Environmental Technology & Innovation 4 (2015) 311–318

Contents lists available at ScienceDirect

Environmental Technology & Innovation

journal homepage: www.elsevier.com/locate/eti

Optimal combination of food waste and maize husk for enhancement of biogas production: Experimental and modelling study

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HIGHLIGHTS

- Optimum combination of 75% FW and 25% MH occurred in digester B.
- Increase in MH above 25% decreased biogas production.
- Post hoc Test in ANOVA showed a significant difference in digesters' yields.
- Gompertz model simulation results corroborated the experimental findings.

ARTICLE INFO

Article history:
Received 3 February 2015
Received in revised form 3 October 2015
Accepted 15 October 2015
Available online 1 November 2015

Keywords:
Biogas optimization
Food waste
Maize husk
Gompertz modelling
Methanogenesis

ABSTRACT

This study was focused on the optimization of biogas production from the co-digestion of food waste (FW) and maize husk (MH). The co-digestion of FW and MH at various mixture ratios was carried out in digesters A to E at 37 ± 1 °C. Digesters A, B, C, D and E contained FW: MH of (100:0; 75:25; 50:50; 25:75; 0:100) respectively. Results obtained showed that average biogas yields of 0.50 ± 0.04, 0.71 ± 0.07, 0.54 ± 0.05, 0.30 ± 0.03, and 0.24 ± 0.02 L/gVS were obtained from digesters A, B, C, D, and E respectively. The modified Gompertz modelling of the experimental data showed that digesters A, B, C, D, and E had latency (λ) of 4.1, 4.9, 6.9, 7.4, and 10.6 days respectively. Digester B had the highest maximum specific biogas production R_m, and maximum biogas production potential (A) of 0.50 L/gVS/day and 20.7 L/gVS respectively. The R^2 values between experimental and simulation data ranged from 0.9913 to 0.9989 in all digesters. The Post hoc Test in ANOVA using the Least Significant Difference (LSD) confirmed that there were significant differences in the mean biogas yield from the different digesters. The study therefore shows that the best combination of FW and MH for enhanced biogas production occurred in digester B.

1. Introduction

Inadequate energy supply and environmental pollution are major problems in Nigeria and many other developing countries of the world (Owamah et al., 2014a; Owamah, 2014). With the tremendous increase in population, access to adequate energy and healthy environment demands for a diversification of sources of energy supply. For instance,

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http://dx.doi.org/10.1016/j.eti.2015.10.001

while South Africa, Brazil, UK and Germany have over 900, 500, 1340, 1500 W/person respectively, in Nigeria, available energy per person is less than 25 W (Onohaebi, 2014; Owamah and Izinyon, 2015a). This according to Oyedepo (2012), represents a serious energy crisis and has paralyzed many commercial and industrial enterprises in Nigeria. Globally, the high dependence on fossil energy fuels for industrial, commercial and domestic energy needs has resulted in climate change and related human health problems (Budiyono et al., 2010). The problem has even become worse by the recent continuous fall in the price of crude oil to less than $ 50 US dollars per barrel since the start of the year 2015 (OPEC, 2015). The interest in renewable research and development has seen a huge increase within the last decade in a bid to proffer solutions to the problems of environmental pollution and depleting fossil reserves (Gueguim-Kana et al., 2012).

Amongst the renewable energy resources, anaerobic digestion of waste organic substances to biogas appears to be the most popular as it helps to generate bio-fuel, reduce environmental pollution and improve agricultural productivity through the use of its digestate as compost for organic farming (Alfa et al., 2014). Biogas comprises approximately 60% methane and has an energy value between 5.4 and 6.4 $kWhm^{-3}$ (Hartman and Ahring, 2006). Since this is close to the energy value of the natural gas (5.7–7.7 $kWhm^{-3}$), biogas could be used as a substitute for the highly demanded natural gas (Hartman and Ahring, 2006).

The sustainability of large scale anaerobic digestion plants, however, depends much on the optimal combination of process factors. It is also important that substrates are obtained in the most cost-effective manner. This therefore requires process optimization. Co-digestion of two or more biodegradable substrates in a digester, has been used by several authors, for the optimization of the biogas production potential of digested substrates (Momoh and Nwaogazie, 2011; Alfa et al., 2014). All these notwithstanding, the best combination of various substrates for optimal biogas yield is still a challenge, despite the enormous number of potential substrates (Owamah et al., 2014b). It is worthy of note, that the biogas yield and methane content of anaerobic digestion process, are the two major factors necessary for the proper evaluation of the economic and technical feasibility of large scale anaerobic digestion plants (Francesco and Cinzia, 2009). Because food waste (FW) contains highly degradable substances and low nitrogen content, co-digestion with complementary substrates such as plant residues of lower biodegradability and high nitrogen content have been found to immensely boost both biogas yield and digester stability (El-Mashad and Zhang, 2010).

Maize husk (MH) is one of the plant residues that is generated in large quantities in Africa. At the moment in Nigeria, MH is either disposed in 'open dumps', or burnt in the open air. These unscientific methods of disposal constitute potential health hazard and contributes immensely to global warming. Although Amon et al. (2007) had reported on biogas production from co-digestion of dairy manure and whole maize varieties, the problem of food insecurity in the world discourages using food resources for renewable energy generation.

There is indeed scanty information in literature on the best combination of FW and MH for optimal biogas production. The focus of this research therefore, is to determine the best combination of FW and MH for optimum biogas production through batch anaerobic co-digestion of varying percentages of FW and MH. The study further used the modified Gompertz model to simulate and fit the experimental data in order to determine relevant kinetic parameters for predicting the performance of digesters.

2. Methods

2.1. Collection of materials

FW used for this study was collected from waste bins of the Cafeteria at Landmark University, Omu-Aran, Kwara State. The collections were done on daily basis, within five working days of a week, from Monday 24th March to Friday 28th March, 2014. In accordance with the procedure in Owamah et al. (2014b), the food waste was collected at 12 noon and 7 pm of each day, to coincide with students' time of peak consumption and waste generation. The purpose of collecting FW over 5-working days was to reduce nutritional variations in the food waste collected. MH was obtained from Landmark University Farm, Omu-Aran, Kwara State. It was initially kept dry in a sack, in the Environmental Engineering Laboratory of Landmark University, prior to the commencement of the anaerobic digestion experiments.

Following the procedures used in Zhang et al. (2007), El-Mashad and Zhang (2010) and Owamah and Izinyon (2015a) the bones and inorganic materials in the food waste were sorted out within 24 h of collection. This was followed by the crushing and homogenization of the food waste using a mini electric blender. The blended FW was then kept in a freezer at approximately 4 °C, before the commencement of anaerobic digestion experiment in April 10, 2014.

Following the procedure in Zhu et al. (2014), Owamah and Izinyon (2015b) the collected MH was ground to powdery form using a grinder. Ground MH was then kept in a container that was air tight until it was used for the experiment.

2.2. Analysis of chemical parameters of the prepared food waste and maize husk substrates

The prepared FW and MH substrates, before they were mixed together for anaerobic digestion experiments were analyzed for their relevant chemical parameters. The total solids (TS) and volatile solids (VS) were measured in triplicate according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2012) using a laboratory oven (DHG-9053A, Controls, Italy). Following standard procedures in APHA (2012), the FW and MH substrates were also analyzed