EFFECT OF USING DIFFERENT PARTICLE SIZES OF SAND AS FILTER MEDIA FOR DEWATERING FAECAL SLUDGE[1] .

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Abstract:

This research is aimed at investigating the effect of different particle sizes of sand for the dewatering of faecal sludge with respect to the dewatering time, contaminant load in the percolate, rate of clogging and quantity of biosolids produced. Three filter media FM1, FM2 and FM3 were used to dewater the faecal sludge. The experiment was conducted on bench scale consisting of miniature drying beds. Six cycles of dewatering were run where FM1, FM2, and FM3 showed average dewatering times of 10, 10 and 9 days respectively without significant differences ($p>0.05$). However the percolate quality showed significant differences between them in the removal of TS, TVS, SS, COD, DCOD and NH_3-N with FM1 having the highest removal for each parameter. Accumulation of organic matter in the top 10cm of the filter bed indicated that FM1 was least likely to clog and it also generated the highest quantity of biosolids.

Key Words: Filter medium, faecal sludge, dewatering time, contaminant load, percolate, biosolids.

Introduction

Human excreta (faecal sludge) is a rich source of organic matter and plant nutrients such as nitrogen, phosphorus and potassium. Each person's excreta in theory at least, is nearly sufficient for production of one's own food requirement [1]. Excreta is not only a fertilizer, its organic matter content, which serves as a soil conditioner and humus replenisher, an asset not shared by chemical fertilizers, is of equal or even greater importance [2]. Chinese peri-urban vegetable farmers have reported that customers prefer excreta-fertilized rather than chemically fertilized vegetables. Thus, vegetables grown on excreta-conditioned soils yield higher sales prices [3].

On-site sanitation (OSS) facilities are the predominant options for faecal sludge FS disposal in developing countries leading to its accumulation which needs to be emptied and treated. FS generated from these facilities is of two main types which are public toilet sludge (PTS) that is fresh and undigested, generated from unsewered public toilets and septage that is partially digested, generated from septic tanks. The most common system used for treating FS in Ghana is the waste stabilisation ponds. [4, 5]. These pond systems are often overloaded and not

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properly operated resulting in very poor performance in the removal of nutrients, pathogens and organic load [6]. The final effluents of these pond systems are discharged into water bodies thus causing environmental pollution. In Kumasi, Ghana, where this study was carried out, about 500m^3 of faecal sludge generated is daily sent to pond systems for treatment. Previous studies in Kumasi, have shown that faecal sludge dewatering using unplanted filter beds to generate biosolids was possible [7]. However, the problems of clogging in filter beds, particle size of sand filter and mixing ratios of PTS and septage, which lead to long dewatering time and high contaminant loads in the percolate need to be addressed. This research aimed to determine the appropriate particle sizes of sand that will assist to improve the faecal sludge dewatering efficiency of filter beds to enhance the treatment of large volumes of faecal sludge generated in Ghana for a better sanitation delivery and agricultural productivity.

Materials and Methods

Design of experiment

A wooden structure of size 4.5m long by 3.5m wide and 2m high was raised and roofed with iron sheets. A wooden platform of 3m long, 2m wide and 0.4m high was constructed in it which served as a bench for the drying beds. Each drying bed was raised in a plastic container having a size of 0.85m long 0.175m diameter. There were 9 drying beds consisting of FM1, FM2 and FM3, with each replicated 3 times. These were arranged in a randomized complete block design on the wooden bench under the roofed shelter.

