Evaluation of the efficiency and benefits of a Pilot Scaled Decentralized Faecal Sludge Treatment System in Kampala

George Otaka[1], Aldo Okullo[2]*, Charles B. Niwagaba[1], Robinah N. Kulabako[1], Alex Y. Katukiza[1]
[1]Department of Civil Engineering, College of Engineering, Design, Art and Technology (CEDAT) Makerere University, Kampala.
[2]Department of Chemistry, Kyambogo University, Kampala. *Corresponding Author
Email: okulloapita@yahoo.com, georgeotaka@yahoo.co.uk,

Abstract: Many peri-urban cities of Sub-Saharan Africa are overwhelmed with overloading the existing centralised wastewater treatment plants and high capital costs of operations and maintenance. In this work, a pilot decentralized faecal sludge treatment system (DEFASTS) was constructed in Kampala for assessing the performance and potential benefits of the treatment system. It consisted of a sedimentation tank, 2 m^3, where liquid overflowed sequentially through anaerobic baffled reactor and anaerobic filter. Effluent was polished by a *Cyperus papyrus* planted gravel filter. The system was loaded daily with 0.5m^3/day of mixed raw faecal sludge from both septic tanks and pit latrines operated with a total retention time of 12.52 days. Monitored parameters were; Chemical Oxygen Demand, five-day Biochemical Oxygen Demand total suspended solids pH, temperature, total phosphorus, total nitrogen faecal coliforms total volatile solids and ash content. Results obtained were 95.7±24 %, 96.4±1.9%, 96.8±1.8%, 78.4± 24.2%, 76.6±29.8% and 99 ±1.6% respectively.

Key words: Pilot Scale, Decentralized faecal sludge treatment, Efficiency, Benefits

1. Introduction

Onsite Sanitation (OSS) facilities have a wider coverage than sewer systems in many cities of Sub-Saharan Africa (SSA) (Strande *et al*., 2014). In terms of access, the variation of coverage of OSS facilities such as pit latrines, aqua privies and septic tanks in the various cities of SSA ranges from 65% to 100% (Strauss *et al*., 2000). In peri-urban areas, high filling rates of OSS facilities necessitate frequent desludging of faecal sludge (FS) and if not well managed exacerbates environmental health problems which may contaminate water sources (Katukiza *et al.*, 2010). Developing solutions for faecal sludge management (FSM) is a serious global problem that has received limited attention over the past decades (Strande *et al*., 2014).

Approximately 2.7 billion people worldwide are served by OSS that generate FS (Strande *et al*., 2014), suggesting that the demand for the operations of the entire FSM service chain is on the rise. Despite the fact that sanitation needs are met through onsite sanitation technologies, there are gaps to effectively manage all the components of the FSM service chain, which include collection, transportation, treatment and end-use/final disposal (Koottatep *et al*., 2001). Furthermore, in most developing countries, high-income areas are served by sewerage systems, whereas the peri-urban population relies on OSS, which are perceived as low cost options (Paterson *et al*., 2007).

In Uganda, the majority of the population currently living in rural areas, peri-urban areas and informal settlements are without basic sanitation facilities (Katukiza *et al*., 2012). For example, in Kampala, the Capital City of Uganda, only about 6.5% of the residential population is connected to the central sewerage system and the remaining 93.5% use OSS and other means of FS disposal (Semiyaga *et al*., 2015; Zziwa *et al*., 2016).

While different stakeholders have been active in attempting to solve the major problem of sanitation by providing FSM services, there is evidence that coverage in slum areas is much lower than the average for urban areas. The problem of sanitation in slums is critical and complex because of high population density, poor urban infrastructure, lack of space, lack of secure tenure, and persistent poverty (Cohen, 2006).

Mechanized centralized wastewater and FS treatment systems used in developed countries require considerable investment, operation and maintenance costs (Strauss & Montangero, 2002). Therefore, there is a need to develop simplified, low-cost small-scale systems for developing countries. These systems will help to reduce fresh water pollution as a result of improved management of FS. Moreover, localized low-cost treatment plants will decrease the costs of transportation of FS, since they can be located closer to the FS generation areas.

