Effect of Carbon to Nitrogen Ratio of Food Waste on Biogas Methane Production in a Batch Mesophilic Anaerobic Digester

Musa I. Tanimu, Tinia I. Mohd Ghazi, Razif M. Harun, and Azni Idris

***Abstract*—Food waste mixture at carbon to nitrogen (C/N) ratio 17 was combined with meat, fruits and vegetable wastes to increase its C/N ratio to 26 and 30 before anaerobic digestion. Results showed that biogas methane yield obtained during the digestion increased from 0.352L/gVS, 0.447L/gVS and finally to a maximum yield of 0.679 L/gVS at C/N ratio of 17, 26 and 30, respectively. A maximum food waste treatment efficiency of 85% was obtained at C/N ratio 30. Generally, increase in C/N ratio through co-digestion resulted in a more stable pH and better methanogenic activity due to enhanced buffering effect of the digestion medium.**

***Index Terms*—Biogas methane, batch digester, carbon to nitrogen ratio, food waste, mesophilic digester.**

I. Introduction

It has been found during anaerobic digestion that the microbial population makes use of about 25 to 30 times carbon faster than nitrogen [1]. Therefore, waste material, which is high in easily biodegradable carbon, can be mixed with waste material low in nitrogen or vice versa to attain the desired carbon to nitrogen ratio (C/N) of 30. Substrate with low C/N ratio may likely result in the production of high amount of total ammonia nitrogen (TAN) and volatile fatty acids (VFAs). These substances are important intermediate products produced during the anaerobic digestion [2]. Increased concentrations of VFAs and TAN could hinder methanogenic activities. Gradual accumulation of these intermediates could lead to total failure of the anaerobic digestion (AD) process.

One of the methods used by researchers to avoid excessive production of ammonia during AD is to increase the C/N ratio of feedstock. This can be done by co-digesting with other waste feedstock that are high in biodegradable carbon to improve the performance of AD. This method has been used by [3] to co-digest municipal solid waste rich in paper (C/N ratio of 173 - 1000) with sewage sludge (C/N ratio of 6 - 16). Co-digestion of chicken waste or cattle slurry with fruits and vegetable wastes is another example to improve C/N ratio [4], [5] obtained a yield improvement of over 60% when fish waste was co-digested with sisal pulp. The benefits of increasing C/N ratio through co-digestion with complementary feedstock include: higher biogas yield and feed loading rate as well as reduction of potentially toxic ammonia concentration. The purpose of this batch AD study was to investigate the effect of increasing the C/N ratio of the available food waste (C/N=17) through co-digestion with meat, fruits and vegetable wastes.

II. Materials and Methods

A. Source and Nature of the Digested Food Waste

Food wastes were collected from a food waste anaerobic digestion treatment plant in Taman Sri Serdang, Selangor, Malaysia. The anaerobic digestion (AD) plant which treats a mixture of source sorted food wastes obtained from commercial restaurants, market and meat industries around Serdang area (population of 300,000 people) is part of an integrated waste management system for the city of Serdang. The main components of the food waste include: raw chicken meat/ beef (5%), kitchen wastes such as rice and noodles (77%), leafy vegetables/ salad (7%), soup (6%) cooked meat/fish (5%). Two other feed mixtures were formulated using the food wastes above as bases by adding fruits, vegetables and meat wastes as complementary co-substrates to the food waste in different proportions (Table I) to increase the C/N ratio from 17 to 26 and 30 respectively. The average composition of the vegetable wastes includes: baby corn (5%), lettuce (24%), carrot (5%), broccoli (18%) and green leafy vegetables (48%), all on wet weight (ww) basis. The average composition of the fruit wastes includes: papaya (27%), orange (19%), pineapple (39%), watermelon (11%) and berries (4%) on ww basis.

B. Substrate and Inoculum Preparation

Each of feedstock 1, consisting the current food waste, vegetable wastes, fruits waste and meat waste were ground using a heavy duty blender model 39BL11 (Waring commercial, USA) and sieved with a 1.0mm sieve size. It was prepared in bulk and stored at -20 ^{o}C for later use. Feedstock 2 and 3 were made by mixing part of the stored food waste (feedstock 1) with portions of fruits, vegetables and meat waste (Table I). The composition of food waste, fruits, vegetables and meat wastes added to achieve C/N ratio of 26 and 30 are presented in Table I. Each feedstock formulated was diluted with tap water to give volatile solids (VS) content of 3.5gVS/L. 8 bottles of 1000ml capacity were used as digesters each with a working volume of 0.8litres. Each C/N ratio was prepared in duplicate. The characteristics of the 3 feed substrates are presented in Table I. Cow manure

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Musa Idris Tanimu is with the Department of Chemical and Environmental Engineering, Universiti Putra Malaysia, on study leave from Chemical Engineering Department, Kaduna Polytechnic, pmb 2021, Kaduna, Kaduna state Nigeria (e-mail: musandadrisu@gmail.com).

