41st WEDC International Conference, Egerton University, Nakuru, Kenya, 2018

TRANSFORMATION TOWARDS SUSTAINABLE
AND RESILIENT WASH SERVICES

Use of chitosan and *Moringa oleifera* as conditioners for improved dewatering of faecal sludge

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PAPER 3014

A pilot-scale dewatering research facility was built in Dar es Salaam, Tanzania, and was used to test chitosan and Moringa oleifera as conditioners to improve the dewatering of faecal sludge. Laboratory-scale jar tests were first conducted to determine optimal dosages for the conditioners in faecal sludge samples with varying total solids concentrations. The results for chitosan were 0.5-0.6 mL/gTS, and for Moringa oleifera 5-15mL/gTS. Based on these results, pilot-scale tests were conducted with chitosan, but the use of Moringa was ruled out as it was too resource intensive. Three loading cycles were conducted, and an average of 15.3% reduction in dewatering time was achieved. Based on the laboratory and pilot-scale tests, chitosan is recommended as a conditioner for improved FS dewatering performance. It could be employed at full-scale, but still requires jar tests to determine optimal dosing.

Introduction

Globally, more than 2.7 billion people are served by onsite sanitation systems such as pit latrines and septic tanks (Strande, Ronteltap, & Brdjanovic, 2014). In Dar es Salaam, Tanzania, 90% of the population uses onsite sanitation systems (Brandes, Schoebitz, Kimwaga, & Strande, 2015). This results in the accumulation of large amounts of faecal sludge (FS) in onsite containment technologies. FS is typically >90% water, which makes dewatering an important treatment goal. Drying beds, which are commonly used technologies for FS dewatering, are land intensive. The use of conditioners to improve dewatering could reduce required land areas. Improved dewatering can also reduce transport costs, and increase the resource potential of treatment products (e.g., soil conditioner or solid fuel). Gold et al. (2016) identified on a laboratory-scale that chitosan and Moringa oleifera can be effective locally produced conditioners. They performed similar to commonly used commercial conditioners (e.g. lime or polymers). However, FS properties are much different than wastewater sludge, and more research is necessary to adapt existing knowledge from wastewater treatment to FS in local contexts.No conditioners are currently used in Tanzania for FS dewatering.

A pilot-scale dewatering facility was constructed at the University of Dar es Salaam in 2015 for research on dewatering of FS. The objective of this project was to select the best conditioner and optimal dose for chitosan and *M. oleifera* based on laboratory jar tests, together with pilot-scale testing.

Methodology

Dewatering facility

The pilot-scale research facility is shown in Figure 1. The plant has a capacity of 37m3 per loading cycle, and the process flow consists of a bar screen, two parallel settling-thickening tanks of 18.5m3 each, a 7m3 mixing tank with a motor driven mixer to ensure homogeneous mixing of conditioner and thickened FS, and six unplanted drying beds (each with a surface area of 2.25m2). The hydraulic loading on the drying beds was 45cm, and the organic loading rate (OLR) was kept between 100-200kg/m2/year as recommended by Strande et al. (2014).

**Figure 1. The pilot-scale facility at the University of Dar es Salaam.
Left: an overview of the facility showing the drying beds (bottom-left)
mixing tank (bottom-right), settling-thickening tanks.
Right: close-up of drying beds.**

Research design

FS from households in Dar es Salaam was delivered to the dewatering research facility by vacuum trucks. One loading cycle consisted of ten trucks delivering FS. To represent a wide variety of FS characteristics, different ratios of pit latrine and septic tank sludge were used. The combined FS was loaded into the facility. Three loading cycles were conducted with chitosan. First, the FS was left to settle in the settling-thickening tank for two days. Afterwards, it was pumped to the mixing tank, where a homogenously mixed sample was taken for laboratory testing. The volume of the conditioner was calculated based on the sludge volume in the mixing tank and total solids (TS) of the thickened FS. Drying beds were loaded in triplicate (three unconditioned FS and three conditioned FS). The FS was dewatered to TS≥ 90%. *M. oleifera* ("Moringa") was only tested in the laboratory.

