INVESTIGATING THE PROCESS EFFICIENCY OF FLEXIGESTER AS AN ON-SITE ANAEROBIC FAECAL SLUDGE SANITATION SYSTEM FOR APPLICATION IN EMERGENCY SITUATIONS

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Abstract

Worldwide, including in Malawi, there is an increase in natural disasters requiring emergency response. During an emergency faecal sludge management gets disrupted especially when the soils are unstable and the water table is high. In such situations there is need for emergency sanitation systems, such as a Flexigester. The Flexigesterwas piloted at AquaidLifeLine orphanage (Latitude 15.62285oS, Longitude 35.055672oE) in Blantyre, aimingat assessing its functionality,applicability and process efficiency regarding stabilisation, sanitisation and useful by-product generation. pH, Temperature, Chemical Oxygen Demand (COD) were monitored for stabilisation,Total Ammonia Nitrogen (TAN) and biogas collection for useful by-product generation and E. Coli and Total Coliforms for sanitisation. Using randomly selected days of May to December, 2014and maintaining the system's 38 days faecal sludge retention time, grab samples were taken from three strategically chosen sampling points namely; feed point, digestate point and Pasteurisation point. The results showed that sanitisation succeeded in summer when temperatures were 34.39, 48.58 and 44.10 oC and not in winter when temperatures were 22.35, 36.79 and 33.24 oC for the feed, digestate, and pasteurised respectively with observed CFU/100ml in winter being greater than WHO guideline of 103 CFU/100ml. On the contrary, the system failed to stabilised effluent, the (COD) values (132.958, 134.337 and 110.077 mg/l in winter and 268.018, 423.982 and 278.191 mg/l in summer) being higher than the Malawi Standardguideline of 60mg/l. pH values remained within limits of 7.1-7.4 and TAN was between 25 and 30 mg/l. The flexigester harvested 1.5 m3 and 5m3 per day of biogas in winter and summer respectively against the designed 10m3 per day. Generally, the Flexigester can work successfully in countries with tropical climates, since during summer, quality of final product was appropriate for direct handling and re-use and the treated product had a high concentration of nutrients making it a useful product for agriculture. However during winter a post-treatment is required to reduce the pathogen concentration. The Flexigester, as an emergency on-site anaerobic sanitation system, if reworked, can be very effective in providing solutions to a series of challenges such as safe waste management, sustainable agriculture, and fuel generation.

Key Words: Flexigester, Feed, Digestate, Pasteurised, Faecal Sludge, Emergency

1.0 Introduction

An emergency is a situation characterised by a clear and marked reduction in the abilities of people to sustain their normal living conditions, with resulting damage or risks to health, life and, livelihoods (Wisner &Adams, 2002a). Emergencies could be complex and over the past decades, the world has experienced an increase in both warfare, civil disturbance and large scale movement of people and natural disasters such as tropical storms, extreme heat/cold winds, floods, earthquakes, landslides and volcanic eruptions (Brown, Jeandron, Cavill,& Cumming, 2012, The Johns Hopkins and the International Federation of Red Cross and Red Crescent Societies, 2008, Malambo, 2014, Wisner et al., 2002a). Figure 1 below shows the trend of number of natural catastrophes worldwide 1980-2010.

