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Biochemical Methane Potential of OFMSW for City of Johannesburg

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Abstract. The accumulation of Organic Fraction of Municipal Solid Waste (OFMSW) in landfills not only pose threat to the environment, it may also lead to potential health hazards. Anaerobic digestion stands a very good chance to mitigate this waste accumulation in landfills and has potential to create green jobs. BMP has been widely studied in anaerobic digestion for the production of sustainable energy. Bioprocess control Automatic Methane Potential Test System (AMPTS) II machine was used to set up the assays and run the tests. OFMSW was observed to have a low pH which affects the production process and biogas yield. Buffer solutions that were used in this study were calcium carbonate ($CaCO_3$) and sodium hydroxide (NaOH). It was observed that $CaCO_3$ not only stabilizes the pH but it also gives nutrients to the microbes and thus results in higher biogas yields. Inoculation also helped in stabilizing the process and improved the yield. The digester with $CaCO_3$ resulted in a higher methane yield than the others. Though $CaCO_3$ gave good results its use was discontinued as it has a negative impact on the environment. The BMP of OFMSW was found to be 200 ml CH_4 / g VS. The methane content was found to be on average 58%.

Keywords: Anaerobic digestion, Landfill, Methane potential, Municipal solid waste

1. Introduction

Due to population growth and urbanization, waste accumulation in landfills is increasing. It is estimated that by 2025 two-thirds of the people will be living in the cities [1]. In a study conducted by Troschinetz and Milhelcic, 2009 [1] they found that on average the amount of municipal solid waste generated by one person per day is approximately 0.77 kg. This leads to high accumulation of the waste in landfills which is a challenge as it contributes to air pollution and can lead to health threats. Hence technologies have been developed to solve this problem; composting, incineration, and recycling [2], [3]. All the above methods are good waste management techniques but they also have limitations. It was found that over 55% of the waste in developing countries is made up of organic material [3].

Development of clean, sustainable and renewable energy is one of the strategies for environmental protection and national security. This is a result of increasing concerns in environmental pollution and global energy crisis. An approach for synthesis of a renewable energy source as an alternative to non-renewable energy source has been evaluated, whereby energy is produced from biogas through an anaerobic decomposition process [4]. Biogas from the anaerobic digestion has multiple benefits, which include reduction of the discharge of house refuses, city sludge, and other wastes, plays a positive role in the reduction of severe greenhouse effect, production of fertilizer from the digestate, and production of energy for different applications. Biogas is a renewable fuel that is 60-70% methane, and a trace of contaminant gases such as carbon dioxide, hydrogen sulphide and can be used to power household appliances and generate electricity using appropriate technologies; it is produced from anaerobic biodegradation of biomass in the absence of oxygen and the presence of anaerobic microorganisms [4].

Most power demand is in the southern parts of the country; making living expenses very high as many equipment and gadgets require energy to operate, for instance the cost of fuel used in transportation is becoming higher and higher [5]. Fuel synthesis concepts of using renewable energy source should be thoroughly looked at, as it offset the use of non- renewable sources of energy such as coal, natural gas and petroleum; in doing so, job opportunities would be created as more biogas plants and stations would be built, greenhouse gas emissions will be reduced, means of transportation would be cheaper because fuel would be produced at the cheaper price and accumulation of waste would be minimized because biogas would be produced from waste material [6].

Biogas is produced by the biodegradation of organic matter through anaerobic digestion. It is aided by bacteria called methanogens and this bacteria are sensitive to change in operating parameters. There are four main stages in biogas production, hydrolysis which is the rate limiting stage, acidogenesis where organic acids are formed, acetogenesis in which the acetogenic bacteria forms acetate, hydrogen and carbon dioxide, and methanogenesis which is the final stage where methane is formed [7]-[9]. The factors that normally affect this process are: temperature, pH, surface area, retention time, volatile fatty acids, and nutrients, C: N ratio and pressure [4], [10]-[13]. This research focuses on the biochemical methane potential of OFMSW from the Robinson Deep landfill.