Chitosan (Heppix A) was purchased from BiologHeppe, Germany and a 0.5% (wt./vol.) stock solution was prepared with 99% distilled water and 1% acetic acid. Moringa seed powder was purchased from Moringa Products Company, Tanzania. A 5% (wt./vol.) stock solution was prepared with demiwater. For each loading cycle, laboratory jar tests were first conducted to determine optimal conditioner dosage. Samples with different dosages were mixed in 800mL beakers for two hours at 100 rotations/min. Samples were then transferred to Imhoff cones and rested for 60 minutes to measure the settleability. Unconditioned FS from the same batch was used as a control. TSS of the supernatant was measured according to standard methods (APHA, 2005). Afterwards, the mixtures were re-suspended and dewaterability was determined using Capillary Suction Time (CST). The optimal dosage for a conditioner was defined as the dosage where both the TSS of the supernatant and the CST reached a reduction of 75% as compared to the unconditioned sample (Gold et al. (2016).

Composite samples of FS from vacuum trucks, thickened FS and leachate were analysed in triplicate for total solids (TS) and total suspended solids (TSS), following standard methods for wastewater analysis (APHA, 2005). Before analysis, each FS sample was homogenised in a blender. Dewatering rate (CST) was measured in triplicate with a Triton 304M apparatus, according to the manufacturer's instructions.

Results and discussion

Laboratory tests

Chitosan

Rates of dewatering increased with increasing doses of chitosan. On average, CST decreased from 385s to 31s at the highest dosage, a decrease of 92%. In the Imhoff cones, the TSS of the supernatant also decreased with increasing dosage. On average, the TSS in the supernatant decreased from 1.67 to 0.03mg/L at the highest dose (2mL/gTS), an improvement of 98%. These CST and TSS reductions are similar to the performance of commercial conditioners (e.g. lime and various polymers), which are 83-97% for TSS reduction and 91-100% for CST reduction (Gold et al. 2016). Dosages larger than the optimal dosage showed no significant improvement in TSS reduction. A dosage of 0.5mL/gTS was optimal for the first and second loading cycles, while 0.6mL/gTS was the optimal dosage in the third loading cycle. Table 1 shows the % reduction in CST and TSS for the optimal dosages. For each loading cycle, an optimal dosage was identified for both settling (TSS reduction), and for dewatering (CST reduction), and for the overall optimal considering both objectives. Presented in Table 1 are either the optimal settling efficiency (TSS reduction) or dewatering rate (CST reduction) depending on which had the lowest dosage, together with the optimal dosage for both settling efficiency and dewatering rate. This illustrates how some sludges settled better, whereas others dewatered faster. Similar observations were reported by Gold, et al. (2016). When selecting optimal dosages for implementation at full-scale, optimal dosages should be selected based on treatment goals and economic considerations. For example, with settling tanks followed by drying beds both settling and dewatering are treatment objectives, and for this sludge with a TS of 18.3g/L, 0.5mL/gTS of chitosan would be an appropriate dosage. With only settling tanks, a lower dosage would be sufficient.

A linear relationship between the TS and conditioner dosage was not observed. As indicated in Table 1, a slight increase in optimal dosage as the TS concentration increases was observed. Since conditioner dosage was based on actual TS variation, it is likely that the observed effect could be due to another unknown factor that might be non-linearly related to TS. For example, Mikkelsen and Keiding (2001) found that in activated sludge flocs an increased surface erosion in sludge with a higher TS resulted in an increased turbidity and increased conditioner requirement.

