Operational experiences in treatment of organic waste from malls via anaerobic digestion, Bokashi fermentation and composting

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ABSTRACT

Organic waste typically comprises the largest fraction of non-recycled general waste in South Africa. Anaerobic digestion, Bokashi treatment and composting are alternative treatments for organic waste, which harness its energy and/or nutrient value.

This paper presents operational experiences at a composting facility, which has a 6m^3 pre-fabricated anaerobic digester on site. A portion of the pre-sorted organic waste from a mall was fed to the anaerobic digester to produce biogas (used on site) and digestate (added to compost). Another portion was treated at the mall with Bokashi bran and transported to the composter to be added to other compost heaps.

Anaerobic Digestion with use of the biogas on site as well as the composting of the digestate had a normalised profit of R 0.67 per kg of organic waste processed compared to R 0.28 for Bokashi treatment with composting. However, anaerobic digestion required technical expertise, had a high capital cost and was subject to efficiency fluctuations with temperature.

1. INTRODUCTION

With escalating landfill prices and constraints in natural resources, minimisation of waste and improved recycling practices are pressing issues bearing both economic and environmental pertinence. The recycling of major commonly used materials (i.e. paper, plastic, glass and metal) has well established value chains in the formal and informal sectors of South Africa. The balance of generated waste is typically composed of multi-layer laminates, low value grades and organic waste, the last category accounting for the majority, often in excess of 50% of the entire waste stream including recyclables (Akacheng, 2003; Troschinetz & Mihelcic, 2009). In urban areas, the amount of waste is rapidly increasing, exacerbated by trends in urbanisation (UN, 2008).

1.1 Common Recycling Practices at Commercial and Retail Institutions

Based on experience in the industry over the last three years, in developing countries such as South Africa, many property and business owners have realised the economic value of recyclables in their waste streams. In some instances, the owners will use their own staff or a cleaning company to separate recyclables and source markets for them. More often though, a dedicated on-site waste management company is appointed (especially at large retail outlets) to manage the waste area. The company will separate recyclables in the waste area, find markets for the recyclables and arrange disposal of the balance. Depending on the business model, some or all of the revenue from recycling generated is rebated to the property owner. In all cases, the purpose of material recovery for recycling is still primarily economically driven. The revenue from recycling is calculated on weight, while transportation is primarily governed by volume, meaning that materials with a high ratio of value to volume (e.g. crushed aluminium cans) are lucrative to recycle relative to low density and low value material (e.g. expanded polystyrene).

Also based on observations in the industry, organic waste can make up to 50% or more of the total waste stream and is not commonly valorised in South Africa. As a recycling grade, it is comparatively dense, and has both a nutrient and an energy value. Finding an alternative to landfill for organic waste usually involved harnessing either the energy and/or the nutrient value of the organic fraction of municipal solid waste (OFMSW) at a net cost which is less than or equal to the landfill disposal rate. Furthermore, it may also reduce contamination of other grades, which will further improve recycling activities (Kasozi, 2010).

1.2 Alternative Treatments for Organic Waste

Currently, the majority of organic waste is sent to landfills, where it decomposes anaerobically to produce landfill gas containing methane. The methane gas has a global warming potential (GWP) which is 21 – 25 times that of carbon dioxide. Landfill gas can be extracted from landfills and used to generate energy, most often in the form of electricity via purpose built engines. Although this practice does reduce equivalent carbon emissions while generating energy, the solution is end-of-pipe and does not mitigate the emissions from transport of the material to the landfill. The returns are significantly lower than if the energy was harnessed directly from fresh organic waste at source. In the commercial sector, the bulk composition of organic waste is food waste, which is extremely high in nutrient and energy content. Since the mixture is heterogeneous, there are a number of alternative treatments which either harness the nutrient value, the energy value or both. Some of these are outlined as follows:

1.2.1 Thermal Treatment Options

Thermal technologies for the conversion of waste to energy are categorized as either mass burn (incineration), gasification/pyrolysis or thermal depolymerisation. 'Mass burn' technologies are arguably the most economical cost option in comparison to the more novel gasification and pyrolysis technologies. However, gasification and pyrolysis can be suitable to smaller scale and decentralised installations. Gasification and pyrolysis processes are descriptions for partial combustion process under controlled oxygen concentration, which create versatile refuse derived fuels (RDF), either as synthetic hydrocarbon gas (syngas) or biochar. Plasma arc gasification technology involves very high temperatures, taking reactants into the plasma phase to improve the yield of syngas. Thermal depolymerisation is now a form of treatment for tyres, and certain plastic grades. It involves heat treatment of the waste to produce syngas and carbon char, or a light fuel oil, respectively.

