Abyss. J. Engg. & Comput. Vol. 1, No. 2, 2021, 22-30
© 2021 Kombolcha Institute of Technology, Wollo University

Abyssinia Journal of Engineering & Computing

Effects of Anaerobic Co-digestion of Cow Dung using Biodegradable Municipal Wastes for Biogas Production

[a*]Teklie Lissanu, [a]Animut Assefa, [a]Lamenew Fenta, [b]Assamen Ayalew & [c]Samuel Gemeda

[a]*Assosa University, P.O. Box 18, Assosa, Ethiopia.*

[b]*Wollo University, Kombolcha Institute of Technology, Kombolcha, Ethiopia.*

[c]*Dilla University, P.O. Box 419, Dilla, Ethiopia.*

ABSTRACT

Biogas is a renewable energy resource produced by anaerobic digestion (AD). Biogas production trough anaerobic digestion was found to be unstable when the cattle manure is used as mono substrate due to the low carbon to nitrogen ratio. The aim of this research is to extract biogas by anaerobic-digestion technique using cow dung (CD) and municipal solid waste (MSW) at different proportions. It was carried out by 15, 0.5 L digesters at 38 °C using oven atmesophilic condition. Samples were analysed for its total solids (TS), volatile solids (VS), fixed solids, organic carbon, moisture content, and potential of hydrogen (pH) according to standard method for the examination of water and wastewater. Biogas yield was recorded by using volume displacement method. Maximum cumulative biogas production by the substrate mixes of 0 % MSW+100 % CD (2818.3 ml) and a maximum daily biogas production for 75% CD+25% MSW (620 ml) with minimum of 0 ml for all substrate mix at end of day 22. Cumulative biogas yield of 100% CD digestion was found to be better yielding. It is also observed that, co-digestion of MSW with cow dung does not increase the amount of biogas production over only with 100 % CD. However, cow dung added with MSW has enhanced the amount of biogas yield and reduction in percentage of VS and TS as compared to 100 % MSW.

Keywords: Biogas technology; Anaerobic Digestion; Renewable; Co-Digestion; Total solids; Volatile solids.

INTRODUCTION

The current problems in developing countries mainly in rural they don't have the access of balanced forms of energy, such as electricity. Thus, they entirely depend on solid forms of fuels like firewood, to meet their basic daily energy needs for their cooking and lighting [1]. The availability of clean, renewable and affordable energy sources at household level seems a mandatory requirement for further societal and economic development in developing countries [2]. Over 60% of the total woods in developing countries like Ethiopia were used as wood fuel in the form of either charcoal or as firewood both in the urban and majority rural areas.

This has resulted in depletion of forests at a faster rate than they can be replaced. Renewable energy resources, such as biogas appear to be one of the most efficient and effective solutions [1].

Biogas is an eco-friendly, efficient, and renewable source of energy, which has been popularized as a substitute for other fuels for the purpose of energy saving in rural areas [3]. Furthermore, it helps to reduce the rate of deforestation and environmental deterioration by providing biogas as a substitute for firewood and dung cakes to meet the energy demand of the rural population [4]. Amongst other processes (including thermal, pyrolysis, combustion and gasification) biogas technology has in recent times also been viewed as a very good source of sustainable waste treatment/management, as disposal of wastes has become a major problem especially to the third world countries [5]. The effluent of this process is a residue rich in essential inorganic elements like nitrogen and phosphorus needed for its healthy plant growth known as bio fertilizer that applied to the soil enriches it with no detrimental effects on the environment [6].

***Corresponding author: teklelisanu21@gmail.com**

Wastes, whether municipal solid waste or manure if not properly handled, can cause serious environmental problems[7]. Municipal solid waste (MSW) generation is significantly increasing in Ethiopian urban areas and started creating massive waste disposal problems and people using it as landfill. In Ethiopia, MSW management is the duty of local municipality[8]. Obviously, all wastes have no high organic content that is amenable for biological treatment [7]. The application of anaerobic household digester offers an encouraging technology for clean energy generation and healthy waste disposal practices at the same time, degrading organic wastes and producing a nutrient rich digests that can be used instead of chemical fertilizers in agriculture [9].

