaded.

Table 4. 2: Solids loading and loading rates of the STTs at Lubigi FSTP

Parameter	Units	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	Mean ± SD
SVI (Inlet)	(ml/g)				48.5	44.5	46.5 ± 2.8
SLR (TS)	[(Kg /d)/m^2]	11.04	16.39	22.03	12.12	9.06	14.13 ± 5.17
SLR (TSS)	[(Kg /d)/m^2]	5.25	11.01	16.38	7.41	5.32	9.08 ± 4.71
Solids loading	(kg TSS/day)	2625.8	5507.2	8191	3702.6	2661.3	4537.6 ± 2353.7
Solids loading	(kg TS/day)	5520.2	8196.0	11017.1	6061.7	4531.5	7065.3 ± 2584.1

Note: SLR- Solids loading rate

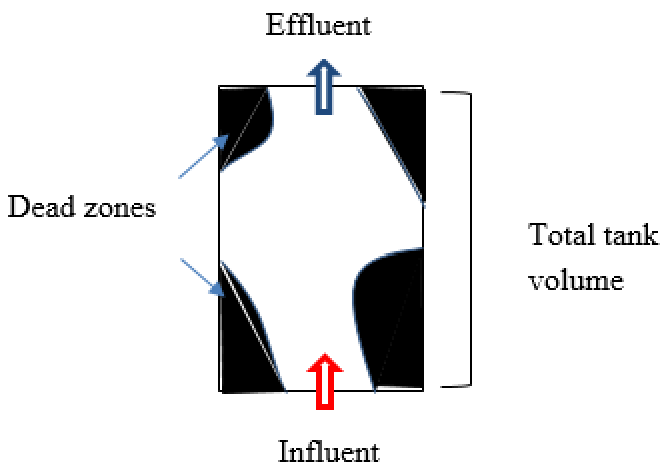

Figure 4. 6: Dead zones in the tank

As a result, these zones do not participate in the removal mechanisms that take place in the remaining parts of the tank causing the FS not to settle as envisioned (Sperling et.al, 2020).

The solids loading rate of the tanks at Lubigi FSTP is 3 times that of the Achimota tanks and Dakar tanks (Table 4.3), but it is lower than the recommended value of 4-6 kg/m^{2}h for gravity thickeners treating primary sludge (Metcalf & Eddy, 2003). However, given that the tanks were underperforming at those SLRs, the recommended values for the treatment of type of sludge received at the plant need to be determined empirically.

Table 4. 3: Summary of comparison of Lubigi tanks to other tanks and recommended values

Design parameter	**Units**	**Achimota FSTP**	**Dakar FSTPs**	**Lubigi FSTP**	**Recommended**
Theoretical HRT	hours	48, reducing as sludge accumulates	8.6 (designed) 1.7 (actual)	35, reducing as sludge accumulates (Design value is 75)	Depends on the influent strength
Surface overflow rate	$(m^3/d)/m^2$	0.75 (0.375 over complete loading cycle)	6–14 (3–7 over complete loading cycle)	1.71 (Design value is 0.8)	12 (Strande et.al, 2014)
Solids loading rate	(Kg TS/d)/m^2	3.75–5 over complete loading cycle	2.25 (designed) 5.5 (actual) over complete loading cycle	14.13 (average) (Design value is 21.12 without grit removal)	4-6 kg/m^2h (Metcalf & Eddy, 2003)

4.4 Suggestions for improvement

The loading period should be shortened and the desludging intervals matched to the effluent quality rather than waiting for the sludge to block the inlet. This will ensure that sufficient tank volume is available for the settling processes to take place even when the influent characteristics vary (Strande et.al, 2014).

Flow equalization tanks should be constructed to mitigate the effect of varying flow rates during the day. This will enable the flow rate of the influent to be uniform, hence stabilising the solids concentrations and reducing short circuiting in the tank (Tayler, 2018).

Another option for improving tank performance is conditioning of FS to improve the settling properties (Gold, et al., 2015). This will increase the capacity of the tanks to handle the high solids loading since more solids will be settling out. This would however need to be balanced with the increased treatment costs arising from the purchase of conditioners.