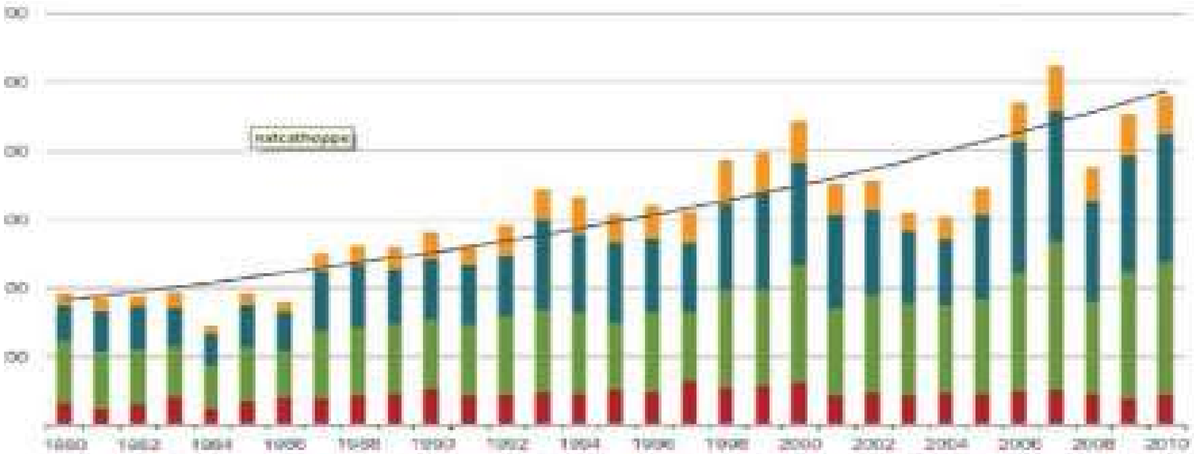


Figure 1: Number of natural catastrophes worldwide 1980-2010, Source: Emergency Events Database (EM-DAT, 2011)

For Malawi, most natural disasters arise from weather related events such as winds hailstorms and heavy rain, which results in floods. Amongst these events floods are the most occurring and have impacted Malawi more than 157 times since 1946(Misomali, 2009).The districts which are most hit by floods include Nsanje, Chikwawa, and Phalombe (in the south), Salima and Nkhotakota (in the central region), and Karonga, Rumphi, and Nkhatabay (in the north).

For quite a long time, Malawi's response to natural disasters, just like the rest of the world, has put shelter and food as a priority at the expense of sanitary facilities (Misomali, 2009, Malambo, 2014, Spit, Malambo, Gonzalez, Nobela, Pooter, & Anderson, 2014). And yet a rapid influx of people in an emergency camp implies both an increased serious problem of produced waste water and sludge disposal. Sanitation becomes more challenging especially when there is flooding and the evacuation camps have unstable soils, high water tables and rocky soils (Wisner & Adams, 2002b,Brown et al., 2012). Looking at how challenging faecal sludge management could become emergency response organisations are obliged to implement sanitation technologies that will not only protect people, the environment and the natural resources but also, as mentioned by Esrey, Gough, Rapaport, Sawyer, Simpson-Hébert, Vargas, &Winblad, (1998) and cited by Kuffour, Awuah, Sarpong, Anyemedu, &Kone, (2013), allows for recycling of organic matter and nutrients.

It is worth mentioning that faecal sludge is a potential health hazard as it contains high numbers of cyst of protozoa, parasitic ova, and faecal pathogens like salmonella spp., shigella spp. and Escherichia Coli (Sinha, Herat, Bharambe, &Brahambhatt, 2009). And yet in emergency situations it is disposed of untreated at the shortest possible distance, on open ground, into drainage ditches, into water courses or onto the sea (Strauss, Larmie, &Heinss, 1997). Literature explains that Poor sanitation and hygiene practices leads to food contamination, outbreaks of faecal-oral related diseases such as diarrhoea, cholera and typhoid (Wisner et al., 2002b, International Federation of Red Cross and Red Crescent Societies, 2010,The Johns Hopkins and the International Federation of Red Cross and Red Crescent Societie, 2008). Such disease outbreak cases have been order of the day in the above mentioned districtsand even Haiti. According to Johannessen(2011), and Bastable, & Lamb, (2012), as cited in Brown et al., (2012) disease outbreak incidences in emergency camps have not only exposed the emergency response gap of not properly managing sanitation at an early stage of an emergency, but also changed the approach to emergency response by organisations. This new approach has led to an ongoing call of investigating low-key faecal sludge treatment technologies, such as a Flexigester, that could both be rapidly deployed and effectively work under challenging physical conditions mentioned above (Spit et al., 2014)

A Flexigester, a faecal sludge anaerobic treatment technology developed by Sustainable One World Technologies (SOWTech), UK, is a water tight Anaerobic Digestion (AD) system that harvests biogas while sanitising and stabilising faecal sludge through solar energy pasteurisation. By definition, AD is a psychrophilic, mesophilic and thermophilic biological decomposition and stabilisation of biodegradable waste in the absence of oxygen and results in stable sanitised material that can be applied to an agricultural land to improve the soil structure or nutrients (Bywater, 2010, Zhang, 2010). It involves a series of stages namely hydrolysis, acidogenesis, acetogenesis and methanogenesis (Bywater, 2010, Sansalone& Srinivasan, 2004,Michigan Department of Environmental Quality, n.d.).