Peri-urban cities of Sub-Saharan Africa are often overwhelmed by the problem of overloading the existing centralised wastewater treatment plants and the high capital costs of operations and maintenance of these facilities. Furthermore, many low-income countries practise co-treatment of FS and wastewater in WWTPs which are not typically designed for FS loading thus resulting into process disruption and failures, moreover, co-treatment of FS suffers operational problems like clogging of sewer pipes, high deposition of solids, overloading of tanks and poor quality of effluent discharge (Heinss and Strauss, 1999; Bassanet *et al*., 2014; Dodane *et al*. 2012; Strauss *et al*., 2000).

Faecal Sludge Management in towns and cities of developing countries is faced with difficulties such as lack of suitable treatment or disposal sites at short distances from the area of FS collection. Furthermore, traffic congestion prevents efficient emptying and transportation of FS to sites of treatment or final disposal areas (Strauss and Montenegro, 2002). Decentralized FS treatment systems have the potential to minimize transport costs and consequently indiscriminate dumping of FS.

There are several wastewater treatment plants in Uganda and those that exist have limited capacity to treat wastewater to the required standards of discharge. For example, in 2013, it was indicated that only four districts in Uganda were able to treat sewage to the required standard of BOD discharge (MWE, 2013). Failure of these central sewer systems to operate to the required standard can also be attributed to the overloading by FS with high solid contents. The existing systems which are designed for treating wastewater cannot cope with treatment and disposal of large volumes of FS generated due to increased population. Therefore, innovations are needed to develop systems which can handle and treat highly concentrated FS, and more so, those which incorporate re-use aspects. The study on the performance of the DEFASTS is expected to provide knowledge and evidence on the system's viability to locally and cheaply treat FS.

The Decentralized Wastewater Treatment System (DEWATS) concept (Figure 1) was adapted to be used in DEFASTS to treat the liquid fraction of FS. The concept was adopted considering that DEWATS has been used successfully in developing countries (tropical and subtropical climate) in addressing urban sanitation (Massoud *et al*., 2005; Singh *et al*., 2009).

DEFASTS is expected to treat FS successfully in Uganda for the reason that DEWATS worked effectively under conditions similar to those in Uganda whose ambient temperatures (between 18°C and 35°C) are suitable for anaerobic digestion and bacterial growth that can enhance the performance of the system. Co-digestion of FS and other organic matter using DEFASTS has been applied in Maseru, Lesotho. The treatment plant consisting of the Digester, Anaerobic Baffled Reactor (ABR) and Planted Gravel Filter (PGF) attained a removal efficiency of above 70% for COD; the biogas produced was used for cooking and digestate as soil conditioner (Muller, 2009).

2 Materials and Methods.

2.1 Materials

The components of the DEFASTS included: plastic tanks of the biodigester (BD), anaerobic baffled reactor (ABR), anaerobic filter (AF), and planted gravel filter (PGF) made out of concrete.

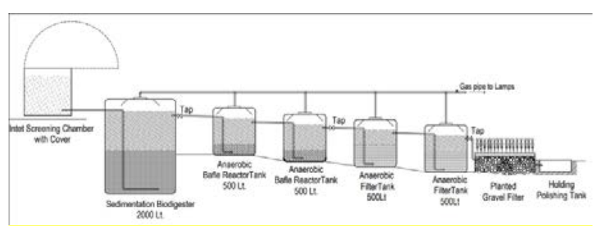

Figure 1: DEFASTS setup for primary, secondary and tertiary treatment

A pilot scale decentralized faecal sludge treatment system (DEFASTS) was setup in Nyanama village, Rubaga division, Kampala City, Uganda. Nyanama village is located within Lake Victoria basin in which rainfall varies from 1250 mm to over 2000 mm per annum. Rainfall is received throughout the year with two rainfall peaks in April-May and October-November; and two relatively low rainfall periods between December -

March and June -July (NEMA, 2009). The temperature and humidity of the area range from 25-30°C and 70-80% respectively (Basalirwa, 1995).

