Enhancing the Production of Biogas through Anaerobic Co-Digestion of Commercial and Animal Wastes

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ABSTRACT: *With the expansion of commercial centers such as hotels, restaurants, markets, etc., the amount of waste generated by these institutions has become an important challenge in large cities. On the other hand, the application of new biotechnologies to convert biodegradable waste into valuable materials such as biogas and other biofuels is increasing dramatically. The aim of this study was to investigate the potential of biogas production from a mixture of cow dung and restaurant wastes using an anaerobic bioreactor. Operational parameters such as pH, Carbon to Nitrogen ratio (C/N), mixing ratio of restaurant and cow wastes in weight percentage (0:100, 50:50, 70:30, and 100:0), total solids (TS) (%5, %10, and %20), temperatures (35, 45 and 55 °C) and oxidation-reduction potential (ORP) were evaluated. The results showed that the maximum yield and percent of the biogas produced from cow manure digestion separately was 1003 mL/day and %52.82. Digestion of the mixing of restaurant and cow wastes showed the best mixing ratio, total solid and temperature were 70:30 (w/w), %20 and 55°C respectively and biogas production yield and percent was obtained 5430 mL/day and %74.4 respectively. The ORP obtained in this study was -327 millivolt (mv), which indicates the appropriate conditions of the anaerobic process in biogas production and confirmation of methanogenesis.*

KEYWORDS: *Food wastes; Animal wastes; Anaerobic digestion; Biogas.*

INTRODUCTION

Each year, approximately 33% of the total food consumed by humans in the world is wasted, which according to the Food and Agriculture Organization of the United Nations report is 35.1 billion tons. On the other hand, the amount of disposed food waste in American restaurants and supermarkets is estimated at about 30 billion a year [1].

Catering waste is any waste produced in kitchens, canteens and restaurants [2]. These wastes are generated

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not only at the household level but also through catering services, which accounts for about 30% of the total food served [3]. Catering waste consists mainly of fruit, meat, vegetable waste and animal by-products, which are not only rich in proteins, carbohydrates, fats, and lipids but also contain a variety of vitamins and other nutrients [4,5].

The most appropriate way to manage of restaurant waste is to reuse it for the poor. But this method requires some measures such as separation and sanitary recycling on site before turning into waste, as well as their transportation and delivery to the poor, which is not economical and also due to the fast degradability of this waste by microorganisms is not healthy. Other methods of treatment and disposal of this type of waste include composting, incineration, sanitary landfilling, and Anaerobic Digestion (AD). The composting method requires a large area of land and also creates an unpleasant odor [6]. Waste incineration is an expensive method and causes health and environmental problems such as the release of toxic chlorinated compounds and dioxins into the atmosphere [7,8,9]. Sanitary landfilling also needs enough land and destroys usable foods and contaminates groundwater resources [10].

Anaerobic digestion, as a biological process that is used to degrade organic compounds by microorganisms in the absence of oxygen [10]. The process has many advantages, including the production of useful various intermediate organic compounds, the generation of energy in the form of biogas, the production of organic fertilizer, and it is a safe method to deal with environmental problems such as water and air pollution. The organic pollutants can be degraded through the metabolism of anaerobic microorganisms to decrease environmental pollution [11]. Up to now, AD technology has been widely applied in many countries for waste treatment [12]. In addition, the produced biogas can be applied as clean renewable energy, and the slurry of this process containing abundant nutrients including nitrogen, phosphorus, and potassium, has great potential for liquid fertilizer preparation [13].

Every year, tons of waste are generated from household, industrial, agricultural, and municipal sources. Inappropriate disposal and decomposition of biodegradable waste lead to large-scale environmental pollution. The degradation of 1 Million tons of organic waste has the potential to release 50-110 m^3 of CO_2 and 90-140 m^3 of CH_4 into the atmosphere. However if the same biodegradable solid waste is converted into biogas through AD, it will lessen the unfavorable environmental impacts and help reduce dependency on conventional fuels [14]. Biogas is a promising approach for the conversion of different types of wastes into efficient bioenergy. Generally, every biomass has the potential to be used as a substrate for biogas production. They have carbohydrates, proteins, fats, cellulose, and hemicelluloses as major components. However, the biogas composition and CH4 yield are highly dependent on the feedstock type, the digestion system, and the retention time [15]. Conventionally, biogas production has mainly been coupled with the treatment of cattle or cow manures and sewage sludge from WasteWater Treatment Plants (WWTP). Currently, most of biogas plants digest cattle manure with other substrates to increase the organic content for enhanced biogas production. Co-substrates commonly include harvest residues, agricultural waste, food waste, and household waste.