1.2.2 Anaerobic Digestion and Biogas

Anaerobic digestion (AD) of the OFMSW can provide a useful on-site or off-site solution, combining waste management with energy production. It involves containing and expediting the anaerobic degradation of waste which naturally occurs in a landfill, but under controlled conditions to improve the yield of methane in the biogas, and to capture and use it effectively. The biogas produced is a versatile fuel which can either be valorised directly (Naik & von Blottnitz, 2012), or converted and stored. The effluent (digestate) from anaerobic digester is nutrient rich and can makes a useful additive to compost. In this way, the energy value from the organic waste is harnessed via biogas production, while the nutrient value is valorised in the composting operation.

1.2.3 Bokashi Treatment

Bokashi uses a mixture of microbes, usually mobilized on a carbon source, e.g. wheat or oat bran, which is layered on food waste and then sealed for 10 to 14 days. In that time, the food waste ferments and the organic waste mixed with it will pass the putrefaction stage (i.e. there will be no more smells). The product is essentially a pre-compost, which can either be applied directly to improve soil quality, or else can be added to compost to improve the nutrient value of the compost.

1.2.4 Composting

Composting works with some types of organic waste, including food waste. Nutrients are liberated from organic waste via aerobic treatment producing a soil conditioner, which improves nutrient value and water retention. Composting operations in South Africa use large amounts of land and use manure and wood chips. Recently, operations have expanded to include food and other (brown) wastes streams that improve the composting quality and therefore fetch a better market price for the product. Depending on the country and the municipal by-laws, if anything other than agricultural (green) waste is used (e.g. brown waste), then there may need to be an initial pre-treatment stage. This could be thermal, aerobic or anaerobic. Anaerobic treatment may take the form of Anaerobic Digestion or Bokashi Treatment above. There is also vermicomposting, which uses worms in the composting process to produce a high value liquid manure which can be suspended in irrigation systems. Composting methods only harness he nutrient value of OFMSW.

1.2.5 Animal Feed

Food waste can be used as animal feed, mostly as swill for pig farming. In South Africa, it is recommend to first have a thermal pre-treatment to reduce pathogen risks. Another alternative is the feeding of food waste to fly larvae. The larvae are then harvested and used to produce either whole dried maggots, or defatted to produce a maggot oil, and then desiccated and crushed to produce high protein fishmeal.

1.2.6 On-site Food Waste Disposal Units

The disposal of food waste into the sewer is becoming more attractive by installing a food waste disposal unit on site. Even though the energy value and nutrient value of the waste is not harnessed directly, the solution is cost effective and in most cases, environmentally more responsible than the normal disposal in a landfill. There are immediate savings (both economic and environmental) in the transportation of the organic waste to a treatment or disposal facility. The food waste is ground up, joining the municipal sewerage system, which eventually reaches a wastewater treatment plant. Wastewater treatment plants are designed to handle organic loading. In South Africa, there is a strong move towards waste-to-energy plants at wastewater treatment works, using the organic content to produce biogas. The organic waste would be beneficiated at such a waste-to-energy facility at the municipal wastewater treatment plant.

The diverse options mentioned above show that there are numerous alternatives to landfill for one of the largest components of the waste sent to landfill. Separation at source is essential and would allow for optimised recycling of organic waste once the most appropriate solution is chosen for the organic waste stream. This paper reports on experiences with composting of Bokashi treated organic waste, as well as anaerobic digestion of the same food waste (treated and untreated with Bokashi) at a composting facility in South Africa.

2. EXPERIMENTS

An operational composting facility in South Africa was chosen as the site for this study. A nearby mall which already practiced on-site separation of waste was then approached to add organic waste to their list of recoverable grades by the on-site waste minimisation service. The organic waste was separated daily at the mall into 240 litre wheelie bins. One wheelie bin was transported to the composting site as feed for the anaerobic digester. The balance was treated with Bokashi as described in Section 2.2, and brought to the composting facility after 14 days as additive to compost.

