SEEK (Sludge to Energy Enterprises in Kampala): co-processing faecal sludge for fuel production

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SEEK (Sludge to Energy Enterprises in Kampala): co-processing faecal sludge for fuel production

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The goal of this project was to improve the resource-recovery value of faecal sludge treatment products. A market assessment identified coffee husks, spent grain, and sawdust as optimal organic wastes to co-process with faecal sludge to increase its fuel value. Drying times of faecal sludge to 90% solids were reduced by half with co-pelletizing with these organic wastes. Briquettes produced with char had comparable heating value, fuel performance, and emissions to charcoal briquettes currently being sold. Use of pellets as a fuel was tested in a gasifier and in several industrial clay kilns (after crushing). High ash content led to clinker formation in the gasifier, but performed well in kilns. The potential market for co-processed faecal sludge fuels is high in Kampala, Uganda, especially among industries, however, the market for pellets needs to be developed.

Introduction

Inadequate faecal sludge collection, transport, and treatment threatens public health and environmental wellbeing. Dewatering of faecal sludge, which is typically > 90% water (Gold et al., 2016), is one of the biggest bottlenecks in achieving a sustainable faecal sludge management service chain. Improved dewatering and faecal sludge processing can produce higher-quality treatment products for resource recovery, for example dried faecal sludge as a solid fuel. The successful valorisation of treatment products can create business opportunities and facilitate increased access to safe faecal sludge management by offsetting costs in the sanitation service chain (Diener et al., 2014).

Market studies can identify optimal treatment products, for example a higher demand for energy in Kampala, Uganda and Accra, Ghana compared to the demand for soil amendments. (Diener et al., 2014). Dried faecal sludge can be used as a fuel, but energy and ash content are not optimal (Gold et al., in press) More information about the requirements of consumers should be gathered to evaluate the suitability of treatment products to meet energy demand.

The Sludge to Energy Enterprises Kampala (SEEK) project was conducted in Kampala, Uganda. Kampala has a population of 1.5 million, which doubles during the day due to the commuting population. Kampala has one existing faecal sludge treatment plant, Lubigi, with a design flow of 400 m^3/day, and faecal sludge is also discharged at a wastewater treatment plant, Bugolobi, at 300 m^3/day. Faecal sludge treatment is at capacity, and more treatment capacity is greatly needed. Resource recovery from treatment products is also minimal, and without adequate protection of public health. The objective of the SEEK project was to evaluate modifications to dewatering and drying processes to increase treatment capacity, explore markets for treatment products, improve faecal sludge fuels, and resource recovery options for heat and electricity. The lessons learned in the SEEK project are directly applicable in other cities that are applying solutions for faecal sludge management.

Methodology

As illustrated in Figure 1, the SEEK project employed a number of strategies along the faecal sludge management service chain. These included: a *waste assessment* where qualities and characteristics of organic waste streams were evaluated; *waste treatment* to evaluate improved treatment; *waste processing* to generate products for resource recovery from treatment; *resource recovery* to evaluate production of heat and electricity; and *market development* for uptake of treatment products.

