

Optimization of Biogas Production from sewage sludge

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Abstract— It is widely known that the degradation of waste activated sludge is a slow process with a low extent of degradation. Improvement methods with regards to bio-methane yield were investigated in this study using a laboratory batch anaerobic digester. Mono-digestion of sludge with a C: N ratio of 15.47 resulted in a lower accumulation of gas volume than co-digested sludge even though the pH decreased rapidly in both cases. The thermophillic anaerobic digestion of sludge and co-digested sludge also produced higher bio-methane yield than mesophillic digestion of waste water sludge. Gas accumulation volume in the digesters during thermophillic digestion increased from 50 Nml to 100 Nml, 200 Nml to 600 Nml and 600 Nml to 750 Nml for sludge, cow dung and sludge and sludge and food waste respectively as the temperature was increased from 37°C to 45°C.

Keywords— Anaerobic digestion, Co-digestion, Mesophilic temperature, Waste Activated Sludge

1 Introduction

South Africa and certain Eskom supplied countries in Africa are currently going through an energy crisis. The process of load shedding and the promoted energy efficiency programmes serves to illustrate the current energy situation. Furthermore, the situation is aggravated by the increases in energy prices. South Africa is becoming one of the higher costing energy suppliers in the world. Additionally, South Africa is one of the highest GHG emitters in the world therefore all efforts must be made in order to reduce its GHG emissions. Treating sewage is a water recycling service. A large variety of disposal routes are possible, however anaerobic digestion proves to be more eminent for its abilities to further transform organic matter into biogas (60–70 volume% of methane, CH₄), which can then be used to generate electricity or used as it is (Gunaseelan, 1997).

Moreover, it in turn reduces the amount of final sludge solids for disposal whilst destroying most of the pathogens present in the sludge and limiting odour problems associated with residual putrescible matter. Anaerobic digestion thus optimises Waste Water Treatment Plant costs. It has an environmental footprint and is considered a major and essential part of a modern Waste Water Treatment Plant.

Biogas is a renewable energy that is produced when bacteria under anaerobic (oxygen free) conditions breaks down organic matter (biomass) biologically. Biomass is the organic matter that is formed from the photosynthetic retention of solar energy and is stored as chemical energy (Wei, 2007). Solar energy stored in biomass such as, municipal and industrial wastes, animal wastes, agricultural crops, forest and mill residues, wood and wood wastes, livestock operation residues, aquatic plants and fast growing trees and plants can be released as biogas through a process called anaerobic digestion (AD). Biogas is a mixture of methane (CH₄), carbon dioxide (CO₂), and trace elements that include oxygen (O₂), nitrogen (N₂), hydrogen sulphide (H₂S), water (H₂O) and ammonia (NH₄) (Rasi, 2009). This gas has various applications like, cooking, heating and electricity provision or it can be utilized as a biofuel for transportation applications.

The production of biogas through AD has been evaluated as one of the most energy-efficient and environmentally beneficial technologies for bioenergy production (Ifas, 2017). AD is the multi-step biological process during which organic material is converted to biogas and digestate in the absence of oxygen (Ifas, 2017 and Al Seadi et al., 2008). Biogas production takes place in series of four fundamentals steps: namely, hydrolysis, acidogenesis, acetogenesis and methanogenesis (Jorgensen, 2009). Figure 1 shows a brief summary of these steps of anaerobic digestion process and the products that are formed after each step. The organisms sequentially decompose the products of the previous step. The process of breaking organic polymers and dissolving the smaller molecules into solution is known as hydrolysis. This is the first process that takes place in AD, followed by acidogenesis. In this process, the products of hydrolysis are converted into methanogenic substrates by the acidogenic bacteria (Sterling et al., 2001). Fatty acids, simple sugars and amino acids are decomposed into acetate, about 70% hydrogen, carbon dioxide, volatile fatty acids (VFA) and about 30% alcohols (Sterling et al., 2001). This process is then followed by acetogenesis. In this process, simple organic acids, carbon dioxide and hydrogen which are products formed during the acidogenic phase by acidogenic or acid forming bacteria, are converted to acetate and hydrogen by obligate hydrogen forming bacteria (Angelidaki et al., 2007). An acetogenesis reaction is shown below:



Then finally, methanogenesis takes place in the last stage, whereby, bacteria convert hydrogen, acetic acid and Carbon dioxide to Methane and Carbon dioxide (Boe, 2006). During the process of methanogenesis, acetate is the source of an estimated 70% of the methane produced (Smith and Mah, 1966, and Kangle, 2012). The reduction of carbon dioxide by hydrogen and other electron donors is responsible for the production of the remaining 30% of methane.

