ISBN 978-81-936279-4-5
9th International Conference on Chemical, Agriculture, Environment and Natural Sciences (CAENS-18)
Antalya (Turkey) May 3-4, 2018

Production of Biomethane through Co-digestion of Cow Manure and Market Fruits Waste

Mohamed Belaid[1*], Anthony Njuguna Matheri[1], Kuroana Samuel Mamabolo[1], Ishmael Ramatsa[1] and Edison Muzenda[1]

[1] Department of Chemical Engineering, University of Johannesburg, Doornfontein, Johannesburg 2028, South Africa

Abstract**:** *This study seeks to determine the possibility of using cow manure and market fruits waste as source of the biomethane production using batch anaerobic digestion. The process parameters optimization to obtain the maximum biomethane production was also studied. The carbon to nitrogen (C/N) ratio of the fruits waste was 54.6 and that of cow manure was 21.1, after co-digestion the C/N ratio had a value of 30.9. The recorded laboratory experimental data at thermophilic temperatures of 45oC from the automated bioprocess control AMPTS II system depicted a maximum biomethane yield of 412.8 Nml for a co-digestion mixture of 75% fruits waste and 25% cow manure. Experimental results indicated mesophilic temperature regions for optimum bio-methane production yield of 487 Nml of bio-methane. The initial pH of the solutions dropped from an average pH of 7.37 to 3.94. Overall, a short retention time for maximum methane yield was experienced for both mesophilic and thermophilic temperatures.*

Keywords: *Anaerobic digestion, Co-digestion, Thermophilic, Mesophilic temperature, Retention time*

1. Introduction

In South Africa, there is a shortage of energy supply coupled with a vast accumulation of organic waste that is deposited in landfills. There is a high demand of energy across the country which unfortunately cannot be met by the main energy supplier, *Eskom*. This has a negative impact on social-economic development of South Africa [1]. An example of this, is the 99 days of load-shedding *Eskom* implemented in 2015 which caused manufacturing and mining output to decrease drastically [2]. The accumulating landfill waste is accompanied by bad odours and large space requirements, which collectively contribute to global warming [3].

Within the renewable energy sector, there is a great demand for extensive research with the main focus on search for viable alternative energy sources. The world is currently facing climate change challenges due to high emission of *Greenhouse Gases* which subsequently lead to increased temperatures, melting of polar icecaps and the rise in oceanic water levels [4]. Current sources of energy are derived from the burning of fossil fuels, such as coal, oil and natural gasses; which not only compound the greenhouse effect but also deplete natural non-renewable resources. A shift of focus needs to be implemented where natural, safer, sustainable and eco-friendly sources are identified and utilized in the production of energy [3].

A suggested method of natural, bio-friendly energy production is the use of anaerobic digestion of animal manure and selected fruits. Anaerobic digestion has received high global interest through its ability to solve two important problems, mainly the depletion of high quantities of animal manure and the production of natural gasses. There are four phases within the anaerobic digestion process with end products being biogas and a low odor, nutrient-rich liquid *i.e.* enriched fertilizer [3].

https://doi.org/10.17758/URST1.U0518208

Anaerobic digestion (AD), refers to the decomposition of organic matter in the absence of oxygen [5], [6]. As mentioned earlier, this AD process can be divided into four main stages namely: hydrolysis, acidogenesis, acetogenesis and methanogenesis, all of these respective stages consist of various biochemical reactions with different substrates and microorganisms. Carbohydrates, proteins, lipids and cellulose are generally the biomass polymers that are used for biogas production. In the hydrolysis stage, the polymers are broken down into smaller molecules for instance, amino acids, fatty acids and simple sugars by enzymes produced by microorganisms [7] namely methanogens. During anaerobic digestion the hydrogen is consumed, and acetate produced from the side reaction that occasionally occurs. The rate of hydrolysis is governed by factors such as pH, composition of substrate particles, temperature and the concentration of the intermediate products [5]. Sugars and amino acids are broken down into carbon dioxide, hydrogen, ammonia and organic acids by acidogenic bacteria [5], [8]. The acetogenic bacteria further convert resulting organic acids into acetic acid, with additional ammonia, hydrogen and carbon dioxide [8]. From the final products of acetogenesis, the intermediate products from hydrolysis and the acidogenesis, the methanogens convert these products to methane and carbon dioxide [9].