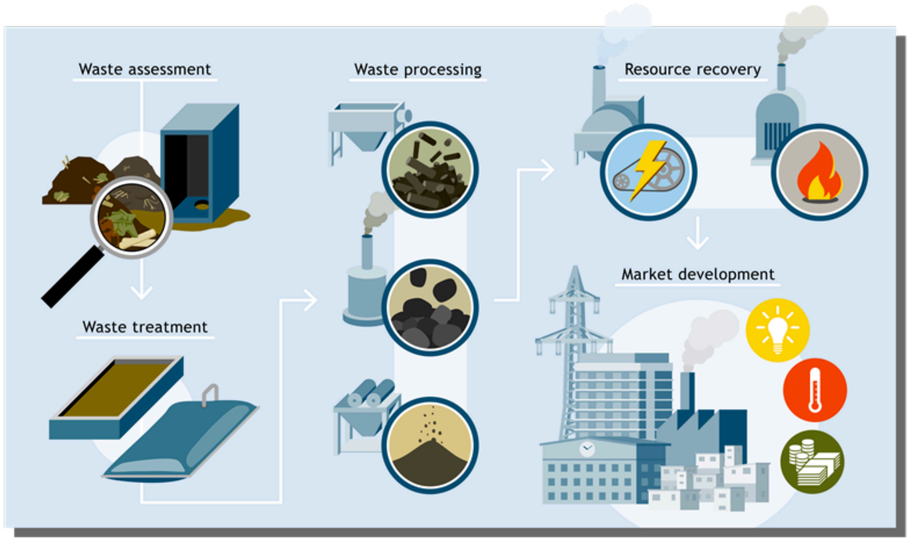

Figure 1. Components of the SEEK project

Waste assessment. Availability and fuel quality of organic wastes for co-processing with faecal sludge was evaluated by interviews and secondary data. Physical-chemical properties of organic wastes were determined with standard methods (APHA, 2005) and ASTM standard protocols. Selection of optimal organic wastes was though multi-criteria analysis (MCA).

Waste (faecal sludge) treatment. Modifications to sand drying beds that were investigated included turning of the sludge, a geotextile layer on the surface of the drying beds, and pelletizing of dewatered sludge. Total solids and ash content were determined with standard methods (APHA, 2005).

Waste (co-) processing. Three processing methods were trialled: 1. co-pelletizing dewatered (40-70% dryness) faecal sludge with organic waste; 2. pyrolysing faecal sludge to produce char; and 3. co-briquetting faecal sludge and organic waste char. Sawdust, coffee husk, and spent grain were used for co-pelletizing, and pyrolysed agricultural waste and waste charcoal dust were used for co-briquetting. Technical feasibility was evaluated by optimization of operating conditions and co-processing ratios. The higher heating value and ash content of pellets, char, and briquettes were quantified.

Resource recovery: Three resource recovery methods were trialled: 1. gasifying pellets for electricity production; 2. burning briquettes for cooking; and 3. combusting crushed dried sludge in industrial kilns. Gasifying performance was determined as voltage produced by a 10 kW gasifier (All Power Labs, USA) and clinker formation. Briquette performance was evaluated with water boiling tests, and monitoring of emissions (CO, CO_2, PM2.5, and black carbon). Briquettes were compared to charcoal and agricultural char briquettes. Combustion of crushed fuel was determined in field trials at a clay company. Kiln temperature measurements and surveys were used to evaluate fuel performance.

Market development. The market potential of treatment products (pellets, electricity, and char) and resource recovery technologies (pelletizers and gasifiers) was assessed through interviews with potential customers. Business models were developed for faecal sludge fuels, including pellets, crushed dry sludge, char, and briquettes. 26 companies in Kampala served as case studies that informed business model development.

Results

Waste assessment

In Kampala, faecal sludge, wastewater sludge, and water treatment sludge are available and accessible at low prices, but have relatively low calorific values and high ash content. As reported in Figure 2, other organic wastes that were evaluated for co-processing were less readily available and accessible than sludge, but had good physical-chemical fuel properties. There are sufficient quantities of sawdust, coffee husk, spent grain, and market waste that would allow for up to 80% organic waste co-processing with faecal sludge (Byrne et al., 2015). Based on the results of the waste assessment, these wastes were considered in the treatment and post-treatment co-processing technologies. Co-processing of faecal sludge together with other organic waste streams can improve its fuel performance and drying time, in addition to increasing the total amount of treatment product for resource recovery.

