Dewatering of faecal sludge with geotextiles:

Results from laboratory and bench-scale experiments in Kampala, Uganda

Sludge to Energy Enterprises in Kampala (SEEK)

Fritzi Ziebell[1]
Moritz Gold[1]
Jafari Matovu[2]
James Maiteki[3]
Charles Niwagaba[4]
Linda Strande[1]

[1]Eawag: Swiss Federal Institute of Aquatic Science and Technology
Sandec: Department of Sanitation, Water and Solid Waste for Development

[2]Private Emptier Association Uganda Limited (PEAU)

[3]National Water & Sewerage Corporation (NWSC)

[4] Makerere University
College of Engineering, Design, Art and Technology (CEDAT)
Department of Civil and Environmental Engineering

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List of Abbreviations

COD	– chemical oxygen demand
CST	– capillary suction time
EC	– electrical conductivity
FS	– faecal sludge
FSTP	– faecal sludge treatment plant
GDT	– geotube dewatering test
HBT	– hanging bag test
NWSC	– National Water & Sewerage Corporation
TS	– total solids
TSS	– total suspended solids
TVS	– total volatile solids

Nomenclature

%TS	– percent total solids
mL/gTS	– milliliter per gram total solids
g/L	– gram per liter
mS/cm	– millisiemens per centimeter
mL	– milliliter
L/min	– liter per minute

1. Introduction

Worldwide, sanitation needs of 2.7 billion people are met by onsite sanitation technology such as pit latrines and septic tanks (Cairns-Smith et al., 2014). These technologies collect large amounts of faecal sludge (FS). FS is *the raw or partially digested, semisolid or slurry resulting from collection, storage or treatment of combinations of excreta and blackwater, with or without greywater that accumulates in these technologies* (Strande, 2014). Onsite sanitation technologies can provide adequate and affordable sanitation given that faecal sludge management (FSM) is in place, including collection, transport, treatment and safe enduse or disposal of FS (Dodane et al., 2012; Strande, 2014). Currently, the majority of FS in low-income countries is discharged inadequately or untreated into the urban environment. For example, in Kampala, Uganda, 46% of excreta is not safely managed (Schoebitz et al., 2016). In other East African cities, even less excreta is adequately managed. In Dar Es Salaam, Tanzania, and in Nakuru, Kenya, 57% and 64% of excreta are not safely managed (Brandes et al., 2015; Furlong, 2015). This has significant public and environmental health, and economic implications (Bartram et al., 2010; Boschi-Pinto et al., 2008; Hutton et al., 2004; Mara et al., 2010).

In urban areas with reliable water supply and/or high groundwater levels, FS commonly consists of > 95% water (Cofie et al., 2006; Gold et al., 2016; Niwagaba et al., 2014; Seck et al., 2015; Sonko et al., 2014; Strauss et al., 1997). For example, in Kampala it is about 97-99% (Gold et al., submitted; Schoebitz et al., in preparation). This makes FS dewatering one of the most important treatment goals. In addition, water is heavy and thus expensive to transport. This suggests that dewatering can contribute to financial viable FS transport logistics. Drying beds are the most commonly used treatment technology for FS (Dodane et al., 2014). In comparison to other dewatering technologies, drying beds have low capital and operational costs and a low operational complexity. However, they require long dewatering times and produce a treatment product that can have a low resource recovery value (e.g. high ash content for use as fuels) (Seck et al., 2015).

Geotextiles are permeable fabrics that have the potential to dewater sludge more efficient than drying beds. Geotextiles are commercial products sold by several manufacturers in a tube or bag form and have been used in many countries for the dewatering of sludge from various sources (e.g. wastewater treatment, aquaculture) at different scales (Ebeling et al., no year; Fowler et al., 1997; Fowler et al., 2002; Tencate, 2002; Wei et al., 2015). During operation, the bags or tubes are filled with sludge. Following filling, the free water drains through the permeable geotextile material with hours or days. Geotextiles operate by gravity, have no mechanical parts, produce no noise and are modular in operation. This makes them potentially suitable for decentralized FS treatment. A disadvantage is that the geotube is usually discarded once the entire volume is occupied by solids.

Limited information is available for the dewatering of septic tank FS with geotubes. Tencate (2013a) reported TS of up to 40% for dewatering of septic tank FS in Canada. Kome (2011) reported the use of tubes for dewatering of septic tank FS in Malaysia without providing details about their performance. According to one manufacturer, for wastewater sludge, solid-liquid separation efficiencies can be > 99% total suspended solids (TSS) with total solids (TS) in the dewatered sludge of 25-30% (Tencate, 2002;2013a). This is in reason to around 25 %TS for dewatered wastewater sludge reported by Fowler et al. (2002).

According to the manufacturer, geotextiles require the use of conditioner to avoid clogging of the geotextile layer. Gold et al. (2016) identified that chitosan, a conditioner that could be produced from shrimp waste locally, can be effective in increasing septic tank FS dewatering.

The objective of this study was to assess the dewatering performance of septic tank and pit latrine FS conditioned with chitosan in geotextiles through laboratory and bench-scale experiments. The overall goal was to identify ways to improve FS dewatering that are scalable. This study also assessed the feasibility of implementing geotextiles for centralized and decentralized FS treatment.

2. Materials and Methods

This research took place over a period of five months (April to August 2016) at Makerere University and at the National Water & Sewerage Corporation (NWSC) Lubigi Wastewater and Faecal Sludge Treatment Plant (in the following referred to as NWSC Lubigi) in Kampala, Uganda.

2.1 Research design

The general research design consisted of three parts:

1. Laboratory experiments with chitosan to identify the optimal conditioner dosage for septic tank and lined pit latrine FS from households in Kampala.
2. Laboratory experiments with geotextiles to assess the general feasibility of geotextiles before bench-scale experiments using the optimal conditioner dosage identified in the preceding laboratory experiments.
3. Bench-scale implementation of geotubes with the Geotube Dewatering Test (GDT) and Hanging Bag Test (HBT) at NWSC Lubigi to collect data in order to assess the feasibility for geotubes for centralized and decentralized FS dewatering using the optimal conditioner dosage identified in the preceding laboratory experiments.