2.1.1 Setup of the DEFASTS

The DEFASTS was constructed by WFP, following the design of DEWATS done by the BORDA. The main components of the design are shown in Figure 1.

Inlet/screening unit made of prefabricated steel tank (volume of $1m^3$); the FS is fed into the inlet tank, from where the slurry flows to the biodigester. A perforated metal sheet of 12mm diameter holes was used as a screen. In this unit, the preliminary treatment took place consisting of removal of non-biodegradable materials, like gravels (coarse and grit), plastics, bottles glasses, polythene, woods, etc.

The Biodigester (BD) unit consisting of a plastic cylindrical container made of linear low density polyethylene materials of volume $2m^3$ tank; the effluent coming out of the outlet of the screening tank entered the BD through a polyvinyl chloride (PVC) pipe link, and the effluent from the BD were released through a gate valve located on the pipe to the ABR.

The Anaerobic Baffled Reactor (ABR) unit consisting of two plastic tanks each with a working volume of $0.5m^3$, the effluent from the ABR served as the influent to the AF. The effluent from ABR was fed into AF through PVC pipes controlled by a gate valve connected to the pipe.

The Anaerobic Filters (AF) consisted of two plastic container tanks (each with a working volume of $0.5m^3$) packed with sand and gravel filtration media to about 2/3 full. The effluent from the AF was discharged into the planted gravel filter (PGF).

The Lateral **PGF** had dimensions of 3m length, 2m width and 0.6 m depth, giving a volume of 3.6 m^3. The PGF was constructed out of bricks and connected by pipes from one end to the AF and the other end to the polishing/holding tank. The PGF was planted with seedlings of macrophytes (*Cyperus papyrus*) which were available within the study area. In order to allow the plants to adapt, sampling was started after one month of macrophyte growth.

The **Holding Tank** connected to PGF by PVC pipe was used for polishing the effluent and temporary storage before recycling to the system or disposal.

2.2 Methods

2.2.1 Influent and Effluent Sampling.

Liquid grab samples (1000mL) were taken monthly from raw FS (influent) and outlet (effluent) sampling points using plastic containers for 10 months and stored in a cooling box with ice at 4°C till analysis. The samples were transported to the central water quality laboratory at the National Water and Sewerage Corporation (NWSC) in Bugolobi and to the Public Health and Environment Engineering (PHEE) laboratory at Makerere University for analysis. The analysis was done within 24 hours from the time of sample collection. The determination of COD, BOD5, TP, TN, TSS and FC were carried out at the NWSC laboratory.

2.2.2 Determination of DEFASTS performance

The determination of performance of DEFASTS in this study was carried out by comparing the amounts of major physico-chemical and microbiological contaminants remaining in the effluent after treatment with those in the influent before treatment to show the effectiveness of removal of these contaminants from FS. Basic equation for the percent removal is: Percentage Removal= (Influent - Effluent)/Influent * 100. For example, for every influent COD there will be an effluent COD such that the percent removal is: [COD % Removal [%]]= ([Influent COD [mg/L]] - Effluent COD [mg/L]) / [Influent COD[mg/L]] * 100

2.2.3 Faecal Sludge Laboratory Analysis

The physico-chemical and biological characteristics of both influent and effluent were analyzed according to the standard methods for examination of water and wastewater described in APHA/AWWA/WEF (2005). The pH and temperature were determined *in-situ* using the electrode method, where portable WTW microprocessor probes and meters were used. Total phosphorus (TP) were analysed following the ascorbic acid method after persulfate digestion, meanwhile total Nitrogen was digested using glutamic acid. Total suspended solids (TSS) were determined using gravimetric method. Chemical Oxygen Demand (COD) was determined using the Closed Reflux, Titrimetric method. Biochemical oxygen demand BOD_5 was determined by pressure difference within a closed system by direct reading apparatus (HCV, Denmark). BOD_5 and COD were determined according to standard procedures (APHA, 2005). All spectrophotometric determinations were made using an Aquamate spectrophotometer (Thermo Electron Corporation, UK Model No. 300).