Biogas is a combustible mixture of gases mainly consisting of methane and carbon dioxide; it is produced by the fermentation of organic matter i.e. without oxygen. Formed gases are waste products of the respiration of decomposer microorganisms and the composition of the biogas is dependent on the substances being decomposed [10].

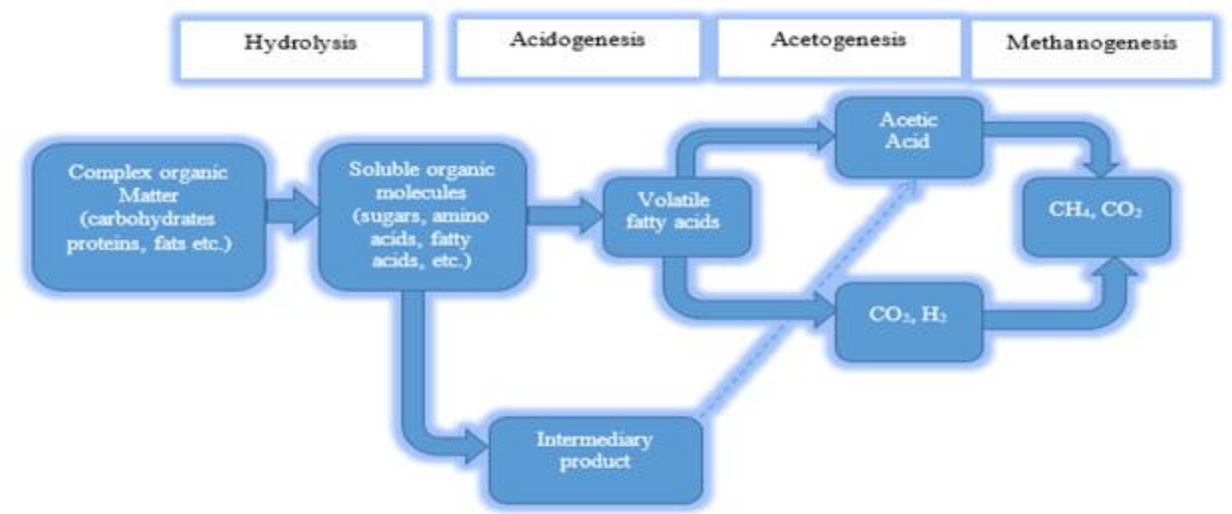

Fig. 1. A Block flow diagram of an anaerobic digestion system

There are several factors that affect the process of biogas production in a typical anaerobic digestion system, and these factors are crucial in understanding how AD technology works. These factors include: temperature, pH, retention time, loading rate, agitation, C/N ratio and the substrate ratio. For instance, with temperature, there are two significant temperature regions prevalent in AD and the two types of micro-organisms which are responsible for digestion at the two respective temperature regions are referred to as mesophilic and thermophilic respectively. At various stages of the slurry the pH changes. The pH should be kept at an appropriate range in the digester to uphold a constant gas supply [11]. In the digester for the buffered range, the pH ranges from 6.5 to 7.5, during this series the micro-organisms are highly active, and bio-digestion is very efficient.

The aim of this study was to produce an alternative and sustainable cleaner, safer and eco-friendly renewable energy source, and to attempt to assist in the reduction of pollution across South Africa by utilizing organic waste. The specific objectives that were met was to generate biomethane production through the anaerobic digestion process, and to investigate ideal operating parameters based on the substrates used in the process.