2.2 Faecal sludge sampling

FS was collected at NWSC Lubigi before each experiment. In each experiment, one sample comprised of ten composite samples was used. Composite samples were collected from vacuum trucks discharging lined pit latrine and septic tank FS respectively. Composite samples comprised of four grab samples collected during vacuum truck discharge, one at the beginning, twice in the middle and one at the end (Klingel et al., 2002; Niwagaba et al., 2014). FS used in this study was collected from households exclusively. Grab samples from trucks which had visually very low solids concentrations, i.e. TS <2 g/L, were discarded. Samples used for laboratory-scale experiments were put on ice following sampling and transferred to the laboratory immediately after sampling. Samples were stored in a fridge at 4°C for a maximum of three days. Samples used for bench-scale experiments were kept at NWSC Lubigi without refrigeration for three to seven days.

2.3 Preparation of conditioner

Based on the results from previous studies, chitosan was selected as conditioner for this research (Gold et al., 2016; Li et al., 2003). Chitosan (Heppix A) was obtained from Biolog Heppe GmbH, Germany, in a solid form. According to the manufacturer`s directions, chitosan was mixed with water and acetic acid in a ratio of 0.01:0.99:0.01 and mixed for two hours to produce a 1% (wt./vol.) solution. This solution was further diluted with distilled water to a 0.5% (wt./vol.) stock solution.

2.4 Faecal sludge conditioning

Before any analysis, FS was sieved through a 5 mm sieve in the laboratory. FS was conditioned with a jar test device (Stuart Scientific, wagtech Flocculator SW5). The conditioner was added to 800 mL FS in different dosages and compared in parallel to a control with no conditioner.

To ensure that the conditioner was well-mixed into the sample, 250 rpm for two minutes was selected for mixing during jar tests (Gold et al., 2016). Following, FS was settled for 30 minutes in graduated Imhoff cones and a change in settling behavior, floc size and TSS concentration was qualitatively monitored. Following settling, 500 mL of FS was decanted from the Imhoff cones without disturbing the settled sludge volume. The remaining settled sludge was transferred to beakers and used for capillary suction time (CST) analysis.

Gold et al. (2016) identified optimal dosages for septic tank FS in Dakar, Senegal, of 0.3-0.75 mL/gTS but also measured improved dewatering at dosages around 0.2 mL/gTS. According to the manufacturer, for wastewater sludge with TS < 3%, dosages of 0.02-0.2 mL/gTS are suitable (Heppe, personal communication). Therefore, dosages between 0 and 2 mL/gTS were assessed in this study. The optimal dosage for conditioning (i.e. the lowest CST) was determined iteratively. In a first iteration, FS was conditioned with 0, 1.0 and 2.0 mL/gTS. In further iterations, the dosages were divided in half if the CST concentration was different form unconditioned sludge or the previous dosage. Experiments were conducted with three different septic tank and lined pit latrine FS samples.

2.5 Laboratory-scale dewatering experiments

Dewatering of unconditioned and conditioned FS was measured in laboratory-scale experiments with a CST unit (Triton Electronics Ltd., Capillary Suction Timer Type 340M) and the cone test according to Tencate (2013b). CST was conducted to determine the sludge filterability as well as to evaluate the performance of the conditioner prior to its application in the cone test. According to the geotextile manufacturer, cone tests provide a direct indication on the performance of FS with geotextiles. Therefore, cone tests were used to assess the dewatering performance of geotextiles in the laboratory before the bench-scale dewatering experiments (Huesker, 2016). CST was carried out in three triplicates.

Based on the manufacturer`s directions, CST analysis was carried out as follows: The test-head assembly was plugged in the CST unit. A filter paper, rough side uppermost, was placed onto the base of the two Perspex blocks and the electrode block was then placed onto the filter paper, ensuring the electrodes contact the filter paper. Thereafter the funnel was inserted into the electrode block. A one centimeter diameter funnel was used in all experiments. After resetting the counter, a well-mixed sludge sample was poured into the funnel using a ladle. The approximate sample volume was 5 mL (Triton Electronics Ltd., 1998).

The study also looked into the potential influence of electrical conductivity (EC) on the CST, based on the manufacturer`s recommendation. Therefore, samples of lined pit latrine FS were diluted with deionized water to reduce the EC to 8 mS/cm or lower before further conditioning and CST.

Geotextile cone tests were performed in single in single with unconditioned mixed FS in a ratio of 60% septic tank and 40% lined pit latrine FS as well as for conditioned septic tank FS at five different dosages identified from the previous CST experiments ranging from 0.125-2 mL/gTS. In the cone test, as shown in Figure 1, a geotextile material in an A4 format was folded into a cone and clamped to a 2 L bucket (Tencate, 2013b). The conditioned FS sample was then poured through the geotextile cone and the filtrate was collected and measured. The filtration rate was calculated from measurements of filtration time of 500 mL FS over a surface area of 113 cm^2. The visual appearance of the flocs formed and the separation of the filter cake from the geotextile were recorded.