4.6 Missing Data

The SVI values for the first 3 weeks are missing. This means that there is no way to know for sure that the difference in performance between the first 3 weeks and the last two weeks is not due to difference in settling properties of the faecal sludges.

Daily loading data and loading variation throughout the day was also not obtained. This would have been useful in determining the effect of flow attenuation on the TSS concentrations and estimates of the actual HRT based on time series graphs.

Data about TS concentrations in the thickened sludge and scum was not obtained. Therefore, a mass balance based on measured parameters was not possible.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study found that the solids loading onto the tanks is within the values stipulated in the design. Therefore, the tanks are not overloaded in comparison to the design values.

The study also found that flows received by the STTs at Lubigi FSTP are beyond the capacity of the tanks. The tanks therefore were underperforming due to the high flows that interfered with the settling processes in the tanks.

It was found that even though the tanks underperformed in terms of solids removal, the effluent TSS concentrations were within the expected range which was to be received by the ponds at the time of design.

The study also found that the performance of the tanks was made worse by the poor operations procedures employed by the staff. The long loading periods adopted reduced the removal efficiency of suspended solids.

5.2 Recommendations

5.2.1 Recommendations for further studies

Further research in the following areas could be pursed.

1) The relationship between sludge build up within the tank and suspended solids removal.
2) The effect of flow variation within the day on the TSS removal efficiencies.
3) The appropriate solids loading rates for settling thickening tanks treating FS of the type in Kampala.
4) The appropriate settling velocities for Kampala sludge and the relationship to other parameters like SVI.

5.2.1 Recommendations for Policy improvement.

More effort, through education and offering of incentives, should be put into use of faecal sludge as manure by farmers. Other approaches to resource recovery such as co-combustion of dry FS with solid waste and pelletizing of FS are currently being pursued, but the use of FS for manure remains the most ideal method given that Uganda is an agricultural country and the potential demand is high. The increased consumption of the dry FS will provide room for more frequent desludging of the treatment units which will in turn improve their performance.

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APPENDIX

Raw Data for quantification

All faecal sludge was got from septic tanks except where indicated by PL, which means the source of the FS is a pit latrine.

Week One (Monday)					
8:00am-10:00am		10:00am-12:00pm		12:00pm-2:00pm	
No. Plate	Volume (m^3)	No. Plate	Volume (m^3)	No. Plate	Volume (m^3)
UAU 584S	3.7	UAX 410R	4	UAY 622C	4
UAW 464W	10	UAM 529T	3.6	UAL 812J	14
UAL 915H	4	UBG 707H	7	UP 5534	15
UBA 628A	3	LG 0400-01	6.5	UAL 314H	4
UBA 704W	14	UBA 497H	14	UBF 070K	2
UAM 607Y	10	UAA 468E	10	UAS 873H	3
UAU 584S	4	UBA 704W	14	UAU 584S	4
UBA 864A	14	UBC 775D	10	UAP 422H	3.6
UBB 532X	3	UBF 070K	2	UAW 876B	4
UBB 504R	10	UBD 024S	20	UAN 030N	3
UBG 788D	3.6	UAM 607Y	10	UBG 707H	7
UAW 464W	10	UAZ 719G (PL)	4.8	LG 0270-01	6.5
UAL 812J	14	UAS 873H	3	UBD 024S	20
UBF 614D	4	UAY 870Y	10	UBC 775D	10
UAH 522R	8	UBF 828S	10	LG 0400-01	6.5
		UAU 290W	8	UAY 878V	3.6
		UAW 876B	4	UAH 522R	8
		UAY 188B	3	UBF 614D	4
		UAL 394H	4	UAF 138U	8
		UAN 030N	3		
		UAF 138U	8		
		UBB 504R	10		
		UBE 325G	10		
		UBB 532X	3		
		UAW 464W	10		
		UAX 410R	4		