2.1 Anaerobic Digestion Experiments

A $6m^3$ pre-fabricated digester was installed at the composting facility in 2014. The digester, with a design capacity of 35 kg/day of (food) waste, was initially inoculated with cow manure and operated on manure for 3 months before being fed with the organic waste from the mall. The food waste was processed in a food waste disposal unit with water to create a slurry which drained into the AD unit. The gas produced was transported via a pipeline back to a small outhouse where a 4.5 kW biogas stove was installed for cooking purposes. The digestate was collected in a tank and used as a composting additive at the composting site. Figure 1 below shows the composting facility (a) and the installation of the anaerobic digester (b).

(a)

(b)

Figure 1. The composting facility (a) and the installation of the biogas plant (b)

Measurements were recorded as frequently as possible (almost every day) as follows:

- the pH was inferred from universal indicator paper, where green meant between 6 and 8, typically acceptable for biogas operations. Builders lime was kept on standby if necessary to adjust pH upwards
- the weight of the food added
- the burning time of gas stove along with the occasional reading of the in-line pressure gauge
- ambient temperature as recorded from weather reports.

2.2 Bokashi Experiments

Separated organic waste was placed on site in 210 litre drums and layered with Bokashi bran. These were then sealed and stored for two weeks, producing a pre-compost. After two weeks, they were transported to the composting facility as shown in Figure 2 (a) where the pre-compost was spliced into the windrow as shown in 2 (b). Later, as an additional experiment, the pre-composted was tested as feed for AD.

(a) (b)

Figure 2. Delivery of Bokashi treated waste (a) and the addition of the waste to the windrows (b)

3. RESULTS AND DISCUSSIONS

The results are divided into two distinct sections. The first is observing the effectiveness of each of the different treatment methods. The second part is an economic comparison of the treatment periods over the 18 month period.

3.1 Performance of the Anaerobic Digester and suitability of Bokashi Treatment

The digester was primed with cow manure and run solely on cow manure for 3 months (April to June). OFMSW was fed in fixed incremental amounts every second day, until the weight fed every second day was 20 kg. From thereon, 10 kg was fed daily and increased stepwise until it was operating at 35 kg/day by 1 October 2014. This process took 3 months from 1 July 2014 and the food waste was supplemented by cow manure. At this stage, one bin (weight varying) was processed through the food waste disposal unit and fed into the digester. The weight of each bin was recorded. These data are shown in Figure 3.

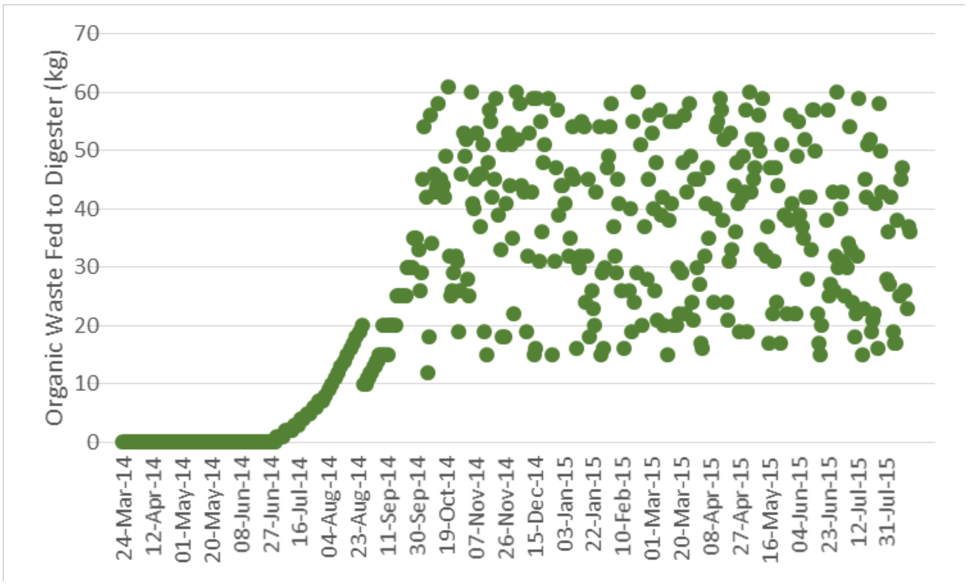

Figure 3. Mass of food waste fed to the AD unit from March 2014 to August 2015

Over the 18 months of the experiment, it was established that there was a correlation between temperature and the efficiency of the digester, as observed in a previous study (Naik & von Blottnittz 2012). As in the previous study, it was undertaken to calculate the efficiency of the digester by comparing the stove burn-time recorded, against the maximum theoretical yield of biogas calculated (by assuming properties of the OFMSW), constantly over a 10 day period. The assumptions and steps taken to calculate the efficiency of biogas yielded from the food waste used are:

