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TRANSFORMATION TOWARDS SUSTAINABLE
AND RESILIENT WASH SERVICES

Potential use of the black soldier fly larvae in faecal sludge management: a study in Durban, South Africa

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This study was performed to determine the bioconversion and waste reduction capabilities using the Black Soldier Fly larvae (BSFL) on treating Urine Diversion Toilet (UDT) sludge on a full-scale plant. A bioconversion of 10 % wet basis and a mean relative waste reduction of 41 % wet basis was achieved over a period of 13 days using 6-day-old larvae. The study is a preliminary study to identify and quantify useful design parameters and material flows, which would assist in improving the system by increasing the bioconversion and waste reduction of UDT sludge.

Introduction

In sub-Saharan Africa, 39 % of people are served by on-site sanitation compared to 7 % served by sewered sanitation systems (WHO and UNICEF, 2017). According to (UNICEF 2017), 89.6 % of the South African population has access to improved sanitation systems, which include on-site sanitation systems. However, there is a lack of data on what proportion of sanitation systems in the country are unsafely managed. A shit flow diagram (SFD) for Durban, South Africa showed that 16 % of on-site sanitation sludge in the city is not contained in onsite sanitation (Cross and Buckley 2016)

In 2013, they were approximately 75 000 UDTs that were installed in eThekwini municipality in Durban, South Africa. The UDT were installed in unserved areas of the eThekwini municipality. The UDT offers waterless sanitation in a water-constrained environment and separates faeces and urine making it possible to handle the two streams of urine and faeces separately. They overcome the problem of desludging ventilated improved pit (VIP) toilets as UDT vaults are smaller and allow easier manual emptying because of the lower moisture content of the faecal sludge (FS)..

In response to users' dissatisfaction at having to handle their own waste (Roma, Philp et al. 2013) and evidence to show that sludge is potentially pathogenic after a year in a UDT vault (Austin 2001), the municipality looked for alternatives to treatment of UDT sludge. Whilst burying waste on-site remains an option for many households, there was a need to cater for areas where densification has led to houses being too close together for this to be a viable solution. Khanyisa Projects, with funding from the Bill & Melinda Gates Foundation, are currently investigating the economic feasibility of treating of FS from UDTs using black soldier fly (*Hermetia illucens*) larvae (BSFL). AgriProtein, based in Cape Town, South Africa, has carried out the treatment of biodegradable waste using BSFL on food waste for several years. A BSFL facility was set up at Isipingo Wastewater Treatment Works (WWTW) designed to treat up to 20 tonnes wet mass of FS per day. The BSFL facility needs to operate as a sustainable business in Durban if the costs of processing and disposing of UDT waste is to decrease. The BSFL is a ravenous insect that consumes any biodegradable waste, which make it feasible as an option for faecal sludge management (Diener, Zurbrügg et al. 2011). The BSFL are high in protein and fat therefore making them a potential animal feedstock (Makkar, Tran et al. 2014). The remaining residue has potential in agriculture (Singh, Mohan et al. 2017). The BSFL is not a vector of diseases as it doesn't feed during its adult life utilizing food obtained during the larval stage (Sheppard et al., 2002).

There is no readily data available on the impact of UDT sludge on the bioconversion process using BSFL. This study was designed to determine the bioconversion and waste reduction capabilities using the

BSFL to treat UDT sludge. In addition, this study identifies ways to improve the bioconversion and waste reduction of UDT sludge using BSFL.

Materials and methods

The UDT sludge (65, 65 ±2 % moisture content) was collected from EThekwini Municipality, Durban, South Africa. Primary Sludge (PS) (98.99 ± 1% moisture content) from primary sedimentation from the Isipingo Wastewater plant was used to increase the moisture content of the UDT sludge (67, 26 % ± 3%) Banks (2014) showed that moisture content had a significant effect on the growth and waste reduction.Approximately 1.78 tons of UDT sludge and 250kg PS were mixed to form a homogenous mixture of UDT sludge and PS.

Experimental set up and sampling

The experimental layout to accomplish the bioconversion and waste reduction was done on a scale factor of 1:6 mass basis as shown by Figure 1. The scale factor was used, to overcome the challenges of manually handling 1.78 tons of UDT sludge.

