From organic waste to energy: A feasible option in South Africa?

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Abstract

Waste in South Africa is disposed of in landfills, which produces unwanted landfill gas (CH_4) and leachate emissions. Biological treatment of the Organic Fraction of Municipal Solid Waste (OFMSW) is an established technology in Europe, applying anaerobic digestion (AD) to produce nutrient-rich sludges and bio-gas. The aim of the study presented here was to investigate the biogas production when kitchen waste, and kitchen waste combined with wet paper waste and later only dry paper waste was digested, operating a laboratory scale anaerobic digester (Vol: 5 L). The results showed the higher the loading rate to the reactor, the higher the volume of gas produced. The highest gas production amounted to 3.3 L/d. This finding corroborates the results as obtained by many researchers globally, stating that the OFMSW can be digested to biogas. The biogas produced can be harvested to generate heat and electricity. With the prediction that Eskom will not be able to supply the power needed for South Africa in the years to come, the mindset of the waste companies/industries and municipalities in South Africa should thus change from: "waste to landfill" to "waste to energy".

Introduction

Waste in South Africa is disposed of in landfills; however, the negative environmental impacts relating to landfilling, such as landfill gas (CH_4) and leachate emissions should be reduced. Moreover, the scarcity of available land in close proximity to areas of waste generation has made landfilling a less attractive option (Hartmann and Ahring, 2006). The internationally accepted hierarchy of waste management has shifted the emphasis from disposal to minimisation, recovery, recycling and treatment (Sakai *et al*. 1996, DEAT, 1999a). Anaerobic digestion (AD), a biological treatment technology applied to the organic fraction of municipal solid waste (OFMSW), has become an established treatment process worldwide. The products generated from this technology comprise biogas (methane), which is a potential energy source and a nutrient-rich sludge, which has beneficial value as a fertiliser. Thus, the recovery of biogas as well as the recovery of nutrients makes AD of organic waste a sustainable waste treatment concept (Hartman & Ahring, 2006). AD is a natural process where the bacterial decomposition of organic materials takes place under anaerobic conditions by a range of different species of indigenous bacteria.

Biological treatment of the OFMSW (40 % by mass) is only marginally recognised in South Africa. This observation can possibly be ascribed to relatively inexpensive landfill fees and lack of an energy policy that recognises organic waste as an (energy) resource rather than just a waste material (DiStefano & Ambulkar, 2006). It does however seem that the thinking around biological treatment of waste for energy recovery in South Africa is starting to change. A biogas digester converting human waste into energy was being tested in Ivory Park Urban Ecovillage in Midrand, Johannesburg, in 2006 (Resource, August, 2006), while a pilot scale digester converting manure and human faecal matter into energy is being tested in Giyane, Mpumalanga, South Africa (Pers. Com. Jotte van Ierland, 2008). The mindset change in this regard can possibly be ascribed to the current electricity shortages experienced in South Africa. Von Blottnitz et al., (2006) have undertaken a study for the South African Department of Science and Technology to evaluate the opportunities for energy from waste in South Africa to influence policy in this regard. They concluded from their investigation that waste to energy has an "exciting future" in South Africa, when approached innovatively and responsibly.

When introducing the AD technology for energy production in South Africa, the environmental, social and economic aspects of the various areas in South

Africa need to be considered. The rural areas of South Africa may be comparable with those in China, which, like other Asian countries (e.g. India, Nepal, Vietnam, Bangladesh), apply the AD technology to generate energy from organic waste for lighting and cooking in rural areas (Van Nes, 2006). The director of the Energy Ecology Division (Chinese Ministry of Agriculture) stated that 15 million households in China were using biogas by the end of 2004, which is predicted to increase to 27 million households by 2010. Livestock and poultry farm waste as well as household waste are the feed sources for the digesters. Not only the benefits of the biogas are recognised in these countries, but also the benefits of the valuable fertiliser, supplying nutrients and organics for the soil. The biogas plants are mainly situated in farming communities where it serves a dual need: the reduction in organic waste and the supply of biogas as energy source in areas where no energy was available previously (Van Nes, 2006). Potentially, the South African Department of Agriculture can apply the rural China example for its sustenance farming communities in the rural areas, provided that the required governance environment is in place.