Faecal coliform contamination was determined by membrane filtration method. Serially diluted samples were filtered through 47 mm mixed cellulose ester membrane disc filters (Michigan, USA) of 0.45 µm pore size and then incubated at 37°C for 48 hours on Chromocult TBX agar as growth medium Dark blue to purple colonies were then counted (APHA, 2005). The TVS and ash content were determined using Muffle oven ignition at 550°C (APHA, 2005) and the temperature was maintained for 8 hours.

The faecal sludge (FS) used for this study was a mixture of FS from pit latrines and septic tanks removed by either manual gulping or cesspool emptier so as to produce FS with characteristics similar to those of sludge from facilities in peri-urban settlement. The average ratio of mixing of septic tank to pit latrines was about 3:8.

2.3 Statistical Analysis

Statistics package for social scientist (SPSS) version-20.0 (IBM-USA, 2011) was used for data analysis. In all the analysis, a 95% confident interval ($p \leq 0.05$) was used.

2.4 Operation and Maintenance (O&M) of the DEFASTS

A caretaker was assigned for the O&M of the DEFASTS. A daily loading of DEFASTS and removal of non-biodegradable materials was done at the inlet chamber, which eventually was put in the sand drying bed (SDB). The removal of the dried FS from SDB was carried out monthly. Meanwhile desludging of BD, ABR and AF was to be done yearly if required.

The operation and maintenance requirements differ from each unit. In the PGF, sludge removal is necessary once every two years and periodic care for plant growth would be required. To ensure proper functioning of the sludge drying bed, the operation and maintenance includes: application of sludge, desludging, control of the drainage system and the secondary treatment for the percolate or dried sludge (Tilley *et al*., 2008). In the drying bed, removal of dried sludge is required once a month and replenishment of the sand after every two months.

3.0 Results and discussions

3.1 Performance and Treatment Efficiencies of DEFASTS

The results of the characteristics of the raw/influent and effluent FS are presented in Table 1. The effluent laboratory results were compared with the national effluent discharge standards to receiving water bodies and land (NEMA, 1999).With the exception of FC, the mean values of effluent concentrations recorded for COD, BOD_5, TSS, TP and TN exceeded the discharge standards. However in some months, the limits were not exceeded. The elevated average values of the concentrations of effluent could be attributed to high initial organic and volume overloading of FS and short HRT recorded during the processes. However the overall average treatment efficiencies for all the parameters were above 70%.

The average COD: BOD ratio of 1:4 obtained was within the range that shows highly concentrated fresh FS which is treatable by biological processes (Bassan *et al*., 2013). The low ratio can be attributed to the short storage time (days/weeks) of FS in onsite systems (Heins *et al*., 1998); Kone & Peter, 2014).

Table 1: FS characteristics of influent and effluent determined over a period of 7 months

Parameters	Maximum Raw FS/influent	Minimum Raw FS/influent	Average Raw FS/influent	Max. final effluent	Min. final effluent	Average effluent ±SD	NEMA, 1999 Standard	Average removal efficiency
pH	9.1	6.8	7.8	8.3	7.89	8±0.1	6-8	
COD (mg/L)	45500	1134	21405	2400	55	920±829	<100	95.7%
BOD_5 (mg/L)	29591	658	14972	1678	48	537.45±522	<50	96.4%
TSS (mg/L)	82688	7455	31780	5400	50	1001.5±1602	<100	97%
TN (mg/L)	2734	755	1844	1723	26	398±661	<10	78%
TP(mg/L)	1088	176	686	629.3	10	167±221	<10	77.%
FC(CFU) /100mL.	$60x10^7$	2710	$9.9x10^6$	4600	0	1076	<10000	99%

The average removal efficiencies of the reactors of DEFASTS with regard to the specified parameters are presented in Table 1. Table 2 shows the percent removal of all parameters in the biodigester.