Tinia I. Mohd Ghazi, Razif M. Harun, and Azni Idris are with the Department of Chemical and Environmental Engineering Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia (e-mail: tinia@upm.edu.my, mh_razif@upm.edu.my, azni@upm.edu.my).

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was used as source of inoculum in this study. The proportion of feed mixture to inoculum was 7:3 by volume. The characteristic of the inoculum is presented in Table II.

C. Analytical Methods

Total solids (TS), volatile solids (VS), COD, Alkalinity and NH3-N were carried out every other day according to the standard methods [6]. Carbon and nitrogen tests were carried out using the CHNS machine model CHNS 932 (Leco corporation, USA). Portions of the digestion medium were collected and centrifuged every other day by using a centrifuging machine (model 2420, Kubota Corporation Japan) at 500 rpm for 15 minutes before carrying out the COD test. Analysis on alkalinity was performed by titration of 10ml of the sample against 1N H_2SO_4 to pH 4.5. Ammonia-nitrogen (NH_3-N) test was performed by Nessler's method using Hach spectrophotometer (Odyssey DR 2500).

TABLE I: CHARACTERISTICS AND COMPOSITION OF FEEDSTOCKS USED

Detail	Feedstock 1	Feedstock 2	Feedstock 3
Characteristics			
Moisture content (%)	97.43	96.15	95.63
TS (%FW)	29.57	25.72	22.85
TS (g/L)	55.10	53.97	52.68
VS (%TS)	94.26	95.50	98.35
VS (g/L)	52.20	50.32	48.64
C	23.99	44.55	62.30
N	1.45	1.73	2.02
C/N	16.50	25.75	30.84
COD (mg/L)	273476	282680	294735
pH	4.25	5.38	5.44
NH_3-N (mg/L)	562.00	730.00	820.00
FOG (%)	24.38	18.24	34.49
Lignin (%)	26.81	19.31	12.31
ADF (%)	8.33	49.04	53.86
NDF (%)	29.30	68.77	49.72
GE (cal/g)	6917.67	3815.95	4915.45
Alkalinity (mg/L)	82500.00	1024.00	1152.00
Feed Composition			
Food Waste (%)	100.00	50.00	61.30
Fruit Waste (%)		40.00	10.00
Vegetable waste (%)		10.00	6.00
Meat waste (%)			22.70

TABLE II: CHARACTERISTICS OF INOCULUMS

Parameter	Value
Moisture content	44.25
TS (mg/L)	192.70
TS (%FW)	19.50
VS (mg/L)	36.00
VS (%FW)	69.50
NH_3-N (mg/L)	625.00
pH	7.30
Alkalinity (mg/L)	953.00

Volume of biogas produced was measured using water displacement method. The gas composition was obtained using a gas chromatograph instrument (Agilent 6890N network GC system) equipped with a thermal conductivity detector and carboxen 1010 plot column 30m × 530 µm × 0 µm nominal (Supelco 25467, USA). The injector, detector and oven temperatures were: 200^{o}C, 230^{o}C and 40^{o}C respectively. Argon gas was used as the carrier gas at a flow rate of 3.0 mL /min. pH was determined using a combined pH and temperature meter (Trans instruments, Singapore).