Often no electricity is supplied to informal settlements in South Africa or the poverty levels are such that households cannot afford electricity (HSRC, 2006). The percentage of households living in informal dwellings increased from 12.7 % in 2002 to 15.4 % in 2007, according to the General Household Survey (Statistics SA, 2007b). The number of households connected to electricity was reported to be 81.5 % in 2007. During the winter months, gas, paraffin, wood, coal and other products are burned for heating and cooking purposes. The burning of these fuels generates gases and particulates, which can result in lung and other respiratory diseases, especially in the young, elderly or immuno-comprised individuals. A need therefore exists for inexpensive, safe, alternative energy sources in communities presently without electricity supply. In situations where the OFMSW can be separated at source and co-digested with manure in an anaerobic digester, the biogas produced could be used to supply heat and light to these communities.

In some cities, e.g. Stockholm (Sweden) co-digestion of sewage sludge together with organic waste resulted in the production of bio-methane gas, which is used as fuel for the city buses (Wellinger, 2007). With the escalating cost of fuel in South Africa (> R10/L, July 2008), the introduction of biogas as a vehicle fuel can possibly be an attractive alternative locally, where biogas has not been earmarked for this purpose before.

The following research study was undertaken to familiarize our research team with the concept of treating organic waste, applying the AD technology. The aim of this study was therefore to investigate the bio-gas production when different kinds of wastes, such as kitchen/food waste, kitchen/food waste combined with wet paper waste and dry paper waste only were subjected to the AD process.

Materials and Methods

Anaerobic Digester Reactor (AR) and microorganisms

A perspex reactor (AR), volume 5 L, was operated at 35℃ (Figure 1). The reactor was heated by an electrical wire, which surrounded the reactor and which was connected to a thermostat, set at 35℃. Sieved (mesh of 0.5x0.5 cm) anaerobic sludge (1 L), obtained from the Anaerobic Digester at Daspoort Sewage works, Pretoria was added to AR to supply the anaerobic microorganisms. Kitchen/food waste mixed with water was shredded in the “Sinkmaster” (an organic waste disposer, normally build into kitchen sinks to remove table scraps) and added to AR, to start the digestion process. The reactor contents were stirred slowly with an overhead stirrer. Regular feeding of AR, followed by sample taking started when biogas production was observed. Sample taking and gas emission took place through two separate openings at the top of the reactor.

Figure 1. Laboratory Scale Anaerobic Digester (AR)

Experimental

The reactor received kitchen/food waste, by shredding 1.7 kg of this waste in 500 ml tap water. The total solids (TS) concentration of the mixture was 21.5 g/L, while the volatile solids (VS) concentration was 16.0 g/L. During the total duration of the experiment, the feed loading rate was increased by increasing the feed rate and the waste concentration. AR was batch fed throughout the duration of the experiment according to the following pattern:

AR received 2 kg waste/500 ml water on day 12, which was changed to 1 kg waste/250 ml water on day 19. On day 22, AR received a more concentrated waste of which the VS was 17 g/L. This feeding regime was repeated 3xweek, till day 50, when AR received a more concentrated feed (VS of this feed was 48 kg/L) every weekday. On day 70, AR received wet paper waste mixed with kitchen/food waste by mixing 7.5 g paper waste with 25 ml tap water. This mixture was added to 100 ml kitchen/food waste. This procedure was repeated on day 71, 72 and 73. When it was noticed that the gas production of AR was not disturbed, 15 g paper waste/25 ml water in addition to 100 ml kitchen/food waste was added to the reactor (days 74-81). On day 82, the wet paper waste concentration was doubled again to 30 g/25 ml, which was increased on day 85 to 50 g/25 ml wet paper waste. When the wet paper waste was finished, dry paper waste was used by making a solution of 280 g dry paper waste dissolved in 500 ml tap water, of which 250 ml was added to the reactor. This was repeated on days 92 and 93, after which day the experiment was finalised, since all paper waste samples were finished. The loading rate for AR is presented in Figure 2. It can be observed that initially the reactor was under-loaded since loading to anaerobic digesters should start slowly. The advised loading rate for digesters is between 1-4 g VSS/L (reactor) day^{-1} to be attained after approximately 40 days of operations (Polprasert, 2007). The loading rate in AR increased when wet paper waste was added (first arrow, Figure 2) to the kitchen/food waste and increased further when only dry paper waste in higher concentrations (second arrow, Figure 2) was added to AR.

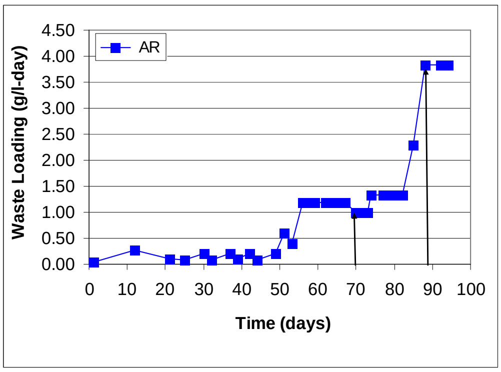

Figure 2: The loading rates (g/L/day^{-1}) for AR.