Wang et al. studied the effect of total solids on the anaerobic digestion process of a mixture of pig and food wastes. The results showed that increasing the total solids from 5 to 15% had no effect on the amount of methane produced, while with TS of 20% the amount decreased [9]. In the study of *Malik et al*., A mixture of food waste and cow dung was used to produce methane gas by the anaerobic process. This study showed that in the ratio of 1:1 food waste to cow dung and 2.5 kg VS, the amount of biogas produced was 1620 liters per day [1]. In the study of Al-Mashhadi and Zhang, in the field of biogas production from a mixture of dairy and food wastes, the amount of biogas production by the anaerobic digester in mesophilic conditions was investigated. In this study, the average amount of methane produced from fine and coarse mixed wastes within 30 days was 302 and 228 liters per kilogram of escape solid, respectively, and the percentage of biogas produced in these two cases was 93 and 87 percent, respectively [7,8]. In the study of *Pati et al.*, Digestion of food waste using cow dung was performed by the anaerobic process. The results of this study showed that the amount of biogas production was influenced by parameters such as pH, temperature, and water-to-solid ratio, so that in the ratio of solid to water 1: 2 and neutral pH, the amount of biogas production was maximum. Also, with increasing temperatures 25 to 40 ° C, the production of biogas increased from 110 to 142 mL and at higher temperatures, this amount decreased [9, 16].

In this study, the effect of the operational parameters such as pH, temperature, TS, C/N, and ORP index in biogas production from a mixture of cow dung and restaurant food waste was evaluated using an anaerobic bioreactor and then the best process conditions according to the performed tests were assessed.

EXPERIMENTAL SECTION

Process description

The first step, the used materials were completely crushed and particle size less than 3 mm by extruder with a speed of 1000 rpm and then the materials were mixed with water by a mixer with a given volume 10 liters. In the second step, the prepared materials were transferred into the homogenizer tank with an operational volume 80 liters. During the homogenization process, the physical and chemical properties of the materials were measured according to the experiment. In the third step, the materials were pumped through the homogenizer tank into the digester. The digester was made of stainless steel with an operational volume 60 liters and the temperature of the inside was adjusted by the thermal coil. There was a tube in the gas outlet of the digester where the produced gas was stored in the storage tank. In Fig. 1 schematic of this process is shown.

Experimental design

Cow dung was collected from the cattle bed in one of the livestock in Iran and catering waste was collected from the University of Mazandaran restaurant. The constituents of food waste are shown in Table 1.

The constituents of the food waste reported in Table 1 were constant throughout the experiment stages. All of these substances are mixed together in all experiments. Table 2 shows the physical and chemical properties of food waste and cow dung.

Table 2: The physical and chemical properties of food waste and cow dung.

Value	Food waste	Cow dung
TS (%)	2	0.9
C/N	37.8	67.5
Volatile solids (%)	0.74	0.13
pH	5.9	6.3
(g/m«) ρ	1.05	1.05
Fe (ppm)	350	2375
Mg (ppm)	15	4.5
Ca (ppm)	16.1	47.1
P (ppm)	0.04	0.66
Cd (ppm)	3.1	0.1
Pb (ppm)	0	0.018
Cr (ppm)	7.15	0
Ni (ppm)	5	0
Total Nitrogen (%)	1.06	1.62

Table 1: Food waste constituents in this study.

Materials	Weight (kg)
Rotten eggplant and cucumber	2.6
Cooked rice	7
Chicken skin and non-consumable chicken	4
Rotten and unusable tomatoes	3.4

Fig. 1: Schematic diagram of the process: Extruder (1); Mixer (2); Pump (3); Homogenizer tank (4); digester (5); Storage tank (6).

Research method (Methodology)

In the first step, the digestion of food waste and cow dung at constant density separately was performed and then the biogas production potential and methane concentration were measured. Secondly, digestion of food waste and cow dung at constant density with different weight ratios: 50:50 and 70:30, respectively, and measure of the biogas production potential and methane concentration were performed. In the third step, the best percent composition based on biogas production potential and methane concentration was selected. After selecting the best percent composition, the best total solids at values of 5%, 10%, and 20% were determined. In the fourth step, after

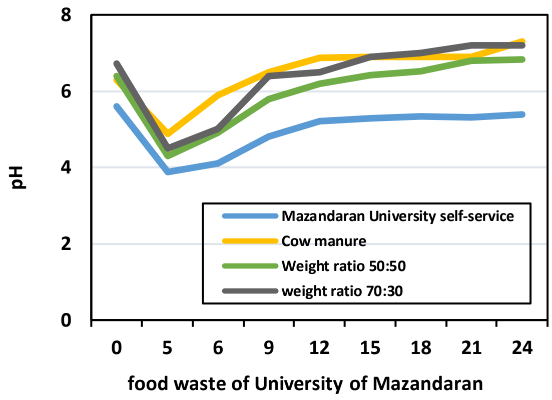

Fig. 2: Changes of pH in anaerobic digestion of food wastes and cow dung wastes.