Table 2: Percent removal of parameters in the Biodigester (BD)

Parameter	Influent	Effluent	Amount removed	% Removal
COD (mg/L)	21405	6326	15079	70
BOD_5 (mg/L)	14971	4716	10255	68
TSS (mg/L)	31780	9505	22275	70
TN (mg/L)	1844	1011	833	45
TP (mg/L)	696	353	343	49
FC (CFU/100mL)	9933489	103549	9829940	99
T (^{o}C)	29			
pH	7.8			

Although the removal efficiencies for the parameters were impressive in the biodigester, the absolute values of the parameters in effluent are still very high as seen in Table 1 and this would affect largely a number of environmental uses of the effluent for irrigation or safe disposal.

The performance of each DEFASTS unit depends on the nature of the raw FS. Table 3 shows the removal efficiency in ABR. The increase in Total Nitrogen (TN) could be attributed to the inhibition of anaerobic metabolism caused by an elevated pH and free ammonia which resulted to the negative percentage.

Table 3 Percent removal of parameters in Anaerobic Baffle reactor (ABR)

Parameter	Influent	Effluent	Amount removed	% Removal
COD (mg/L)	6326	4028	2298	36
BOD_5 (mg/L)	4716	2864	1852	39
TSS (mg/L)	9505	3108	6397	67
TN (mg/L)	1011	1281	-270	-27
TP (mg/L)	353	303	50	14
FC (CFU/100mL)	103549	20848	82701	80
T (^{o}C)	28			
pH	7.6			

In Table 4, the percent removal of parameters in anaerobic filter are shown. The increase of faecal Coliform (FC) in the effluent of AF could be due to shock loading over washout of anaerobic bacteria which contradicts the effective performance of AF.

Table 4 shows percent removal of parameters in Anaerobic Filters (AF)

Parameter	Influent	Effluent	Amount removed	% Removal
COD (mg/L)	4028	2370	1658	41
BOD_5 (mg/L)	2864	2035	829	29
TSS (mg/L)	3108	2186	922	30
TN (mg/L)	1281	724	557	43
TP (mg/L)	303	250	53	17
FC (CFU/100mL)	20848	73566	-52718	-253
T (^{o}C)	30			
pH	7.9			

Table 5 shows percent removal of the parameters in planted gravel filter (PGF). Results show that the percentage removal efficiencies in PGF unit were above 60% for all the parameters except the removal of TN and TP which were 45% and 27% respectively.

Table 5: Percent removal of parameters in Planted Gravel Filter (PGF)

Parameter	Influent	Effluent	Amount removed	% Removal
COD (mg/L)	2370	920	1450	61
BOD_5 (mg/L)	2035	537	1498	74
TSS (mg/L)	2186	516	1670	76
TN (mg/L)	724	398	326	45
TP (mg/L)	250	183	67	27
FC (CFU/100mL)	73566	1076	72490	99
T (^{o}C)	26			
pH	8.1			

The results further showed that PGF performed best in the removal of FC with 99%. The relatively high removal efficiency of FC by PGF may be attributed to several processes supported by plant roots and gravel such as: sedimentation, natural die-off, temperature, oxidation, predation and unfavorable water chemistry, adhesion to biofilm, mechanical filtration, and UV radiation. Comparing with a study conducted in Ghana on co-treatment of FS in anaerobic systems, the average removal efficiencies were 71% for COD and 73% for TSS (Lopez-Vazquez, Dangol, Hooijmans, & Damir, 2014), which were higher than 61 % but lower than 76% respectively for COD and TSS obtained in DEFASTS suggesting that the performance PGF unit reactor of DEFASTS was lower than that obtained in Ghana for COD removals but higher for TSS than that in Ghana.

3.2 Chemical Oxygen Demand (COD) Removal

The DEFASTS attained an average removal efficiency of 99.7 % on COD in the month of March 2015 (Table 6). The percentage removal of COD was above 90% throughout the period of monitoring except for the month of September-2014 where it was 20.7%. The low removal efficiency of 20.7% for COD recorded in the month of September-2014 could be attributed to the high degree of stability of the raw FS from the source. In addition, the COD concentrations in the influent during the low rainfall periods (December - March and June – July) were generally higher than those in the rainfall peaks (April-May and October-November), this could be due to leaching of liquid feacal sludge to soils in unlined pits during rainy seasons. The average ratio of COD:BOD was less than two, indicating readily biodegradable influent faecal sludge and higher biological metabolism than chemical oxidation. This could be due to possible conditions that were favorable to harness the metabolism and growth rate of microorganisms in the system. Moreover, the high organic loading and high concentration of non-biodegradable materials during the dry season intermittently reduced anaerobic digestion. Furthermore, the DEFASTS suffered inadequate treatment during rainy season (September) as shown in Table 6, this could be attributed to low temperature (25-29^{o}C) during rainy season which does not give suitable conditions for chemical oxidations.