Anaerobic digestion of biomass materials directly converts to biogas using mixture of methane and carbon dioxide with small quantities of other gases such as hydrogen sulphide[10]. In the anaerobic digestion of wastes, complex organic materials are first hydrolysed and fermented by rapidly growing acidogenic bacteria into volatile fatty acids (VFA), which are then oxidized by slowly growing acetogenic bacteria into acetate, molecular hydrogen, and carbon dioxide that are suitable as substrates for the methanogenic slowly growing bacteria [11]. It is known that VFAs are important intermediary compounds in the metabolic pathway of methane production and cause microbial stress if present in high concentrations, resulting in a decrease of pH, and ultimately leading to failure of the digester. Also, anaerobic digestion has been proven to be a reliable and economically feasible technology in full scale operations [12, 13].

The majority of the work done to promote the use of biogas technology has used cow dung as their raw material. However, degradability of cattle manure is typically in the range of 30 – 43% [14] and 25% of the unused methane potential is bound in the bio-fibres[15]. It is also noted that when the cattle manure is used as mono-substrate anaerobic digestion was unstable due to the low C to N ratio [16]. As a result, they require supplementary treatments such as co-digestion which is the simultaneous digestion of more than one type of waste in the same unit [7].

Based on the above-mentioned problems, generation of biogas energy using co-digestion of cattle manure and municipal solid wastes was investigated in this research. Moreover, the effect of substrate mixing ratio on biogas yield and biodegradable municipal solid waste has been also analysed.

MATERIALS AND METHOD

Materials

An analytical grade sodium hydroxide (NaOH, purity 99% ± 1) was purchased from Fischer Scientific, hydrochloric acid (35–37% assay) was purchased from Barhanu Chemicals, Addis Ababa, Sulphuric acid (purity 95%) purchased from Sigma Aldrich. Sodium chloride (NaCl) was purchased from Oxford Laboratory Ltd, Mumbai, India. The chemicals used are analytical grade and used as purchased without further purification. The acidified brine solution was prepared by adding NaCl to distilled water until a supersaturated solution is formed to prevent the dissolution of biogas in the water. Super glue was used to seal each digester tightly to prevent any intervention.

Substrate Collection

Substrates utilized in this research work were cattle manure and MSW obtained around Assosa town and Assosa Dale farm, Ethiopia. The biomass was systematically homogenized with predetermined mixing ratio to particle size suitable for easy digestion. Fresh rumen was collected from nearby slaughterhouse around Assosa, Ethiopia and filtered through0.5 mm sieve diameter fabric and then with filter paper to separate solid content from slurry. Prior to use, the inoculum was starved for 1 week by incubating at 38 °C to remove easily degradable VS present in inoculum [17].

Instrumentation - Experimental Setup & Design

Anaerobic digesters were carried out in 0.5 L plastic digester connected with bottle digester by plastic tube. The experiments for this study were conducted in microbiology laboratory, Department of Biology, in Assosa University, Ethiopia, located at latitude of 10^{0}04' N, longitude of 34^{0}31' E with an elevation of 1570 meters.

For the anaerobic digestion of cow dung (CD) and municipal solid wastes (MSW) were carried on using full factorial design with different substrate mixing ratio of 0%, 25%, 50%, 75%, and 100% and three republications of about 15 experimental runs. The following responses were investigated to identify its total solid and volatile solid degradation of substrates, average daily and cumulative biogas production of substrates. The biogas digestion was carried in 15L, 0.5 L digester in batch mode labeled A to E made in the following proportion. The total solid content of the five digesters was set at 8% (w/w) as recommended in literature [18] for low solid loading as follows: Digester A: Comprised of 100 % CD in 400 ml of water (i.e. 128 g of CD), Digester B: Comprised of 75% CD and 25% MSW in 250 ml of water (i.e. 96 g of CD and 8 g of MSW), Digester C: Comprised of 50 % CD and 50 % cow dung in 250 ml of water (i.e. 64 g of CD and 16 g of MSW), Digester D: Comprised of 25%

CD and 75% cow dung in 250 ml of water (i.e. 32 g of CD and 24 g of MSW), Digester E: Comprised of 100 % of MSW in 250 ml of water (i.e. 32 g of MSW).

Anaerobic Digestion

The anaerobic digestions were conducted in anaerobic digesters in batch wise mechanisms. The substrates were feed into digesters (by taking care from contact with bare hand by wearing gloves, masks and eyeglass) and mixing with equivalent amount of water. Filtered rumen fluid was used as inoculum [19]. Prior to use, the inoculum was starved for 1 week in incubating at 38°C to remove the easily degradable volatile solid (VS) [17]. Anaerobic digesters were constructed in bench-scale experiments, where biogas is produced out of the degradation of organic matter in 0.5 L digester. The four bottles' digesters were arranged in order in such a way that the first bottle contained slurry, second one with scrubber solution that remove the carbon dioxide, third with acidified brine solution and the last for collecting brine solution that was expelled out from the third container (Fig. 1). The acidified brine solution was prepared by adding NaCl to distilled water until supersaturated solution was formed.