Filter material and drying bed preparation

Course and fine gravels of about 2.0-3.0 cm and 0.5-1.0 cm diameter respectively, served as base support for the filter medium (sand) which was collected from a local community about 35km from project site. The sand was sieved into ranges of 3 different particle sizes ≥ 0.1- ≤ 0.5mm; ≥ 0.5 - ≤ 1.0mm; and ≥ 1.0 - ≤ 1.5mm by sieve analyses, constituting the filter media FM1, FM2 and FM3 respectively. Effective sizes (Es) and uniformity coefficients (U_o) were determined. The permeabilities of the different filter media were determined using constant head permeability test. The base of the filter bed was filled with the course gravel to 15cm depth, followed by the fine gravel to 10cm depth and the sand to 20cm depth. Nylon net was placed on the sand on which the FS was poured, (Figure 1) to ensure easy removal of the dewatered biosolid.

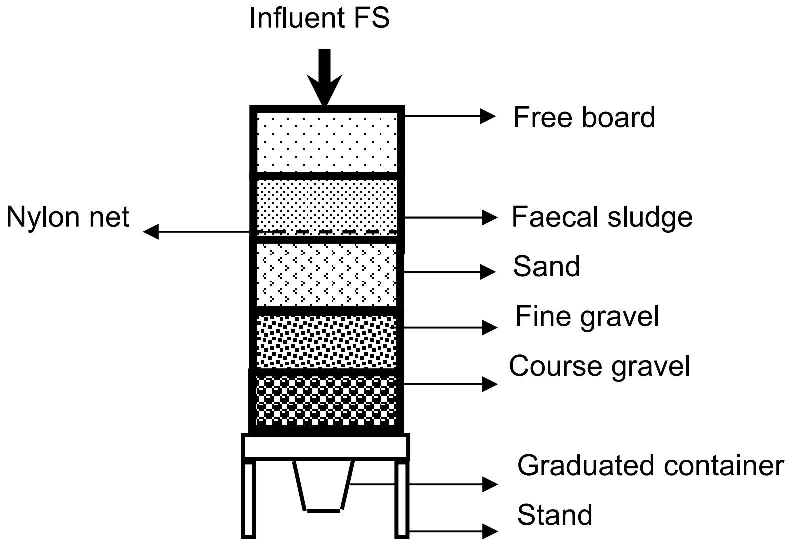

Figure 1: Schematic design of the bench scale set up

Collection of faecal sludge (FS) and dewatering

PTS from public toilet and septage from septic tank were collected in separate plastic drums of about 90 liters each from faecal sludge suction trucks discharging at Dompoase landfill site in Kumasi, about 20 km away from the project site. The FS used for the dewatering consisted of PTS and septage, mixed in a ratio of 1:1 by volume, and a hydraulic loading of 20cm (equivalent to 5 liters) was applied on each filter bed. The volume of the percolate and depth of sludge were measured every 24 hours while the numbers of days taken for the sludge to dewater were also recorded. Dewatering was considered complete when biosolid accumulated was spadable for possible removal from the filter bed.

Laboratory analyses

The raw FS was analyzed just after collection from the treatment plant before dewatering. Percolate collected daily from each filter bed was analyzed daily for temperature, pH and conductivity insitu. It was then kept below 4°C till dewatering was complete. After the dewatering, composite sample of the percolate from each drying bed was analyzed. Biosolid and sand from top 10cm of each filter bed were analyzed for TS and TVS after each cycle. The parameters analyzed in the raw FS and percolate were, COD, DCOD, TS, TVS, TKN, $NH_{3-}N$, NO_3-N, TP, electrical conductivity, temperature and pH. Methods outlined in standard methods for the examination of water and wastewaters [8] were used for the analyses of the parameters.

Results and Discussion

Sand characteristics

Sands for municipal anaerobic digester effluent dewatering beds should ideally have an effective diameter of between 0.30 and 0.75 mm and a uniformity coefficient less than 4, [9,10]. The uniformity coefficient (U_o) values obtained for FM1, FM2 and FM3 were 2.422, 1.727 and 2.029 respectively using sieve analyses. The permeabilities of FM1, FM2 and FM3 were 9.0×10^{-2}, 14.0×10^{-2} and 36.0×10^{-2} (cm/sec) respectively.