The Flexigester has been preferred, as an emergency sanitation system, over other sanitation systems due to the following reasons; Firstly, it is water tight making it more suitable for disasters resulting from floods. Secondly, it uses AD when treating faecal sludge, a well-known process for energy production, nutrient management, waste stabilisation, and pathogen reduction (Bywater, 2010). Finally it has four bags which collect biogas, a by-product which can be used for both lighting and cooking in the camps. However, despite having the above mentioned qualities it is unknown whether the Flexigester can successfully treat faecal sludge. Hence this paper seeks to investigate, for a period of two seasons (Winter and Summer - May 2014 to December 2014), the functionality and applicability a flexigester as an on-site faecal sludge treatment system during emergency situations by quantifying the process efficiency in terms of stabilisation, sanitization and useful by-product generation, determining the impact of weather, seasonal and environmental factors on system performance and devising the process conditions required for the on-site sanitation systems to achieve Malawi Standard guidelines.

2.0 Materials and Methods

The flexigester, while placed above the ground, was connected to a pour flush toilet, as shown figure 2 below, and was used by 400 orphans, despite being designed for 200 people, found at AquaidLifeLine orphanage village (GPS coordinates: Latitude 15.62285oS, Longitude 35.055672oE) in Blantyre, Malawi.

Figure 2 : Flexigester connected to pour flush toilet

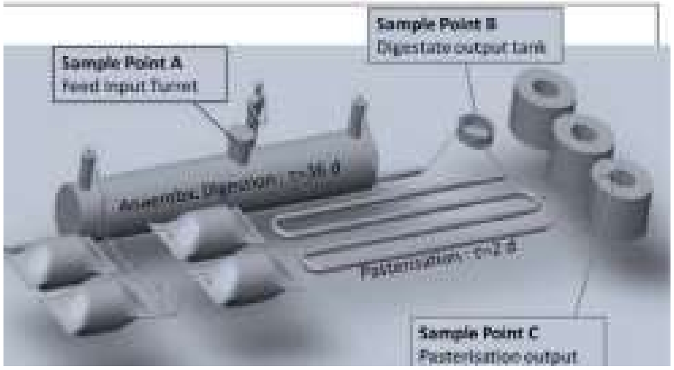


Figure 3 : Flexigester connected to pour flush toilet

To assess the Flexigester's sanitisation, stabilisation and capability of faecal sludge treatment the following parameters were analysed; pH, Temperarture, Chemical Oxygen Demand (COD) Total Ammonia Nitrogen (TAN) and Pathogen reduction(E. Coli and Total Coliforms). The table 1 below shows the adopted American Public Health Association (APHA) specific methods for determining each parameter.

Table 1: Analysed parameters with their methods

No.	Parameter	Method
1	pH	Potentiometric SM-4500-H+
2	Temperature (°C)	SM-2550B
3	Escherichia coli	Pour plate SM-9020
4	Total Coliforms	Pour plate SM-9020
5	Total Ammonia Nitrogen (TAN)	Indophenol blue method Hach LR/HR TNTN tube test
6	Chemical Oxygen Demand (COD)	Hach tube test HR Oxidation by Potassium dichromate

Using the randomly selected days of the study period (May, 2014 to December, 2014), and while maintaining the system's 38 days faecal sludge retention time, 36 days for the digestion bag and 2 days for pasteurisation tubes, grab samples, in 1 litre sterilised sampling bottles, were taken from three strategically chosen sampling points, as indicated in Figure 3 above, and then transferred from the sampling site (Aquaid Lifeline) to Soche Pollution Control Laboratory for analysis. Parameters such as COD and TAN were analysed in triplicates while that of E. coli and Total Coliforms were analysed in duplicates with averages of both duplicates and triplicates analysed reported. Temperature and pH were measured in situ immediately after collecting the samples from the above mentioned sampling points.