Week One (Monday)			
2:00pm-4:00pm		4:00pm-7:00pm	
No. Plate	Volume (m^3)	No. Plate	Volume (m^3)
UAH 706D	4	UAU 290W	10
UAU 584S	4	UBB 504R	10
UAY 622C	4	UAP 422H	3.7
UBF 828S	10	UAW 876B	3.7
UAN 628D	4	UBF 614D	3.6
UAX 493K	3.6	UAM 529T	3.6
UAV 525F	3	UBA 704W	14
UBB 532X	3	UBE 346Y	6.5
UAQ 932V	14	SSD 786G	12
UAA 468E	10	UBC 775D	10
UAK 035R	3.6	UAN 628D	3.7
UBF 070K	2	UAF 138U	10
UAA 542H	4	UBB 532X	3
UBA 859R	14	UBG 707H	7.2
UAU 812J	14	UBF 070K	2
UAU 930D	3	UAL 394H	4
UBE 346Y	6.5	UAP 422H	3.7
UAZ 566R	10	UAM 529T	3.6
UBA 864A	12	UAS 873H	3
		UBE 877V	3.6
		UAW 464W	10
		LG 0400-01	6.5
		UBC 775D	10
		UAN 030N	3
		UAU 584S	4
		UAB 548G	4
		UAF 138U	8
		SSD 786G	10
		UAZ 719G (PL)	5
		UAP 422H	3.7
		UAY 878V	3.7

Week Two (Thursday)					
8:00am-10:00am		10:00am-12:00pm		12:00pm-2:00pm	
No. Plate	Volume (m3)	No. Plate	Volume (m3)	No. Plate	Volume (m3)
UBC 775D	10	UAA 548G	4	UAU 290W	8
UAP 314C	10	UBB 532X	3	UAS 365G	4
UAN 755D	14	UAY 210X	8	UBD 787G	8
UBF 614D	4	UAM 529T	3.6	UAW 308J	3
UBE 817V	4	UBA 864A	14	UAV 754B	3.7
UBA 864A	14	UBF 614D	4	UBB 504R	10
UBA 704W	14	UBE 817V	4.5	UAU 584S	4
UAD 548G	4	UBG 707H	7	UBF 614D	4
LG 0400-01	6.5	UAN 755D	14	UAP 314C	14
UAS 873H	3	UAN 087N	3.6	UBD 987G	7
UBF 070K	2	LG 0366-01	6.5	UAW 673V	8
UAY 188B	3	LG 0400-01	6.5	UAL 812J	14
UAA 734L	20	UAW 314V	7.5	UBE 325G	10
UAW 447V	10	UAQ 932V	14	UBG 788D	3.6
UAW 464W	10	UAY 188W	2.7	UBA 497H	14
UAL 915H	4	UAS 873H	3	UAU 290W	8
UAZ 719G (PL)	5	UBA 859Q	14	UAD 548G	4
UAY 622C	3.6	UAT 490Z	3.7	UAY 870Y	10
UAQ 932V	14	UBA 704W	14	UBB 739W	4
UAW 673V	8	UAM 607Y	10	UAV 418C	3.6
UBB 504R	10	UAY 870Y	10	UAW 464W	10
		UAB 754B	3.6	UAF 138U	8
		UAP 422H	3.7	UBA 864A	14
		UAU 930D	3	UAY 622C	4
		UBF 070K	2	UBF 615P	10
				UAU 930D	3
				UAP 422H	3.7
				UBG 788D	3.6