(a) (b)

Fig. 1: Photograph images of (a) an electronic balance and (b) digester configuration setups

It is to prevent the dissolution of biogas in the water. Then three droplets of sulphuric acid were added to acidify the brine solution. All three containers were interconnected with a plastic tube of 1 cm diameter. Then the tubes are interconnected between first and second bottles just above the slurry. Here the first bottle is to use for gas collection. The biogas produced by fermentation of the slurry is driven from first bottle then enter into second bottle which contains scrubber solution. The pressure which builds inside the second bottle was displaced with brine solution equivalent to the volume of methane gas produced. The displaced solution was then measured to find the amount of methane produced [20]. The lids of each digester were sealed tightly using super glue in order to control the entry of oxygen and loss of biogas. The temperature of all digesters was maintained at 38°C by keeping in oven, atmesophilic condition.

Total Solids (TS)

The percentage of TS was calculated using the equation 1[21]. First a clean evaporating dish was oven dried at 105^{0}C for 1h, then cooled in a desiccator and weighed immediately before usage. Sample of fresh feedstock of about 10 gm was placed on the evaporating dish and put in an oven at 105°C using crucible to evaporate for 24 h. After 24 h, the crucible was taken out from the oven, then cooled in desiccators and weighed.

$$\%TS = m(DSm/FS) * 100 \quad (1)$$

Where, TS %represents percentage of total solids, mDS represents mass of dry sample (final weight) in gm and mFS represents mass of fresh sample in gm. Then, the percentage of total solid removed (i.e. after anaerobic digestion process) was calculated using the following formula [22].

$$\%TS\ removal = m(TSi - TSf)/TSi * 100 \quad (2)$$

Where, represents percentage of total solids removal, Tsi represents initial total solids before digestion (%) and Tsf represents final total solids after digestion (%).

Volatile and Fixed Solids

To determine the volatile and a mound of fixed solid, the oven dried samples were ignited at 550 °C in a muffle furnace for 3 h. The percentage of volatile solids content was calculated using the following expression: [21, 22].

$$\%\ VS = ([mDS - m\ (ash)]/mDS) * 10 \quad (3)$$

Where, % VS percentage of volatile solids, mDS mass of dry solids in gm and m (ash) remaining mass after ignition (fixed solid in grams).

$$\%\ VS\ removal = [(VSi - VSf)/VSi] * 100 \quad (1)$$

Where, % VS removal is the percentage VS removal, Vsiis the initial volatile solids (%) and Vsf is the final volatile solids (%).

Moisture content

To determine the percentage of moisture content (MC) in the samples, 10 gm of fresh substrates were dried in an oven at 105^0C for 24 h and reweighed. The moisture content was calculated using the following expression:[21, 22].

$$\% MC = [(W - D)/W] * 100. \quad (5)$$

Where, MC is the moisture content, W is the initial weight of sample in grams and D is the weight of sample after drying at 105^0C in gm.

pH Determination

The pH values were determined using digital pH meter before and after anaerobic digestion(AD). In the first case, an electrode was inserted into samples of feedstock that was diluted using distilled water before and after inoculation of rumen fluid. pH measurement after AD was done using pH electrode which was inserted into samples of feedstock that was digested for a certain period of time in AD process.

Organic Carbon

The carbon content of the feed stock was obtained from volatile solids data using an empirical equation stated below [22, 23]:

$$\% Carbon = \% Vs/1.8 \quad (2)$$

Where, VS - volatile solids

Total Liquid Quantity

Distilled water and rumen fluid needed to be added to the digester was then determined by the formula [18,22]:

$$Y = (mTS - 8\,\% X)/ 8\,\% \quad (3)$$

Where, mTSis the mass of total solids, X is the mass of water within the feedstock and Y is the mass of water to be added to get 8 % total solids in the digester.

