

# Sludge to Energy Enterprises in Kampala (SEEK)

## Drying of faecal sludge pellets

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## Introduction

Kampala, the capital of Uganda has a population of approximately 1.5 million people (Ugandan Ministry of Water and Environment, 2014). In Uganda, 94% of the population use onsite sanitation technologies such as pit latrines or septic tanks which are not connected to a sewer (Ugandan Ministry of Water and Environment, 2014). This results in the production of large amounts of faecal sludge (Byrne et al., 2016; Strande, 2014). According to the Ugandan Ministry of Water and Environment, in Uganda, faecal sludge from 30% of latrines is discharged into the environment (Ugandan Ministry of Water and Environment, 2014). In Kampala, a treatment capacity of only 400 m<sup>3</sup> FS/day exist whereas over 600 m<sup>3</sup> FS/day are being collected (Orwiny, personal communication). Currently, large amounts of faecal sludge are discharged untreated directly into the urban environment, jeopardizing public and environmental health.

Among others, one reason for inadequate faecal sludge management are insufficient financial capacities. Resource recovery from faecal sludge treatment endproducts such as use as soil conditioner, solid fuel or feedstock for biogas production can provide financial resources to offset faecal sludge management costs and work towards providing sustainable and safe sanitation (Diener et al., 2014). The SEEK (Sludge to Energy Enterprises in Kampala, [www.sandec.ch/seek](http://www.sandec.ch/seek)) project researched resource recovery from faecal sludge through pelletizing and gasification (Englund et al., 2016; Tukahirwa et al., 2016)

Dewatered faecal sludge (e.g. from drying beds) has unsuitable fuel properties for gasification (Byrne et al., 2016; Gold et al., in press; Tukahirwa et al., 2016). Pelletizing of faecal sludge can be used to produce a homogeneous fuel size (Englund et al., 2016). Various biomass pelletizers exist on the market. However, they commonly only operate with biomass with a moisture content of 10 to 15%. As faecal sludge commonly has a moisture content > 95% this means costly and space intensive drying is required before pelletizing and gasification (Seck et al., 2015)

The objective of this study was to investigate the optimal moisture content of pelletizing faecal sludge as well as drying of faecal sludge pellets using different drying techniques in comparison to drying of faecal sludge on unplanted drying beds commonly used for faecal sludge treatment in developing countries. It was also investigated whether the pellets are safe for handling at 10% moisture content through analysis of helminth eggs.

## Materials and methods

Drying experiments in this study were conducted at National Water and Sewerage Corporation (NWSC) Lubigi Wastewater and Faecal Sludge Treatment Plant (in the following referred to as NWSC Lubigi) in Kampala, Uganda. Laboratory analyses was conducted at the College of Engineering, Design, Art and Technology at Makerere University. Samples were analyzed for helminth eggs at the University of KwaZulu Natal in Durban, South Africa.

### Experimental setup

Conventional pelletizers can only pelletize feedstocks with a moisture content of around 10%. This means that feedstocks need to be dried before pelletizing. In contrast, the Bioburn pelletizer can pelletize wet biomass. In this study, the optimal moisture content range for quality pellets was determined by pelletizing faecal sludge with different moisture contents and classifying them using a scoring system. A higher moisture content means lower energy requirements for mechanical dewatering and shorter drying times for gravity dewatering (e.g. by unplanted drying beds) of faecal sludge. Following, the quality of pellets was dried on drying racks and tarpaulin to determine the drying time of faecal sludge pellets. Improving the drying rate was further assessed by use of a greenhouse and silo dryer. The drying time of faecal sludge to the optimal moisture content range on drying beds in addition to the drying time of faecal sludge pellets to around 12% moisture content (pelletizing scenario) was compared to faecal sludge drying on unplanted drying beds (drying bed scenario) (see Table 1). Drying beds are the technology currently used for faecal sludge dewatering and drying at NWSC Lubigi.

Table 1: Description of faecal sludge drying scenarios used in this study.