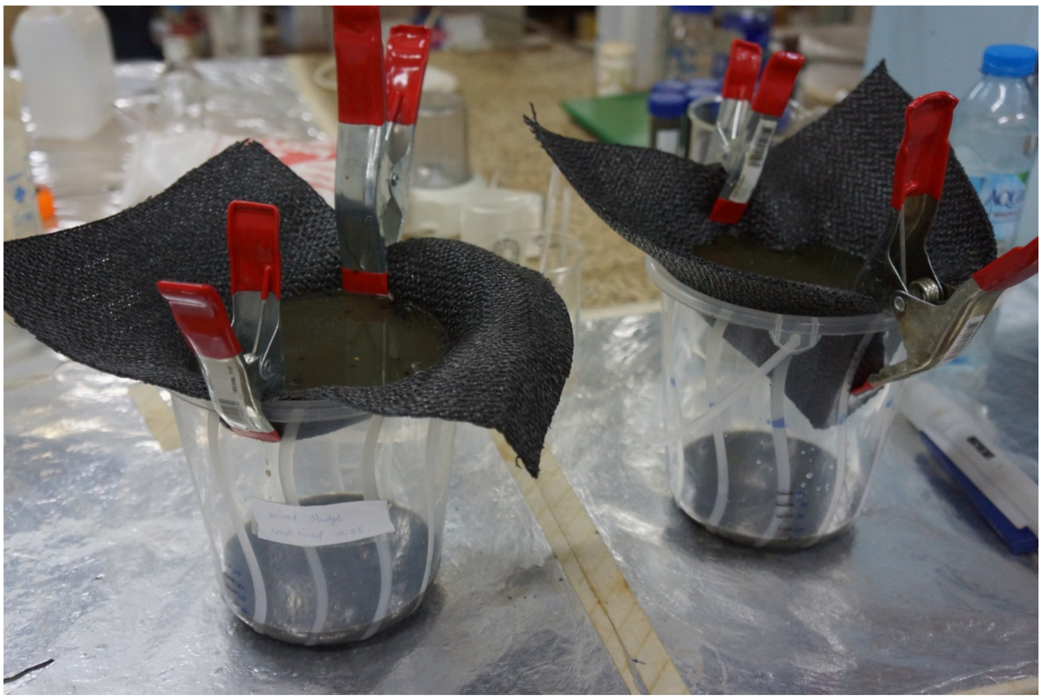

Figure 1: Experimental set up of geotextile cone tests

2.6 Bench-scale dewatering experiments

Two bench-scale experiments, namely GDT and HBT (see Figure 2) were carried out following the laboratory experiments to further determine the treatment and filtration performance of geotextiles. Both experiments were carried out based on protocols provided by Tencate and should imitate full-scale sludge dewatering (Tencate;2007;no year).

Figure 2: Experimental set up of GDT (Left) and HBT (right) (Tencate;2007)

The GDT used a geotextile pillow with a volume of 19 L. The small geotextile pillow was placed on a crate inside a basin to collect the effluent. It was filled with conditioned septic tank FS in two repetition and two dosages, 0.5 and 1 mL/gTS. The FS was poured into the pillow through the top of a standpipe (see Figure 3). Once full, the FS inside the geotextile pillow was let to dewater (see Figure 4). Each pillow was filled continuously for four times. In contrast to the pillow volume of 19 L provided by the manufacturer, it was possible to fill it with up to 60 L.

Figure 3: Loading of geotextile pillow with conditioned septic tank FS.

Figure 4: Geotextile pillow loaded with FS.

The HBT follows a similar procedure than the GDT. The geotextile bags have a volume of 300 L, an opening on one end and are hanging on a frame (see Figure 5). It was carried out with conditioned septic tank FS in three repetitions for the dosage of 1 mL/gTS. The well-mixed, conditioned sludge was filled into the bags by pumping it through a 3m long hose pipe until full and let to dewater. During the second repetition, the bag was refilled with conditioned sludge for three times. The effluent exiting the bag at the bottom was collected in buckets below the hanging bag. The dewatering process of the FS was monitored, samples of the effluent were taken at the beginning, in the middle and at the end of each trial for further analysis.

Figure 5: Experimental set up of HBT

2.7 Analyses

Before conditioning, FS was analyzed for pH, EC, temperature, TS, total volatile solids (TVS), TSS and CST. In each experiment, all analysis of one of the two sludge types was analyzed in triplicates. CST was measured in duplicates. CST analysis with a difference of >20% were repeated multiple times.

Dewatered FS and effluent from the dewatering processes were analyzed for pH, EC, and temperature. In addition, dewatered FS was analyzed for TS and TVS and the effluent was analyzed for TSS. Analysis of solid parameters were based on Standard Methods (American Public Health Association (AWA) et al., APHA et al., 2012). TS were measured gravimetrically by drying in an oven at 105 °C, and TVS at 550 °C. Glass fiber filters with a diameter of 47mm and a pore size between 1.0 and 1.6 µm were used for TSS analysis. EC, temperature and pH were measured with a Hach HQ30d meter according to the manufacturer`s directions.

3. Results and Discussion

3.1 Faecal sludge characteristics

Results of the physical characteristics of FS collected from vacuum trucks and used in the experiments are presented in Table 1. Septic tank FS in this study had higher TS concentration compared to septic tank FS in Dakar, Senegal. Seck et al. (2015) and Gold et al. (2016) reported TS concentrations of 5.5 g/L and 9.2 g/L respectively compared to 11.7 g/L in this study. Sonko et al. (2014) reported TS concentrations ranging from 2.1-21.4 g/L. The variability in FS characteristics between cities should be considered when transferring the results of this study.

FS characteristics are also variable within Kampala. Fichter Water & Transportation et al. (2008) and Gold et al. (submitted) reported TS concentrations of 22 g/L and 8 g/L for septic tank FS and 40 g/L and 22 g/L for pit latrine FS. Based on the TS concentrations for septic tank FS of 11.7 g/L and lined pit latrine FS of 28.7 g/L in this study, FS used in the experiments is representative of FS in Kampala.

pH for septic tank and lined pit latrine FS was 7.9. This in line with previous studies that reported results for pH of 7.8-7.9 (Gold et al., 2016; Seck et al., 2015). EC was very different for the two sludge types which is in line with previous studies. Previous studies reported EC of 4.3-4.5 mS/cm for septic tank FS and 18.1 mS/cm for lined pit latrine FS in comparison to 7.8 mS/cm and 13.4 mS/cm in this study (Gold et al., 2016; Seck et al., 2015)(unpublished data. Sandec/Eawag). pH and EC are parameters that can have an influence on the effectiveness and dose of conditioners (Kopp et al., 1998; Turovskiy et al., 2006).

Table 1: Physical characteristics of FS used in the experiments.

Sludge Type	Repetition	TS (g/L)	TVS (g/L)	TSS (g/L)	pH (-)	EC (mS/cm)
Septic tank FS	1	7.1	4.2	5.2	7.8	9.4
Septic tank FS	2	18.2	12.1	17.0	7.5	5.0
Septic tank FS	3	14.1	8.7	12.1	7.9	11.3
Septic tank FS	4	9.3	5.7	7.6	7.9	11.6
Septic tank FS	5	7.5	4.4	5.9	8.0	11.9
Septic tank FS	6	7.4	4.4	5.0	-	-
Septic tank FS	7	11.8	9.0	10.2	7.7	4.8
Septic tank FS	8	7.4	5.1	5.7	8.1	4.0
Septic tank FS	9	20.0	12.9	18.3	8.0	4.0
Septic tank FS	10	14.2	7.1	11.6	8.4	8.4
Septic tank FS	**Average**	**11.7 ± 18**	**7.4**	**9.9**	**7.9**	**7.8**
Lined pit latrine FS	1	15.2	8.2	10.2	7.8	13.2
Lined pit latrine FS	2	34.1	21.4	26.6	7.8	15.3
Lined pit latrine FS	3	25.6	15.4	22.7	7.9	12.0
Lined pit latrine FS	4	28.6	17.4	24.4	8.0	12.5
Lined pit latrine FS	5	39.8	21.8	32.8	8.0	14.0
Lined pit latrine FS	**Average**	**28.7 ± 1**	**16.8**	**23.3**	**7.9**	**13.4**

3.2 Faecal sludge conditioning (Repetition 1-3)

FS conditioning in the laboratory was different between lined pit latrine and septic tank FS. Figure 6 shows lined pit latrine FS and septic tank FS conditioned at a dosage of 1 mL/gTS. Septic tank FS showed a formation of flocs and an increased solid-liquid separation (see CST results below). In contrast, no flocs formed for lined pit latrine FS and the sample stayed similar to the control.