Table 1. Optimal dosage results for FS conditioning with chitosan in laboratory jar tests

Loading cycle	TS of thickened FS (g/L)	Optimal dosage (mL/gTS)	TSS reduction (%)	CST reduction (%)	Comments
1	18.3	0.4	83	64	Optimal for settling
		0.5	99	77	Optimal (≥75%)
2	30.3	0.5	64	74	Optimal for dewatering
		0.6	73	83	Optimal
3	39.3	0.5	88	62	Optimal for settling
		0.6	88	75	Optimal (≥75%)

Moringa

The dewatering rate decreased with increasing dosage of Moringa. Illustrated in the left-hand graph of Figure 2 is the observed reduction in CST with the four replicates. On average, the CST improved from 183 to 19s at the highest conditioner dose (20mL/gTS), a 90% improvement. The right graph shows the reduction of TSS in the supernatant. TSS also decreased with increasing dosage, though a smooth trend was not visible in all replicates. On average, the TSS reduced from 0.4s in unconditioned FS to 0.04s at the highest dosage (20mL/gTS), also a 90% improvement.

As in Table 1, presented in Table 2 are results for the lowest dosage at which either TSS reduction or CST reduction was optimal, and the optimal dosage where both settling efficiency and dewatering rate were optimal. For replicate 1, both reached >75% reduction at the same dosage (5.0mL/gTS). For the two sludges with a relatively low concentration of TS (2.1 and 4.0g/L), it was observed that much higher dosages of conditioner were required to obtain ≥75% reduction for both TSS and CST. For replicate 2, none of the tested dosages fulfilled the ≥75% reduction requirement for CST. At the highest dosage of 20mL/gTS, CST was still only reduced by 38%, as presented in Table 2. This could be due to the lower concentration of particles being too sparse to come into contact and coagulate effectively.

Doses of Moringa conditioner needed for application on the pilot-scale drying beds was calculated based on TS. To condition the 3500L of sludge at optimal dosage, 688, 147, 486, and 175L of Moringa solution were necessary to condition replicates 1-4 respectively. Based on these laboratory results, it was decided not to proceed any further with Moringa testing due to the large volumes that would be required, making implementation prohibitively expensive.

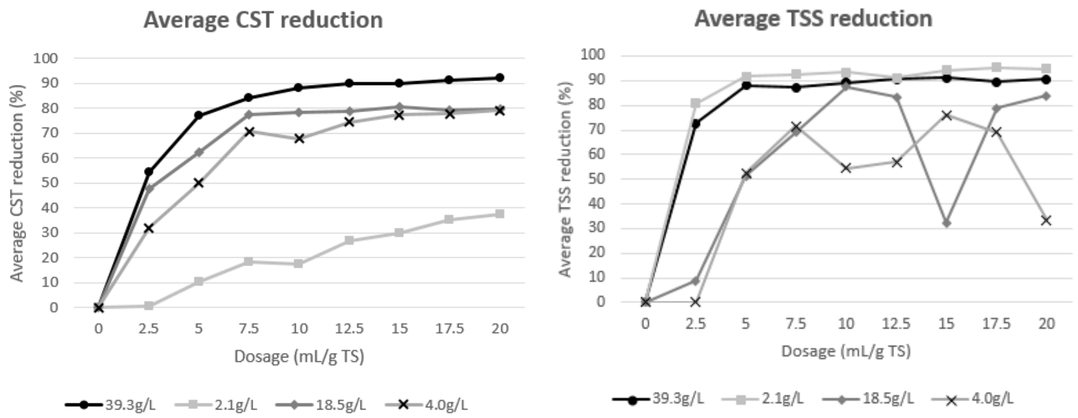

Figure 2. Average reduction in CST and TSS per dosage of Moringa for four FS replicates

Table 2. Optimal dosage of Moringa for FS settling and dewatering in laboratory jar tests.