Except the month of September- 2014, the high average removal efficiency values of DEFASTS for COD (90.2-99.7%) were above the COD removal range (65-90%) that was attained in warm climates by DEWATS (Sasse, 1998). The performance of the DEWATS was however improved by increasing the number of series of treatment unit tanks, suggesting that the performance of the DEFASTS can as well be improved by increasing the number of reactors (Gutterer *et al*., 2009; Massoud *et al*., 2005; Singh *et al.,* 2009).

Table 6: Monthly COD concentration in different equipment and overall percentage reduction

Month	COD (mg/L)					
	Raw FS	BD	ABR	AF	PGF	% Reduction
June-2014	20570	19580	5748	3535	1886	90.8%
August-2014	45500	1164	6290	700	2400	94.7%
September-2014	1134	1255	916	1197	899	20.7%
November-2014	12250	6800	3840	2150	830	93.2%
December-2014	33447	17651	8560.6	5046.9	143.3	99.5%
January-2015	27290	3976.5	2355	1759.2	891.5	96.7%
February-2015	17505.2	3741.2	3796.5	3296.3	1712.6	90.2%
March-2015	21240.2	2172.9	2612.9	2274.4	55.0	99.7%
April-2015	11236	3621.9	3586.4	3215.7	256.1	97.7%
July-2015	23882	3296	2572	2523	122.1	99.5%

In a similar study with DEFASTS conducted in TED-in Lesotho (Mrs. Ntsihele site) for co- treatment of black water and pig waste, the system attained a much lower COD removal efficiency of 11%, the low removal rate was attributed to system overload with pig waste (Tilley, Lüthi, Morel, Zurbrügg, & Schertenleib, 2014).

3.3 BOD_5 Removal

An average overall BOD_5 removal efficiency of 96.4±1.9%, was attained by the treatment system (Table 1). A higher average percentage of BOD_5 removal was registered in the BD (68%) and PGF (74%) compared to ABR (39%) and AF (29%) (Tables 2, 4 and 5).

A comparison of the overall average removal efficiencies of the DEFASTS obtained in this study with the findings of previous studies showed that, DEFASTS has a higher average removal efficiency on BOD (96.4%) than those reported in DEWATS by (Singh *et al*. (2009) and (Sayadi, Kargar, Doosti, & Salehi, 2012) which were 90% and 92% respectively. Given the lower HRT in the DEFASTS and high organic load of the system compared to the DEWATS, the results of the removal efficiencies is considered reasonable.

In a similar set up of DEWATS in Vietnam, the average BOD removal efficiency of 59.31% for a big model and 71.47% for small model was attained. The removal efficiency improved with addition of anaerobic filter placed at the end of baffled chamber, by arrange of 10-15% *(Anh et al.*, 2002). Implying that, the performance of DEFASTS could be improved by increasing the number of reactor units.

3.4 TSS Removal

The pilot system provided excellent average removal efficiency for TSS, with up to 97 % realised during the study period (Table 1). The unit reactors BD and PGF had relatively high removal efficiencies of TSS compared to ABR and AF. The high removal likely follows from enhanced filtration capability in a PGF provided by the developed plant roots over time and a sufficient HRT.

However, considerable average concentrations of TSS in the effluent of 1001.5 mg/L were still above the stipulated national wastewater discharge standard to receiving land and water bodies (NEMA, 1999). Discharge of effluent with high concentration of TSS to the environment however, has a potential negative impact on the aquatic environment and a risk to human health in urban slums (Katukiza et al., 2014).