Figure 6: Conditioned lined pit latrine FS (left) and septic tank FS (right) at a dosage of 1 mL/gTS.

These qualitative results were confirmed by the CST results. CST was used in this study as a proxy for the dewatering rate. A lower CST means a faster dewatering rate. Absolute CST results are presented in Table 3 in the appendix. Figure 7 shows CST results of repetitions one to three (also see Table 1).

Conditioning of lined pit latrine FS with chitosan did not reduce the CST by more than 15%. The variability of CST results for the same sample of lined pit latrine FS was 1-20%. Thus, conditioning of lined pit latrine FS with chitosan reduced the CTS by only a few percent. According to the chitosan manufacturer (Heppe, personal communication), this low effectiveness could be attributed to the high EC. High EC concentrations are likely attributed to high dissolved solids concentrations, salts and ammonia and can have an important influence on the effectiveness of the conditioner (Kopp et al., 1998; Turovskiy et al., 2006). Previous problems were encountered with liquid manure and an EC > 8 mS/cm (Heppe, personal communication).

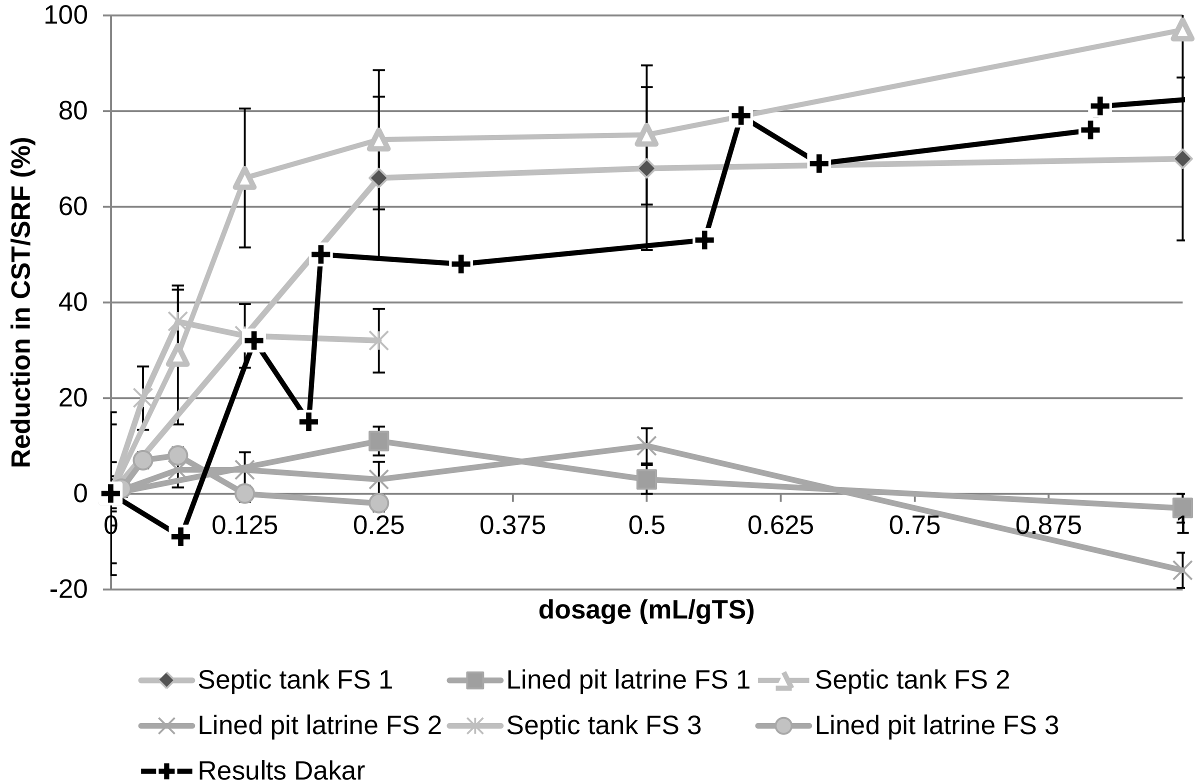

Figure 7: Reduction in CST by conditioning with chitosan in Kampala and Dakar (Gold et al., 2016). The number behind the sludge type refers to the repetition (see Table 1).

To assess the influence of EC on conditioning with chitosan, FS samples were diluted with water from an EC of 13.4 mS/cm to an EC of 5 mS/cm. Figure 8 compares CST reduction of undiluted to diluted lined pit latrine FS. Lowering the EC does show an effect on the reduction in CST, however, it does not exceed 15% for both dosages. These experiments were only done in single and require to be replicated. Based on the low reduction in CST for lined pit latrine FS, chitosan was found to be not applicable for conditioning of lined pit latrine FS in Kampala.