Replicate	TS of sludge (g/L)	Optimal dosage (mL/g TS)	TSS reduction (%)	CST reduction (%)	Remarks
1	39.3	5.0	88	77	Optimal (≥75%)
2	2.1	2.5	81	0	Optimal for settling
		20.0	95	38	Optimal for settling, (no optimal dosage for dewatering)
3	18.5	7.5	69	78	Optimal for dewatering
		10.0	88	78	Optimal (≥75%)
4	4.0	12.5	57	75	Optimal for dewatering
		15.0	76	77	Optimal (≥75%)

Pilot-scale tests

TS of the sludge on drying beds was measured from the time that free water was removed, as indicated by no more leachate draining from the beds. This was on average 9 and 19 days for the conditioned and unconditioned FS respectively, representing a 53% reduction in dewatering time. The TS concentration on the drying beds was monitored to complete dryness, as designated by 90% TS. This level was selected, as FS that is 90% TS is acceptable for use as a solid fuel. The drying times to reach 90% TS are shown in Figure 3 for all three loading cycles. The difference in total days needed for drying between the three loading cycles is attributed to the difference in TS of the sludge and thus a difference in OLR. The first loading cycle with a TS concentration of 18.3g/L (OLR 107kg/m2/year) had an average drying time of 21 days for the conditioned FS and 24 days for unconditioned FS, which is a 12.5% reduction in drying time. The decrease in dryness that was observed in the second loading cycle around days 19-26 was due to heavy rainfall during monsoon season in Dar es Salaam, which directly affected the performance of the drying beds. Due to rain interference, the difference in drying between conditioned and unconditioned FS in this cycle was unclear. For this reason, the experiment was stopped and a new loading cycle was started. In the third loading cycle (OLR 230kg/m2/year), the conditioned FS dried to 90%TS in 68 days, and the unconditioned FS in 83 days, which is a 18% reduction in drying time. The longer drying time in loading cycle 3 as compared to loading cycle 1 was likely due to the higher resulting OLR based on the different TS concentrations. The observed decrease in drying times of 12.5% and 18% could result in an increased loading frequency when using chitosan as a conditioner, meaning based on these results 12.5% - 18% more sludge could be treated. A similar range of 9-26% was also observed by Gold et al. (2016).