Before the samples were taken, faecal sludge was mixed using a manually driven roller in order to ensure uniformity of the samples collected. Most of the analysis for E. coli were done within six hours from the time samples were taken and those that were not analysed within the six hours were refrigerated at 10oC till the next day. Due to flexigesre's failure to absorb enough solar energy, a plastic paper cover was created to raise the temperature. To enhance biogas production, 10% w/v of the cow dung was added to the flexigester. In addition to the cow dung kitchen waste was put into the flexigester to boost up the concentration of carbohydrates, lipids and fats which are central to the anaerobic digestion stage called hydrolysis.

3.0 Results

A total of 24 samples, 13 in winter and 11 in summer, were analysed for COD, Temperature, pH, TAN, E. coli and Total Coliforms and table 2 below shows the results of the analysis.

Table 2: Average Values for COD, Temperature pH, TAN, E. coli and Total Coliforms

	Winter				Summer			
	N	Mean		Std. Deviation	N	Mean		Std. Deviation
	Statistic	Statistic	Optimal Limit	Statistic	Statistic	Statistic	Optimal Limit	Statistic
Stabilisation								
COD (mg/l)								
Feed	13	132.958	**60**	86.133	11	268.018	**60**	276.589
Digestate	13	134.337		57.654	11	423.982		239.076
Pasteurised	13	110.077		26.910	11	278.191		256.460
Temperature(°c)								
Feed	13	22.35	**42 - 75**	2.31395	11	34.39	**42 - 75**	2.74133
Digestate	13	36.79		7.01104	11	48.58		1.62654
Pasteurised	13	33.24		5.72532	11	44.10		2.09046
pH								
Feed	13	7.2146	**6.5 - 9**	.30934	11	7.1582	**6.5 - 9**	.07985
Digestate	13	7.2777		.45192	11	7.3018		.12327
Pasteurised	13	7.2792		.33315	11	7.3655		.08825
Useful By-Product								
TAN (mg/l)								
Feed	13	15.387		3.817	11	25.515		5.214
Digestate	13	15.738		2.527	11	24.970		4.708
Pasteurised	13	15.172		2.598	11	25.5766		5.114
Biogas (M^3/day)		1.5	**10**			5	**10**	
Pathogen Reduction								
E. coli (CFU/100ml)								
Feed	13	3.04×10^6	**$<10^3$**		11	$<10^3$	**$<10^3$**	
Digestate	13	1.57×10^6			11	$<10^3$		
Pasteurised	13	7.96×10^5			11	$<10^3$		
Total Coliforms (CFU/100ml)								
Feed	13	5.60×10^6	**$<10^3$**		11	$<10^3$	**$<10^3$**	
Digestate	13	2.46×10^6			11	$<10^3$		
Pasteurised	13	9.76×10^5			11	$<10^3$		

4.0 Discussion

The Flexigster will only be deployed for use in emergency situations if it demonstrates that it can stabilise faecal sludge, generate useful by-products from faecal sludge and most importantly reduce pathogens that are found in human waste. The paragraphs below outline a detailed description of how effective the sanitation system has been.