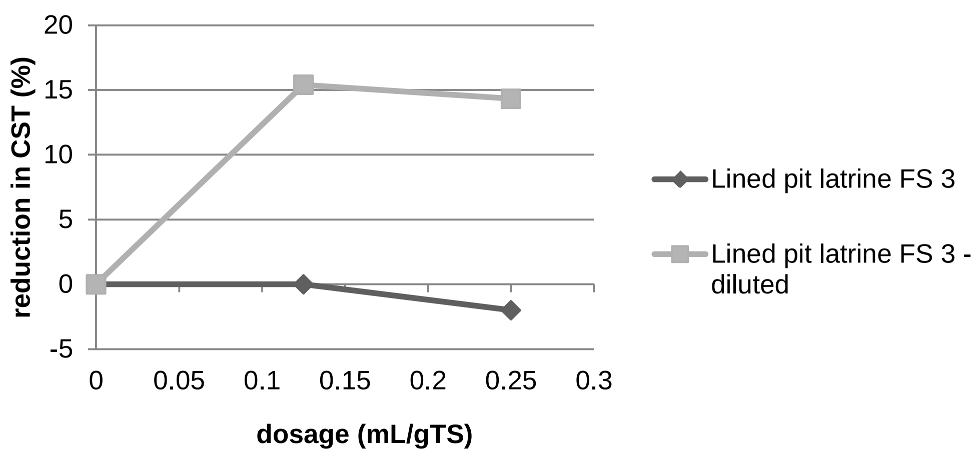

Figure 8: Reduction in CST for lined pit latrine FS, diluted and undiluted.

In contrast, conditioning of septic tank FS with chitosan reduced the CST by 29-97% in repetition one and two. The CST increased with conditioner dosage. The reduction in CST in repetition 3 did not exceed 40% which can be associated with the high EC of 11.3 mS/cm (see Table 1) (Heppe, personal communication). Figure 7 also includes results on the reduction of specific resistance to filtration (SRF) of septic tank FS after conditioning with chitosan in Dakar (Gold et al., 2016). These results are in reason with the results of this study.

Gold et al. (2016) concluded that the optimal dosage for septic tank FS conditioning in Dakar with chitosan was 0.75 mL/gTS as consistent increase in the dewatering rate of 75% was measured. In this study, reduction of around 75% was recorded at a dosage exceeding 0.25 mL/gTS. Using the same definition for the optimal dosage as Gold et al. (2016), the optimal dosage of chitosan for septic tank FS in Kampala can be estimated as 0.25-0.5 mL/gTS. The difference in the optimal conditioner dosage could be attributed to different septic tank FS characteristics between Kampala and Dakar, or with an optimized methodology to determine the FS dewatering rate (i.e. SRF versus CST). Optimal dosages for Dakar and Kampala are still higher than those recommended for wastewater sludge of 0.02-0.2 mL/g TS (Heppe, personal communication).

Based on these results, a conditioner dosage of 0.25-0.5 mL/gTS was selected for further laboratory experiments with geotextiles.

3.3 Laboratory experiments with geotextiles (Repetition 4-5)

Geotextiles were operated in cone test with mixed and septic tank FS in the laboratory before bench-scale experiments. Unconditioned mixed FS as well as unconditioned septic tank FS clogged the geotextile following filtration for a few seconds (repetition four and five). A filtration rate could not be determined. Therefore, these sludge types were not considered for further bench-scale experiments.

In contrast, laboratory experiments with septic tank FS conditioned with chitosan suggest that dewatering with geotextiles is feasible. Based on the filtration rate and solid-liquid separation efficiency with geotextiles, a dosage of ≥ 0.125 mL/g TS is optimal. Figure 9 demonstrates that filtration rates, thus, the dewatering time varied depending conditioner dosage, and a higher filtration rate can be achieved by increasing the conditioner dosage. The solid-liquid separation efficiency (TSS_{in} - TSS_{in} / TSS_{in}) for all dosages had a low variability and ranged from 76 to 83%. Sludge with the lowest dosage of 0.125 mL/gTS had a solid-liquid separation efficiency of 79%, whereas sludge with the highest dosage of 2 mL/g TS had a solid-liquid separation efficiency of 82%.

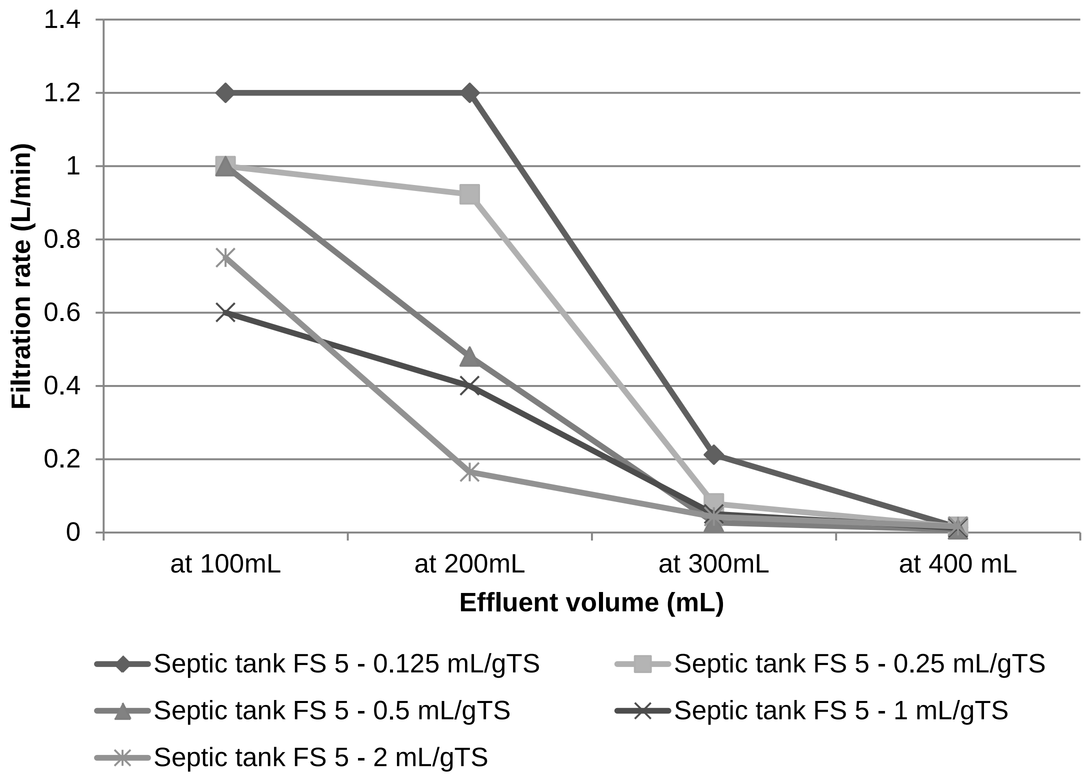

Figure 9: Filtration rate of conditioned septic tank FS in cone tests.