Characteristics of raw FS

The raw FS from septage and PTS analyzed had very high values for TS, SS, COD, NH_3-N, TKN NO_3 etc. (Table 1). These concentrations are several times (10 -100) the strength of sewage [11]. Such sludge with high contaminant loads, pose treatment challenges but has high potential of generating large quantities of biosolid that may be useful in agriculture.

Table 1: Average characteristics of raw FS (no. of cycles = 6)

Parameter	Mean values with SD	Parameter	Mean values with SD
TS (g/l)	36.64 ± 7.73	COD(g/l)	50.32 ± 28.78
TVS (g/l)	25.34 ± 9.98	DCOD(g/l)	10.98 ± 5.31
SS (g/l)	19.68 ± 6.59	NH_3-N(g/l)	2.83 ± 1.68
Conductivity (mS/cm)	22.67 ± 3.45	TKN(g/l)	3.58 ± 2.07
Temperature (°C)	28.07 ± 1.05	NO_3(g/l)	1.38 ± 0.42
pH	7.77 ± 0.13	TP(g/l)	1.85 ± 0.53

± Standard deviation (SD)

The associated high concentration of NH_3-N is an additional problem to its treatment. This is because ammonia concentration greater than 30 mg/l is the tolerance limit of algae in facultative ponds though some special species are able to adapt themselves to concentrations up to 50mg/l [12]. Thus ammonia concentration of 2,830mg/l as found in this type of sludge is excessively high and will hamper algal and bacterial growth. At such concentrations, malodor and eye irritations are added challenges of the sludge treatment [13]. These characteristics are major contributors to the failure of treatment of FS in pond systems in Ghana and many other developing countries and resulted in the need to use alternatives like the unplanted drying beds for effective sludge management.

Dewatering time (DT) of the different filter media in different cycles

The averages of DT of the filter media (FM1, FM2 and FM3) were 10, 10 and 9 days respectively. Generally, the DT for the entire filter media decreased from C1 to C5 until it rose suddenly in C6 (Figure 2). The initial long dewatering times of all the filter media especially C1, might be due to comparatively low temperatures (20.3°C – 22.5°C minimum and 27.4°C - 31.6°C maximum) and high humidity (88.5 – 91 high) during the project period [14]. Moreover, for municipal sludge dewatering, fine organic particles are created and sand-bed drainability deteriorates during the early stages of digestion leading to increase of DT but as digestion proceeds, the fine organic particles are destroyed and dewaterability of the sludge improves resulting in decrease of DT [15]. The state of the sludge also affect the dewatering time. The sharp rise in the DT in C6 might due to factors like temperature, humidity, state of the FS. Onset of clogging in the filter beds could also be possible.