2. Materials and Methods

The biochemical methane potential tests were carried out to determine the potential of the (organic fraction of municipal solid waste) OFSMW from the Robinson Deep Landfill.

2.1. Materials

The materials used were OFSMW from City of Johannesburg Robinson Deep landfill, cow dung to provide the necessary bacteria for the digestion process. The following chemicals were used to adjust the pH since they were mostly acidic to a range of 6.5-7.5, Sodium Hydroxide (NaOH) and calcium carbonate ($CaCO_3$). Deionized water (H_2O) was used to prepare the solutions and also for the equipment (water bath and flow cell). Nitrogen (N_2) gas is used to purge the entire system, allowing for an anaerobic environment.

2.2. Experimental methods

The biochemical methane potential tests were carried out using bioprocess control AMPTS II. The machine is made up of 3 components (i) biogas producing unit, (ii) CO_2 fixing unit, and (iii) gas collecting unit. It’s a batch system which is set up and led to run until digestion is complete. OFMSW samples collected from the landfill were used as substrate. A 500 ml digester, with effective volume of 400 ml, was used for biogas production which had head space of 150 ml. the temperature of the process was kept constant at mesophilic temperature of 37 °C.

Sodium hydroxide, obtained from Sigma-Aldrich (South Africa), was used for CO_2 removal. A 3M NaOH solution was prepared to be used as the scrubbing solution to absorb the impurities. A pH indicator solution was added to determine the saturation point for the cleaning solution for replacement. The substrate as obtained from the site was made up of different type of wastes in different sizes. A household blender was used to homogenize the feedstock which was then prepared and fed into the digester. A pH test was done after the substrate was inoculated using cow dung to adjust it to the optimum of 6.5-7.5. Nitrogen gas was used to purge the system by removing the oxygen and creating an anaerobic condition. The digester was connected to a 100ml bottle (used as scrubber) filled with 80 ml of the 3M NaOH solution. The gas exiting the CO_2 fixing unit was sent to the flow cell (gas collection) where the volume of biomethane is determined as shown in Fig. 1. The gas produced was analyzed using the gas chromatograph machine to determine the composition of the biogas.

Fig. 1: Bioprocess AMPTS II experimental setup for BMP analysis

3. Results and Discussion

The biochemical methane potential of OFSMW from the Robinson Deep Landfill was studied and the results that were obtained are discussed below. The initial pH of the feedstock was low during the preparation of the feed and thus buffer solutions were used to increase the pH to 6.5-7.5. The observation from the assays was that the digester which used $CaCO_3$ as a buffer resulted in higher yields of methane 4431 Nml/g VS as depicted in Fig. 2. It yielded more CH_4 than the other digesters that were inoculated with cow dung and no inoculum respectively. $CaCO_3$ as used in the study not only stabilizes the pH and keep it within the optimum range, it also plays a role in providing nutrients for the micro-organisms. Ca^+ ions present in the digester means that the microbes are excited and their performance in the process is high [7].