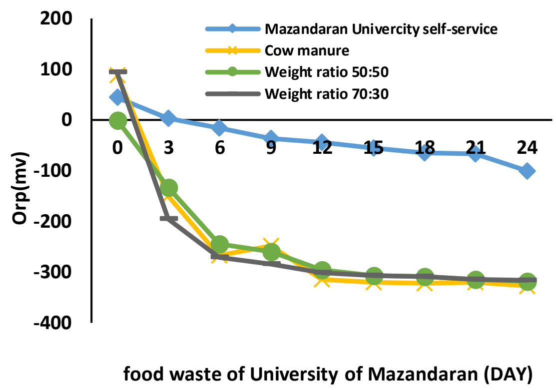

Fig. 3: Changes of ORP in the digestion of catering wastes, cow dung, and co-digestion of these two wastes.

selecting the best total solids in the best percent composition, the appropriate temperature (35, 45, and 55℃) conditions for biogas production, and the appropriate gas concentration were studied. At all stages of the measurement of biogas production and methane concentration, the amounts of pH and ORP were determined.

Chemical analysis

After biogas production, the gas was stored in the storage tank and the amount of gas produced every three days was measured using a flow meter (MSA ALTAIR 4X). Total carbon and nitrogen, total solids, volatile solids, and other elements such as Fe, Ca, Mg, Cd, Pb, Cr and Ni were measured by the standard methods [17]. The pH and ORP amounts of the process in all stages were measured by pH meter (MTT65 model) and ORP meter (BANTE Company, Scan 20 model).

RESULTS AND DISCUSSION

Anaerobic digestion of food wastes and cow dung wastes

pH effect

Fig. 2, shows the pH changes in the anaerobic digestion of food wastes and cow dung wastes.

As can be seen in Fig. 2, the pH changes in the digestion of food waste at the University of Mazandaran were slow and finally reached 5.3, which is not suitable for the growth of methanogenic bacteria [18]. Therefore, the concentration of methane during the food waste digestion process was low. On the other hand, pH changes in the digestion of animal waste indicated that the accumulation of volatile fatty acids from the digestion of these substances was low, so the pH changes after 15 days, reached above 6.8, which indicates growth conditions were suitable for the methanogenic bacteria and naturally the methane concentration was higher than the food waste [19].

The optimum pH for methanogenic bacteria growth is 6.8 to 7.2 [20]. As can be seen, by increasing the amount of cow waste to the food waste, the time of hydrolysis and acidogenesis processes are reduced and after the 18th day onwards, the condition will be reached at pH=7 (stability condition).

ORP effect

As can be observed from Fig. 3, the changes of ORP for food waste individually were low during 24 days and this value was eventually reduced to -100 mV, indicating that the digestion process of food waste was slow. The food waste digestion separately, ended up in the acidogenesis stage and consequently, the pH did not rise above 5.44, which due to the lack of methanogenic bacteria growth and consequently the concentration of methane was decreased.

However, in the co-digestion of food wastes and Cow dung in weight ratios of 50:50 and 70:30, the amount of ORP variable was -318 and -327 mV, respectively. Also, pH variations in the co-digestion of food wastes and cow dung in weight ratios of 50:50 and 70:30 were increased by 7.2 and 7.3 on the 24th day, respectively, which indicates that in these two conditions, was appropriate for good operation of the anaerobic digester and methanogenesis phase. The optimum of ORP and pH during the acidogenesis and methanogenesis phases were -284 ± 32.71 mV;