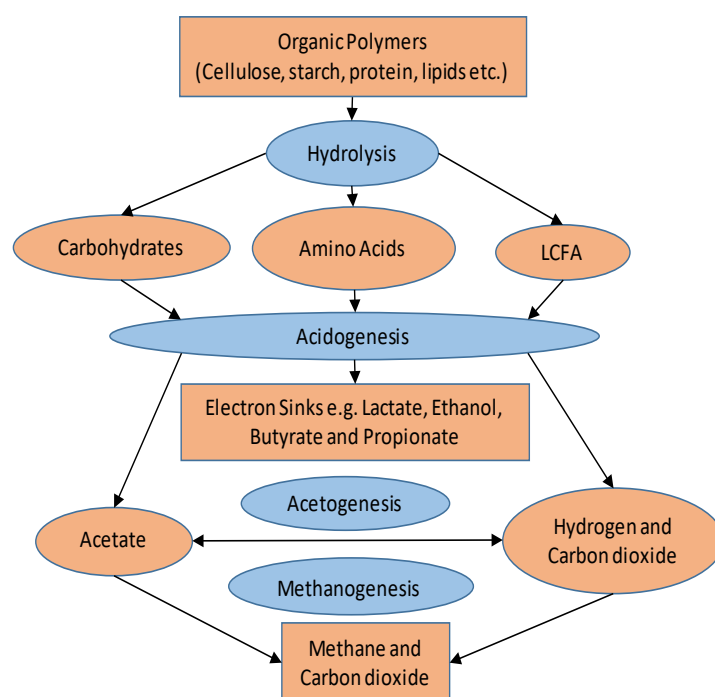


Figure 1: Bio-process degradation in the anaerobic digestion processes

The efficiency of an AD process is affected by the following operating parameters which in turn, affect the metabolic activity in the microbiological production of methane (Chen, 2014, Matheri et al., 2016, Matheri et al., 2017, Matheri et al., 2018).

- Temperature
- pH value
- Carbon to nitrogen ratio (C/N)
- Retention time
- Co-digestion
- Pre-treatment methods

However, the aim of this experiment was to investigate the effect of co-digestion and temperature in biogas production using waste water sludge.

2 Methodology

2.1 Waste characterization

The wastewater sludge was collected from the municipality of Tshwane Pretoria at Daspoort wastewater treatment plant in the early hours of the morning to eliminate rise in temperature and pre-digestion before collection. This was sludge that remains after the three stages of water purification have been completed at the plant. The cow dung was collected from Niger farm in Johannesburg. The food waste was collected for the hotel refuse from the University of Johannesburg canteens. The samples were analysed in order to determine the characteristics of the substrates like total solids, volatile solids, C: N ratio and calorific value according to standard methods.

2.2 Biomethane Production

Firstly, all three substrates namely, wastewater sludge, cow dung, food waste, co-digested wastewater sludge and cow dung were measured using a mass balance. Then they went through a pre-treatment process which involved adjusting the pH of the substrate by adding sodium hydroxide (NaOH) to all three substrates since they were too acidic. Once the pH was at approximately 7, the substrates were taken to the bio-methane potential set-up for start-up procedures.