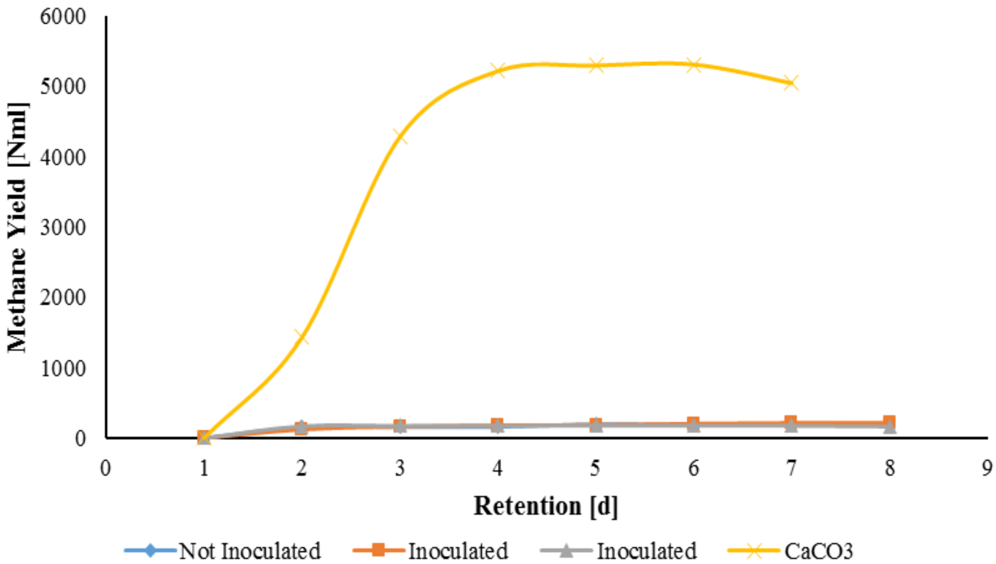

Fig. 2: Cumulative methane yield from the different digesters

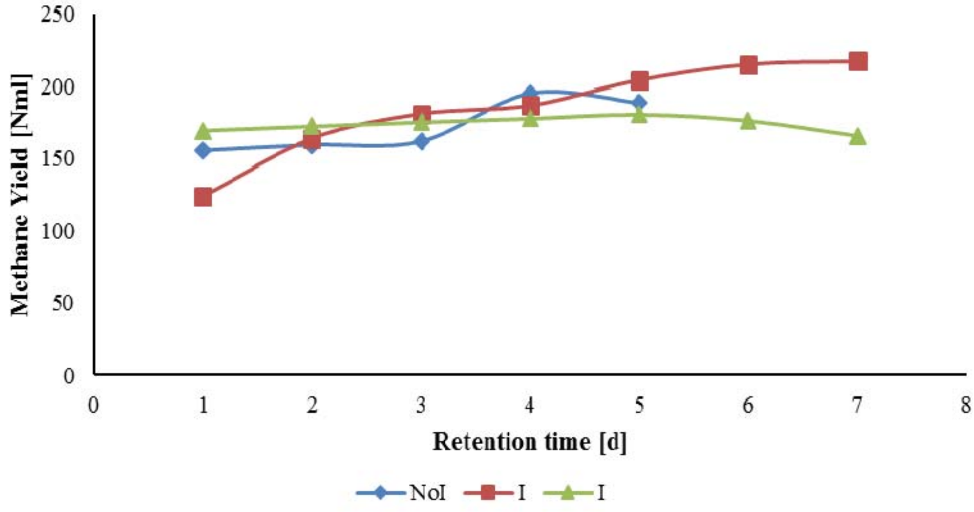

Fig. 3: Effect of inoculation on biogas production

The BMP for the OFSMW was determined to be on average 200 ml CH_4 /g VS added and this results are in agreement to the results obtained by [14]-[18]. The digester that had no inoculum stopped producing earlier than the other digesters which might be due to the accumulation of VFA in the system and pH degradation during the process as these are some of the process inhibitors. The inoculated digesters ran longer as the cow dung didn't only maintain an optimum pH range also provided the necessary bacteria for the digestion. From the results $CaCO_3$ buffered digester produced more methane. However due to the negative impact of $CaCO_3$ on growth of plant as it has been reported to reduce water permeation into the soil hence retarding growth of plants, and thus its use is not advised.