3.4 Bench-scale experiments with geotextiles (Repetition 6-10)

GDT and HBT were used to assess the dewatering performance of septic tank FS conditioned with chitosan at NWSC Lubigi. Table 2 summarized the FS volume used in experiments, the volume collected below the GDT/HBT, the TSS in the effluent and the TSS solid-liquid seperation efficiency. Due to time limitation and to assure the success of the experiments, higher conditioner dosages than the optimal dosages identified in the previous experiments were applied.

Table 2: Results GDT and HBT for septic tank FS conditioned with chitosan.

Repetition	Cycle	Dosage (mL/gTS)	Input volume (L)	Output volume (L)	TSS effluent (g/L)	TSS removal (%)	Dewatering time (h)
GDT							
7	1	0.5	30	22	0.55	95	24
	2		17	13	-	-	24
	3		20	12	-	-	24
	4		22	19	-	-	24
10	1	1	40	37	0.35	97	24
	2		46	40	0.20	98	24
	3		60	50	-	-	24
	4		30	-	-	-	24
HBT							
6	1	1	300	240	0.62	88	72
8	1	1	260	210	0.29	95	48
9	2		130	110	0.10	99	24
	3		130	119	-	-	24

Based on the solid-liquid seperation effincies from GDT and HBT experiments, septic tank FS can be efficiently seperated by geotexiles. In both experiments, the effluent was clear in colour and nearly odorless. Solid-liquid seperation effiencies were 97% ± 2% (mean, stdev) in both experiments. This performance is is reason to that reported by the manufacturer of 99% (Tencate, 2002;2013a). Ebeling et al. (no year) and Wei et al. (2015) applied geotextiles for sludge dewatering in aquaculture systems and reported solid-liquid seperation efficienies of 82% to 99% respectively.

The ratio of output and input volume, the absolute TSS concentrations are important design variables for geotexiels (see below). In GDT experiments, 79% ± 13% and in HBT 84% ± 6% of the input volume passed through the geotextile. Absolute TSS concentrations ranged from 0.2 to 0.6 g/L in GDT and 0.1 to 0.6 g/L in HBT experiments.

TS in the dewatered sludge from geotexiles was much lower in this study compared to literature values and experience by the manufucter. %TS in the dewatered sludge was only analyzed in one repetiton and was > 5%. This is likely due to a low initial TS of < 1% and because the sample was collected directly after percolation was completed. According to the manufactuer of the geotextiles, based on experience from wastewater sludge dewatering, TS of > 15% are feasible (Wiemers, personal communication). Tencate (2013b) reported TS of up to 40% for dewatering of septic tank FS in Canada. This should be validated by future research.

The solid-liquid seperation efficienies of geotextiles in this study of 97% ± 2% are in reason to those reported for unplanted drying beds. Cofie et al. (2006) and Heinss et al. (1998) reported TSS solid-liquid separation efficiencies of 96-99% and > 95% in Ghana respectively. This means that a similar separation of COD in the effluent of 70-90% as reported by Heinss et al. (1998) can be expected for geotextiles. However, one should keep in mind that the results in this study were obtained after a dewatering time of only one to three days whereas FS in the drying beds in the studies mentioned were let to dewater for a minimum of one week. That makes the use of geotextiles for FS dewatering more time efficient.

3.5 Implications for faecal sludge treatment and resource recovery

Some relevant aspects for the implementation of geotubes for centralized and decentralized FS dewatering will be discussed in this section for Kampala. For this case study, the geotubes were sizes and costs provided by a geotubes manufacturer in Germany (see annex). The folllowing discussions should highlight some relevant considerations relevant when considering the implementation of this technology. All restuls are highly depend on the input parameters such as TS, FS volume and performance of the geotubes. This should be considered when using the results.

Centralized FS dewatering (see scenario Ca and Cb in the annex)

Dewatering of FS with geotubes is more efficient and requires less space than settling-thickening tanks and drying beds. To dewater 400 m^3/day FS, goetubes would require 788 m^2 and 1050 m^2 for a %TS of 0.6% and 0.8% respectively. In contrast, settling-thickening tanks and drying beds at NWSC currently require approximately 1,000 m^2 and 4,000 m^2 respectively. This means that geotubes could be an interesting treatment technoloy when space is limited. Additonal space for drying of FS from geotubes would need to be considered for furtehr dewatering and drying required before use as soil conditioner or solid fuel.

In contrast to the requires space, dewatering with geotubes appears to have higher costs when considering a treatment operation of 20 years. At NWSC Lubigi, dewatering (incl. conditioning) would cost 15,633 USD/month and 20,844 USD/month for a TS of 0.6% and 0.8% respectively. These costs are much are higher than the current operation and maintenance costs for settling-thickening tanks and drying beds at NWSC Lubigi which are in the order of 1,000-3000 USD/month (Wolf, 2015). Investment costs were around 435,000 USD for settling-thickening tanks and 595,000 USD for drying beds (without side preparation) (Meistermann, personal communication). Therefore, considering a lifetime of these technologies of 20 years, settling-thickening tanks (around 1,800 USD/month) and drying beds (4,130 USD/month) would have lower costs than geotubes. However, these additonal costs could be outweight by the increased dewtaering efficiency and treatment space reduction. In additon, geotubes could be a suitable technology for temporary dewatering, for example during the construction of a FS treatment plant.

Decentralized FS dewatering (see scenario A and B in the annex)

Septic tank FS consists mostly of water. This means vaccum trucks are mostly transporting water which is heavy and expensive to transport. Sewer discharge stations along existing sewer lines could be used to reduce the need for FS transport (SNV, 2016).

FS should not directly be discharged into the sewer considering that FS commonly has one to two orders of magnitude higher concentrations in solids and organigs compared to wastewater (Lopez-Vazquez et al., 2014; Niwagaba et al., 2014). Therefore, among others, the potential of geotexiles for decentralized dewatering will depend on the ability to reduce solids and organics in FS. Other parameters such as nutrients are also relevant but not considered in this report.