For the CO₂ fixation, sodium hydroxide (NaOH) bottles for CO₂ fixation were prepared by making a solution of 3M NaOH – solution by mixing 240 g pure NaOH with distilled water up to 2l. A solution of 0.4% Thymolphthalein pH indicator (40 mg in 9 ml ethanol 99.5%- and 1-ml water) was prepared, adding 10 ml pH- indicator solution to the prepared 2l NaOH solution. Thereafter, 100 ml bottles containing about 80 ml NaOH solution (3M) together with Thymolphthalein pH- indicator were prepared. Finally, the rubber lid (with two metal pipes) was used to close the bottle.

The inoculum to substrate ratio was chosen to be 1:1. Digestate from previous study was used as inoculum. The 500 ml reactors and their lids were marked. Reactors were then fed with inoculum and substrate in the ratio of 1:1, reactor 1 containing waste water sludge, reactor 2 co-digested between wastewater sludge and cow dung and reactor 3 co-digested between wastewater sludge and food waste. The rubber stoppers were then lubricated with silicon spray on the side that is in contact with the bottle and closed tightly. The stirring stick to the motor was fastened. The water bath was filled with distilled water to an indicated level. All the reactors were placed in the water bath and connected to the CO₂- fixing bottles and to the flow cells. Contacts for the stirring were connected to the individual motors as well as the gas volume measuring device. Lastly, the internet cable was connected to the computer and to the gas volume measuring device. All the reactors were flushed with N₂ for approximately 1 minute, using the extra inlet in the lid to achieve anaerobic conditions and all the flow cells emptied. The data logging program was started, and the experiment took 15 days to analyse all the samples and the methane produced in each sample was automatically recorded in the software both in hours and in days. Fig 2 illustrates the BMP set-up.

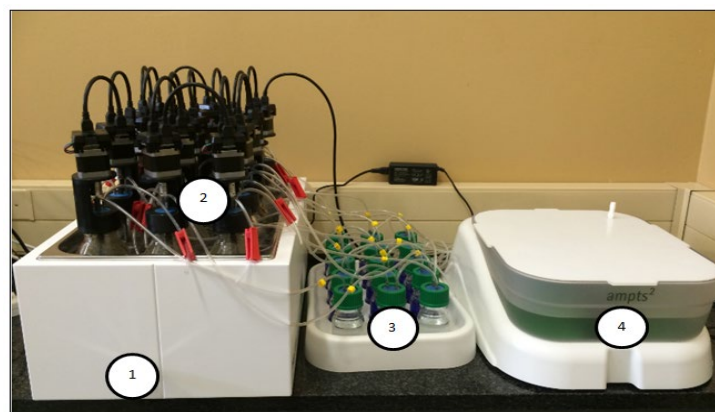


Figure 2: Biochemical methane potential (BMP) set-up (1), Thermostatic water bath (2), Glass bottle reactor (3), CO₂ Fixing unit and (4) Gas volume measuring device.

3 Results and Discussion

3.1 Substrate Characterization

The main characteristics of the substrates (wastewater sludge) and co-substrates (cow dung and food waste) have a great impact on the amount of biogas produced. Table 1 illustrates the characteristics of the materials used in this research.

Table 1: Substrate characteristics

Substrate	C (%)	H (%)	N (%)	S (%)	TS (%)	VS (%)	C: N Ratio	Calorific value (MJ/kg)
Sludge	47.66	6.64	3.18	1.16	62.82	37.18	15.47	23.85
Cow dung	41.61	5.44	1.97	1.81	98.18	1.81	21.12	17.31
Food Waste	41.54	5.59	1.33	0.00	62.01	37.99	31.37	17.68

Table 1 shows the characteristics of the material used during digestion of sludge and co-digestion of sludge with cow dung and food waste. The quality of biogas produced methane in particular is mainly dependant on the characteristics of the feed stock during anaerobic digestion (Oleszek, 2014), If total solid (TS) of the main substrate is above 20% the material then the material is suitable for digestion (Dhamodharan, 2015). In this study, TS of sludge, cow dung, and food waste were 62.82%, 98.18%, and 62.01% respectively. Volatile Solid (VS) values were 37.18 %, 1.81% and 37.99% respectively. The characteristics results found in this study therefore fall within the range and therefore can be concluded that these substrates were suitable for anaerobic digestion. The C: N ratio plays an important part during AD. If the C:N ratio is above 25 methanogens consume nitrogen rapidly and this may ultimately result in a lower gas production due to CO₂ production which then results in accumulation of acid. While ammonia accumulation may be the result of a lower C: N ratio which may cause the pH levels to rise above 8.5 and result in a toxic methanogenic bacteria, which consequently results in lower gas production or ultimately stop the process of methanogenesis. Based on these facts, it is important to find a balanced C: N ratio to ensure optimum gas production. In this study, C: N ratio was found to be 15.47%, 21.12% and 31.37% for sludge, cow dung and food waste respectively. However, a C:N ratio of 20-30 is said to be optimal for AD (Pamdey, 2012).