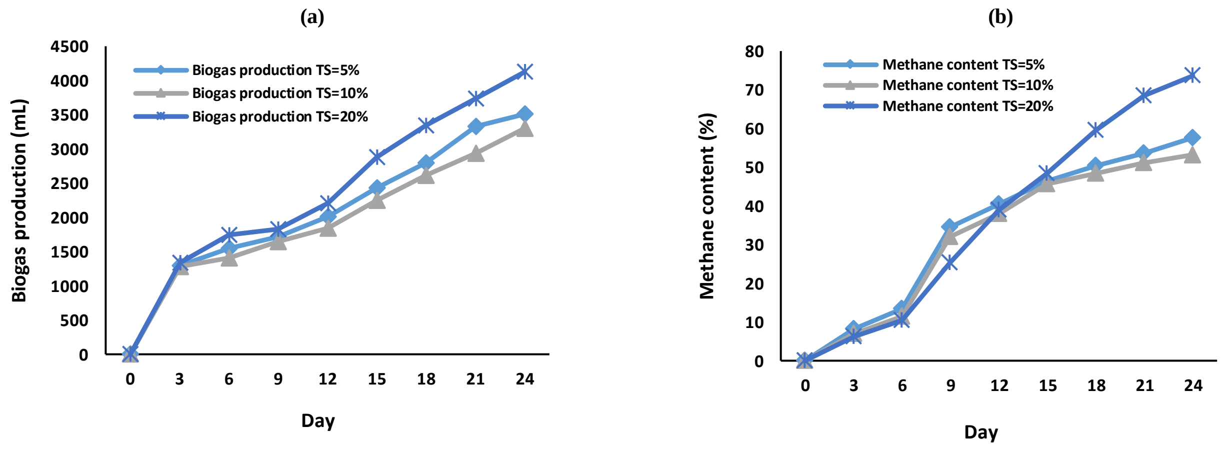

Fig. 4: Biogas production (a) and methane content in different total solids.

5.76 ± 0.24, and -335.63 ± 28.97 mV; 7.49 ± 0.24, respectively [21].

TS effect

Most research has shown that TS content in wastes more than 20 % decreased methane production [9]. Some studies have shown that the decrease in methane production can be due to the reduction in mass transfer rate, which occurs due to the decrease in water content in high TS [7]. In this study, the mixture has been diluted with water to obtain the studied TS contents (TS 5%; TS 10%; TS 20%) and then fed into the digesters after fully mixing. As can be observed from figure 4, When TS of lignocellulose materials decreases from 20 to 5 %, the biogas production decreases (Fig.4a) but the amount of methane content in terms of percentage increases (Fig.4b). The reason of this can be related to the mass transfer phenomenon [9]. In this study, we considered the range of biogas production between 5 to 20% of TS. According the results, the amount of biogas production and the methane content in TS 20% were the highest in 4125.6 mL and 73%, respectively.

Temperature effect

As the results reported in previous section, the biogas production and methane content in TS 20% and temperature 35℃ were the optimum condition. Regarding of the effect of temperature variations on the biogas production and methane content, so in addition to 35℃ (mesophile), two temperatures of 45℃ and 55℃ (thermophile) were studied. As can be seen from Fig. 5, the temperature changes in the biogas production and methane content were effective. The reason for this phenomenon is associated with increasing the growth rate of methane-forming bacteria in anaerobic digestion with increasing temperature [22].

According to Fig. 5, with increasing temperature until 55 °C, the amount of biogas production increased by 5200 mL, and the amount of methane produced at 55 °C was higher than at other temperatures (35 and 45°C). Considering Fig. 5, a certain amount of methane gas was produced at different temperatures due to the lack of substrates and Food per Microorganisms (F/M) ratio in the digestion reactor [23].

CONCLUSIONS

Biogas is a promising renewable energy source and can be produced from a variety of wastes in residential, institutional, commercial, and agricultural areas. With the technological progress and political support from governments, the real potential of biogas was known and can be applied in many cases such as electricity generation and as fuel for automobiles. This study aimed to investigate the potential of biogas production from a mixture of cow dung and restaurant wastes using an anaerobic bioreactor. The results showed that the maximum yield and percent of the biogas produced from cow manure digestion separately was 1003 mL/day and %52.82. Digestion of the catering waste and cow manure as a mixture showed the best mixing ratio, total solid and temperature are 70:30 (w/w), %20 and 55°C respectively and biogas production yield and percent in this conditions was obtained 5430 mL/day and %74.4 respectively. The ORP obtained in this study was -327 millivolt (mv),