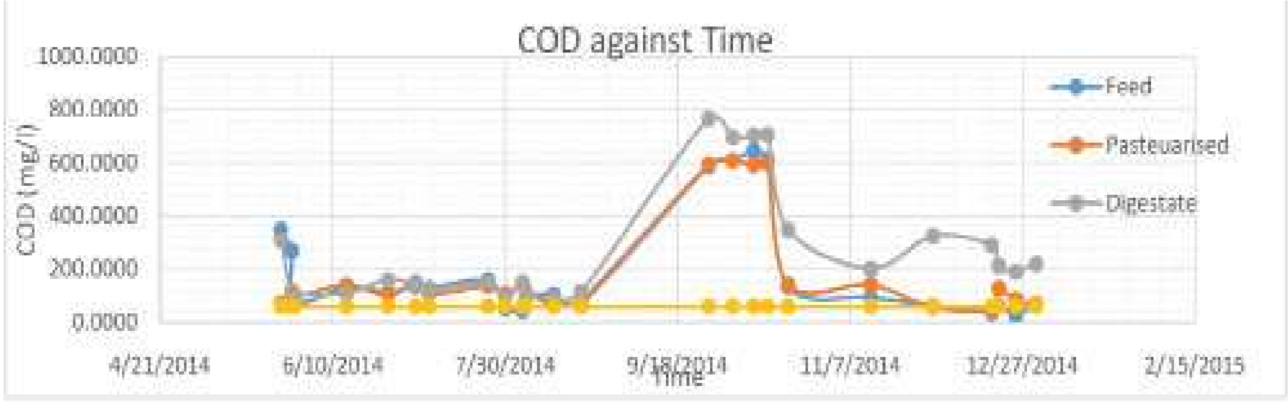
4.1. Stabilisation

In order to assess the Flexigester's process efficiency in terms of stabilisation, three parameters were analysed namely COD, Temperature and pH.

4.1.1 Chemical Oxygen Demand (COD)

Mean COD values in summer were 11/2 times more than their counterparts in winter (see table 2 above) with COD values for the digestate indicating a stronger positive linear relationship (r = 0.512) than those of both feed (r = 0.338) and pasteurised (r = 0.235) such that 26.2% of the digestate's COD values, unlike 15% and 5% of both the feed and pasteurised respectively, are being explained by temperature. COD values for the digestate were generally higher as compared to those of feed and pasteurised. The higher digestate's COD could be due to the following reasons; firstly, because the digestate samples had more suspended solids (physically observed biodegradable organic compounds) than those of feed and pasteurised. This observation is strange since the Flexigester, being anaerobic digestion in nature should have had a steady sludge volume reduction (Wong & Law-Flood, 2011). This means that the system did not successfully wash out the suspended solids. Secondly, if the digestate had suspended solids in it, more than the feed, it could mean that the overloading of the system that took place, system was used by an average of 400 orphans against the designed 200, led to the sludge being washed out in the digestate by the high inlet flowrate/hydraulic load.

Figure 4: Graph of COD against Time



The graphical representation of COD values showed that COD for the feed, digestate and pasteurised went extremely high as the system was switching from winter season to summer. The higher COD values in September could be the result of the Flexigester's response to the temperature changes, from mesophilic to thermophilic ranges, because COD values went down again in early November. This COD sharp rise was expected because a rise in wastewater temperatures demands more oxygen for nitrification process (Atta, 2011). Overall the Flexigester's COD hardly went below the Malawi Standard guideline of 60mg/l which means that the faecal sludge was being discharged unstabilised.