Results of this study indicate that the effluent from geotubes can have similar TSS concentration (Table 3) than wastewater, but much higher COD concentrations. In this study, TSS concentration from geotubes were 0.1-0.6 g/L in comparison to 0.12-0.4 g/L typical for wastewater (Tchobanogous et al., 2003). Assuming that 70-90% of COD are seperad by geotubes and stays in the solids, which is common for drying beds that have a similar solid-liquid separation efficiency compared to geotubes (Heinss et al., 1998)(see above), COD concentrations of 1,805-5,415 mg/L can be expected. In comparison, typical COD concentrations in wastewater are 250-800 mg/L (Tchobanogous et al., 2003). This should be considered for the use of geotubes for sewer discharge stations and for the design of effluent treatement technologies (e.g. waste stabilization ponds).

Space is another imporant consideration for decentralized dewatering with geotubes as land is scare and expensive in urban areas. Space requirements were calculated for discharge of 50 and 100 m^3/day septic tank FS. According to the geotexile manufacturer, space requirements for the geotubes would be 200 and 300 m^2. This does not include space for the vacuum trucks discharge area, conditioning or offices. Dewatering costs (incl. conditioning) were estimated at 4,328 USD/months for 50 m^3/day and 6,267 USD/month for 100 m^3/day.

4. Conclusions

The results of this study indicate that the use of geotextiles could be an option for dewatering of FS, thereby increasing treatment capacity or reducing required land area for FSTPs in urban areas. Findings include the following:

- Chitosan as a conditoner is suitable for septic tank FS but not aplicable for lined pit latrine FS;
- Geotextiles have a similar performance compared to drying beds and are suitable for septic tank FS dewatering;
- The use of geotextiles for FS dewatering is time efficient;
- Further research for GDT & HBT is needed to clearly identify the optimal conditioner dosage <0.5 mL/gTS.
- More data on geotextile performance parameters is needed to evaluate the suitability of geotextiles for large-scale FS dewatering

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Appendix

Table 3: CST results (sec).

Sludge Type	Repetition	Conditioner dosage chitosan 0.5% (mL/gTS)								
		0	**0.01**	**0.03**	**0.0625**	**0.125**	**0.25**	**0.5**	**1**	**2**
Septic tank FS	1	266	-	-			92	86	81	63
Septic tank FS	2	552	-	-	394	188	143	136	18	
Septic tank FS	3	519	-	414	331	347	354			
Septic tank FS - diluted	3	462				264	264			
Lined pit latrine FS	1	738					658	715	763	967
Lined pit latrine FS	2	1247			1186	1181	1212	1127	1445	
Lined pit latrine FS	3	996	984	925	921	1000	1020			
Lined pit latrine FS - diluted	3	649				549	556			
Mixed FS 50/50	4	772	-		623	613				

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SoilTain® Calculator for the estimation of the required number of SoilTain® Dewatering Tubes[1]

(Up-dated 29.02.2016; V2.02)

Project-Nr.:	2007461	**Date:**	07.09.2016
Project:		**Person in charge:**	WIE
Client:	EAWAG Swiss		

1. Sludge input parameters

Insitu sludge volume to be dewatered	10.800	m³	
Percentage of solids of the insitu sludge[2]	0,6	%	
Percentage of solids of the hauled sludge[2]	0,6	%	(assumption)
Specific gravity of the sludge solid particles	2,40	t/m³	(assumption)
Percentage of solids to be achieved[2]	6,4	%	(assumption)

2. Pumping/hauling capacity

Delivery rate[3]	50,0	m³/h
Dredging efficiency rate	100,0	%
Working hours per day	8,0	h

3. SoilTain® Dewatering Tubes parameters

Perimeter	15,0	m	
Maximum filling height	2,2	m	
SoilTain® Dewatering Tube storage capacity[4]	11,3	m³/m	
SoilTain® width (unfilled)	7,5	m	(unfilled; flat outlayed)
Expected width after filling[4]	6,5	m	
SoilTain® length (unfilled)	35,0	m	(unfilled; flat outlayed)
SoilTain® Dewatering Tube volume (approx.)[4]	390,0	m³	

4. Derived sludge parameters

Insitu sludge density	1,0035	t/m³
Input sludge density	1,0035	t/m³
Estimated dewatered sludge density	1,0388	t/m³
Existing dry solids (DS)	65,0	t
Estimated amount of sludge to be pumped	10.800	m³
Expected filtrate volume	9.822	m³
Expected dewatered residuals	**978**	m³

5. Estimation of the required pumping time

Required days for pumping (net)[5]	27	d
Daily pumped sludge volume	400,0	m³
Daily treated amount of dry solids	2,4	t

6. Project requirements

Required number of SoilTain® Tubes	**3**	[-]	(according to 3.)
Required lenght of SoilTain® Tubes (unfilled)	105	m	
Required minimal space (no stacking)	788	m²	

SoilTain® Calculator for the estimation of the required number of SoilTain® Dewatering Tubes[1]

(Up-dated 29.02.2016; V2.02)

Project-Nr.:	461	**Date:**	07.09.2016
Project:		**Person in charge:**	WIE
Client:			

1. Sludge input parameters

Insitu sludge volume to be dewatered	10.800	m³	
Percentage of solids of the insitu sludge[2]	0,8	%	
Percentage of solids of the hauled sludge[2]	0,8	%	(assumption)
Specific gravity of the sludge solid particles	2,40	t/m³	(assumption)
Percentage of solids to be achieved[2]	6,4	%	(assumption)

2. Pumping/hauling capacity

Delivery rate[3]	50,0	m³/h
Dredging efficiency rate	100,0	%
Working hours per day	8,0	h

3. SoilTain® Dewatering Tubes parameters

Perimeter	15,0	m	
Maximum filling height	2,2	m	
SoilTain® Dewatering Tube storage capacity[4]	11,3	m³/m	
SoilTain® width (unfilled)	7,5	m	(unfilled; flat outlayed)
Expected width after filling[4]	6,5	m	
SoilTain® length (unfilled)	35,0	m	(unfilled; flat outlayed)
SoilTain® Dewatering Tube volume (approx.)[4]	390,0	m³	

4. Derived sludge parameters

Insitu sludge density	1,0047	t/m³
Input sludge density	1,0047	t/m³
Estimated dewatered sludge density	1,0388	t/m³
Existing dry solids (DS)	86,8	t
Estimated amount of sludge to be pumped	10.800	m³
Expected filtrate volume	9.494	m³
Expected dewatered residuals	**1.306**	m³

5. Estimation of the required pumping time

Required days for pumping (net)[5]	27	d
Daily pumped sludge volume	400,0	m³
Daily treated amount of dry solids	3,2	t