Week Two (Thursday)			
2:00pm-4:00pm		4:00pm-7:00pm	
No. Plate	Volume (m^3)	No. Plate	Volume (m^3)
UBB 504R	10	UBA 859Q	14
UAW 464W	10	SSD 786G	12
UAD 548G	4	UAM 607Y	10
UAM 607Y	10	UBE 817V	4
UAT 767H	12	UAK 493K	2.7
UBC 775D	10	UBA 704W	14
UAZ 566R	10	UAQ 762L	3.7
UBA 864A	14	UBF 670E	3.7
UAS 873S	4	UBF 614D	3.6
UAT 490Z	3.5	UAU 107D	10
UAF 138U	8	UAA 734L	20
UAU 754B	4	UBA 864A	14
UAX 493R	3.6	UAD 548G	4
LG 0400-01	6.5	UAS 873H	3
UAU 290W	10	UAW 447V	10
UAW 673V	8	UAM 529T	4
UAQ 932V	14	UBB 514J	6.5
UAT 920V	14	UAY 870Y	10
UAU 584S	3.7	UBE 346Y	6.5
UAP 314C	14	UBB 213R	14
UBG 788D	3.6	UAN 755D	14
UAU 107D	10	UBD 987G	8
UBD 024S	15	UBB 532X	3
UAV 525F	3	UAL 394H	4
		UAN 087N	3.6
		UAP 610Z	14
		UBE 817V	4
		UAY 188W	2.7
		UAQ 932V	14
		LG 0366-01	6.5
		UBG 707H	7
		LG 0400-01	6.5
		UAW 308J	3
		UAL 915H	4

Week Three (Wednesday)					
8:00am-10:00am		10:00am-12:00pm		12:00pm-2:00pm	
No. Plate	Volume (m3)	No. Plate	Volume (m3)	No. Plate	Volume (m3)
LG 0400-01	6.5	UAF 663M	3.6	UAF 663M	3.7
UAS 873H	3	UBF 828S	10	UAU 290W	8
UAY 188W	3	UBB 504R	10	UAZ 566R	10
UBA 704W	14	UBA 704W	14	UAM 607Y	10
UAF 138U	8	UBB 532X	3	UAU 930D	3
UBF 614D	4	UAN 755D	14	UBG 325G	10
UBA 864A	14	UBA 864A	14	UAP 422H	3.7
UBB 532X	3	UAM 529T	3.7	UBF 670E	4
UBE 346Y	6.5	LG 0270-01	6.5	UBD 024S	20
UBE 817V	5	UBG 707H	7	UAY 270Y	10
UAU 584S	3.7	SSD 786G	10	UAL 915H	4
UAL 812J	14	UAN 354U	3	UAQ 932V	14
UAN 628D	4	UAN 628D	4	UBB 504R	10
LG 0400-01	6.5	UAF 138U	6.5	UAN 219F	4
UBD 024S	20	UAL 812J	14	UAH 522R	8
UAQ 932V	14	UBB 739W	3.7	UAY 622C	4
LG 0400-01	6.5	UBE 817V	3.7	LG 0270-01	6.5
UAU 290W	8	LG 0400-01	6.5	UAN 354U	3
UAF 138U	8	UBA 859Q	14	UBF 614D	4
		UBB 739W	3.7	UBF 070K	2
		UAN 030N	3	UAW 300L	3
		UAY 188W	2.7	UAY 878V	3.7
		UAZ 719G (PL)	4.8	UBE 817V	4
				UBF 828S	10
				UAU 107D	10
				UBA 864A	14
				UAL 812J	14
				UAW 098A	10
				UAW 876B	4

Week Three (Wednesday)			
2:00pm-4:00pm		4:00pm-7:00pm	
No. Plate	Volume (m3)	No. Plate	Volume (m3)
UBF 670E	4	UBB 504R	10
UAN 219F	4	UAW 464W	10
UAS 873H	3	UAU 107D	10
UBE 817V	4	LG 92601	8
UAV 754B	3.7	UBF 614D	3.7
UAQ 932V	14	UAV 523F	2.7
UBC 775D	10	UAN 354U	3
UAN 354U	3	UAY 878V	3.7
UBD 024S	20	UAF 663M	3.6
UAW 300L	3	UAY 188W	2.7
UBE 325G	10	UAW 300L	3
UAL 812J	14	UAQ 762L	20
UBB 504R	10	UAH 522R	10
UAU 107D	10	UAA 734L	20
UAU 930D	3	SSD 786G	12
UAZ 566R	10	UAP 422H	3.7
UAA 542H	4	UBF 828S	14
UBA 859Q	14	UAM 607Y	10
UAM 529T	3.7	UAW 673V	8
UAL 915H	4	UBG 788D	3.7
UAL 394H	4	UBF 614D	3.7
UBG 788D	3.7	UBE 346Y	6.5
		UAP 314C	15
		UAY 188W	2.7
		UAL 812J	14
		LG 0400-01	6.5
		UBB 504R	10
		UBD 024S	20
		UAQ 932V	14
		LG 0270-01	6.5
		UBA 859Q	14
		UAZ 719G (PL)	5