Statistical Analysis

The results were analyzed using descriptive statistics (mean and standard deviation). Data was first checked for their normality. Data that were not normally distributed was log transformed and there after subjected to analysis of variance (one-way ANOVA) using SAS version 9.1. Fishers Least Significant Difference (LSD) was used to investigate the statistical significance between different treatments, whereas paired samples, T-test within a treatment. Difference between means was considered statistically significant at P<0.05

RESULTS AND DISCUSSIONS

Physicochemical Characteristics of the Substrates Used for Co-Digestion

As shown in Table 1, pH value of 100% CD was optimum for biogas production, whereas that of 100% MSW was less optimal [24, 25]. The value of pH increases with increase in content of CD in the mixture, which helps to maintain the pH of MSW. It indicates that co-digestion is a optimum way for pH adjustment [25]. Significance difference (P<0.05) were observed for pH value before and after AD except for 100 % MSW and CD as well as production of alkali compound (ammonium ions) changes the pH of anaerobic digestion during the degradation of organic compounds [26]. In addition to speedy the start up in the digestion process, rumen fluids has good buffering capacity especially for MSW. In this study, high pH value were recorded after AD for 75% CD+25% MSW and 100% CD this may be due to increased production of ammonia [27].The pH value increases with increasing the ammonia concentration and same way it decreases by increasing the VFA content resulting from protein degradation.

Organic carbon can be removed from anaerobic digesters either by being converted to cellular materials for growth and reproduction of bacteria or biogas production [26]. The decrease in carbon (C) reflects the degradation process during anaerobic digestion [26]. The results also revealed that there were significant differences (P<0.05) in the percentage of organic carbon for all mix ratios before and after AD. It is also noted that, mixing resulted an increasing MSW degradation but not for CD. As shown from the Table 1, the higher rate of degradation observed in organic carbon for 100 % CD (from 1.29 ± 0.021 to 0.79 ± 0.021, i.e., 38.8 % reduction) and least amount recorded in MSW.

The moisture content of 100% MSW, 75% MSW+25% CD, 50% MSW+50% CD, 25% MSW+75% CD and 100% CD were 10.0±1.00%, 26.67±0.33%, 42.33±0.88%, 56.00±0.58%, and 72.67±0.33%, respectively. These results show that, the moisture content of CD was higher than MSW (P<0.050) which increase the degree of digestion as bacteria that can easily access to liquid substrate for relevant reactions. Studies on the most favourable percentage of total solids for biogas productions suggested 8% as the optimum TS [18]. The initial moisture content of substrates used for this study was not optimal for wet anaerobic digestion process. Hence, dilution is required to bring the total solids percentage to 8%.

Table 1: Comparison of pH and organic carbon of the various substrates (values are mean ± SE, n=3)

Sample Code	Initial pH	Final pH	Initial organic C	Final organic C
100% MSW	4.95±0.203aD	6.17±0.153aC	4.23 ± 0.067aA	3.68 ± 0.053bA
75% MSW+25% CD	6.40±0.065aC	8.13±0.176bB	3.49 ± 0.008aB	2.93 ± 0.024bB
50% MSW+50% CD	6.77±0.093aBC	8.33 ± 0.09bAB	2.65 ± 0.078aC	2.09 ± 0.058bC
25% MSW+75% CD	7.01±0.017aB	8.13±0.176bA	2.03 ± 0.048aD	1.58 ± 0.061bD
100% CD	7.90±0.173aA	8.67±0.120aA	1.29 ± 0.021aE	0.79 ± 0.021bE

***Means followed by different small letters in row are significant at 0.05 probability levels for paired samples T-test within treatment. Means followed by different capital letter in column are significantly different at 5% level of significance between treatments. CD = Cow dung, MSW = Municipal solid wastes.**

Total Solid and Volatile Solid Degradation of Substrates

It has been noted that, the initial solid content of all mixtures before inoculation and digestion fall between 27.3 ± 0.33% (i.e., 2.73 gram of TS from 10-gram sample) and 90.0 ± 1.00%. As shown in Fig. 2**,** the total solid content of all mixtures decrease after anaerobic digestion. Maximum total solid content of 9gm and 8.27 gm; 2.7gm and 1.72 gm were recorded for 100 % MSW and CD before and after digestion respectively. The TS content of 90.0 ± 1.00% of MSW used for this experiment is closer to the value as reported in literature [29]. They reported that the TS content of dried MSW is about 87.94 %. Similarly, the TS obtained (27.3 ± 0.33%) in this experiment from cow dung was in the range of 15% to 48 % as reported by Fulford [30] for cow dung. Almost a maximum TS reduction of 0.98 gm for 100 % CD mixture and 0.6 gm for 25 % CD + 75 % MSW mixture were obtained. Fig. 3 shows the variation of VS before and after anaerobic digestion. The value of VS decreases after digestion for all mixture and maximum result were obtained in100 % CD and MSW was85.12 and 84.5% respectively, which complied with the finding of Fulford [30], who reported the composition of animals and human wastes typically consist of 15% - 48 % of TS and VS is 77%- 90 % of TS. The maximum and minimum reduction in VS was 1.01gm and 0.82 gm for 50 % CD + 50 % MSW mixture and 75 % CD + 25 % MSW mixture respectively. Compared to the values measured before anaerobic digestion, TS and VS content decreased significantly ($P<0.05$) after digestion for all mixtures. Total solids and volatile solids destruction is a good parameter for evaluating the efficiency of anaerobic digestion [31] and it is a good indicator for biogas production [32]. It can be seen that the VS and TS reductions for MSW alone were 13.1 % and 8.1 % respectively. Most of the volatile solids contained in 100% MSW remains unaffected after the anaerobic treatment indicating either the low bioavailability of organic material in the samples [33] or high inhibition rate during the digestion process.