Drying bed scenario	Pelletizing scenario
$t_{DB}$	$t_p = t_1 + t_2$
$t_{DB}$ = drying time of FS to 10% MC with drying beds	$t_p$ = drying time of FS to the moisture content range for pelletizing and drying of pellets to 10% MC $t_1$ = drying time to the moisture content range for pelletizing $t_2$ = drying time of pellets to 10% MC

### Optimal moisture content range for faecal sludge pelletizing

Faecal sludge with a moisture content of 30-60% was collected from drying beds. Visual observation was used to identify faecal sludge with different moisture contents that would be pelletized. Around 90kg of faecal sludge was collected from drying beds and homogenized using a metal rod before pelletizing (for more details on sample preparation see Englund et al. (2016)). Pelletizing experiments were conducted in triplicates for 30 minutes (for more details on pelletizing see Englund et al. (2016)). After approximately 10 to 15 minutes of pelletizing the production rate and extruder temperature were recorded. A faecal sludge sample for analysis of moisture content was collected from the hopper of the pelletizer where it was well mixed by shovels. This sample was packed in a sealed plastic bag to avoid change of the moisture when transporting it to the laboratory for analysis.

### Drying of faecal sludge pellets

The pellets were considered dry when a moisture content of 10% or less was measured. Pellets were turned manually twice daily to increase drying (Seck et al, 2015). During the night pellets were covered with a tarpaulin to prevent damages by rain or absorption of moisture from the

ambient air. At NWSL Lubigi the drying beds have transparent roofs for rain protection with open sides that allow air flow.

### Tarpaulin and drying racks

Pellets were solar dried at NWSL Lubigi using double drying racks and tarpaulins (see Figure 1 and 2).



Figure 1: Drying of faecal sludge on tarpaulins.



Figure 2: Faecal sludge pellets packed in plastic bags for transport.

Drying racks were made out of wood and wired mesh with a surface area of 0.75m x 1.1m. For double drying racks, the bottom rack had a distance of 35 cm to the ground and a distance of 75 cm to the top drying rack (see Figure 3).

The different drying technologies were placed at a distance of one meter apart from each other to allow free air flow (see Figure 4). Drying technologies were loaded with two different loading rates of two and five cm respectively as the loading rates affects drying rates (find references). Monitoring of drying was done by sampling of pellets from the different drying technologies every 24 hour  $\pm$  1 hour until a moisture content of pellets of 10%.



Figure 3: Dimensions of drying racks



Figure 4: Faecal sludge drying with drying racks

Sampling was done by dividing the drying area into six sections. Grab samples were picked from each section and combined to make one composite sample comprising of six to twelve pellets for lab analysis.

Pellet drying on drying technologies was done in duplicates. Next to the drying technologies, temperature and relative humidity readings were recorded three times a day; around morning, midday and evening (8am, 1pm and 5pm respectively) using a thermo-hygrometer (TFA KlimaLogg).

### **Greenhouse and silo dryer**

To enhance fast drying of pellets, two different dryers were constructed. Their performance was compared based on the drying time to 10% moisture. These pilot-scale dryers were sized for the current pelletizing production rate at NWSC Lubigi of 240kg/day wet basis for eight working hours per day. The detailed drawings of the dryers are attached to this document.

Greenhouse dryer: The greenhouse dryer is shown in Figure 5. It was made of a wooden frame on which a UV polyethylene sheeting was fixed. The greenhouse dryer was loaded through an access door on one side. An opening was provided at the front and the back of the dryer. The air was sucked through the dryer and the bed of pellets (1m x 1.6m) made of wire mesh/perforated metal by two fans. Based on the experiments with drying racks and tarpaulins, the greenhouse dryer was loaded in the experiments with a thickness of 5cm.



Figure 5: Greenhouse dryer

Silo dryer: The silo dryer shown in Figure 6 (0.8 m diameter, 1.8m high) was fabricated out of metal and was painted black to increase the air temperatures in the dryer. The silo had a perforated metal base inclined to the center (pyramid shaped). This base was designed in way that the air gets evenly distributed over the entire area. The silo dryer was loaded from the top with 5cm of pellets. The silo was ventilated vertically with a blower. Following drying, pellets were removed through an opening at the bottom of the silo.

From the two dryers, samples were collected every  $24 \pm 1$  hour for moisture analysis. At 10% moisture, samples were also collected for helminth eggs analysis. In the greenhouse dryer,

samples were collected by dividing the drying area into six sections and collecting one grab sample consisting of two pellets from each section. For the silo dryer, grab samples were collected at three points: at the bottom, in the center and at the top. The grab samples were combined to one composite sample comprising of twelve and six pellets for the greenhouse and silo dryer respectively for laboratory analysis.