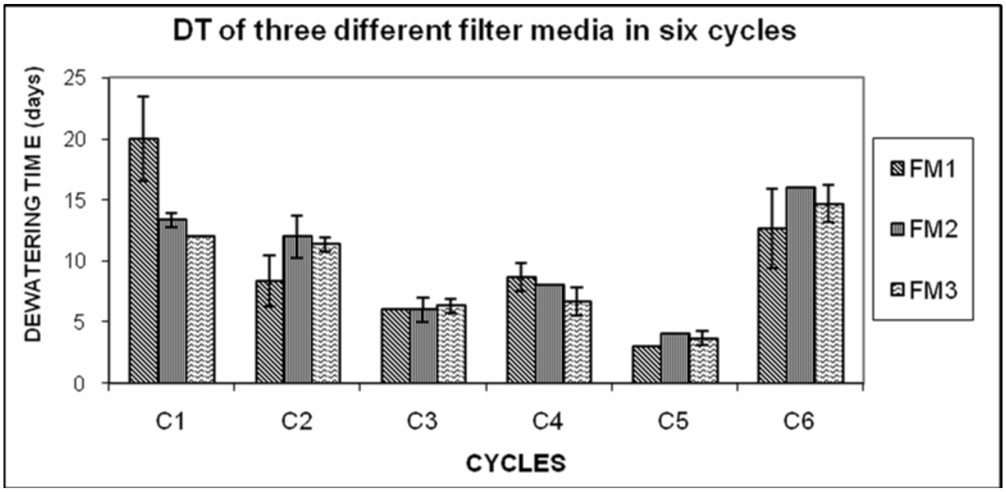

Figure 2: The dewatering time (days) of different filter media in six cycles

FM3 dewatered in the shortest time as compared to the others. Not withstanding the above observation, the ANOVA of the results at 95% confidence level showed that there was no significant difference in the DT with respect to the three different filter media.

Dewatering efficiencies of the different filter media in removing contaminant loads

Removal of solids (TS, TVS and SS)

Though the average TS, TVS and SS values in the percolate were still high, the filter media FM1, FM2 and FM3 were able to dewater the FS of between TS loading rate of 217 - 360 kg TS/m^2/year in 10, 10 and 9 days respectively (Table 2). This compares well with and even shows an improvement over the results of experiment conducted by Larmie in Accra, Ghana, where FS of TS loading rate of 130 kg TS/m^2/yr was dewatered in 9 days [16]. The average percentage removals of TVS for FM1 FM2 and FM3 within the range of 73.6% - 78.2% (Table

2), compares well with the TVS removal achieved by sand bed dewatering research earlier [17]. The generally high average removal efficiencies of SS between 88.9% – 95.1 % in all the filter media is an impressive performance for dewatering FS. This is also comparable to works by Larmie et. al. in Accra [16] and Esseku in Kumasi [7]. Ability of FM1 (95.1%), to outperform FM2 (93.4%) and FM3 (88.9%) in the removal of SS (Table 2), may be due to its ability to remove finer sludge particles than the other media. As particle size of sand bed increases the dry weight recovered by dewatering reduces [17].

Table 2: Average Characteristics of percolate (no. of cycles = 6)

		Percolate from filter media			Removal of contaminant load in percolate (%)		
Parameter	units	FM1	FM2	FM3	FM1	FM2	FM3
Dewatering time	days	10 ± 6	10 ± 5	9 ± 4	-	-	-
TS	g/l	8.62 ± 2.46	9.51 ±3.02	10.84 ± 3.18	76.2	74.0	70.5
TVS	g/l	4.41 ± 1.58	4.83 ± 1.62	5.86 ± 1.62	78.2	77.2	73.6
SS	g/l	0.86 ± 0.34	1.19 ± 0.49	1.96 ± 0.92	95.1	93.4	88.9
Temperature	°C	27.54 ± 1.28	27.42 ± 1.28	27.47 ± 1.24	nd	nd	nd
pH	-	8.36 ± 0.25	8.3 ± 0.12	8.21 ± 0.20	nd	nd	nd
EC	(mS/cm)	13.56 ± 5.38	15.85 ± 4.32	16.18 ± 3.69	40.8	30.4	28.6
COD	g/l	5.48 ± 2.20	5.79 ± 2.37	6.7 ± 2.01	87.9	87.4	85.3
DCOD	g/l	2.3 ± 0.97	2.8 ± 0.88	3.12 ± 1.07	77.7	70.8	65.8
NH3-N	g/l	0.64 ± 0.55	0.89 ± 0.68	0.84 ± 0.62	78.0	71.1	71.6
TKN	g/l	0.8 ± 0.61	1.0 ± 0.76	1.4 ± 1.05	78.1	71.7	60.8
NO3	g/l	0.63 ± 0.31	0.64 ± 0.20	0.83 ± 0.24	56.0	52.5	39.6
TP	g/l	0.759 ± 0.23	0.872 ± 0.25	0.948 ± 0.25	58.9	52.9	48.7