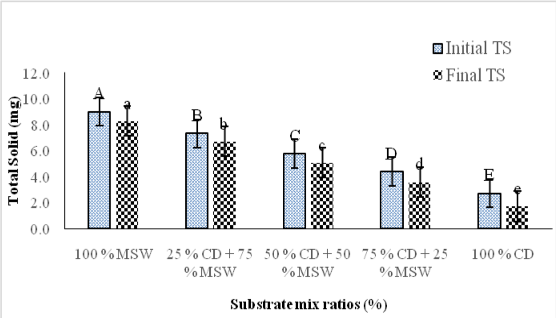

Fig. 2: Total Solid

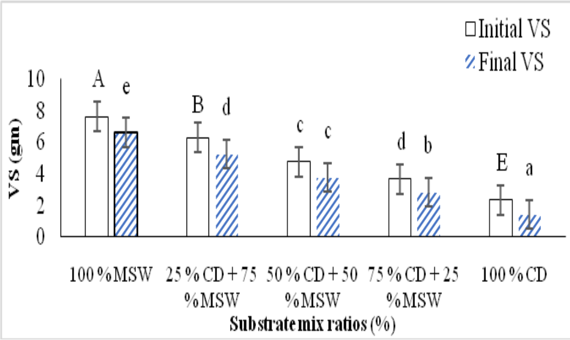

Fig. 3: Values of VS of substrate

From the figures [Fig.2 and Fig.3], capital letters represent differences between % VS and TS of the various substrates before digestion while small letters represent that of after digestion. Bar graphs with the same capital or small letters are not significantly different, whereas those with different capital or small letters are significantly different. Asterisk (*) shows there was significant difference in %TS before and after co-digestion.

Daily Biogas Production

In Fig. 4**,** the volume produced varied with substrate mixture, gas production was noticed from the very initial day of measurements. This could be due to the presence of microbes in the rumen fluid inoculums and that the substrates have readily available nutrients that are easily digestible by microbes [34]. The results show that biogas production is a function of feedstock's organic content and its biodegradable organic matter [35] and for all mixtures the maximum production observed were 407.7 ml (day 1), 508 ml (day 14), 460 ml (day 2), 620 ml (day 1), and 440 ml (day 1) for substrate mixtures of 0% CD +100% MSW, 100% CD+0% MSW, 50% CD+500% MSW, 75% CD+25% MSW, and 25% CD+75% MSW respectively. In this research, the maximum biogas productions were observed in75% CD+25% MSW (620 ml) and minimum of 0 ml were recorded for all substrate mixture at day 22 as indicted in Fig. 4. Initially, digester with MSW alone or digesters having MSW as co-substrate produces higher amount of biogas than digester with CD alone. This could be due to the presence of higher amount of readily biodegradable organic matter in 100% CD [33, 36]. After the first day of biogas production, there was a temporary decline observed in biogas production from all substrates except for the mixture of 0% MSW+100% CD. This declination might be due to depletion of readily decomposable substrate [37]. The biogas yield of 0% MSW+100% CD become maximum at 14thday. On this day, the other mixtures stopped or produced small amount of biogas. The biogas yields then slowly decreased to 0 ml after 22ndday. Again, this may be attributed to the depletion of the necessary nutrients from the digesters and increase in content of ammonium concentration that results an increased pH [38].