3.2 Bio-Methane production of co-digestion of substrates

Digestion took place under mesophilic temperature and yielded the following results as shown in Figure 3.

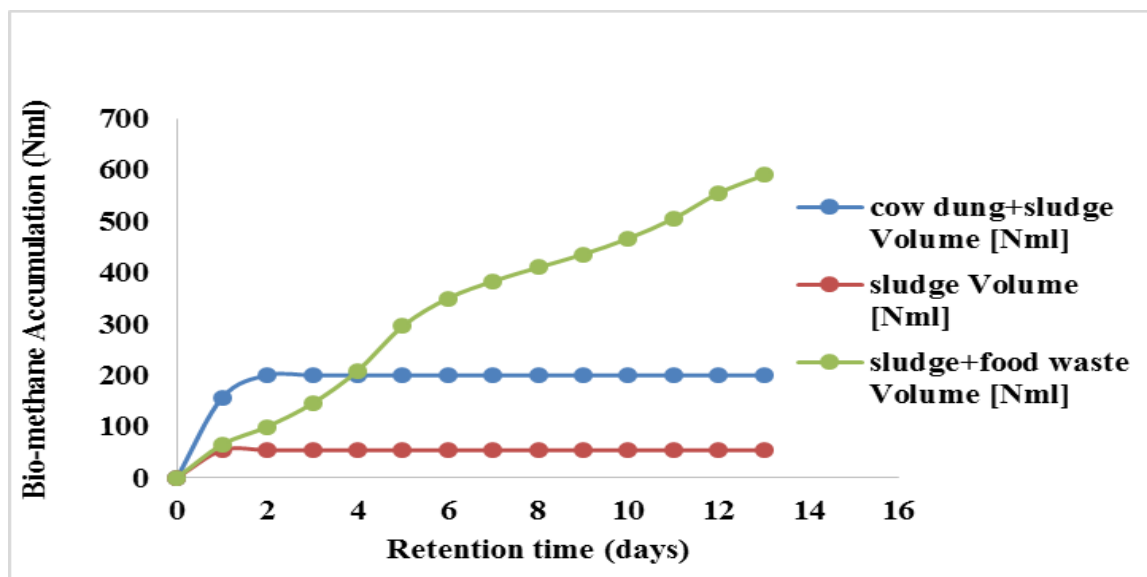


Figure 3: Mesophilic temperature 37 °C on co-digestion of bio-methane production

The graphs do not have a lag phase indicating that substrates started producing gas on the first day. This is due to the fact that the digesting system had agitators, and the cow dung was crushed to allow for optimum surface area for reaction. The mono-digestion of sludge shows the lowest gas accumulation of 45 Nml which stopped after one day. If a substrate has a low C:N ratio, it results in accumulation of ammonia and a pH that is higher than 8.5 (Matheri, 2015). However, this was not the case with sludge. The C:N ratio of sludge was initially 15.47 but as soon as the experiment started, the nutrients in the substrates rapidly produced acid which resulted in a pH of 4.15. The problem of pH creating a toxic environment for bacteria could be solved by introducing other substrates by co-digestion. Co-digestion of sludge with cow dung showed a slight increase in gas production with a gas volume of 200 Nml. However, the process of accumulation stopped on the second day. This was due to an increase in C:N ratio which took place within the first two days and resulted in a low pH of 4.15. Co-digestion of sludge with food waste shows continuous increase in accumulation for the 15 days with a final gas volume of about 600 Nml on the 15th day and a pH of 6.40. Thermophilic bio-methane was then investigated as another alternative for optimum bio-methane production.