III. RESULTS AND DISCUSSION

The characteristics of the food wastes are shown in Table I. The moisture content (MC) of the food waste ranged between 95 - 97%. This is an indication that the food waste has sufficient moisture content for anaerobic digestion. The volatile solids (VS) content ranged from 94-98% and this is an indication that the food waste is rich in organic solid content which can be converted to biogas during anaerobic digestion. The carbon to nitrogen (C/N) ratio of the initial food waste was about 17. The formulated feedstock 2 and 3 had C/N ratio of approximately 26 and 30 respectively. Researchers have found that microbial population utilizes 25 to 30 times carbon as much as nitrogen [7], [8]. Feedstock 2 and 3 were therefore formulated with higher C/N ratio to provide adequate nutrition to the anaerobes. The COD of the three feedstocks ranged from 273,000 to 294,000. This is an indication of high presence of organic pollutants in the food waste. The cumulative methane profile for each of the three feedstocks is shown in Fig. 1(a). Highest cumulative methane produced during the anaerobic digestion of feedstock 1 (F1); feedstock 2 (F2) and feedstock 3 (F3) were 0.365L/gVS, 0.4465L/gVS and 0.679L/gVS, respectively. It also indicates that biogas production with F1 and F2 at C/N ratio 17 and 26 stopped on day 16 and 28 respectively while gas production continued up to day 30 for F3 (C/N=30). The cessation in gas production was seen to follow a continued drop in pH from neutral to 4.5 in both cases. pH drop in anaerobic digestion most likely indicates that acidic intermediates such as volatile fatty acids (VFA) are produced in considerable quantities. Lower pH as a result of VFA accumulation can lead to inhibition of the biogas methane producing methanogens. Fig. 3 showed that the 3 feedstocks provided different buffering effect to the acid intermediates with F1 having the least buffering capacity or alkalinity. F2 provided better buffering than F1and F3 had the best buffering capacity. In this study, buffering capacity (or alkalinity) was observed to increase with C/N ratio of feed thereby leading to better process stability. This is in agreement with [7], [9] that increased C/N ratio through co-digestion help achieve better process stability. Essentially, no significant difference in methane yield was found in the anaerobic digestion of F1 and F2 (p =0.06). The methane yield recorded during the digestion of F2 and F3 in this study, were higher than the value obtained in a similar study by [10] and [8] who obtained 0.435L/gVS and 0.489L/gVS respectively under the same mesophilic condition.

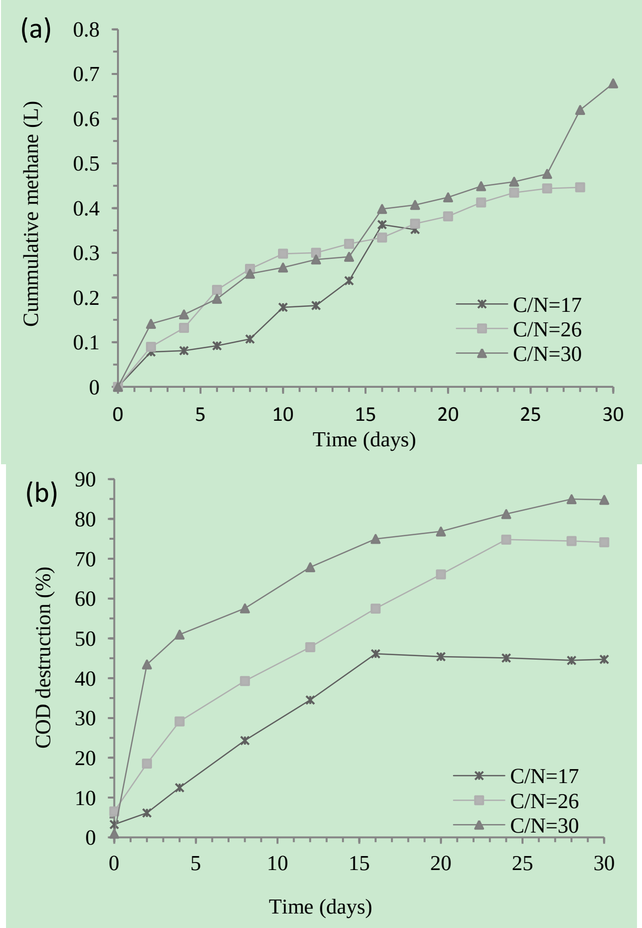

Fig. 1. (a) Cumulative methane yields with time, and (b) COD destruction with time, during the digestion at C/N ratio 17, 26, 30.