The results of TSS removal efficiency in this study are in line with the range (96-99%) reported by Koottatep *et al*. (2005) for a pilot constructed wetland used as a low-cost treatment option for treating septage operated by the Asian Institute of Technology (AIT) in Bangkok. Showing a promising great potential of DEFASTS to treat FS.

3.5 Total Nitrogen Removal

As showed in Table 1, the average Total Nitrogen (TN) removal efficiency of 78.4±24.2% was attained by the DEFASTS. The results also indicated that the PGF and BD among the unit reactors were the key contributors to the removal of TN. The high TN removal in AF could be attributed to filtering of organic matter by gravel and subsequent decomposition, resulting in a lower TN value in the final effluent. Furthermore, the results also support that nitrogen might have been lost from the DEFASTS by anaerobic ammonium oxidation (ANAMMOX), where nitrite-nitrogen (NO_2-N) and ammonium-nitrogen (NH_4-N) are anaerobically converted to nitrogen gas, using nitrate as an electron acceptor and considering that the pH range of anaerobic digester were 7.6-7.8. In the PGF, several removal mechanisms including filtration, sedimentation, adsorption, microbial and plant uptake (Vymazal, 2007) could have contributed to nitrogen removal. The average concentration of effluent was 398mg/L, which was still higher than the permissible national discharge value of 10mg/L (NEMA, 1999). Generally, considerable concentrations of TN were still present in the effluent, above the discharge standard (>10mg/l, NEMA, 1999) of wastewater quality guidelines. The high content of TN in effluent can be used as organic fertilizer, if post treatment could be done to further destroy pathogens in the effluent. Otherwise disposing such effluent in land and water bodies is an environmental and public risk.

3.6 Total Phosphorus Removal

The average value for total phosphorus in the effluent was (167±221) mg/L (Table 1), which was above the allowable discharge standard of 10 mg/L (NEMA, 1999). The BD and PGF performed better in removals of TP than ABR and AF. The overall percentage removal of TP in DEFASTS is likely due to adsorption onto plant roots/filter media, plant and microbial uptake.

In a study by Tilley *et al* (2014), a horizontal subsurface flow PGF of DEWATS achieved removal efficiencies for TP in the range of 30 to 45 % in the treatment of blackwater, greywater, and brownwater. The relatively higher treatment efficiency (76.6%) of DEFAST with regard to TP in this study could be a function of high surface area (length multiplied by width) of the PGF and the cross-sectional area (width multiplied by depth) which, determines the maximum possible flow. The surface area increases the contact time between the filter materials and the FS, such that filter material filters out particles and microorganisms degrade the organics.

3.7 Faecal Coliform Removal

There was a significant overall removal efficiency of FC by an average of (99±1.6) % as shown in Table: 1. The performance of DEFASTS in removing FC was considered excellent compared to all parameters studied, since all the effluent values complied with the discharge standard (<1000cfu/100mL, NEMA, 1999).

Faecal coliforms may have been removed by several processes supported by plant roots and gravel such as sedimentation, natural die-off, temperature, oxidation, predation and unfavorable water chemistry, adhesion to biofilm, mechanical filtration, and UV radiation. Since the rate constant of the PGF is temperature dependent, the average temperature of (26.4±1.9)ºC could have been suitable for the rate of FC removals. Furthermore, The HRT in PGF (2.52 days) agrees with the findings of a similar study by Vymazal *et al.* (1998), which recorded the HRT of 2.0, 3.0, 5.5 and 7 days with a resultant respective removal efficiency of 76.2, 79.4, 92.1 and 95.3% on FC. The HRT attained in this study could have provided sufficient time for the pathogen die off in the system.

In addition the higher removal efficiency (99±1.6%) of FC reported in this study corresponds with other findings that attained average removal efficiency of 93.2±6.13% for FC (Mairi, Lyimo, Njau, 2001).