± Standard deviation; nd = not determined

Removal of salts or Reduction of Electrical Conductivity

The removal efficiencies of 40.8%, 30.4% and 28.6% respectively achieved by FM1, FM2 and FM3 were comparatively low, with respect to percentage removals achieved for the solids (Table 2). Conductivity is the result of ionic mobility of dissolved salts. Thus the higher the dissolved salts, the higher the electrical conductivity [18]. Poor reduction of the electrical conductivity is an indication of poor removal of salts. High magnitude of conductivity between 13.56 – 16.8 mS/cm in the percolates of FM1,FM2 and FM3 (Table 2) will put osmotic stress on the plants when discharged into the environment. However the poor removal of the salts means little was retained in the biosolids which indicates safe use of the biosolid in agriculture.

Removal of Degradable Organics (COD, DCOD)

There were high percentage removals of COD with FM1 showing the highest removal efficiency in almost all the cycles (Table 2). This efficiency achieved by the drying beds might be due to the ability of the filter media to remove the solids from the sludge and the availability of the dissolved organics for microbial action [19]. The ability of FM1 to remove more solids and the fact that its particles present the largest surface area for microbial action might have contributed to its highest performance. A good reduction in the DCOD is an indication of the availability of the dissolved substrate for bacterial action [19]. The removal efficiencies of 77.7%, 70.8% and 65.8% by FM1, FM2 and FM3 respectively, well explain that some fine particles of dissolved organics were degraded by microbes. The outstanding performance of FM1 over the FM2 and FM3 may further support the role played by the effective size of the filter media [20].

Removal of Nutrients (NH_3-N, TKN, NO_3-N, TP)

All the filter media achieved high NH_3-N removal efficiencies yet the concentrations in the percolates were very high (Table 2). This might be due to the high concentrations in the influent FS and ammonification of organic N [21]. NH_3-N removal is believed to be basically due to volatilization and nitrification by nitrifying bacteria [5]. The filter media achieved high efficiency in the TKN removal, between 60.8% – 78.1%. Of the three filter media, FM1 showed the highest potential for TKN removal with average removal efficiency of 78.1%. This might be due to organic-N removal through high TVS removal (Table 2) and mineralization of organic-N. The comparatively low percentage removal of nitrate (NO_3-N) might be due to the fact that it was continually being produced in the percolate through mineralization of organic-N [21]. Irrespective of the percentage removals of nitrate and total phosphorus (TP) achieved (Table 2), the concentrations in the effluents were still very high.

Organic matter (TVS) accumulation in the sand (Filter medium)

Since TVS is a function of organic matter, [18], its increase in the filter media is an indication of organic matter build up. FM3 has the highest potential of organic matter accumulation (Figure 3). The organic matter accumulation is likely to fill the pore spaces between the particles of the filter bed which can subsequently result in clogging. Though clogging did not take place during the running of the six cycles, there was the possibility for it's occurrence since there was significant increase in the organic matter content in the filter media especially in the FM3.

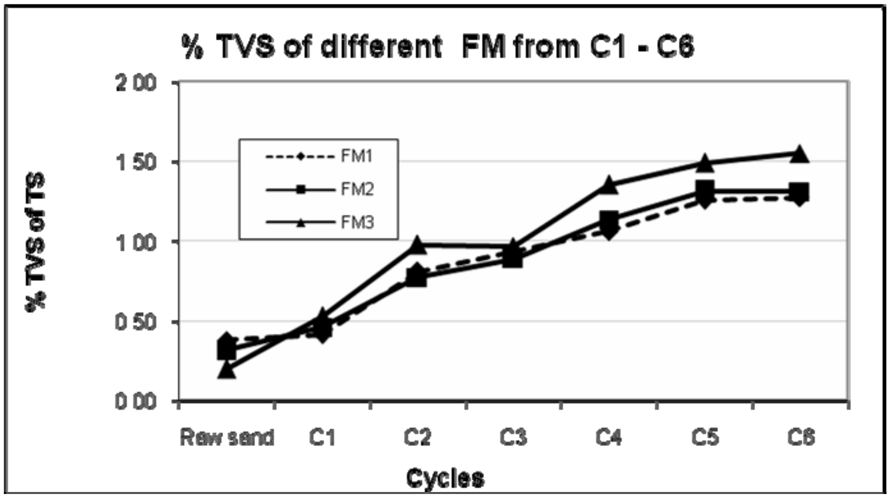

Figure 3: Percentage TVS of filter media from C1 – C6.