The difference can be attributed to different food waste composition and higher C/N ratio in this study. The percentage of COD removal in Fig. 1(b), which is an indication of treatment efficiency showed maximum values of 69%, 74% and 85% and maximum VS destruction of 38%, 54% and 71% were achieved during anaerobic digestion of F1, F2 and F3, respectively. VS destruction and COD removal are an indication of percentage solid and organic pollutants removal from the food waste during the anaerobic digestion process. The VS and COD removal stated above showed that the treatment efficiency for the food waste increased with increase in C/N ratio with the highest treatment efficiency of 85% achieved during the digestion of F3. Over 50% of the produced gas was achieved by day 10 during the anaerobic digestion of F1 and F2 while over 60% of gas production was achieved during the digestion of F3 within the same period of digestion. The slope of the plot of cumulative methane (Y) versus time (X) during the digestion of each feedstock F1, F2 and F3 was obtained. This slope is an indication of the methane production rate. The equations obtained for F1, F2 and F3 gas production were: $Y = 0.0187X$, (R_2=0.918); Y=0.0193X, (R_2=0.800) and $Y = 0.0217X$ (R_2=0.905). Therefore the calculated average volumetric rate of biogas methane was approximately 0.019 L/d for F1 and F2 and 0.022 L/d for F3. This suggests that there was higher methanogenic activity during the digestion of feedstock 3 with C/N ratio 30 as compared to digestion of F1 and F2. pH during digestion was seen also to drop gradually from neutral to a final value of 3.5 for F1, 4.5 for F2 and 6.2 for F3. These showed better pH stability during anaerobic digestion with increase in C/N ratio from 17 to 26 and finally to 30 respectively. The methane content of the biogas produced during the digestion of F1, F2 and F3 ranged from 45% to 60% within the first six days. However, the overall highest methane content in biogas produced from feedstock F1, F2 and F3 were 65%, 70% and 85% respectively in Fig. 2(a). This showed that the methane content of F3 was higher than F2 and F1 during the anaerobic digestion. Therefore the activities of the methane producing methanogens were most enhanced during the anaerobic digestion of F3 (C/N=30) followed by F2 (C/N=26) and lastly F1 (C/N=17). The average biogas yield obtained for F1, F2 and F3 include: 0.479L/gVS, 0.620L/gVS and 1.002L/gVS. The methane composition obtained during the digestion of F1 and F2 as stated above is comparable to that obtained by [9] with 73% methane composition in a similar batch food waste digestion at mesophilic condition. However, the 85% CH_4 composition obtained during the digestion of F3 (C/N=30) is higher than the 73% obtained by the researchers at C/N ratio of 14.8. This showed that the C/N ratio increase in food waste through co-digestion has enhanced the methanogenic activities. This has also help to overcome limitations posed by high ammonia-nitrogen concentrations in Fig. 2(b) associated with food waste [10]. The resulting medium during the digestion of F3 (C/N=30) is seen in Fig. 3 to have the highest buffering effect on acid formation during acidogenesis. This is likely the reason why F3 (C/N=30) is most stable in terms of pH stability during this study.

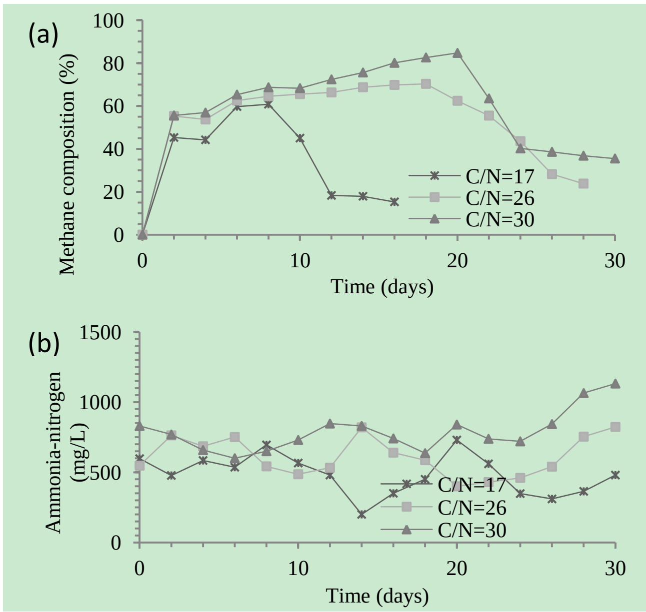

Fig. 2. (a) Methane composition obtained and (b) ammonia-nitrogen profile, during the digestion of different C/N ratio.