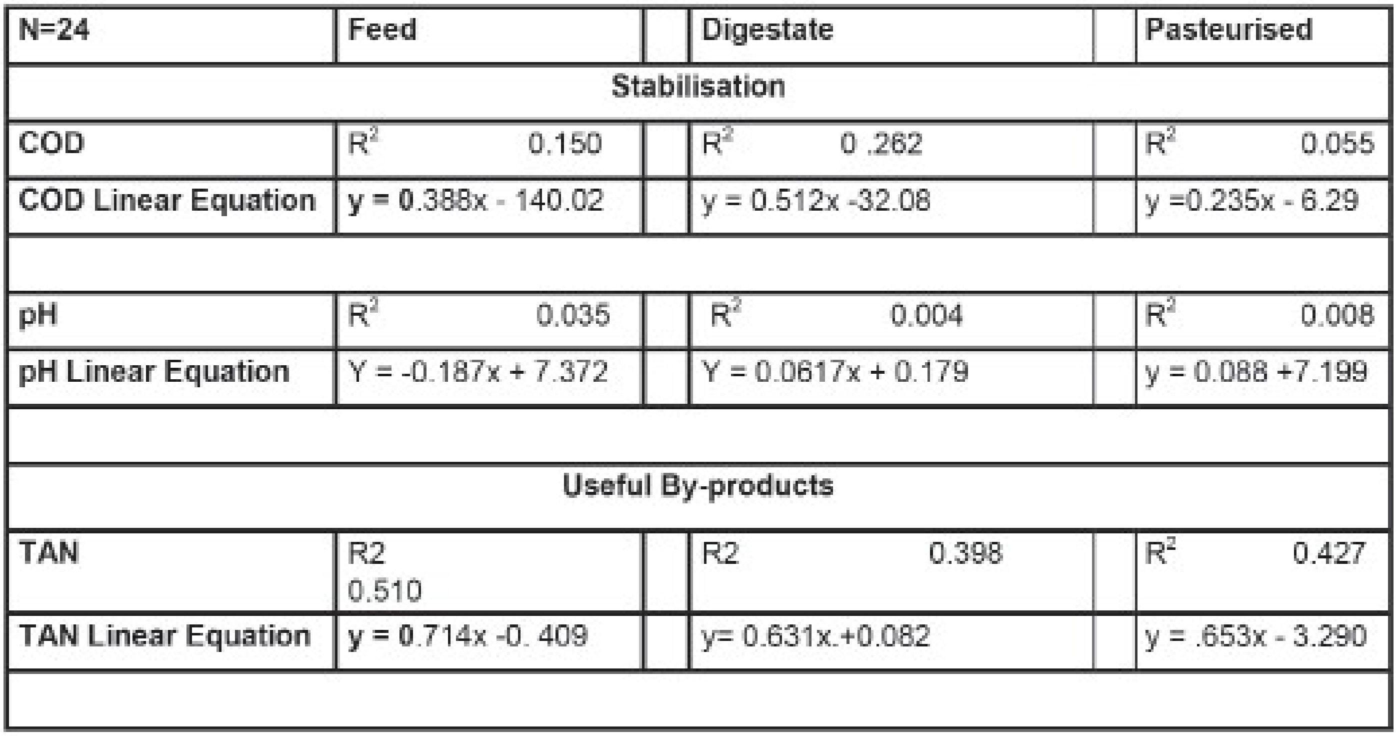
4.1.2 Temperature

During winter, the pasteurisation tubes were covered by a niche so that the temperature could be raised. However, despite covering the pasteurisation tubes, the raised temperatures were not able to meet the required thermophilic temperatures during this winter season. Itisinteresting to note that mean temperature values for the digestate were significantly higher than those of the feed and pasteurised in both seasons. This is regardless of being mesophilic (22.35, 36.79, and 33.24 oc for the feed, digestate, and pasteurised respectively) in winter and thermophilic (48.58, 44.10oC), except feed (34.39oC), in summer as can be seen in table 1 below. There was much variations in temperatures recorded during winter (25 – 42oC) as compared to those recorded during summer (42–48oC). The temperatures in winter were within mesophilic range (20-42oC) (Metcalf & Eddy, 1995) as cited by Kuffour et al., (2013) while those in summer were within thermophilic ranges (42-75oC) (Lettinga, 1995, Rajeshwari, Balakrishnan, Kansal, KusumLata, & Kishore, 1999). These variation actually explain the poor pathogen reductions explained in the paragraphs below as AD largely depends on operating conditions like temperature, PH, loading rate and influent strength because of the sensitivity of the methane producing bacteria (Rajeshwari et al., 1999)

4.1.3 pH

There were no significant changes for the mean pH values for both winter (7.22, 7.28, & 7.28) and summer (7.16, 7.30, & 7.37) for the feed, digestate and pasteurised faecal sludge respectively. The pH range recorded for the entire study period were within optimal ranges (6.5-9) required by microrganisms to biologically degrade the organic matter(Veenstra&Polprasert, 1997) as cited by Kuffour et al., (2013),Rajeshwari et al., 1999, Strauss, Larmie, Heinss, &Montangero, n.d.).This suggests that the Flexigster perfumed well in as far pH stabilisation is concerned. However there was weak positive linear relationship (r =0.0617 and 0.088) between pH values and temperature over the observed data with only 0.4% and 0.8% of the pH values being explained by temperature (see table 3 below).

Table 3: Regression Analysis for, COD, pH and TAN with Temperature as independent variable



N=24	Feed		Digestate		Pasteurised
Stabilisation					
COD	R^2 0.150		R^2 0 .262		R^2 0.055
COD Linear Equation	y = 0.388x - 140.02		y = 0.512x -32.08		y =0.235x - 6.29
pH	R^2 0.035		R^2 0.004		R^2 0.008
pH Linear Equation	Y = -0.187x + 7.372		Y = 0.0617x + 0.179		y = 0.088 +7.199
Useful By-products					
TAN	R2 0.510		R2 0.398		R^2 0.427
TAN Linear Equation	y = 0.714x -0. 409		y= 0.631x.+0.082		y = .653x - 3.290