Biosolids accumulated by filter media

The percentage accumulation of the biosolids by the different filter media F M1, FM2 and FM3 (Table 3) is an indication that FM1 had the highest potential to generate biosolids. Since the same FS was used for all the filter media, it was assumed that the TVS content of the bioslids was directly proportional to the biosolids accumulated on the respective beds. FM1 gave the highest percentage TVS of TS of biosolid accumulated by the different filter media, (Table 3). Furthermore, the percentage TVS accumulated by each filter medium from the influent FS were in the order of 76.0, 66.8 and 62.5 for FM1,FM2 and FM3 respectively, (Table 3). These performances exhibited by FM1 proved that it had the highest potential of biosolid generation amongst the others. Annual biosolid production with respect to dewatering time, was estimated (Table 3) and based on that the organic matter accumulation per m^2 per year was determined where FM1 showed the highest potential to generate biosolids, 154.5 kgTVS/m^2 year, (Table 3).

Table 3: Biosolid accumulation performance of the different filter media

Parameter	**FM1**	**FM2**	**FM3**	**Parameter**	**FM1**	**FM2**	**FM3**
Total dry solid of FS (g) *	183	183	183	%TVS accumulated	76.0	66.8	62.5
Total org. matter of FS (g)*	135	135	135	Days in a cycle	10	10	9
Ave. fresh biosolids/cy. (g)	410	414	400	Cycles/year	36	36	41
Ave. dry biosolid TS (g)	155	148	147	Ave dry bio/yr.(g/yr)	5580	5328	6027
TVS of biosolid (g)	103	90	84	TVS/filter bed/yr (g/yr).	3708	3240	3444
% TVS of TS of raw FS*	74.0	74.0	74.0	kg/yr.(TVS)	3.71	3.24	3.44
% TVS of TS (biosolids)	66	61	57	Area (m^2)of filter bed*	0.024	0.024	0.024
% TS accumulated	84.9	80.5	80.3	kgTVS/m^2yr (kg/yr)	154.5	135	143.5

*Same for all filter media; Ave=Average; cy = cycle; yr = year; bio = biosolid

Conclusion

All the filter media with respect to particle size configuration used for the research were found to be able to improve the dewatering performance of the unplanted filter bed. However, FM1 was most efficient of all in terms of contaminant load removal while in terms of dewatering time they were statistically not different. The filter media with bigger particle sizes (FM3 and FM2) were relatively faster in accumulating organic matter and thus likely to clog faster than the FM1. FM1 had the added advantage of being able to generate more biosolids than the FM2 and FM3. Generally there were significant differences statistically, in the contaminant load removal between the different filter media. The different filter media were all not efficient in salts removal since they showed low EC reduction efficiencies. The pH and temperature were within favorable limits for microbial growth but the high ammonia levels in the percolate could be toxic to the microbes responsible for biological degradation. The contaminant load in the percolates from all the different filter media were all beyond permissible levels for discharge into the environment.

Although high removal efficiencies were achieved by all the filter media, the parameters in the effluent needed to be treated further either through column filters, constructed wetlands or stabilization ponds for more polishing before final discharge. Having determined the particle sizes best suited for the sludge dewatering, further research into solid loading rate with respect to the mixing ratios of PTS and septage and other possible technologies (eg. addition of physical conditioners like saw dust to the FS) to compliment the findings achieved for this studies will be effective approaches to improving the dewatering process of unplanted drying beds.

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