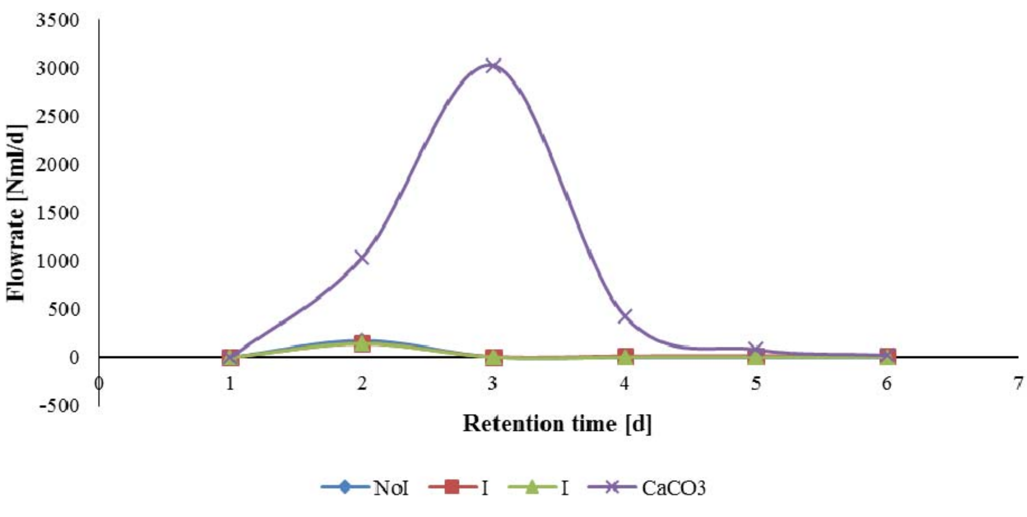

Fig. 4: Gas production rate

The rate of daily methane production was studied and depicted in Fig. 4. The digesters with calcium carbonate had a higher production rate as compared to all the other digesters and this results from the micro-organisms boost by the salt as nutrient. The rate of methane production can be affected by factors including, microbial activity inside the digester, the surface area or micro-organisms to substrate ratio, the pH in the digester at any given time, and solid retention time [19]. The effective production days were 1-3 days for the inoculated and non-inoculated digesters, and 1-4 days for the $CaCO_3$ buffered digester.

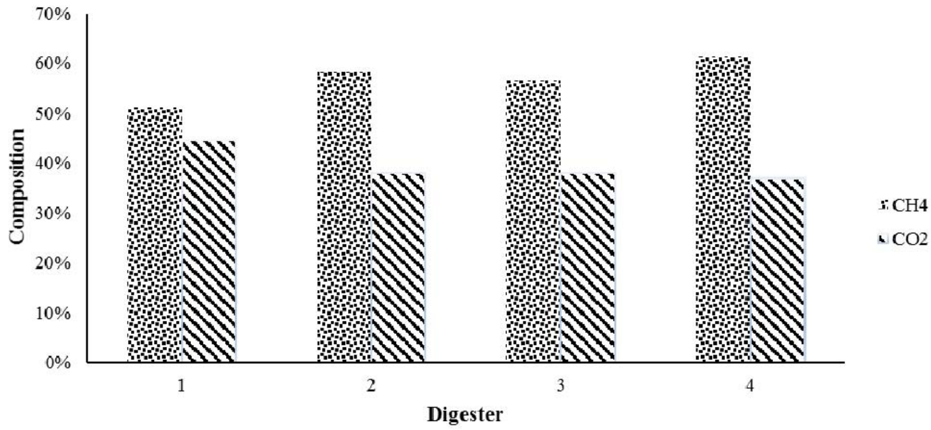

Fig. 5: Biogas composition for the digesters

The composition of the biogas was tested using Gas Chromatography to determine mainly methane and carbon dioxide. Fig. 5 shows the compositions of the different digesters. The digester without inoculum (1) yielded less methane which could have resulted from the availability of microbes as it was not initially seeded with bacteria. The inoculated digesters (2, 3) showed similar trends because the inoculum provided the necessary bacteria for the digestion and then methane content was increased. $CaCO_3$ not only buffers the solution, it also provides nutrients to the microbes which result in high methane yields as shown in Fig. 5 (4).

4. Conclusions

The biochemical methane potential of OFMSW from the Robinson Deep landfill was investigated using Bioprocess AMPTS II. Calcium carbonate is a good buffer for the process and as nutrients to the microbes but has a negative impact on vegetation as a result it’s not advisable to use it. The BMP for OFMSW from the Robinson Deep landfill was determined to be on average 200 ml CH_4 /g VS added, which can be improved with altering the operating parameters and via co-digestion. The ratio of the feed to inoculum can also be investigated in order to optimize the production process. The methane content was found to be 58% on average. Therefore, OFMSW has potential to produce biomethane which can be used as energy and can ease the dependence on fossil fuel derived energy.

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