- The AD unit can store approximately 1m^3 of biogas which equates to an average of 3.1 kWh on the occasions that the burner (always opened to maximum) lasted for a full hour, (based on 60% methane content of the biogas and the heating value of methane)
- It was assumed that the mall waste was 80% moist and that 90% of the total solids are volatile solids as well as a theoretical yield to calculate how much methane, therefore the volume of total achievable biogas.

Temperatures and calculated efficiency of the digester are shown in Figure 4. Since there was no OFMSW fed to the digester for the first three months, and that cow manure supplemented the organic waste between June 2014 and August 2014, efficiencies for the first 6 months of operation were not calculated.

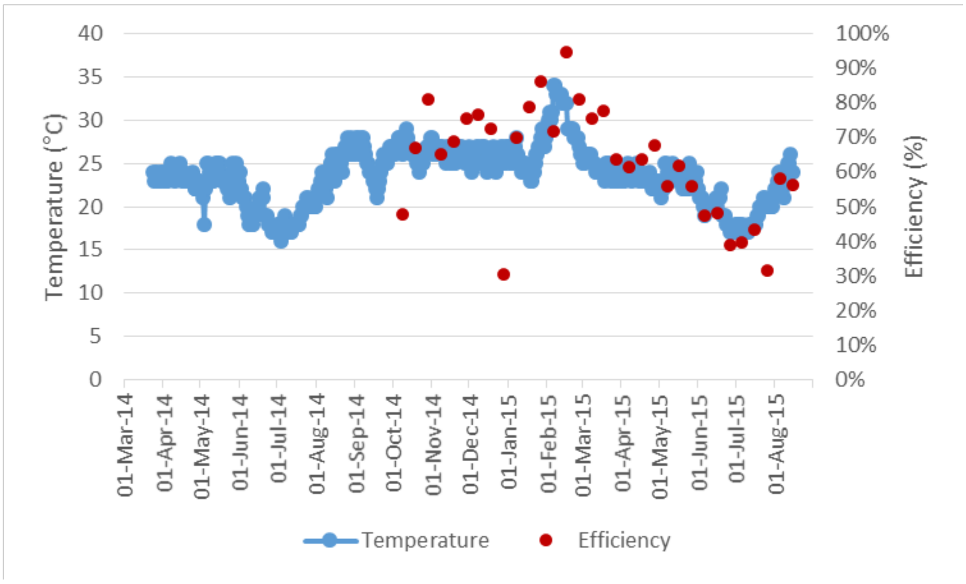

Figure 4. Temperature and efficiency in the Anaerobic Digester from March 2014 to August 2015

Overlaying the efficiency graph on top of the temperature graph shows a clear correlation between the amount of food waste converted to biogas by the AD unit, and the temperature. Over the warmer summer months, the productivity of the AD unit was up to 50% higher than in the winter months. The first exception is the first reading in October 2014, which may be attributed to a small lag phase in the digester's operation (adjusting to operation without cow manure). The second anomaly is at the end of December, where closer interrogation of the data revealed that a large amount of food was fed to the digester, but there was no use of the biogas, which therefore produced a low efficiency in the calculation.

Digestate produced was stabilised for a 2 - 3 days before being added to the compost heap.

It was found that Bokashi treatment was also effective. The food which arrived at the composting plant was easily tipped and formed into the windrows. Both the digestate and the Bokashi treated waste (pre-compost) added nutrients and increased the nutrient value and sale value of the compost produced (see section 3.2).