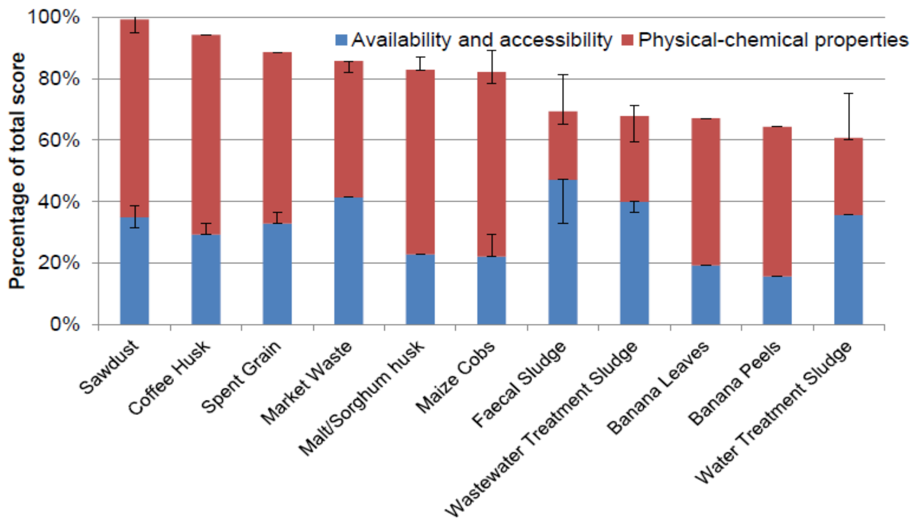

Figure 2. Results of organic waste assessment for suitability for co-processing with faecal sludge in Kampala

Waste (faecal sludge) treatment

In full-scale trials with sand drying beds, turning of sludge on sand beds increased the drying rate by 30%, which agrees with previous findings from Dakar, Senegal (Seck et al., 2015). However, turning sludge also increased the sand content, which reduced fuel performance. To address this, the sand filter layer was covered with a geotextile sheet. This reduced ash content by 20%, improving the fuel value of the dried sludge (Ngobi et al., 2015), however added operational complexity.

In pilot-scale tests, geotextile bags (geotubes) dewatered septic tank sludge conditioned with chitosan at 97% separation efficiency, and took 1-3 days to dewater sludge fully. These results indicate that use of geotubes could reduce required land area for dewatering by 75% while also reducing sand content (Ziebell, 2016). Geotubes could thereby increase capacity or reduce required footprint, or be used as dewatering transfer stations, however, it is not known whether geotubes are reusable and hence could be a resource intensive option.

Dewatered sludge with 50% total solids was pelletized with the Bioburn pelletizer, and produced viable pellets based on the developed ranking as outlined in (Turyasiima et al., 2016). Pellets dried from 50% to 90% solids in one week, using only 25-12% of the land area that would be required for drying beds. Depending on the season, it takes 1-3 months to achieve 90% with sand drying beds at Lubigi (Byrne et al. 2015). The Bioburn pelletizer is innovative, in that it can process sludge into pellets at high moisture content without the use of a binder, which can then be passively air-dried to 90% solids. By removing sludge from drying beds at 50% solids and pelletizing, the sludge drying capacity of the treatment facility for 90% solids could effectively be doubled. This is important, as for use as a fuel, industry requires faecal sludge to be at least 85% solids (Muspratt et al., 2014, Nantambi et al., 2016).

Waste (Co-) processing

Co-pelletizing of coffee husk and spent grain at a 1:1 wet mass ratio with faecal sludge produced strong pellets at rapid production rates (16-18 kg dry mass/hour), which can be readily upscaled in a modular format. Pellets made with sawdust were of high fuel quality, but were not structurally robust. Co-processed pellets had 1.6 times higher energy content (16 MJ/kg) and about half of the ash (22-27%) compared to pellets made from faecal sludge alone (Englund et al., 2016).

For char production, a pyrolysis temperature of 350°C with a hold time of 10 minutes had the highest calorific value and lowest ash content. Pyrolysing faecal sludge can improve the fuel quality (H:C and O:C molar ratios) (Ward et al., 2014), destroys pathogens, and eliminates volatile odor-causing compounds. However, even when produced at optimal conditions, faecal sludge char can have a high ash content (up to 56% of dry solids), which contributes to a low calorific value (Bleuler, 2016). Because pyrolysis can concentrate ash content in faecal sludge, char is best co-briquetted with lower ash, higher energy organic wastes.