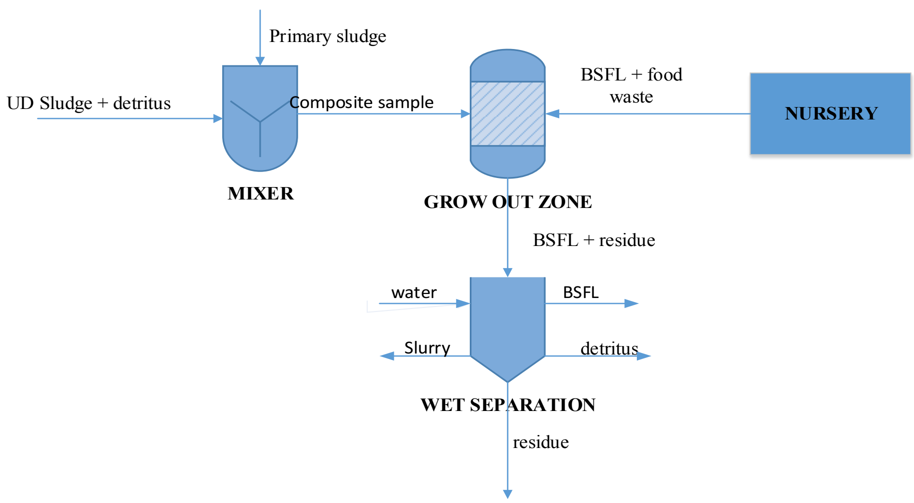

Figure 1. A process flow diagram of the experimental layout

Three trials (5.32 ± 0.46) m^2 were set up on consecutive days in the grow-out area on the growing beds. According to Brits (2017) the depth of feed substrate, the BSF larvae feeding efficiencies was significant at less than 50 mm. The composite sludge (UDT +PS) was laid on the growing beds at a depth of 50.56 ± 6.35 mm. Environmental conditions in the grow-out zone was not controlled, data loggers were used to record the temperature and humidity measurements during the investigation.

AgriProtein (Cape Town) supplied the neonates (1-2 day old larvae) in layer mesh of 3 g of neonates. The neonates were fed nutritious food waste for 4 days to allow development before being transferred to the grow-out area. The humidity and temperature in the nursery was controlled at 28 °C-30 °C. The 5-6 day old BSFL were spread evenly on the trials. Diener et al. (2009) suggested an optimal feeding rate of

100mg/larvae/day on chicken feed, the feed rate used was 70mg/larvae/day as the UDT sludge has low nutritional value than chicken feed.

The trials were operated as a batch process for 13 days. After 13 days, residue and BSFL were separated using wet separation as moisture content was high to allow effective sieving to separate BSFL and residue. During the trials, heavy floods were experienced and water leaked into through the gutters into trials. Samples were collected at the beginning and at the end of the bioconversion process to determine the change in physiochemical properties of the UDT sludge and BSFL. The trials were weighed at the beginning and at the end of the bioconversion process.

Mass balance

A mass balance was carried out to quantify all material flows. In a full waste processing plant, the nutritional content of the feed stream may need monitored to ensure the larvae consume a balanced diet and the process can be optimised.

The mass balance was carried out on the grow-out area, which defines the system boundary. The choice of these boundaries was based on the total amount that the facility can process is determined by the relative waste reduction and bioconversion. The outputs are the inputs of the processing unit.

The nutrient content of the analysed samples was used to determine the concentration by multiplying with the total solids. It was assumed that the UDT sludge would be homogenously mixed and the BSFL would not feed the detritus. The difference in the mass balance was assumed to have been metabolised and or via evaporation. In addition to undertaking a mass balance, laboratory analysis of the various samples of the inputs and outputs shown by Figure 1 was carried out to determine the physio-chemical properties of the BSFL, sludge and residue. This included total solids, moisture content, volatile solids, ash, chemical oxygen demand, pH and temperature. The samples were analysed for total solids in order to quantify the moisture content and volatile solids to quantify the organic matter.

Calculations

Nutritional indices are used to assess food suitability of the substrates used for feeding insects (Huffaker et al., 1984).

$$\text{Relative Waste Reduction (\%)} = \frac{\text{intial feed (tons) - final feed(tons)}}{\text{intial feed (tons)}} * 100\%$$

Where initial feed is the total quantity of feed given (t), final feed is the residue remaining after bioconversion, which includes non-digested food and excreted products,

$$\text{Bioconversion (\%)} = \frac{\text{yield of larvae (tons)}}{\text{total UDT sludge (tons)}} * 100\%$$

Results and discussion

Physiochemical characteristics

The amount of organic represented by the volatile solids, there is a decrease of volatile solids (g of VS/ g of TS) and an increase in ash content (g of ash/g of TS) as shown Figure 2. Reduction in Chemical oxygen demand during the bioconversion process shows that organics are being reduced. There decrease in moisture content is due to both the environmental conditions and the BSFL. The trials showed a decrease in depth from average of 51 mm to an average of 34 mm.