It should also be noted that for four months after the completion of the AD experiments (September to December 2015), the AD unit was fed with Bokashi treated waste instead of fresh food waste. No deductions could be made about the efficiency of the system under Bokashi treatment as it was unclear whether the variance was due to simple temperature fluctuations, or to the change in the nature of the feedstock (which is why no graphs are depicted showing the efficiency of this study). However, it is worthwhile to mention that during normal operation, builders lime was regularly added to the digester whenever the universal indicator paper showed that the pH was below 6. Over the entire four month period while operating on Bokashi treated food waste, the addition of builders lime was only needed once to mitigate the 'souring' of the digester.

3.2 Comparison between Treatment Options

An attempt was then made to quantify the costs and benefits of the two waste treatment options. The AD unit was purchased once-off, and was therefore depreciated over a 36 month period (the total time of operation of the experiment) to determine a monthly cost (this would be the monthly rental on the piece of equipment if hired from the supplier). AD produced biogas, which was compared to its equivalent LPG value to quantify the value of the biogas, it was estimated that 1 m^3 of biogas produced 2 hours of cooking time and was equivalent to 1.2 kg of LPG on the stove used.

Regarding the value of the nutrients added to compost, it is common to take the value of the individual elements in the digestate/pre-compost and convert them to equivalent values in fertiliser. However, since each of these were used to improve the grade of normal compost, these values were used as more 'real world' scenario. Both the digestate and the pre-compost were added to 3rd grade compost, which retails at R 130 /m^3. The digestate increased the value to be classified at 2nd grade compost, which retails at R 200 /m^3, while the pre-compost increased the value to first grade compost, which retails at R 240 /m^3. A summary of the total costs and revenues is shown in Table 1.

Table 1. Average Monthly Costs and revenues for Anaerobic Digestion and Bokashi Treatment

Anaerobic Digestion				Bokashi			
Equipment Cost	R	73,000.00					
Monthly Rental	R	2,220.80		Monthly Operational Costs	R	9,800.00	
Average Monthly Burntime		74.5	hours				
Equivalent Value of LPG	R	883.78					
Volume of compost upgraded (3rd to 2nd)	R	30.00	m3	Volume of compost upgraded (3rd to 1st)	R	95.00	m3
Increased Revenue	R	2,100.00		Increased Revenue	R	10,450.00	
Profit	**R**	**762.98**	per month	**Profit**	**R**	**650.00**	per month
Average mass treated		1138	kg/month	Total Mass Treated		2352	kg/month
Normalised Profit	**R**	**0.67**	**per kg**	**Normalised Profit**	**R**	**0.28**	**per kg**

From these data, it is apparent that there are increased savings in the anaerobic digestion operation, (biogas and composting) compared to Bokashi treatment and composting, despite the high capital cost of equipment. The revenue was calculated as the value of the biogas produced (compared to LPG) as the upgrade of 3rd grade compost to 2nd grade compost. Furthermore, it is important to note that the composting of the digestate (as opposed to simply disposing of it), significantly affects the profitability of the technology.

For the Bokashi treatment, the monthly cost included the Bokashi bran, rental of the drums and transport to the composting facility. There was increased revenue of R 650.00 by addition of Bokashi treated waste to 3rd grade compost to produce 1st grade compost.

Importantly, the two technologies treated different amounts of organic waste. Therefore, the profit calculated on each technology was normalised by dividing by the amount of food waste treated. For AD (with gas recovery and composting of the digestate) a normalised profit of R 0.67 per kilogram of food waste treated was calculated, compared to R 0.28 per kilogram for Bokashi treatment with composting.

It should also be noted that Bokashi operation requires very little technical expertise. The operation of the AD unit was successful as there was significant knowledge support and resources available to safeguard the investment.

4. CONCLUSIONS

Firstly, it can be concluded that the OFMSW can be a sole feedstock for anaerobic digestion. Knowledge support is required and the occasional addition of builders lime to mitigate souring is crucial to maintaining operational stability. Stability was improved when Bokashi treated waste was used as feedstock for digestion, with only one incidence of lime addition required in 3 months. The efficiency of the digester at producing biogas from the OFMSW was significantly affected by the 20 variance in ambient temperature, averaging 75% in the summer months and dropping as low as 40% in winter.

Comparing the cumulative associated costs and revenues, there is a strong case to be made for anaerobic digestion, if both the biogas and the digestate are used effectively. There is also a case to be made for Bokashi treatment only, which has the added advantages of not being dependant on a capital cost, and requiring significantly less technical expertise.

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