6. Project requirements

Required number of SoilTain® Tubes	**4**	[-]	(according to 3.)
Required lenght of SoilTain® Tubes (unfilled)	140	m	
Required minimal space (no stacking)	1.050	m²	

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SoilTain® Calculator for the estimation of the required number of SoilTain® Dewatering Tubes[1]

(Up-dated 29.02.2016; V2.02)

Project-Nr.:	2007461	**Date:**	08.09.2016
Project:		**Person in charge:**	WIE
Client:	EAWAG Swiss		

1. Sludge input parameters

Insitu sludge volume to be dewatered	1.350	m³	
Percentage of solids of the insitu sludge[2]	0,7	%	
Percentage of solids of the hauled sludge[2]	0,7	%	(assumption)
Specific gravity of the sludge solid particles	2,40	t/m³	(assumption)
Percentage of solids to be achieved[2]	6,4	%	(assumption)

2. Pumping/hauling capacity

Delivery rate[3]	50,0	m³/h
Dredging efficiency rate	100,0	%
Working hours per day	8,0	h

3. SoilTain® Dewatering Tubes parameters

Perimeter	8,0	m	
Maximum filling height	1,3	m	
SoilTain® Dewatering Tube storage capacity[4]	3,5	m³/m	
SoilTain® width (unfilled)	4,0	m	(unfilled; flat outlayed)
Expected width after filling[4]	3,4	m	
SoilTain® length (unfilled)	10,0	m	(unfilled; flat outlayed)
SoilTain® Dewatering Tube volume (approx.)[4]	30,0	m³	

4. Derived sludge parameters

Insitu sludge density	1,0041	t/m³
Input sludge density	1,0041	t/m³
Estimated dewatered sludge density	1,0388	t/m³
Existing dry solids (DS)	9,5	t
Estimated amount of sludge to be pumped	1.350	m³
Expected filtrate volume	1.207	m³
Expected dewatered residuals	**143**	m³

5. Estimation of the required pumping time

Required days for pumping (net)[5]	4	d
Daily pumped sludge volume	400,0	m³
Daily treated amount of dry solids	2,8	t

6. Project requirements

Required number of SoilTain® Tubes	**5**	[-]	(according to 3.)
Required lenght of SoilTain® Tubes (unfilled)	50	m	
Required minimal space (no stacking)	200	m²	

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SoilTain® Calculator for the estimation of the required number of SoilTain® Dewatering Tubes[1]

(Up-dated 29.02.2016; V2.02)

Project-Nr.:	2007461	**Date:**	08.09.2016
Project:		**Person in charge:**	WIE
Client:	EAWAG Swiss		

1. Sludge input parameters

Insitu sludge volume to be dewatered	2.700	m³	
Percentage of solids of the insitu sludge[2]	0,7	%	
Percentage of solids of the hauled sludge[2]	0,7	%	(assumption)
Specific gravity of the sludge solid particles	2,40	t/m³	(assumption)
Percentage of solids to be achieved[2]	6,4	%	(assumption)

2. Pumping/hauling capacity

Delivery rate[3]	50,0	m³/h
Dredging efficiency rate	100,0	%
Working hours per day	8,0	h

3. SoilTain® Dewatering Tubes parameters

Perimeter	10,0	m	
Maximum filling height	2,0	m	
SoilTain® Dewatering Tube storage capacity[4]	6,1	m³/m	
SoilTain® width (unfilled)	5,0	m	(unfilled; flat outlayed)
Expected width after filling[4]	4,2	m	
SoilTain® length (unfilled)	20,0	m	(unfilled; flat outlayed)
SoilTain® Dewatering Tube volume (approx.)[4]	120,0	m³	

4. Derived sludge parameters

Insitu sludge density	1,0041	t/m³
Input sludge density	1,0041	t/m³
Estimated dewatered sludge density	1,0388	t/m³
Existing dry solids (DS)	19,0	t
Estimated amount of sludge to be pumped	2.700	m³
Expected filtrate volume	2.415	m³
Expected dewatered residuals	**285**	m³

5. Estimation of the required pumping time

Required days for pumping (net)[5]	7	d
Daily pumped sludge volume	400,0	m³
Daily treated amount of dry solids	2,8	t

6. Project requirements

Required number of SoilTain® Tubes	**3**	[-]	(according to 3.)
Required lenght of SoilTain® Tubes (unfilled)	60	m	
Required minimal space (no stacking)	300	m²	

Table 4: Costs estimates for the use of geotubes for centralized and decentralized FS dewatering.

Item	Unit	Scenario A	Scenario B	Scenario Ca	Scenario Cb	Comment
FS volume	**m^3/day**	50	100	400	400	decentralized: Assumption; Centralized: Treatment capacity NWSC Lubigi
Working hours	**hours/day**	8	8	8	8	asssumption
Working days	**days/week**	6	6	6	6	asssumption
Weeks	**weeks/month**	4.5	4.5	4.5	4.5	asssumption
FS volume	**m^3/month**	1350	2700	10800	10800	calculated
TS	**%TS**	0.7	0.7	0.6	0.8	Schoebitz et al., in preparation
TS	**kg/m^3**	7	7	6	8	Schoebitz et al., in preparation
FS mass	**tons/month**	9.5	18.9	64.8	86.4	calculated
Tubes	**per month**	5	3	3	4	see Annex
Width	**m**	4	5	8	8	see Annex
Length	**m**	10	20	35	35	see Annex
Area	**m^2**	200	300	788	1050	see Annex
Tube cost	**USD/tube**	801	1'872	4'469	4'469	based on information provided by Huesker, including transport with full 20ft container
Tube costs	**USD/month**	**4'003**	**5'617**	**13'406**	**17'874**	**calculated**
Chitosan dosage	**mL 0.5%/g TS**	0.25	0.25	0.25	0.25	median of optimal dosage of this study
Chitosan dosage	**g dry chitosan/g TS**	0.00125	0.00125	0.00125	0.00125	calculated
Chitosan price	**USD/ton**	27'500	27'500	27'500	27'500	Biolog Heppe GmbH, Germany
Conditioner costs	**USD/month**	**325**	**650**	**2'228**	**2'970**	**calculated**
Total costs	**USD/month**	**4'328**	**6'267**	**15'633**	**20'844**	**calculated**