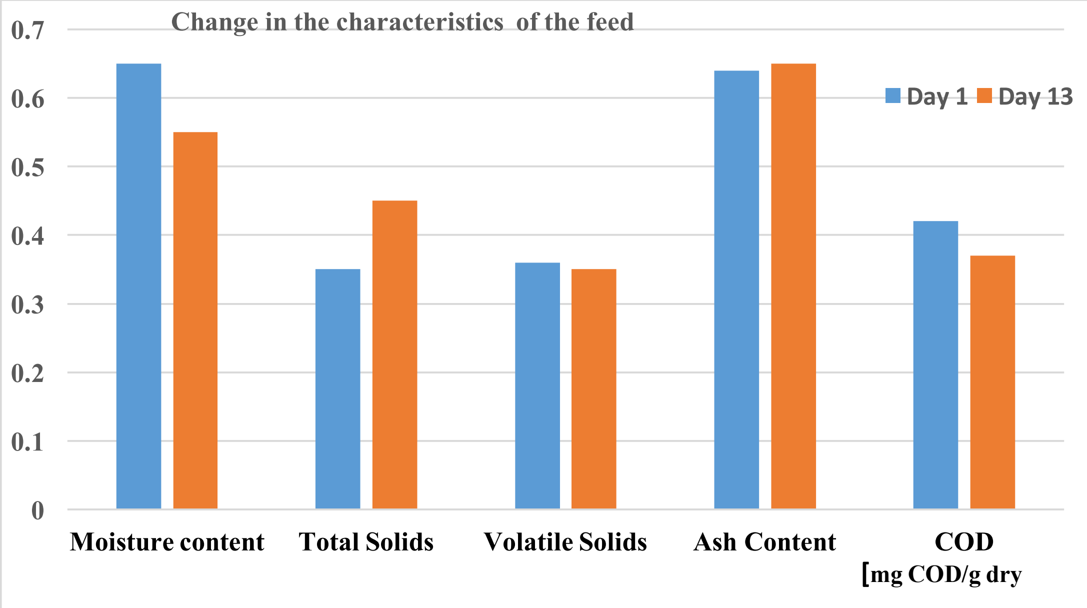

Figure 2. The change in characteristics of the feed during processing with the BSFL

Mass balance

Based on the measurements taken, a mass balance over the mixer and the grow-out area was calculated. The mass of sludge feed (mix of UDT and primary sludge) after the mixer prior to the grow-out area, and the mass of sludge remaining in the grow-out area after 13 days of BSFL feeding was measured.

The data from the 300 kg trial was used to change the feed basis to 1 tonne of UDT sludge in Figure 2.

The results from the chemical analysis of the BSFL and UDT sludge are shown in Figure 2 for volatile solids, water and ash content.

The bioconversion yield of UDT sludge to larvae based on a wet basis on Figure 2 is 10 % (mass larvae/mass UDT sludge) and is within the range of other laboratory studies for faecal sludge - 5.5 % on wet basis for pit latrine sludge (Banks 2014) and 22 % on a wet basis for fresh faeces (Banks, Gibson et al. 2014). The low bioconversion shows the low nutrient value of the UDT sludge as highlighted by the volatile solids (12 %) in Figure 2, which represents the organic matter. There is therefore a need to use a nutritional additive to increase the bioconversion.

Environmental conditions affect the bioconversion process, and these were not controlled. The temperature ranged from 19 °C to 40 °C. The relative waste reduction on a mass basis is 41 % wet basis could be due to both the environmental conditions and the BSF larvae. However, the relative reduction waste on dry basis of 31 % will give an indication of waste reduction due to BSF larvae dry basis. Banks (2014) found a relative waste reduction of 50 % and 55 % on pit latrine sludge and fresh faeces respectively on wet basis. Lalander, Diener et al. (2013) found the waste reduction on a dry basis to be 73 % of FS. In other feed substrates such as chicken feed, market waste and municipal organic waste there was a dry material reduction of 66.4 to 78.9 % (Diener et al., 2011a). This study has a relative waste reduction on dry basis was 31 %; this shows that the type of substrate has an effect on the waste reduction by BSFL.

The BSFL depend on their environment for heat for their growth and development. The ambient temperature significantly regulates their metabolism and the development rate of the BSFL (Jarošík, Kratochvíl et al. 2004). High feed conversions occur at optimal temperatures of 27-31 °C (Tomberlin, Sheppard et al. 2002). There is therefore the need to control the environment for the bioconversion process.