Cumulative Biogas Yield

Cumulative biogas yield of the three mixtures of CD and MSW was not significantly (P >0.05) higher for both MSW substrate and CD alone (Fig. 4**.**). Even if it is not significant, the addition of CD to MSW increases the amount of biogas produced by the digestion process. The maximum biogas yield was produced by the mixing of 0 % MSW+100 % CD (2818.3 ml). Cow dung alone produced 222 %, 241 %, 247 % and 261 % higher biogas than 75% CD+25% MSW, 50 %CD+50% MSW, 25% CD+ 75% MSW and 0% CD + 100% MSW, respectively. Thus, co-digestion of MSW with cow dung does not increase the amount of biogas production over the CD alone. However, MSW adding to CD enhances the amount of biogas yield over the MSW one. In contrary to this, cow dung alone would yield less biogas production as it is a product of a substrate that has already undergone partial fermentation in the intestinal tract of animal, and contains less degradable material that mainly composed of structural carbohydrates [39, 40]. However, in this research work cow dung was found to be a good source of biogas than MSW. Though its %VS was higher, the 100% MSW did not result more biogas than other three CD to PL substrate mixtures and CD alone. This might be due to the less favourable situation of 100% MSW to microorganisms as compared to that of substrate mixtures and CD alone. As the proportion of MSW in the mix ratio increased from 25% to 75%, the cumulative biogas yield has been decreased, suggesting less favourable situation in increasing MSW proportion from that of 25%. From three CD to MSW mixtures, the maximum biogas yield was obtained from 75% CD and 25% MSW substrate mixture. This mix produced about 11.9 % higher biogas than that of 25% CD + 75% MSW, 2.34 % higher than 50% CD+ 50% MSW.

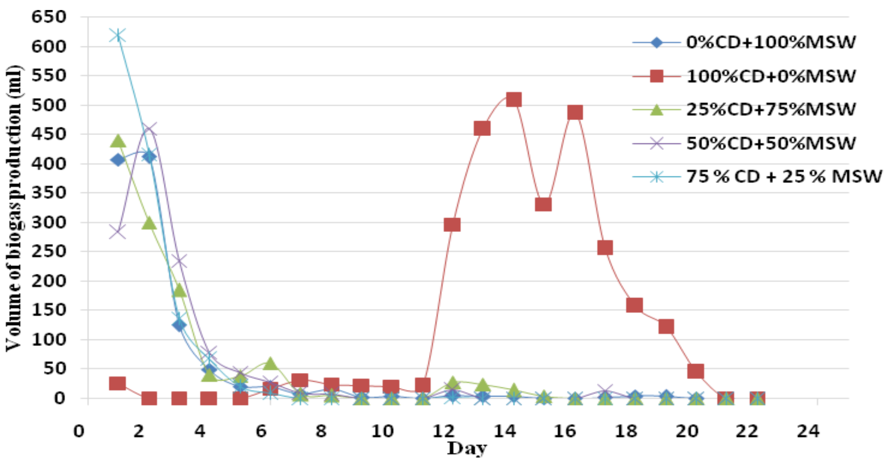

Fig. 4: Biogas yield of different substrate combinations

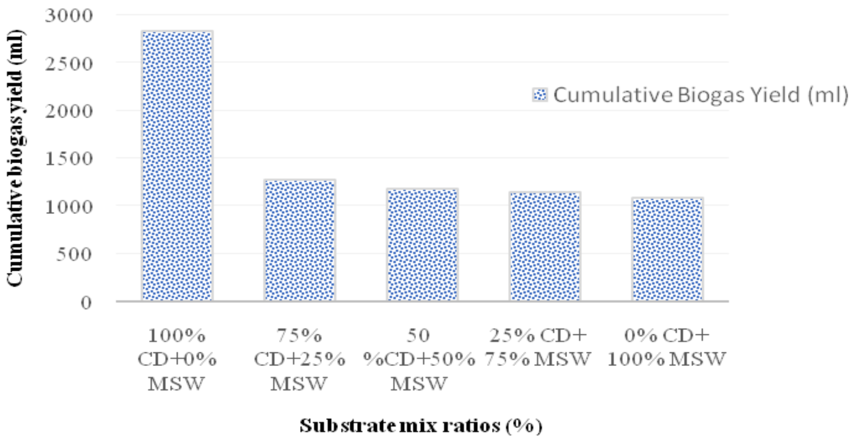

Fig. 5: Cumulative biogas yield of the different substrate combinations (Values are mean ± SE).

In Fig.5, Bars with different letters indicate significant differences between means while those with same letters show no significant difference between means. CD=Cow dung, MSW=Municipal solid wastes. (%CV=19.16, LSD= 521.25).