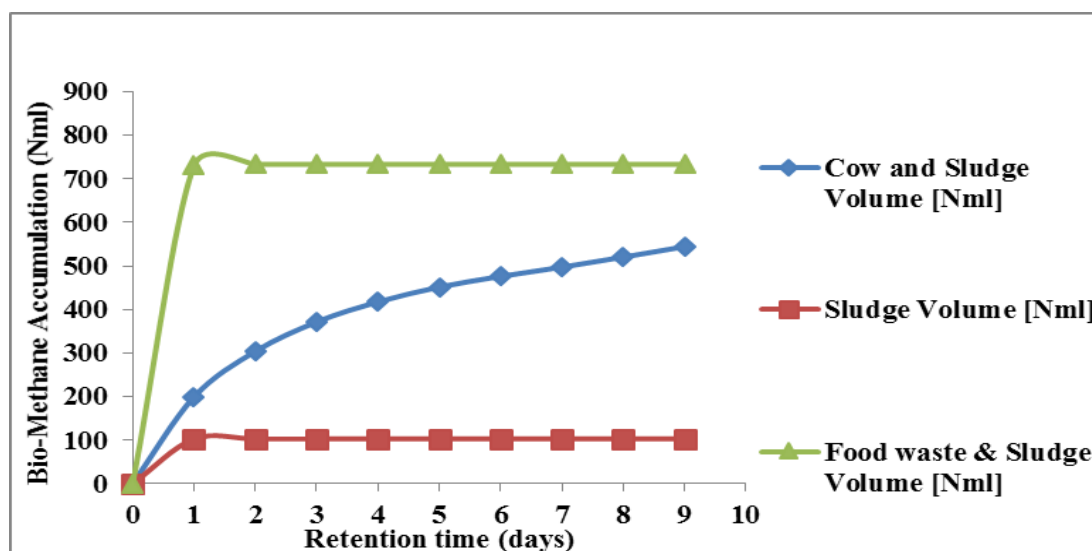


Figure 4: Thermophilic temperature 45 °C on co-digestion of substrates in bio-methane production

3.3 Effect of temperature on bio-methane production

Digestion that took place under thermophillic temperature resulted in a slight improvement in the accumulation of bio-methane gas as opposed to gas produced under mesophillic temperature. Mono-digested sludge has a gas accumulation of 100 Nml which stopped increasing in a day. However, this is twice the gas produced in mesophillic temperature. Co-digestion of sludge with cow dung has a gas accumulation of about 600 Nml within two days and a pH of 5.32. The pH having decreased from 7.83. Moreover, the co-digestion of food waste and sludge resulted in a gas accumulation of about