2. Methodology

2.1. Substrate Characterization

The cow manure was obtained from a local farm just outside Nigel town, in the Far East Rand of the greater Johannesburg region. The selected market fruits waste was obtained from the Johannesburg Market waste area located in the Johannesburg city deep. Inoculum was used to supply the batch reactor system with microbial properties. Nitrogen was used to expel air and to create anaerobic conditions.

Waste characterization comprised of elementary analysis, volatile solids, total solids, calorific value, ash and moisture content according to the standard methods (APHA 1995) [12].

To determine biomethane production rate, a batch reactor was fed with the co-digested substrates and inoculum under pre-set conditions of 37^{o}c and 45^{o}C with a pH of 7.37 as shown in *Figure 2*. The pH was neutralized by a solution of 8g NaOH in 100 ml because of the acidic nature of the fruits. Anaerobic conditions were achieved in all bio-reactors by expelling oxygen with nitrogen gas. The reactors were immersed in the thermostatic water bath and kept under the set conditions. The gas produced was measured by the automated bioprocess control "AMPTS II" system. *Figure 2* shows the biomethane production set up.

Fig. 2. biomethane production set-up

Figure 2 refers to the biogas production set up comprised of: Sample incubator, CO_2 – Fixing unit, Thermostatic water Bath, Gas – Volume measuring device and AMPTS software for bio-methane gas production analysis.

3. Results and Discussion

3.1. Characteristics of the Substrates

In this study, co-digestion of cow manure and fruits were evaluated to get the bio methane potentials at mesophilic and thermophilic temperatures of 37^{o}C and 45^{o}C respectively with an initial average pH of 7.37. *Table 1* depicts the substrate characterization. Fruits were found to contain less volatile solids compared to cow dung which had more nutrients. The C/N ratio of the cow manure from the elementary analysis was 21.1 and was a lower result than the fruits C/N ratio which turned out to be 54.6. The C/N ratio increased to 30.9 through co-digestion.

Table I: Characterization of substrates

Substrate	C	N	H	S	VS (%)	TS (%)
Fruits	44,20	0,81	5,99	0	12,37	57,93
Cow Manure	41,61	1,97	5,44	1,81	47,10	98,19

Where: C – carbon, N – nitrogen, H – hydrogen, S – sulphur, VS – volatile solids and TS – total solids.

The pH and TS are crucial aspects when assessing anaerobic digestion efficiency [12]. TS is the sum of the suspended and dissolved solids. VS is the organic portion of TS that is biodegradable in AD. C/N ratio is an important factor in bacteria stability in AD. The C/N ratio required for producing biomethane ranges from 15 – 30 [12]. Equations 1 & 2 were used for calculating VS and TS as follows [12]:

$$VS(\%) = \frac{M_{dried} - M_{burned}}{M_{wet}} * 100 \quad (1)$$

$$TS(\%) = \frac{M_{dried}}{M_{wet}} * 100 \quad (2)$$

Where:
M_{dried} = Amount dried sample (mg)

M_{wet} = Amount of wet sample (mg)

M_{burned} = Amount of burned sample (mg)

Equation 3 was used to calculate the C/N ratio:

$$\frac{C}{N} = \frac{(F * C_f) + (S * S_f)}{(F * N_f) + (F * N_f)} \quad (3)$$

Where: F = first substrate, S = second substrate, C_f = carbon composition for the first substrate, C_s = carbon composition for the second substrate, N_f = nitrogen composition for the first substrate and N_s = nitrogen composition for the second substrate.

Table 2 constitutes the calorific values for the substrates that were used for this study.

Table II: Calorific Value of the substrate

Substrate	Weight(g)	Energy(MJ/KG)
Fruits	0,53	18,373
Cow Manure	0,51	17,309

Effects of Mono and Co-Digestion of Fruits and Cow manure
A laboratory batch anaerobic reactor was used for studying the production of biomethane from cow manure and selected fruits.