CONCLUSIONS

The need for exploring and exploiting new sources of energy which are renewable, sustainable, and eco-friendly is inevitable. Anaerobic biotechnology is a sustainable approach that combines waste treatment with the recovery of useful by-products and renewable bio fuels. Co-digestion of substrates has gained much attention to improve biomass conversion efficiency and biogas yield. With the objective of maximizing biogas yields from wet co-digestion of cattle dung with MSW, anaerobic degradability test were carried out under mesophilic conditions at 38ºC using batch digester for 22 day of hydraulic retention time.

The overall results of the study indicate significant ($P<0.05$) reduction in TS and VS content after digestion for all mixtures with maximum TS reduction of 0.98 gm for 100 % CD and 0.6 gm for 25 % CD + 75 % MSW, mixture. Maximum cumulative and daily biogas production of 2818.3 ml and 0 ml were observed by the mixture of 0 % MSW+ 100 % CD and 75% CD +25% MSW (620 ml) with minimum of 0 ml for all substrate mixtures at 22^{nd} day with a better cumulative biogas yield for 100% CD (total solid concentration about 8%) digestion. In this research shows that, the cow dung was found to be a good source of biogas than MSW. As well as additions of CD to MSW increases the amount of biogas produced by the digestion process.

ACKNOWLEDGEMENTS

We would like to acknowledge Asossa University for financial support of this research work and Wollo University for supporting the corresponding author in giving some free time to review literatures and moral motivations to prepare the manuscript for publication..

REFERENCES

[1] Amigun, B., et al., *Anaerobic biogas generation for rural area energy provision in Africa.* Biogas; Kumar, S., Ed.; InTech: Rijeka, Croatia, 2012: p. 35-62.

[2] Smith, M.T., J.S. Goebel, and J.N. Blignaut, *The financial and economic feasibility of rural household biodigesters for poor communities in South Africa.* Waste management, 2014. **34**(2): p. 352-362.

[3] Yu, L., et al., *Popularizing household-scale biogas digesters for rural sustainable energy development and greenhouse gas mitigation.* Renewable Energy, 2008. **33**(9): p. 2027-2035.

[4] Bhattacharya, S., P.A. Salam, and M. Sharma, *Emissions from biomass energy use in some selected Asian countries.* Energy, 2000. **25**(2): p. 169-188.

[5] Arvanitoyannis, I.S., A. Kassaveti, and S. Stefanatos, *Current and potential uses of thermally treated olive oil waste.* International journal of food science & technology, 2007. **42**(7): p. 852-867.

[6] Bhat, P., H. Chanakya, and N. Ravindranath, *Biogas plant dissemination: success story of Sirsi, India.* Energy for sustainable development, 2001. **5**(1): p. 39-46.

[7] Singhal, Y. and S.K. Bansal, *Evaluation of biogas production from solid waste using pretreatment method in anaerobic condition.*

International journal of emerging sciences, 2012. **2**(3): p. 405.

[8] Yusuf, M., A. Debora, and D. Ogheneruona, *Ambient temperature kinetic assessment of biogas production from co-digestion of horse and cow dung.* Research in Agricultural Engineering, 2011. **57**(3): p. 97-104.

[9] Appels, L., et al., *Anaerobic digestion in global bio-energy production: potential and research challenges.* Renewable and Sustainable Energy Reviews, 2011. **15**(9): p. 4295-4301.

[10] Beenackers, A., *Biomass gasification in moving beds, a review of European technologies.* Renewable energy, 1999. **16**(1-4): p. 1180-1186.

[11] Öztürk, M., *Degradation of acetate, propionate, and butyrate under shock temperature.* Journal of Environmental Engineering, 1993. **119**(2): p. 321-331.

[12] De Bere, L., *Anaerobic digestion of solid waste: state-of-the-art.* Water science and technology, 2000. **41**(3): p. 283-290.

[13] ten Brummeler, E., *Full scale experience with the BIOCEL process.* Water Science and Technology, 2000. **41**(3): p. 299-304.

[14] Møller, H.B., S.G. Sommer, and B.K. Ahring, *Methane productivity of manure, straw and solid fractions of manure.* Biomass and bioenergy, 2004. **26**(5): p. 485-495.

[15] Hartmann, H. and B.K. Ahring, *Anaerobic digestion of the organic fraction of municipal solid waste: influence of co-digestion with manure.* Water research, 2005. **39**(8): p. 1543-1552.