4.2. Useful By-Products

4.2.1 Total Ammonia Nitrogen

TAN observed data shows that the Flexigester is capable, just like any other functioning AD, of recovering useful by-products. TAN mean values in winter were approximately 40% lower than those in summer, regardless of the different sampling points (see Table 2). The recorded summer TAN concentrations have similar value trends (25-30mg/l) to what Siegrist, (1997) as cited by Montangero&Strauss, (2002) found while inhibiting methane-forming bacteria in digesters treating wastewater treatment plant sludge. However, TAN values, despite falling within optimal range, kept on increasing throughout the study period probably due to their being temperature dependent. The increasing trend explains why, regardless of the sampling point, the mean TAN obtained in summer were relatively higher than those obtained in winter. Unlike PH and COD values, TAN indicated a strong positive linear relationship (see table 3 above) at all sampling points with changes in temperature at all sampling points (r = 0.714, 0.631, and 0.653) with 51%, 39.8% and 42.7% of TAN for the feed, digestate and pasteurised respectively being explained by temperature.

4.2.2 Methane Gas

In order to assess Flexigester's capability of recovering useful by-products, four biogas collecting bags, were connected to the system. Three out of the four connected bags, filled with biogas, are shown in Figure 5 below and figure 6 shows a stick being burnt by the methane from one of the bags. The fact that methane was successfully harvested from the Flexigester and could ably burn shows that it is a good sanitation system especially during emergency situations because the harvested biogas could be used for both lighting and cooking.By design it was anticipated that the flexigester would harvest 10m3 of biogas per day. However only half of the anticipated volume was been observed so far. This suggests that the COD is not currently being converted to methane (CH4) and from the data collected so far it is only 17% of the COD that is being removed. The low methane gas production further suggests that there is need for improving the AD as this could further reduce COD and increase CH4 generation.

Figure 5: Filled Biogas Bags *Figure 6:Methane Burning a Stick*

4.3 Sanitisation/Pathogen Reduction

Results evidently revealed that flexigester failed to remove or completely eliminate the pathogens from the pasteurized sludge in winter but significantly reduced them during summer (see Table 2 and Figures 7&8) despite its capability of harvesting biogas. This could be attributed to the system's failure to absorb enough energy from the sun in order to meet the required thermophilic temperature range. The fact that standard pathogen reduction was not achieved during winter suggests maintaining thermophilic temperatures is very crucial for sanitisation to be met. Unlike the rest of the observed study period, the digestate indicates that it achieved Malawi Standard pathogen reduction guideline from mid Nevember, 2014 to late December, 2014 probably due to either reduced number of people using the toilet or due to longer faecal sludge retention times as during this period the school's orphanage had closed for Christmas Holiday.