Week Four (Friday)					
8:00am-10:00am		10:00am-12:00pm		12:00pm-2:00pm	
No. Plate	Volume (m3)	No. Plate	Volume (m3)	No. Plate	Volume (m3)
UAA 734L	20	UBE 346Y	6.3	UAA 734L	20
UAH 522R	10	UBE 325G	10	UAV 523F	3.6
UAS 365G	4	UAP 422H	3.7	UAL 915H	3.7
UBF 070K	2	UAW 464V	10	UBG 788D	3.7
UBB 532X	3	UAY 622C	4	UAY 188W	2.7
UAN 628D	3.7	UAM 529T	3.7	UAN 467V	10
UAY 082Y	6.5	UBB 532X	3	UAU 930D	3.7
UAZ 560R	10	UAU 290W	10	UAP 314C	15
UBA 704W	14	UBB 504R	10	UBF 614D	3.6
UBA 864A	14	UAY 878V	3.7	UBB 504R	10
UAW 300L	3	UAF 138V	10	UAU 290W	10
UAM 607Y	10	UBB 739W	4	UBG 707H	7.2
UBF 614D	3.7	UAF 314C	15	UAN 030N	3
UBG 788D	3.7	UAA 542H	3.7	UAY 378V	20
UAU 584S	3.7	UAY 870Y	10	UAF 662M	3.6
UAL 394H	4	SSD 786G	12	UAW 300L	3
UAY 870Y	10	UAP 662M	5	UAW 673V	8
UAQ 932V	14	UBC 775D	10	UBA 704W	14
UAL 812J	14	UBB 532X	3	UAY 870Y	10
UBG 707W	14	UBF 070K	2	UBG 788D	3.7
UAW 673V	8	UAN 628D	3.7	UAN 628D	3.7
		UAZ 566R	10	UAA 734L	20
		UAL 812J	14	UAL 394H	4
		UAY 082Y	6.5	UBB 532X	3
		UBE 346Y	6		
		UAV 878V	3.7		

Week Four (Friday)			
2:00pm-4:00pm		4:00pm-7:00pm	
No. Plate	Volume (m3)	No. Plate	Volume (m3)
UAP 422H	3.7	UAS 365G	4
UBC 775D	10	UBF 070K	2
UBE 070K	2	UBB 532X	3
UAL 812J	14	UAN 628D	3.7
UAV 754B	3.7	UAY 082Y	6.5
UAS 873W	6.5	UAZ 560R	10
UAZ 566R	10	UBA 704W	14
UBF 828S	10	UBA 864A	14
UAZ 989G	4.5	UAW 300L	3
UBB 532X	3	UAM 607Y	10
UAW 464V	10	UBF 614D	3.7
UBB 504R	10	UBG 788D	3.7
LG 92601	6.5	UAU 584S	3.7
UBF 614D	3.7	UAL 394H	4
UAV 523F	2.7	UAY 870Y	10
UAY 878V	3.7	UAQ 932V	14
UAF 662M	3.6	UAL 812J	14
UAY 188W	2.7	UBG 707H	7
UAW 300L	3	UAW 673V	8
UAQ 762L	15	UBE 346Y	6.5
UAH 522R	10	UBE 325G	10
		UAP 422H	3.7
		UAW 464V	10
		UAY 622C	4
		UAM 529T	3.7
		UBB 532X	3
		UAU 290W	10
		UBB 504R	10
		UAY 878V	3.7
		UAH 522R	10