[16] Li, X., et al., *Anaerobic co-digestion of cattle manure with corn stover pretreated by sodium hydroxide for efficient biogas production.* Energy & Fuels, 2009. **23**(9): p. 4635-4639.

[17] Liew, L.N., *Solid-state anaerobic digestion of lignocellulosic biomass for biogas production*. 2011, The Ohio State University.

[18] Tchobanoglous, G., *Integrated solid waste managementengineering principles and management issues*. 1993.

[19] Seno, J. and I. Nyoman, *The effect of feed to inoculums ratio on biogas production rate from cattle manure using rumen fluid as inoculums.* International Journal of Science and Engineering, 2010. **1**(2): p. 41-45.

[20] Itodo, I., E. Lucas, and E. Kucha, *The effect of Media materials and its Quality on Biogas yield. Nig. J.* Renewable Energy, 1992. **3**(1): p. 2.

[21] Rice, E.W., et al., *Standard methods for the examination of water and wastewater*. Vol. 10. 2012: American Public Health Association Washington, DC.

[22] Lami, M., *Biogas Production from Co-Digestion of Poultry Manure and Orange Peel through Thermo-Chemical Pre-Treatments in Batch Fermentation.* International Journal of Environment Agriculture and Biotechnology, 2016. **1**(4): p. 0777-0795.

[23] Badger, D., M. Bogue, and D. Stewart, *Biogas production from crops and organic wastes. 1. Results of batch digestions.* New Zealand Journal of Science, 1979. **22**(1): p. 11-20.

[24] Thy, S., T. Preston, and J. Ly, *Effect of retention time on gas production and fertilizer value of biodigester effluent.* Livestock Research for Rural Development, 2003. **15**(7): p. 2003.

[25] Sreekrishnan, T., S. Kohli, and V. Rana, *Enhancement of biogas production from solid substrates using different techniques—a review.* Bioresource technology, 2004. **95**(1): p. 1-10.

[26] Gerardi, M.H., *The microbiology of anaerobic digesters*. 2003: John Wiley & Sons.

[27] Gray, K., *A review of composting-part 1.* Process Biochem., 1971. **6**: p. 32-36.

[28] Abdel-Hadi, M. and S.A. El-Azeem, *Effect of heating, mixing and digester type on biogas production from buffalo dung.* Misr Journal of Agricultural Engineering, 2008. **25**(4): p. 1454-1477.

[29] Fantozzi, F. and C. Buratti, *Anaerobic digestion of mechanically treated OFMSW: Experimental data on biogas/methane production and residues characterization.* Bioresource technology, 2011. **102**(19): p. 8885-8892.

[30] Fulford, D., *Running a biogas programme: a handbook*. 1988: Intermediate Technology Publications.

[31] Abubakar, B. and N. Ismail, *Anaerobic digestion of cow dung for biogas production.* ARPN journal of engineering and applied sciences, 2012. **7**(2): p. 169-172.

[32] Rafique, R., et al., *Effect of thermal, chemical and thermo-chemical pre-treatments to enhance methane production.* Energy, 2010. **35**(12): p. 4556-4561.

[33] Hobson, P.N., S. Bousfield, and R. Summers, *Methane production from agricultural and domestic wastes*. 1981: Springer.

[34] Kamthunzi, W., *Anaerobic digestion of cattle manure in batch digesters at ambient temperature.* Bunda Journal of Agriculture, Environmental Science and Technology, 2008. **3**(2): p. 8-12.

[35] Macias-Corral, M., et al., *Anaerobic digestion of municipal solid waste and agricultural waste and the effect of co-digestion with dairy cow manure.* Bioresource technology, 2008. **99**(17): p. 8288-8293.

[36] Yeole, T. and D. Ranande, *Alternative feedstock for Biogas.* Tropical Animal Production, 1992. **9**(3): p. 10-16.

[37] Ahn, H.K., et al., *Evaluation of biogas production potential by dry anaerobic digestion of switchgrass–animal manure mixtures.* Applied biochemistry and biotechnology, 2010. **160**(4): p. 965-975.

[38] Hansen, K.H., I. Angelidaki, and B.K. Ahring, *Anaerobic digestion of swine manure: inhibition by ammonia.* Water research, 1998. **32**(1): p. 5-12.

[39] Chawla, O., *Advances in biogas technology.* Advances in biogas technology., 1986.

[40] Deublein, D. and A. Steinhauser, *Biogas from waste and renewable resources. An Introduction. WILEYVCH*. 2008, Weinheim, Alemania.

Conflict of Interest

The author declares no conflict of interest.