Analytical methods

Daily samples (125 ml) were taken from AR for pH and for the determination of the Ripley ratio. The Ripley ratio is a function of the volatile fatty acids (VFA) and alkalinity concentrations, which were determined by titrating a reactor sample to pH values of 5.75 for the VFA concentration and to 4.3 for the alkalinity concentration with 0.5 M HCl (Ross *et al*., 1992). The Ripley ratio is an important parameter to monitor the degradation process in the digester as it represents a measure of both the VFA and the alkalinity concentrations: two important parameters in the AD process. An excess in VFA production can usually be ascribed to reactor overload. The methane producing bacteria become inhibited when the reactor pH decreases to values lower than 6.8. During the operation of AR the pH was measured daily and when the reactor pH was < 6.8, the pH was manually corrected by adding a saturated solution of $NaHCO_3$, such that the pH increased to > 6.8. When the Ripley ratio is lower than 0.3, the anaerobic digester is functioning optimally, with the required ratio of VFA and alkalinity in the reactor. The produced alkalinity buffers the VFA concentration in the reactor maintaining the ideal reactor pH for the methanogenic bacteria to produce methane gas.

The daily gas production was measured by the water replacing method. The gas volume produced in the anaerobic reactor was captured in a bottle filled with water, which was kept under pressure. When a gas bubble entered the bottle with water, the gas replaced the water, which was then forced out of the bottle into a measuring cylinder. The volume of water in the measuring cylinder thus resembled the gas production in the reactor, measured in ml. The determinations of pH as well as for the mixed liquor suspended solids (MLSS) and volatile suspended solids (VSS) were carried out according to standard analytical procedures as described in *Standard Methods* (APHA, 1985).

RESULTS AND DISCUSSION

Gas production

The gas production in AR is shown in Figure 3. Since regular reactor feeding of 3x week only started on day 22 the obtained data are presented from day 25 onwards (Figure 3). The results show that the gas production increased in a similar pattern as the loading rate, showing a clear relationship between the increased organic mass to the digester and the improved gas production. Ross *et al*., (1992) described that approximately 1 m^3 gas can be produced from the degradation of 1 kg sewage sludge at a HRT of 20 days and at a temperature of 35℃.

As observed from Figures 2 & 3, the gas production in AR increased when the loading rate increased, especially when the paper waste mixed with the kitchen/food waste was administered to the digester. Saint-Joly *et al*., (2000) also showed that paper and cardboard waste have a certain anaerobic biodegradability with biogas potential.

The initial gas production from day 25-46 in AR was < 500 ml/day, which period coincided with the reactor "acclimatisation period" (Figure 3).

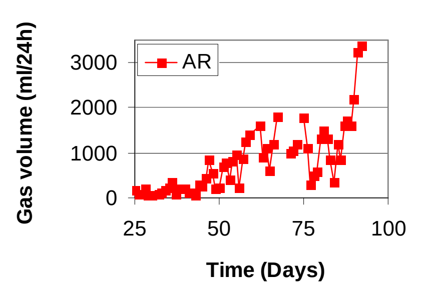

Figure 3. Gas production in AR (ml/d).

When the reactor was fed on a daily basis (from day 56 onwards), the gas production increased to volumes > 1500 ml/d, which decreased slightly when the paper waste was added to the kitchen/food waste (day 70). However, when only the paper waste was added (from day 88) the gas production increased rapidly. The gas volume was 1720 ml/d, 1600 ml/d, 2200 ml/d, 3250 ml/d and 3380 ml/d from days 88-95, respectively. These increased gas volumes seem to indicate that paper waste can be treated in an anaerobic digester. Supposedly, paper waste contains different kinds of chemicals from the bleaching process that could possibly inhibit the microbial degradation process, though this was not observed from the presented results. It must, however, be remarked that the paper waste was only added from day 70 till day 88 in combination with kitchen/food waste, where after only dry paper waste (dissolved in tap water) was fed to the digester, which was stopped on day 95. Thus the long term effects of adding paper waste to the reactor could not be determined.