Week Five (Tuesday)					
8:00am-10:00am		10:00am-12:00pm		12:00pm-2:00pm	
No. Plate	Volume (m3)	No. Plate	Volume (m3)	No. Plate	Volume (m3)
UBG 707H	10	UAU 290W	10	UAM 529T	3.6
UAM 529T	3.6	UAV 878V	3.7	UAU 754B	4
UAP 314C	15	UBE 325G	10	UAS 373H	3
UAL 812J	14	UAL 812J	12	UAN 522R	10
UAW 464V	10	UAH 522R	10	UBB 532X	3
UBE 346Y	6.3	UAV 754B	3.6	UAN 628D	3.7
UAN 628D	3.7	UBB 739W	3.5	UBG 707H	10
UAL 915H	3.7	UAY 622C	4	UAU 290W	10
UAU 584S	3.7	UAP 314C	15	UAA 734L	20
UAV 754B	3.6	UBB 504R	10	UBE 325G	10
UAP 422H	3.7	UAW 464V	10	UAY 878V	3.7
UBB 739W	3.7	UAW 303J	3.6	UAL 915H	3.7
UAM 529T	3.6	UBA 864A	14	UBF 614D	3.6
UBA 859Q	14	UBA 704W	14	UAX 493R	3.6
UAM 607Y	10	UAW 673V	8	UBA 704W	14
		UAZ 506R	10	UAS 365G	4
		UBD 987G	20	UAV 754B	3.6
		UBF 614D	3.6	UBF 670E	3.7
		UBA 859Q	14	UAU 290W	10
		UBF 070K	2		

Week Five (Tuesday)			
2:00pm-4:00pm		4:00pm-7:00pm	
No. Plate	Volume (m3)	No. Plate	Volume (m3)
LG 0400-01	6.5	UBC 775D	10
UBF 614D	3.6	UAK 035R	3.6
UAF 138U	10	UAW 673V	8
UAW 876B	4	UAL 394H	4
UAV 754B	3.6	UAW 300L	3
UAU 930D	3.6	UBG 788D	3.7
UBG 788D	3.7	UBE 070K	2
UAL 394H	4	UBB 504R	10
SSD 786G	12	UAY 082Y	6.5
UAY 082Y	6.5	UBF 620E	3.6
UAY 878V	3.7	UBB 532X	3
LG 02701	6.5	UAW 048S	9
UAL 812J	14	UAY 188W	2.7
UAZ 719G (PL)	4.8	UAF 138U	10
		UBA 859Q	14
		UAK 035R	3.6
		SSD 786G	12
		UBA 704W	14
		UBF 828S	14
		UAF 662M	3.6
		UBF 614D	3.6

Raw data from Lab tests

Week One (Monday)				
Weight of beakers	TS (Inlet)	TDS (Inlet)	TS (Outlet)	TDS (Outlet)
W_A (g)	51.7504	42.9973	50.6687	46.2872
W_B (g)	51.3867	42.8066	50.31	46.0784

Settleability (ml/L)	

Week Two (Thursday)				
Weight of beakers	TS (Inlet)	TDS (Inlet)	TS (Outlet)	TDS (Outlet)
W_A (g)	49.621	33.5024	49.1239	42.942
W_B (g)	49.2165	33.3697	48.8202	42.8093

Settleability (ml/L)	

Week Three (Wednesday)				
Weight of beakers	TS (Inlet)	TDS (Inlet)	TS (Outlet)	TDS (Outlet)
W_A (g)	35.6096	34.8498	35.7474	35.0881
W_B (g)	35.042	34.7042	35.5096	34.9565

Settleability (ml/L)	

Week Four (Friday)				
Weight of beakers	TS (Inlet)	TDS (Inlet)	TS (Outlet)	TDS (Outlet)
W_A (g)	46.4132	50.4926	51.2417	51.5946
W_B (g)	46.0759	50.3613	50.9754	51.4676

Settleability (ml/L)	200

Week Five (Tuesday)				
Weight of beakers	TS (Inlet)	TDS (Inlet)	TS (Outlet)	TDS (Outlet)
W_A (g)	51.6335	36.2205	50.7253	34.4531
W_B (g)	51.2808	50.3559	36.0734	34.2983

Settleability (ml/L)	183