Briquettes made with 30-50% char from faecal sludge co-processed with charcoal dust and char from organic waste had calorific values from 18-20 MJ/kg, comparable to briquettes made entirely from pyrolysed agricultural wastes. Ash contents of faecal sludge briquettes were reduced by 50% with co-processing (Kiwana et al., 2016). For briquette production, co-processing with organic waste and charcoal dust improved the fuel quality substantially over only faecal sludge char.

Resource recovery

Pellets from faecal sludge and organic waste did not perform well in the gasifier due to clinker formation as a result of high ash content (Tukahirwa et al., 2016). Pellets are an ideal fuel for gasification based on their homogeneous size and high energy density. More robust gasifiers exist for electricity production from high-ash content fuels like sewage sludge and municipal solid waste, and faecal sludge pellets would be more practical for use in this type of technology. Due to high cost and technical complexity, this type of gasifier would need to be implemented at a centralized scale. Pellets can also be used as a fuel by combustion, or as a soil conditioner.

Briquettes made from char from faecal sludge and organic waste had the same cooking efficiency (tier 4), and better thermal efficiency (75-85%) compared to wood charcoal and organic waste char briquettes burned on the same Jikokoa cookstove. Emissions from faecal sludge char briquettes were comparable or better than the other charcoal fuels (Kiwana et al. 2016). Based on these results, blended faecal sludge and organic waste char briquettes are technically viable as a cooking fuel, but due to public health and consumer perception are possibly better used in industrial applications.

Market assessment

Crushed dry faecal sludge and char have an immediate market in Kampala’s brick making industry. Industry could supplement increasingly expensive agricultural wastes, that also have fluctuating price and availability depending on the season (Kakooza et al. 2016). The cement industry was also highly interested in the use of faecal sludge fuels, however, due to high energy demands, they were only interested if 400 tons/day could be produced, which could not currently be achieved with faecal sludge alone. They currently use coffee husks, sawdust, and other organic wastes as fuel, and so represent a potential market for co-processing with faecal sludge to lower costs and increase fuel supply.

Two companies were identified that already produce briquettes made from faecal sludge char and organic waste in Kampala. They reported confidence that as long as faecal sludge briquettes have equal or better performance to other briquettes currently on the market, that they will be marketable (Nantambe et al. 2016).

Other surveyed industrial representatives also recognized the benefits of fuel pellets (e.g. easy to store and transport, high energy density), however, pellets are not compatible for the feeding of their current combustion technologies, which mostly require powdered fuel. If a market can be created for fuel pellets with the introduction of compatible combustion technologies, the estimated market size including industrial and institutional use in Kampala is $2.8 million, with a firewood savings of almost 80 tons/year (Kakooza et al. 2016).

Conclusions

The methods implemented in this study could be readily implemented in other cities to improve dewatering and drying of faecal sludge, increase treatment capacity or reduce required land area, improve the quality of treatment products for resource recovery, optimize co-treatment with other waste streams, and more fully develop potential markets. Based on the results in Kampala, general conclusions included:

- Competitive values needs to be considered, for example there are multiple organic waste streams available in Kampala, but many of them are already in use.
- Dewatering to 50% solids with geotubes could reduce required land area by 75% compared to using drying beds.
- Pelletizing for drying from 50-90% solids could reduce required land area by 50% compared to using drying beds.
- Producing pellets, char, and briquettes by co-processing faecal sludge with organic waste streams substantially increases its fuel quality, and could increase fuel production for large-scale industrial customers.
- Gasifying faecal sludge most likely requires a specifically designed robust gasifier to handle high-ash content, implemented at a centralized treatment scale.
- Pellets can be used as a soil conditioner and/or dry fuel for combustion.
- Briquettes from faecal sludge and organic waste are effective as a fuel for cookstoves, but should be considered for industrial applications due to concerns with public health and consumer perception.
- There is an existing industrial market for crushed-dried and pyrolysed faecal sludge, and an existing domestic and industrial market for faecal sludge char briquettes.
- The market for pellets in Kampala is potentially large, and should be developed with pellet-compatible combustion technologies, or as a soil amendment.

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