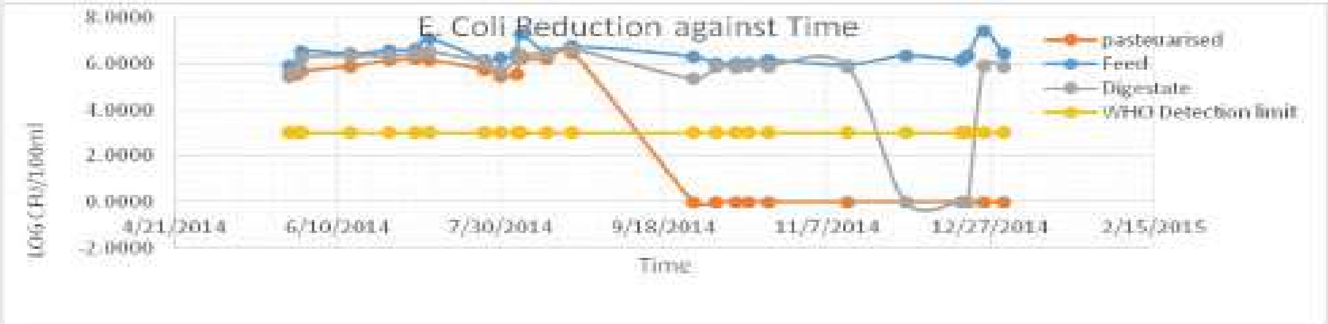


Figure 7: Graph of E. coli reduction against Time

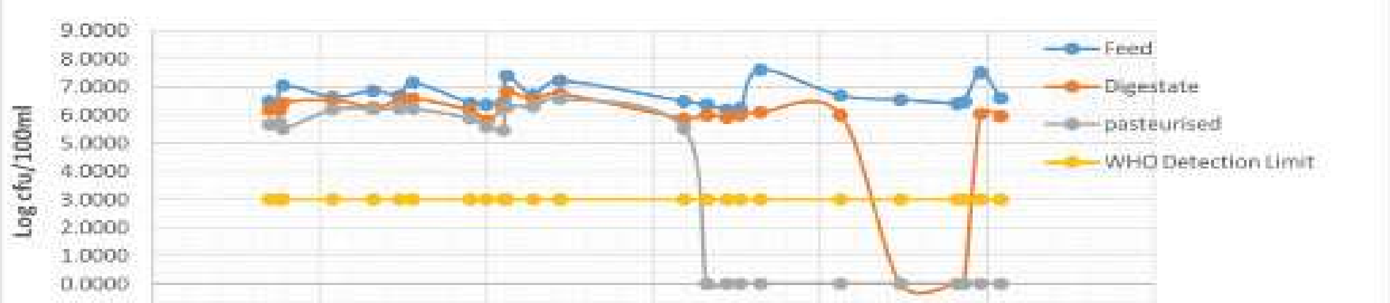


Figure 8: Graph of Total Coliforms reduction against Time

5.0 Conclusion

Generally, the Flexigester can work successfully in countries with tropical climate. The results indicate that during summer quality of the final product was appropriate for direct handling and re-use. The treated product had a high concentration of nutrients rendering it useful for agriculture. However, during winter either a post-treatment or an extension of sludge retention time is required to reduce the pathogen concentration. Overall, the Flexigester, as an emergency on-site anaerobic sanitation system, if reworked, can be effective in providing solutions to a series of challenges such as safe waste management, sustainable agriculture, and fuel generation.

6.0 Recommendations

In order for the flexigester to ably meet the pathogen reduction standards, stabilise faecal sludge, generate useful by-products and its performance be consistent regardless of variations, seasonal and environmental changes, it is necessary to;

raisetemperatures which could employ the biogas collected despite the mesophilic temperatures observed. The biogas could be employed to generate steam by boiling water which in turn could be used to heat the pasteurisation tubes to make the faecal sludge reach thermophilic temperatures. This could make the treatment process effective. It is proposed that this may be modelled from the design of a distillation process' condensing tube where there will be no direct contact between the faecal sludge and steam. This would enable the flexigester to be deployed to emergency sites that have mesophilic temperatures as the ones observed between May, 2014 and August 2014. Alternatively, the pasteurisation tubes could be modified by having stainless steel pipes at strategically placed points, where the burning biogas could be used to heat the pipes thereby raising the temperatures so that pasteurisation of faecal sludge gets achieved.

increase faecal sludge retention time by putting retention bags at the end of the pasteurisation tubes. The retention bags could act as faecal sludge maturation ponds before the actual disposal into the donuts because treating faecal sludge using maturation ponds has proven successful in many cities. Further modifications could be construction of drying beds at the end of pasteurisation tubes. The faecal sludge discharged in these drying beds could further be treated using lime or urea, one of the off-site faecal sludge treatment options.

join the flexigester system to a constructed wetland to help in disposing the effluent into a scientifically proven waste water treatment system. As mentioned above, the flexigester has failed to meet the 10m3 biogas production target. Further research could be carried in order to establish the right loading rates that could produce the designed 10m3 biogas volume per day. It is worth mentioning that the designed 10m3 is achievable as there is a lot of existing evidence that AD registers high energy recovery

vermicomposting the flexigester's effluent in order to enhance nutrient concentration and reduce the pathogen concentration. According to literature biogas from AD systems is a mixture of methane, Carbon dioxide, and hydrogen sulphide among other components. Amongst these gasses methane constitutes approximately 50 - 75%. However, despite the flexigester producing biogas it is not known what percentage of the gas is methane and this could be another area of further studies.

7.0 Acknowledgement

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