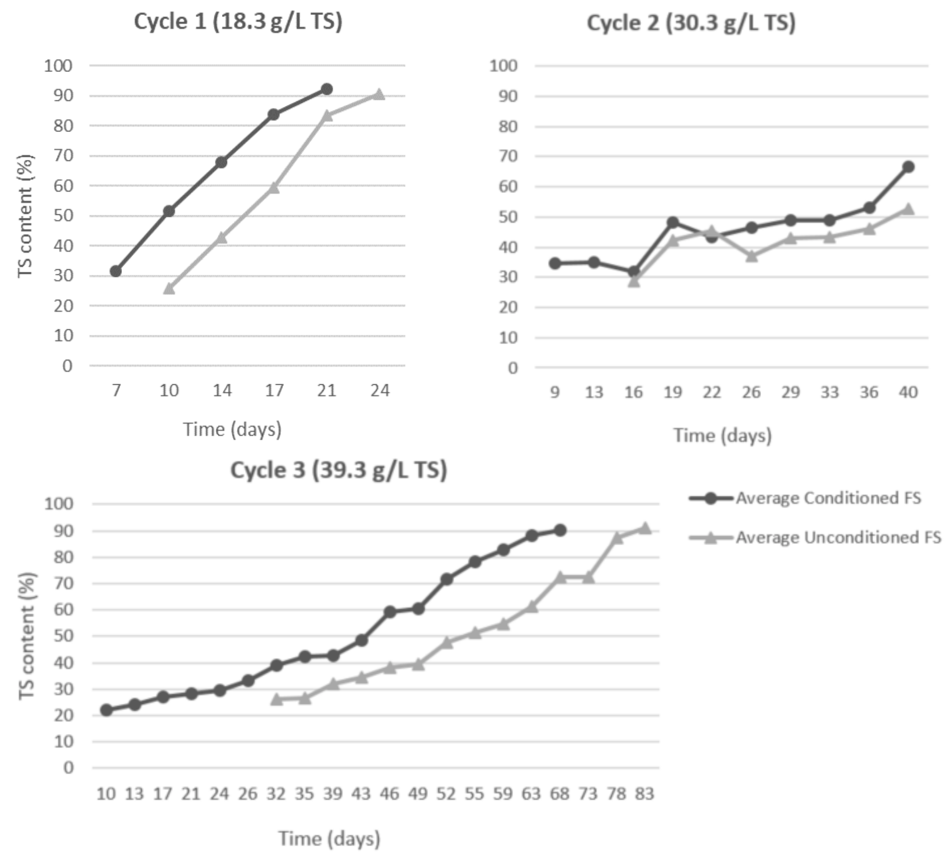

Figure 3. Average drying time on unplanted drying beds

The leachate from the drying beds loaded with unconditioned sludge had an average TS of 2.1g/L, and the leachate from conditioned FS 1.9g/L. An increase in TS was observed near the end of the loading cycle for both. A low TSS of 0.02-0.11 g/L in the leachate was achieved in each of the loading cycles. No significant difference between conditioned and unconditioned FS could be distinguished in terms of the quality of the leachate.

Based on these results, the amounts of conditioner that would be required for a full-scale (i.e. for 1,000 L) implementation are summarized in Table 3. The difference between chitosan and Moringa is 8-20 fold. Application of a 0.5 mL/gTS dose of chitosan to a drying bed that is loaded within the advised OLR range of 100-200 kg TS/m2/year, 50-100L chitosan solution is needed. That equals 2.5-5kg chitosan product/m2/year. For the use of conditioners to be beneficial, the associated costs would have to be balanced with the need for reduced land area or increased treatment volume.

The lack of a sustainable supply for operational materials (which includes conditioners) has been mentioned as a reason for failure of treatment plants (Bassan, Koné, Mbéguéré, Holliger, & Strande, 2015). In countries where sourcing synthetic conditioners is difficult or expensive (e.g. due to high import taxes or difficult transportation networks), chitosan could be a less expensive alternative as it could feasibly be produced locally, for example from waste shrimp shells from shrimp farms (Gold et al., 2016). This would avoid delays in delivery through import or transportation problems, and so could result in a more sustainable conditioner supply.

Table 3. Amount of conditioner needed to condition 1000L of FS at optimal dosage

Replicate	TS (g/L)	Chitosan (L)	TS (g/L)	Moringa (L)
1	18.3	9.1	39.3	196.5
2	30.3	15.1	2.1	-
3	39.3	23.6	18.5	185
4	NA	NA	4.0	60

Conclusion

Although Moringa was effective as a conditioner to improve dewatering in laboratory jar tests, it is not recommended as a conditioner for FS as the required dosing is extremely high (5-10mL/gTS). Based on laboratory jar tests, the optimal dose of chitosan was 0.5-0.6mL/gTS. This was confirmed in field tests with an average of 15.3% reduction in drying time, and thus 15.3% more sludge that could be treated or land area that could be reduced. These results confirm the dosages that Gold et al. (2016) obtained in Senegal, and indicate that the use of chitosan as a conditioner can be replicated in different locations, and be scaled up to improve the dewatering of FS. The optimal dosages found in this study can serve as an appropriate starting point for implementation at full-scale. However, to implement conditioning of FS at full-scale, an approach like this still needs to be employed where TS is determined prior to dosing, as FS is highly variable and conditioning performance is dependent on the specific sludge characteristics. In-line dosing of conditioners would be desirable, but further research is needed into fundamental mechanisms of dewatering of FS to understand what and how to monitor for before that can become a reality.

Acknowledgements

Funding for this research was provided by the Swiss Development Corporation (SDC).

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