750 Nml. This is more than the gas accumulation obtained in a mesophilic anaerobic digestion of sludge.

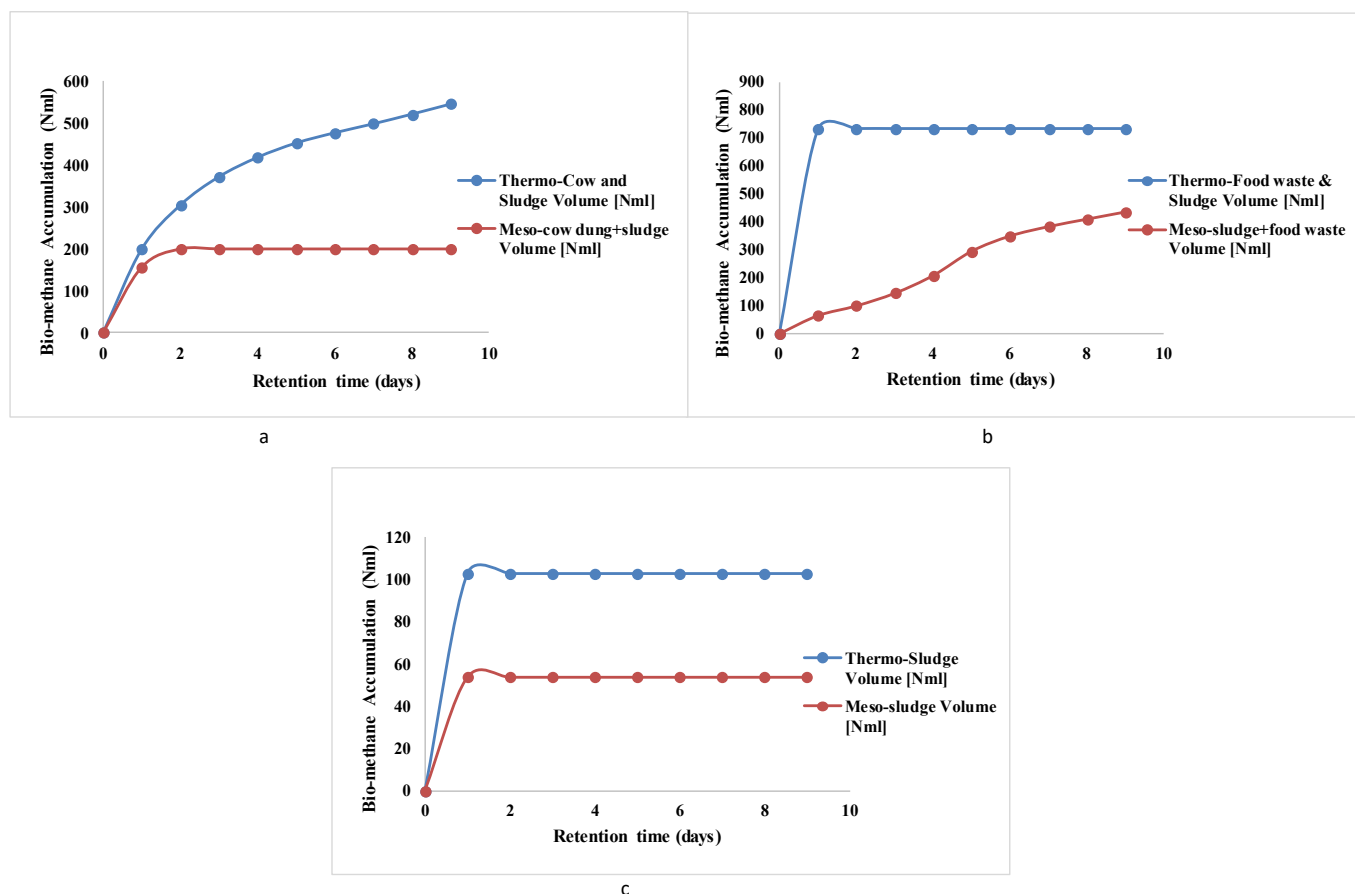


Figure 5: Influence of digestion temperature on the bio-methane production

The Figure 5 show mono-digestion and co-digestion of sludge. Higher biogas production was observed under thermophilic temperature compared to mesophilic condition with lower retention time. There were more mesophiles than thermophiles; they are also more resilient to changes in the conditions of their environment in comparison to the thermophiles. Therefore, mesophilic digestion and systems are considered to have more stability than thermophilic systems. On the contrary, even though thermophilic digestion systems are said to be less stable, they have a higher methane yield. Since their heat energy input is higher which allows for removal of biogas from the substrate at a retention time that is the same as that of a mesophilic system. Furthermore, it is known that high temperature results in fast movement of molecules which then results in a fast rate of reaction and thus faster gas production. Another advantage is that the high temperature facilitates greater reduction in pathogens in the digestate.

4 Conclusion

Anaerobic digestion of a substrate conducted under thermophilic temperature resulted in a higher bio-methane yield than mesophilic range with lower retention time. Therefore, thermophilic can be used as an alternative to mesophilic temperature, although the drawback would be the costs involved in the energy input that comes with a higher temperature. The co-digestion of the substrate enhanced increased in biogas production than the mono-digestion with control of pH and distribution of the nutrients.

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