The conversion of organic matter to biogas is a useful process control parameter. Typical gas yields obtained at full scale digesters for wastes originating from different waste collection strategies are generally > 100 m^3 biogas/ton of treated waste (Polprasert, 2007). The difference in gas yield from different processes can possibly be ascribed to the nature of the waste and to other important parameters, such as the operating temperature. A too low loading rate will not provide sufficient biogas (Polprasert, 2007), as was seen from the presented results during the acclimatisation period of AR. When no gas production is observed, it can be safely assumed that no organic matter is being degraded, mainly due to the inhibition of the methane producing bacteria. This can most likely be ascribed to a reactor pH change, since the methanogenic bacteria mainly function at a pH of 6.8-7.2. The obtained gas production in AR correlated with the results of Matekenya and Vorster (2006), who showed that food waste had a gas production of 69%. Generally, food waste provides the highest biogas yield, which will decrease with increased amounts of garden waste (Hartmann and Ahring, 2006). Vermeulen et al., (1993) also observed that the addition of paper to the AD process resulted in an almost doubling of biogas production.

The gas production from the loading rate per gVS/L day^{-1} was calculated during the last few days of the study, when only the dry paper waste was used as feed to AR. The results from that period (day 88-95) showed that 0.45, 0.42, 0.57, 0.85 and 0.88 L gas was produced from 1 gVS/L day^{-1}, which is according the theoretical value as indicated by Ross *et al*., 1992, who indicated that 1 L gas can be produced from 1 gVS/L day^{-1} at a HRT of 20 days. The empirical finding from this study was on average 0.63 L gas from 1 gVS/L d^{-1} at a HRT of 40 days.

pH and Ripley ratio

The average pH value in AR during the experimental period was 7.07. Ideally, the anaerobic digester pH should be between 6.8 and 7.2. When the digester pH is < 6.8, it usually indicates that the VFA concentration increased (Ross et al., 1992), which then results in a decrease in the buffer capacity of the alkalinity produced.

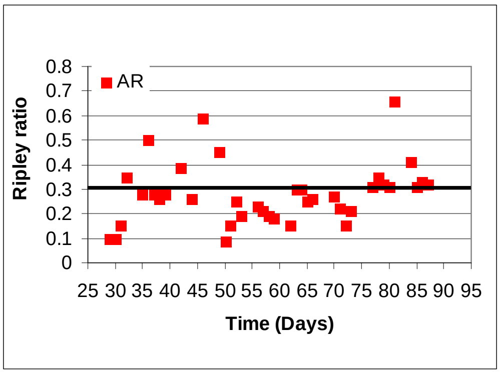

Figure 4. The Ripley ratio in AR

The Ripley ratio results in AR (Figure 4) showed that over the experimental period of 90 days, the ratio was mainly < 0.3. It increased slightly towards the end of the experiment, when the reactor adjusted to the higher loading rates, but it recovered soon there after.

Discussion

The results obtained from the presented study showed that AD for the OFMSW is feasible. With these promising results, the mindset of the municipalities of sending organic waste to landfills can potentially be changed to the treatment of organic waste, resulting in the production of biogas and digestate, a potential fertiliser. The biogas produced is an alternative source of energy, which in South Africa, where energy shortage is a fact, is a very important consideration when pursuing the AD treatment of the OFMSW. The biogas can be utilised as gas for cooking and lightning or alternatively can be sent to a gas turbine providing electrical energy. It is interesting to note that a study to investigate the Best Practicable Environmental Option (BPEO) procedure conducted by Kramadibrata and Smith (2006) to diverse OFMSW from landfill showed that waste management techniques, such as energy recovery, performed better than for instance recycling and composting. The other outcome of that study indicated that landfill was identified as the management option with the least benefits. During their study, they compared amongst others: recycling, composting, AD, mechanical and biological treatment, incineration, pyrolysis, gasification and landfill.

In Europe the biological treatment of organic waste was boosted by the introduction of waste separation at source before collection (De Baere, 2006), which may be one of the constraints for the implementation of AD using OFMSW in the urban areas of South Africa, where presently very limited waste separation at source occurs. This, however, does not apply to the rural areas, where waste is seldom collected. The South African Environment Outlook Report (DEAT, 2006) identified waste stream separation in the near future as an opportunity in waste management. Although waste minimization, such as composting and recycling, is applied in South Africa, the

AD technology is not yet in the same league.

CONCLUSIONS

From the presented results, it can be concluded that the performance of reactor AR showed promise for the anaerobic degradation of kitchen/food waste, resulting in elevated volumes of biogas, at increased loading rates. When wet paper waste was added to the reactor, the relationship between the increased loading rate and the improved gas production rate was remarkable. The more easily degradable carbon a waste product contains, the higher the gas production. This relationship was especially noticed when only dry paper waste was added to the reactor, since the increased loading rate resulted in increased volumes of biogas. Whether the resource potential of organic waste will be taken to the next level in South Africa, is largely dependent on an enabling governance environment, including national legislation and priorities of both the environmental and energy sectors in South Africa.

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