Figure 6: Silo dryer

### Scoring of pellet quality

The quality of the pellets was determined using a scoring system as shown in Table 2 and Table 3. The scoring was done after the pellets were dried to 10% MC for all the drying techniques.

Table 2: Definition of the parameters used to quantify the pellet quality of different FS and biowaste mixtures.

<b>Texture</b>	Describes visually the appearance of the pellet surface. The surface varies between coarse and smooth as shown in Figure 7.
<b>Strength</b>	Describes the resistance of the pellet against breaking it in two pieces by hand. Strength is evaluated at <12% moisture content.
<b>Compactness</b>	Describes visually the increase of the pellet diameter after leaving the nozzle as shown in Figure 7.
<b>Production rate</b>	Described how many kilos of pellets are produced per hour on dry basis (kg dry mass/h). See Table 3.





Figure 7: Compactness, texture of three different pellets.

Table 3: Scoring system to compare pellet quality.

Description		Score
<b>Poor</b>	texture, compactness, strength, production rate <10 kg dry mass/h	1
<b>Good</b>	texture, compactness, strength, production rate <10-20 kg dry mass/h	2
<b>Very good</b>	texture, compactness, strength, production rate >20 kg dry mass/h	3

### Electricity consumption of pelletizing

The energy requirements of pelletizing were determined by reading from the electricity meter. This was done to compare to the energy value of pellets to the energy consumption of the pelletizer.

### Analyses

**Moisture content:** Faecal sludge before and after pelletizing was analyzed for moisture content. Moisture content was determined gravimetrically at 105°C according to the standard method (APHA et al., 2005). All moisture content results were determined in the lab.

**Helminth eggs** Helminth eggs were determined according to Moodley et al. (2008)

**Extruder temperature:** The extruder temperature was recorded at intervals of one minute during pelletizing. A thermocouple temperature data logger with USB interface (OM-EL-USB-TC) was used to log the temperatures over time. A K-type (measurement range of 0-1,100°C) thermocouple was used to measure the temperature at the extruder through two holes on the cover of the extruder located close to the nozzle.

**Production rate:** The production rate of pelletizing rate was measured as the weight change of a bucket by ten minutes of pelletizing.

**Bulk density:** Bulk density of pellets at a moisture content of 10% was measured according to standard methods (ASTM International, 2013). Due to the sample size a small bucket with a volume of three liters was used.

**Drying conditions:** Temperature and relative humidity at the inlet and outlet of dryer were recorded using humidity and temperature probes (Vaisala, HMP60) and a data logger (Vaisala, DL4000).

## Results & discussion

### Optimal moisture content range for pelletizing of faecal sludge

The results of the moisture content range for pelletizing FS are summarized in Table 4. This experiment was conducted first with an old extruder and also done after replacement with a new extruder. Results after replacement reflect a good production rate compared to those before. Reduced production rates were observed when using the old extruder which was worn off after being used to pelletize different biowastes. Results included in Table 4 and Figure 8 show that FS with a high moisture content had a lower production rate compared to faecal sludge with a lower moisture content. At a moisture content of 55% to 60% the production rate was 20.4 to 21.5 kg/hour wet basis. In contrast, at a moisture content of 37% to 51%, the production rate was 23.5 to 35.9kg/hour wet basis. Overall, it can be concluded that in this study FS could be pelletized with a moisture content ranging from 30–60% (all pellets in this range had a score of 3) (see Table 4). Difficulties were encountered when pelletizing using FS with moisture content of less than 30% or greater than 60% resulting into failure of pellet production.

Table 4: Production rate of faecal sludge pellets as a function of moisture content.

Sample ID	Repetition	Moisture content %	Production rate kg wet/hour
FS1	1	57	15.2
	2	63	9.7
	3	58	20.1
FS2	1	49	27.4
	2	51	29.7
	3	40	28.2
FS3	1	35	38.1
	2	41	35.9
	3	36	35.9
FS4	1	51	23.4
	2	48	20.7
	3	52	22.2
FS5	1	35	15.7
	2	36	12.1
	3	36	11.9
FS6	1	58	21.5
	2	50	22.7
	3	55	20.4
FS7	1	51	23.5
	2	50	23.6
	3	48	29.1
FS8	1	45	30.1
	2	49	31.5
	3	48	28.4
FS9	1	44	32.4
	2	42	26.4
	3	44	33.1
FS10	1	38	38.1
	2	37	35.9
	3	37	35.9