3.8 pH

The variation of mean pH during the study period is shown in Figure 2. The findings indicated that the average pH of raw FS reaching the bio-digester was 7.8±0.6. After the anaerobic digestion process of FS, the pH increased to 7.9±0.4 in the AF, and later to 8.1±0.1 in the final effluent, (Tables 2, 4 and 5 respectively), suggesting continuous degradation of organic matter during anaerobic and tertiary treatment. The steady increase in pH in the reactors may be attributed to the formation of ammonia, which was a result of the interaction of the carbon dioxide-bicarbonate buffering and volatile acids taking place during the process.

The pH values were consistently lower in the raw FS than in the final effluent. The overall ranges of pH between 6.8 and 9.1 were outside the optimum pH 6.5-7.5 (Table 1) (Vögeli *et al.*, 2014; Khalid et al., 2011; Mata-Alvarez, 2003) range for anaerobic digestion, suggesting that the present design conditions of DEFASTS have less potential to achieve optimum treatment and high biogas yield.

The mean pH (8.1) of the final effluent was slightly above 6.0-8.0 range of the national allowable limits required for discharge to water and land (NEMA, 1999). This could have been caused by less organic load which does not favor acid production and hence alkaline pH. An effluent of neutral pH indicates optimal treatment performance. Alternatively, FS with a pH below 4 to 5 (acidic) and above 9 (alkaline) is difficult to treat because the acidic and alkaline conditions make the microorganisms responsible for biological treatment process inactive (Bassan, Dodane, & Strande, 2014).

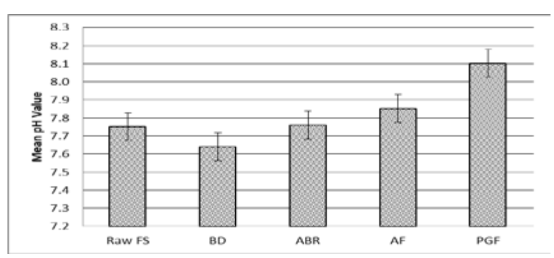

Figure.2: Variations of mean pH along the treament process of DEFASTS.

3.9 Temperature

The variation of temperature along the DEFASTS units during the monitoring period is indicated in Figure 3. The final effluent temperature was within recommended range (20-35˚C) for discharge to land and water, according to NEMA (1999). Furthermore, the BD exhibited temperature of 29ºC which is within the optimum mesophilic range of temperatures (28 to 33°C) for anaerobic digestion (Kossmann et al., 1988). This is implied that DEFASTS operated under mesophilic condition, which is considered more stable and require less energy input compared to thermophilic systems (Vögeli *et al*., 2014).

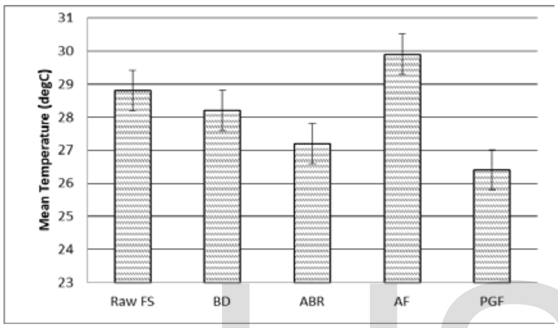

Figure 3: Variations of mean Temperature along the treatment process of DEFASTS.

4.0 Conclusions

This study demonstrated that the performance of a pilot DEFASTS system at Nyanama, Kampala achieved high removals of organic matter, nutrients and faecal coliforms of faecal sludge. The treatment system achieved average removals efficiency of 95.7±24 % for COD, 96.8±1.8% for TSS, 78.4±24.2% for TN, 76.6±29.78% for TP, 99.0±1.6% for FC and 96.4±19.3 % for BOD. In spite of DEFASTS high removal efficiencies for all the parameters, the mean absolute values of COD, BOD5, TSS, TP and TN do not meet the discharge standard except FC. And this would affect a number of environmental uses of the final effluent for irrigation or safe disposal.

Overall, the study generated enough evidence to show satisfactory performance of DEFASTS with regard to providing an alternative treatment option of FS for peri-urban areas. It is important to note that the performance of DEFASTS with respect to treatment efficiencies varied from one-unit reactor to another, such that generally BD and PGF performed better than ABR and AF in removals of all the analyzed parameters.

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