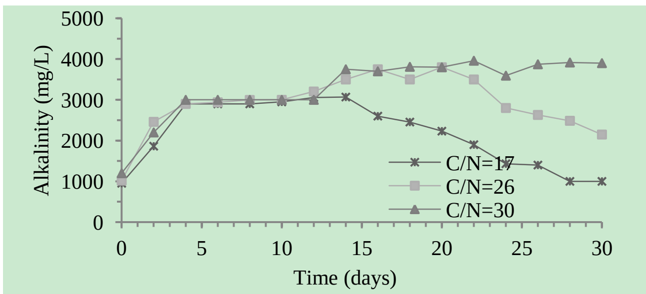

Fig. 3. Variation in alkalinity during the digestion of different feedstocks.

IV. Conclusion

Increase in C/N ratio of food waste from its initial value of 17 to 26 and 30 by anaerobic co-digestion with fruits, vegetables and meat wastes resulted in increased yield of biogas methane from 0.352 to 0.4465 and 0.679L/gVS respectively. However, there was no significant difference in the gas production rate during the digestion of F1 and F2. The methane composition of biogas increased with increasing C/N ratio with the highest methane composition of 85% obtained during the digestion of feedstock 3 with C/N ratio of 31. Similarly, the treatment efficiency of food waste during the digestion also increased from 69% to 74%, for C/N ratio of 17 to 26, respectively and to the highest value of 85% at C/N ratio of 30. Results generally showed that increase in C/N ratio of food waste resulted to better pH stability and enhanced methanogenic activities.

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Idris T. Musa obtained Higher National Diploma (chemical engineering) from Kaduna Polytechnic, Kaduna, Kaduna state, Nigeria in 2000 and Post Graduate Diploma (chemical engineering) from Federal University of Technology Minna, Niger state, Nigeria in 2012. He is currently concluding his masters' research thesis work at Universiti Putra Malaysia. His research focuses on the recovery of biogas methane from food waste as a renewable source of energy that could be used for heat and electricity generation.

He is currently a lecturer II at Kaduna polytechnic, Kaduna, Nigeria. His research interests include: Innovative technology in waste utilization, anaerobic digestion, composting, and environmental impact assessment/audit. Mr. Musa is a registered member of the council for the regulation of engineering in Nigeria (COREN), Graduate Member of Nigeria Society of Engineers (GMNSE) and Member Nigeria Society of Chemical Engineers (MNSChE).

Tinia I. Mohd Ghazi obtained her Diploma in industrial chemistry from Institute of Technology MARA in 1994; B. Eng. (Hons.) of chemical process engineering and fuel technology, University of Sheffield, United Kingdom in 1996; Doctorate of Philosophy in Chemical Engineering from the University of Cambridge, United Kingdom in 2005.

She is currently an associate professor in the Department of Chemical and Environmental Engineering, Universiti Putra Malaysia. Her research interests are photochemical technology, wastewater treatment, renewable energy, and oscillatory flow mixing. Dr. Ghazi is a member of Institute of Chemical Engineers (IChemE) and Malaysia Society for Engineering and Technology (MySET). She is the corresponding author (email: tinia@upm.edu.my, office: +603 89464427, fax: +603 86567120).

Razif M. Harun obtained his B.Eng. (Hons) in chemical engineering at Universiti Teknologi, Malaysia (UTM), Johor, in 2006 and a Ph.D. in chemical engineering from the Monash University, Australia, 2011.

He is currently a senior lecturer in the Department of Chemical and Environmental Engineering, Universiti Putra Malaysia. His main research interests are renewable energy, biochemical engineering, micro-algae cultivation, and bioconversion of biomass, biofuels, biogas and bioethanol. Dr Harun is a member of Institute of Chemical Engineers (IChemE) and Malaysia Society for Engineering and Technology (MySET).

Azni Idris obtained his B.Eng (Hons) in chemical engineering at the University of Birmingham, UK in 1980; M.Sc. in environmental pollution control at the University of Leeds, UK in 1982; PhD in environmental engineering from the University of Newcastle-Upon-Tyne, UK in 1989.

He is currently a professor and was the head of Department of Chemical and Environmental Engineering Universiti Putra Malaysia. His research interests are environmental management, waste utilization, renewable energy from waste, wastewater treatment, toxic waste and sludge treatment. Prof. Idris is a member of Malaysian Water Association (MMWA), International Water Quality Association London (MIWA) and Member of Pacific Basin Consortium on Hazardous Wastes USA (MPBCHW). He has written many publications including a patent on bio-filter system for organic waste treatment.