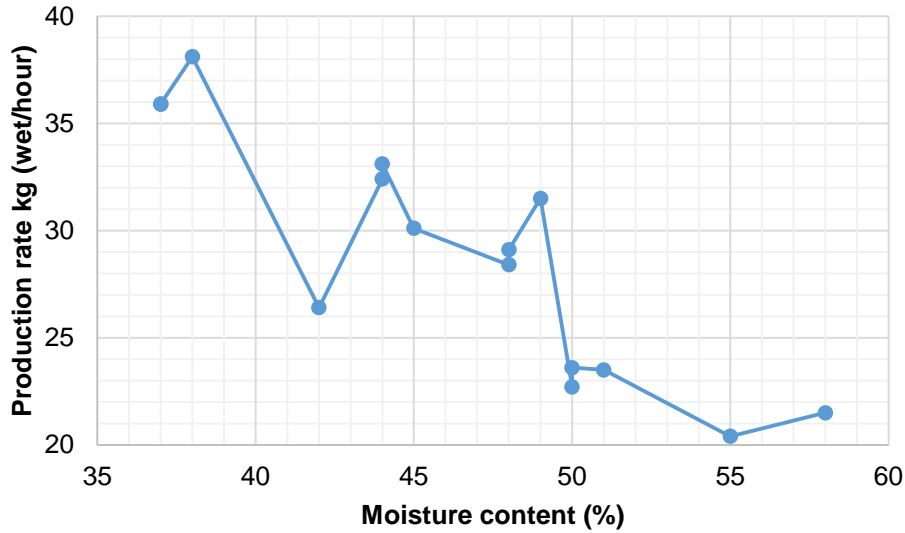


Figure 8: Pellet production rate as a function of moisture content.

### Pellet drying using drying racks and tarpaulin

Figure 9 shows the drying rate of FS pellets on a double drying rack at 2cm for both the bottom and the top shelf. The results obtained show that the pellets took seven days to dry from 45% to 10% moisture at ambient temperatures ranging from 25.2 to 27.2 °C.

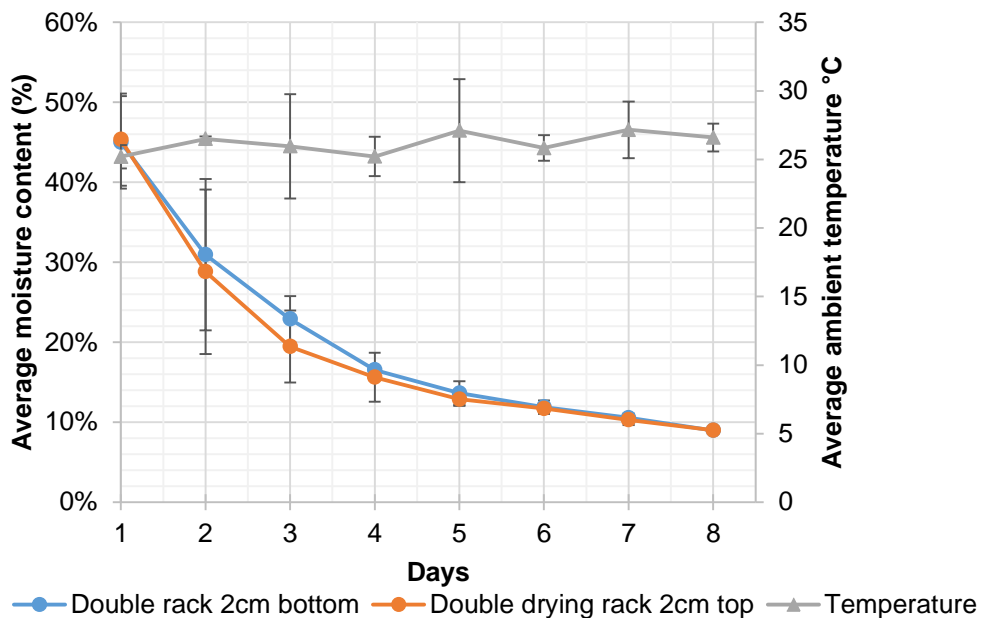


Figure 9: Graph showing drying rate for pellets on double drying racks at 2cm

Figure 10 shows the drying rate of pellets at 5cm on double drying racks for both the top and bottom shelf. The results obtained show that pellets took eight days to dry from 45% to 10% moisture at ambient temperatures ranging from 25.2 to 27.2 °C.