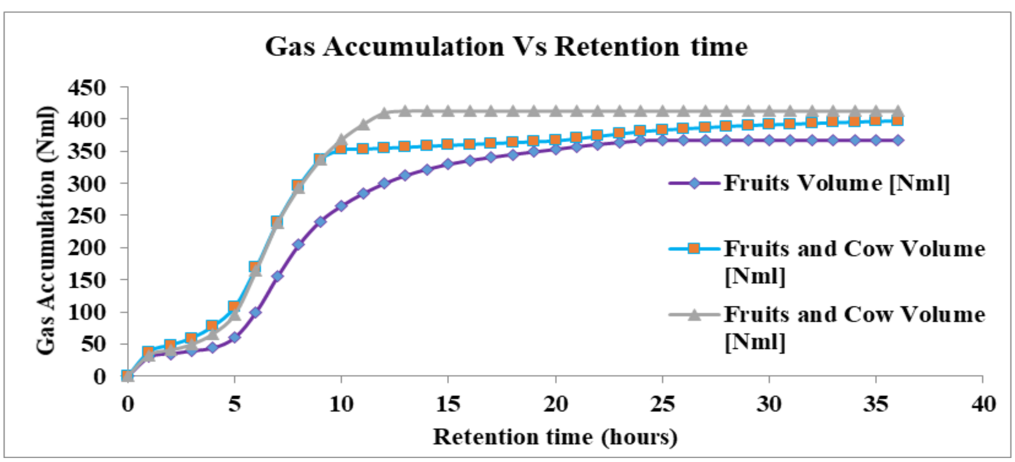

Fig. 3. The influence of co-digestion of the fruits waste and cow manure on the biomethane production under thermophilic temperatures 45°C.

Figure 3 shows that for a 100% fruit solution, the biomethane that was yielded amounted to 367.2 Nml with a retention time of 25 hours. For a 50% Fruit waste and 50% cow manure mixture the biomethane yield was 397.6 Nml at a retention time of 36 hours. A 75% fruit and 25% cow manure mixture that was co-digested produced 412.8 Nm/l in 13 hours as indicated by the light purple graph in *Figure 3* and was found to have the highest yield in terms of bio-methane production with the shortest retention time experienced in the thermophilic temperature range.

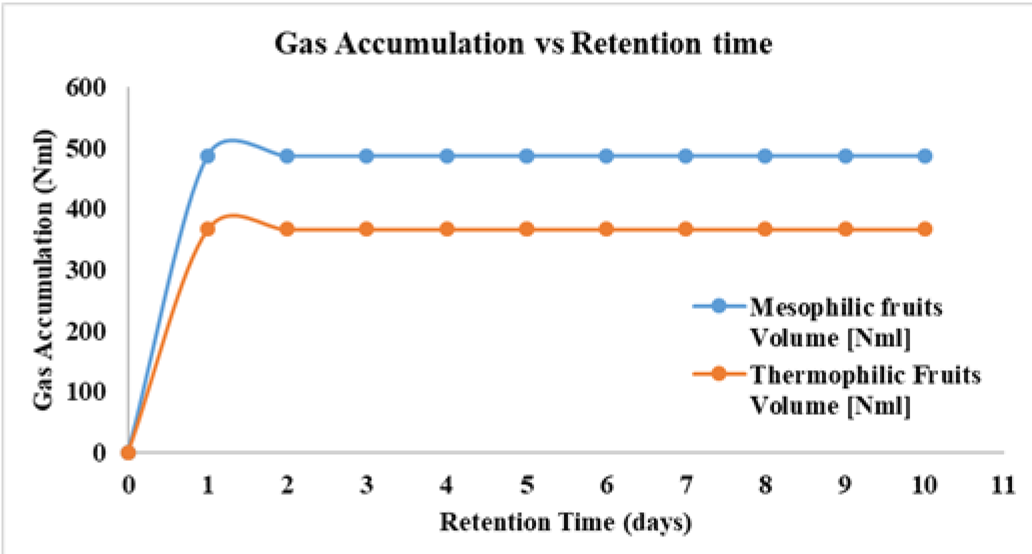

Fig. 4: Variation of biomethane accumulation with retention.