The high waste reduction and high bioconversion observed in literature of organic waste could be due to the feed, feeding rates, larval density and environmental conditions (Tomberlin, Adler et al. 2009, Paz, Carrejo et al. 2015, Tschirner and Simon 2015).

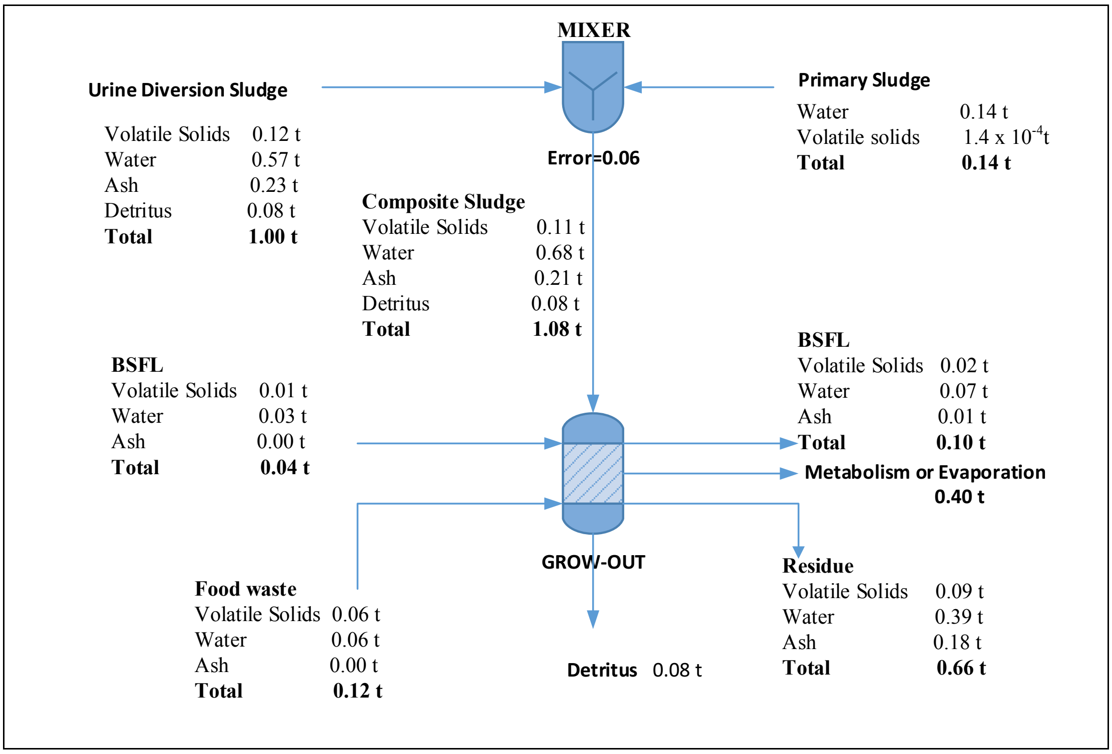

Figure 3. The Preliminary mass balance based on 1 tonne (wet basis) of UDT faecal sludge

Lesson learnt

The environmental conditions have an impact on the development of the BSFL and hence having an effect on the waste reduction and bioconversion capabilities. Results from the mass balance showed that there is a significant amount of food waste remaining from the nursery. The remaining food waste is an input into the grow-out area therefore affecting the amount of UDT that can be reduced. Not all BSFL survive throughout the nursery so it's necessary that the feeding rate is based on the yield from the nursey not the neonates supplied.

There is need to use a closed feeding reactor to avoid damages or leaks during bioconversion process.

Implication of study

This study shows the potential to use the BSF larvae as a treatment option for faecal sludge management. However a combination of different factors like the feeding rate, larval density and feed should be explored to see if the waste reduction and bioconversion can be increased. There is also need to replicate the trials to validate the data since the trials were based on one trial.

Conclusion

The BSFL show potential to be used as faecal sludge management with resource recovery as they managed to reduce the UDT sludge by 31 % dry basis on a full-scale operation operating on an uncontrolled and low maintained system. The bioconversion (mass of larvae / mass of feed) as 10 %. The values are comparable to literature values, which occurred at laboratory scale and in a controlled system. The bioconversion process is sensitive to the environmental conditions and nutritional value of the feed as they have an effect on the relative waste reduction and bioconversion rates. The low bioconversion and relative waste reduction observed can be improved by increasing the nutrition value of the UDT sludge and controlling environment conditions (temperature and humidity).

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