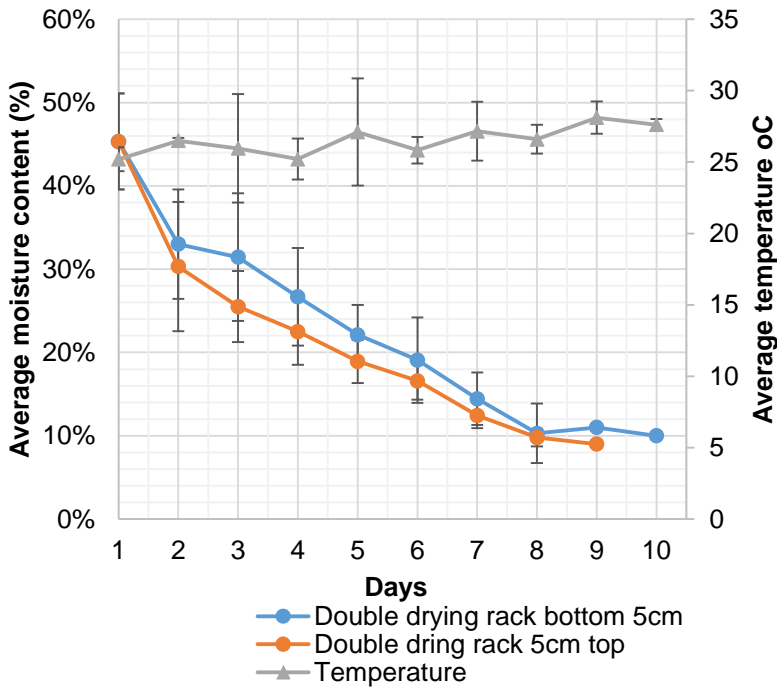


Figure 10: Graph showing drying rate experiment for pellets at 5cm on double drying racks

Figure 11 shows the drying rate of pellets on tarpaulin at 2cm and 5cm respectively. The results obtained show that pellets on a tarpaulin at 5cm took eleven days and seven days at 2cm (from 45% to 10% moisture).

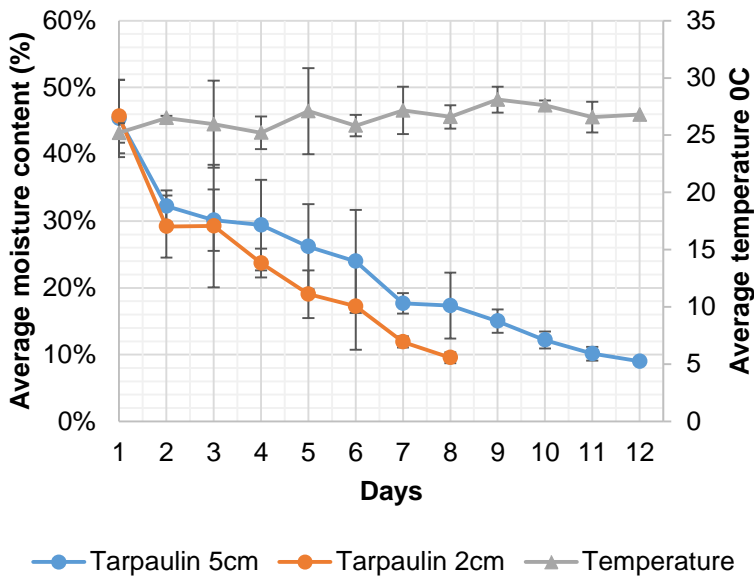


Figure 11: Graph showing drying rate of pellets on tarpaulin

Table 5: Summary of drying rate of pellets using the double drying racks and tarpaulin.

	Repetition	Experiment 1 (days)	Experiment 2 (days)	Experiment 3 (days)
Double rack 2cm bottom	1		6	7
	2	7	6	7
Double rack 2cm top	1		6	7
	2	7	6	6
Double rack 5cm bottom	1		7	9
	2	7	7	9
Double rack 5cm top	1		7	8
	2	7	7	8
Tarpaulin 2cm	1		6	7
	2	7	6	7
Tarpaulin 5cm	1	10	10	11
	2		10	11

Drying times of pellets was similar between the double drying rack (2cm and 5 cm) and the tarpaulin with a pellet thickness of 2cm, with drying times between 6 and 9 days) In comparison, drying times with the tarpaulin and a thickness of 5 cm was much longer and between 10 to 11 days. This could be attributed to poor air circulation within the pellets. Considering the drying time and the amount of pellets that can be dried, the drying rack with a pellet thickness of 5cm is optimal.