Figure 4 depicts the effects of temperature on the production of methane. The thermophilic temperature of 45°C yielded a biomethane production of 367.2 Nml with a retention time of 2 days while the mesophilic temperature 37°C had a bio-methane production of 487 Nml with a retention time of one day. Short retention times were experienced for both the temperature regions as maximum retention amounted to days. The results indicated that temperature region for optimum bio-methane production was the mesophilic temperature range.

4. Conclusion

Biomethane was produced through the co-digestion of cow dung manure and market fruits waste. Overall, a short retention time was observed on the biomethane production due to degradability of the fruit waste and moderate size reduction of the cow manure. Optimum biomethane was 487 Nml for mesophilic and 367.2 Nml for thermophilic thermophilic condition.

5. Acknowledgements

The authors would like to extend their gratitude to the Department of Military Veterans of South Africa for funding this project, the South Africa National Energy Development Institute (SANEDI), Technology Innovation Agency are acknowledged for funding the Process Energy Environmental and Technology Station (PEETS) and Chemical Engineering and Applied Chemistry Departments at the University of Johannesburg for granting us access to their laboratories. Mr Ryan D Rattray for technical support.

6. References

[1] J. Booysen, “Eskom crisis a brake on economy,” Business/Companies, Nov-2014.

[2] E. Du Preez, “Eskom’s 99 Days of Load Shedding have limited mining and manufacturing output, causing the economy to behave as if it has lost a ‘major industry’.,” Mail & Guardian, Johannesburg, Aug-2015.

[3] S. Xie, G. Wu, P. G. Lawlor, J. P. Frost, and X. Zhan, “Methane production from anaerobic co-digestion of the separated solid fraction of pig manure with dried grass silage,” Bioresour. Technol., vol. 104, pp. 289–297, 2012. https://doi.org/10.1016/j.biortech.2011.11.076

[4] K. Vasskog, P. M. Langebroek, J. T. Andrews, J. E. Ø. Nilsen, and A. Nesje, “The Greenland Ice Sheet during the last glacial cycle: Current ice loss and contribution to sea-level rise from a palaeoclimatic perspective,” Earth-Science Rev., vol. 150, pp. 45–67, 2015. https://doi.org/10.1016/j.earscirev.2015.07.006

[5] N. Sibiya and E. Muzenda, “A Review of Biogas Production Optimization from Grass Silage,” vol. 2028, pp. 51–54, 2014.

[6] R. Q. Pain, B.F. and Hepherd, “Anaerobic digestion of livestock wastes.,” Anaerob. Dig. Farm Wastes, pp. 9–14, 1985.

[7] J. Cheng, “Biomass to Renewable Energy Process,” CKC Press, New York, pp. 151–163, 2009.

[8] R. D. Appels, L., Baeyens, J., Degre’ve, “Principles and potential of the anaerobic digestion of wast-activated sludge,” Bioresour. Technol., vol. 69, pp. 249–254, 1999.

[9] E. Jigar, “Study on renewable biogas energy production from cladodes of opuntis ficus-indica,” ISABB J. Food Sci. Agric. Sci., vol. 1, no. 3, pp. 44–48, 2011.

[10] P. Jørgensen, “Biogas-green energy. Process - Design - Energy supply - Environment,” Process. Des. Energy supply, Environ. Fac. …, p. 36, 2009.

[11] S. Jain, S. Jain, I. T. Wolf, J. Lee, and Y. W. Tong, “A comprehensive review on operating parameters and different pretreatment methodologies for anaerobic digestion of municipal solid waste,” Renew. Sustain. Energy Rev., vol. 52, pp. 142–154, 2015.
https://doi.org/10.1016/j.rser.2015.07.091

[12] A. N. Matheri, M. Belaid, T. Seodigeng, and C. J. Ngila, “The Kinetic of Biogas Rate from Cow Dung and Grass Clippings,” pp. 1–5, 1911. Available: http://www.halcyon.com/journals/21ps03-vimar (Journal Online Sources style)