### Comparison of the drying bed and pelletizing scenario

Table 1 summarizes the two drying scenarios that were compared as part of this study. Unfortunately, due to leaking roofs at NWSC Lubigi, it was not possible to accurately determine  $t_{DB}$  which is the time to drying faecal sludge to 10% moisture content on drying beds. However, based on personal communication with NWSC and visual observations of the authors, this can take one to several months (Orwiny, personal communication).

Dewatering and drying of faecal sludge at NWSC to a moisture content of around 50% suitable for pelletizing ( $t_1$ ) takes around four weeks (Ngobi et al., 2015). Pelletizing and drying of these pellets on drying racks takes around week ( $t_2$ ). This means a total dewatering and drying time of five weeks. This is much faster than those one drying beds which could reduce the required treatment footprint of future treatment plants, or increase the treatment capacity of existing plants. Future work should compare these two scenarios based on a mass balance (i.e. drying time for one ton of sludge per square meter and week).

### Pellet drying with the greenhouse and silo dryer

The greenhouse and silo dryer were operated in one experiment. These preliminary experiments suggest that these technologies have the potential to reduce the drying time to 90% dryness in comparison to drying racks and tarpaulins.

Pellets dried from around 50% dryness to 90% dryness in five days with the greenhouse dryer, and four days with the silo dryer. In comparison, pellets took seven days on the drying racks. Building on these results, Bioburn will further investigate improving the drying of pellets in Kampala.

### Electricity requirements of pelletizing in comparison to the cost of pellets

Pelletizing of faecal sludge consumed  $36.9 \pm 15.3$  kWh per tonne 50% dry sludge/pellets and  $73.9 \pm 30.5$  kWh per tonne 100% dry sludge/pellets. Considering an electricity price for

0.21 USD/kWh in Kampala, this would mean average electricity costs of 7.8 USD/ton 50% dry pellets and 15.5 USD/ton 100% dry sludge/pellets. Production of pellets for energy recovery and improved drying needs to be balanced with these costs. The pelletizer used as part of the project was not optimized for electricity consumption (i.e. the engine was over dimensioned). Therefore, this electricity consumption can be reduced for future implementation.

### **Helminth eggs analysis**

Table 6 and 7 in the appendix include results for helminth eggs from experiments with the drying racks and greenhouse dryer. Sludge before pelletizing with a dryness of around 50% and pellets with a dryness of around 90% had helminth eggs. These helminth egg concentration were low in comparison to other studies (Seck et al., 2015; Strauss et al., 1997). Workers should wear adequate personal protection equipment during handling of pellets (e.g. long sleeve shirts, face masks gloves).

### **Adaption of the Bioburn technology for faecal sludge in the context of Kampala**

Overall, during pelletizing of faecal sludge and biowastes at NWSC Lubigi, the project identified three key challenges. Below the project presents these challenges and proposes ways to mitigate them.

**Challenge 1:** Faecal sludge in Kampala has a high ash content (Byrne et al., 2016; Gold et al., in press; Tukahirwa et al., 2016) which is a challenge for pelletizing and energy recovery. Ash is an estimate of the amount of inorganic material in faecal sludge. In Kampala, the high proportion of inorganic material in faecal sludge is potentially due to the poor construction quality of onsite sanitation technologies (e.g. clay bricks, unlined or partially lined), flushing of inorganic material from shoes through the drop hole into the onsite sanitation technology and the long digestion times in the onsite and treatment technologies. During pelletizing, this inorganic material causes high abrasion of the extruder which increases maintenance costs of this technology.

The project proposes the following interventions to mitigate this:

- Reduce the amount of inorganic material in faecal sludge by improving the construction quality of onsite sanitation technologies (e.g. lined which also allows faecal sludge collection and protects groundwater).
- Use of different dewatering and drying technologies that do not increase the amount of inorganic material in faecal sludge. Drying beds tend to increase the amount of inorganic material (Seck et al., 2015). Alternative technologies could be geotubes or mechanical dewatering technologies (Ziebell et al., 2016).
- Improve the quality of the extruder against abrasion. Together with its research partner, Bioburn works on designing a new type of extruder with a different surface and shape that reduces abrasion.

**Challenge 2:** During the project, the extruder of the Bioburn pelletizer tended to clog at a moisture content exceeding 60%. During clogging, the production rate decreases as less feedstock can enter the extruder. An unclogged extruder is absolutely essential for an hands-free pellet production.

The project proposes the following interventions to mitigate this:

- Bioburn already improved the shovels in the hopper to prevent the inlet to the extruder from clogging.
- Redesigning the extruder to prevent clogging (linked to challenge 1 presented above).

- Faecal sludge should only be pelletized with a moisture content ranging from 30 to 60% moisture.

**Challenge 3:** Currently, it appears that the Bioburn pelletizer is too expensive for the Ugandan market as it has been designed and manufactured in Switzerland, for the Swiss market. This has the advantage of a high quality and durable product, but high labour costs, shipment and import duties contribute to the high capital cost.

The project proposes to mitigate this by partial construction of the pelletizer in Uganda. The engines of the pelletizer can be produced locally, so that only the parts which are not available in Uganda can be imported from Switzerland. This will also reduce the costs of shipment and import duties.

### **Conclusions**

This study demonstrated that dewatered faecal sludge can be processed into faecal sludge pellets at a moisture content ranging from 30 to 60%. Sludge with a lower moisture content has a higher production rate. Faecal sludge in a pellet form can then be dried faster than sludge on drying beds. This could reduce the required treatment footprint of future faecal sludge treatment plants, or increase the treatment capacity of existing plants. In addition, these pellets can be used as soil conditioner or solid fuel. These benefits need to be balanced with increased operation and maintenance costs, and the capital costs of the pelletizer.

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## Appendix

Table 6: Helminth egg results (eggs/g sample) of drying experiments with drying racks.

Description	Sample No.	Ascaris (eggs/g sample)		Trichuris (eggs/g sample)		Capillaria (eggs/g sample)		Toxocalla (eggs/g sample)	
		Total Potentially Viable	Total Dead	Dead	Immotile Larva	Dead	Dead	Immotile Larva	Viable
Before pelletizing	1	5	25	16	1*	1*	0	0	15
	2	1*	5	8	0	0	0	0	18
	3	2	8	10	1	1*	1*	0	13
After pelletizing	4	3	8	7	2	0	0	0	8
	5	1*	9	6	1*	1*	0	1*	6
	6	2	15	8	3	1*	0	0	5
After drying to 10% moisture	7	0	8	5	0	0	0	0	3
	8	0	10	7	0	0	0	0	0
	9	0	8	6	0	0	0	0	0

Note: 1.0 eggs/g is equivalent to an egg count between 0.1 and 1.0 eggs/g sample.

Table 7: Helminth egg results (eggs/g sample) of drying experiments with the silo and greenhouse dryer.

Sample Number	Description	ASCARIS EGGS (eggs/g)							TRICHURIS (eggs/g)					TAENIA (eggs/g)	CAPILLARIA (eggs/g)	TOXOCARA sp. (eggs/g)		
		Infertile	Dead	Necrotic Larva	Immotile Larva	Motile Larva	Undeveloped	Developing	Pre-Larval Stage	Dead	Necrotic Larva	Undeveloped	Immotile Larva	Motile Larva	Dead	Dead	Dead	Immotile Larva
1	Powdered	0.0	3.0	1.0*	1.0	1.0*	1.0*	1.0*	1.0*	3.7	1.0*	1.0*	1.0*	1.0*	1.0*	0.0	0.0	0.0
2	Dry pellets	0.0	3.2	1.0*	0.0	0.0	0.0	0.0	0.0	3.8	2.1	0.0	0.0	0.0	0.0	0.0	1.0*	0.0
3	Dry pellets	0.0	2.2	1.0*	0.0	0.0	0.0	0.0	0.0	1.2	1.0*	0.0	0.0	0.0	1.0*	0.0	1.0*	0.0
4	Dry pellets	0.0	4.8	1.0*	1.0	0.0	0.0	0.0	0.0	6.8	1.5	0.0	1.0	0.0	0.0	0.0	1.0*	0.0

Note: 1.0 eggs/g is equivalent to an egg count between 0.1 and 1.0 eggs/g sample.