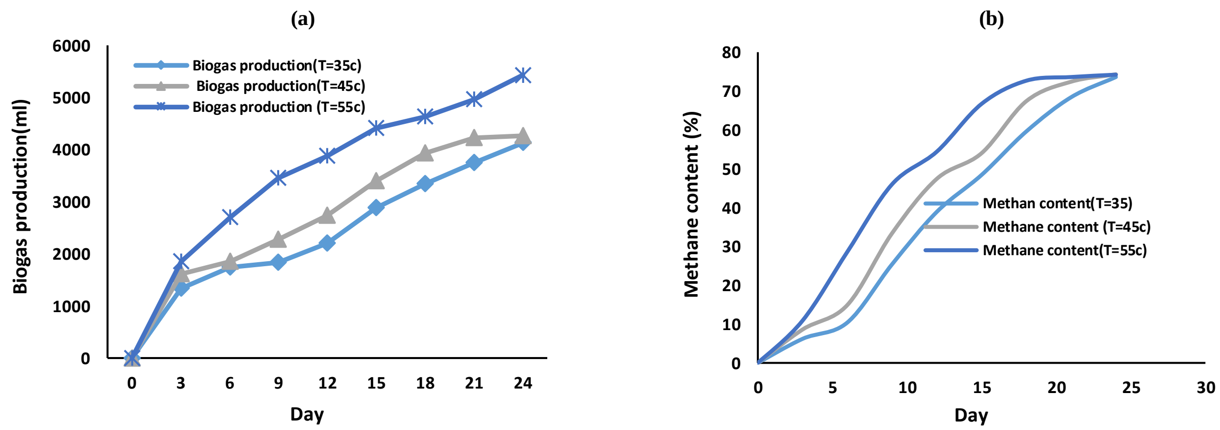

Fig. 5: Biogas production (a) and methane content in different total solids.

which indicates the appropriate conditions of the anaerobic process in biogas production and confirmation of methanogenesis. Also, for better operation and reduction of hydraulic time, the temperature should be set at 55 ° C to have the best performance for biogas production.

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REFERENCES

[1] Malik W., Mohan C., Annachhatre A.P., https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8225055/ *Proceedings*, **28(3)**:1910-1915 (2020).

[2] Sarkar O., Sai K., Butti S., Venkata M., Acidogenic Biorefinery: Food Waste Valorization to Biogas and Platform Chemicals, *Waste Biorefinery Potential Perspect*, *Elsevier* (2018).

[3] FAO, Food Wastage Footprint: Impacts on Natural Resources, *FAO*, Rome (2013).

[4] Ayomoh M.K.O., Oke S.A., Adedeji W.O., Charles O.E., An Approach to Tackling the Environmental and Health Impacts of Municipal Solid Waste Disposal in Developing Countries, *J. Environ. Manag*, **88**:108–114 (2008).

[5] Hoornweg D., Tata PB., What a Waste: A Global Review of Solid Waste Management, *Urban Dev Ser Knowl Pap*, (2012).

[6] Yousefi Z., Amouei AI., Asgharnia HA., Nemati A., Vaezzadeh M., Compost Production from Household Solid Wastes by Earthworms, *JBUMS*, **14**:30-35 (2012).

[7] Al-Mashadi H., Zhang R., Biogas Production from Co-Digestion of Dairy Manure and Food Waste, *Biores Technol*, **101**: 4021-4028 (2010).

[8] Gou C., Yang Z., Huang J., Wang H., Xu H., Wang L., Effects of Temperature and Organic Loading Rate on the Performance and Microbial Community of Anaerobic Co-Digestion of Waste Activated Sludge and Food Waste. *Chemosphere*, **105**: 146-151 (2014).

[9] Pati AR., Saroha1 S., Behera A.P., Mohapatral S.S., Mahanand S.S., The Anaerobic Digestion of Waste Food Materials by Using Cow Dung: A New Methodology to Produce Biogas, *J. Instit. Eng. (India), Series E*, **100**:111–120 (2019).

[10] Shakeri N., Amooey A., Amouei A.I., Evaluation of an Anaerobic/Aerobic System for Reactive Black 5 Removal: Kinetic Study, *Iran. J. Chem. Chem. Eng. (IJCCE)*, **40(5)**: 1512-1522(2021).

[11] Wang Z., Jiang Y., Wang S., Zhang Y., Hu H., Hu Z., Wu G., Zhan X., Impact of Total Solids Content on Anaerobic Co-digestion of Pig Manure and Food Waste: Insights into Shifting of the Methanogenic Pathway, *Waste Management*, **114**: 96–106 (2020).

[12] Akhiar A., Battimelli A., Carrere MT., Comprehensive Characterization of the Liquid Fraction of Digestates from Full-Scale Anaerobic Co-Digestion, *Waste Management*, **59**: 118-128 (2017).

[13] Sawatdeenarunat C., Surendra KC., Takara D., Oechsner H., Kumar Khanal S., Anaerobic Digestion of Lignocellulosic Biomass: Challenges and Opportunities, *Biores Technol.*, **178**: 178-186 (2015).

[14] Macias-Corral M., Samani Z., Hanson A., Smith G., Funk P., Yu H., et al., Anaerobic Digestion of Municipal Solid Waste and Agricultural Waste and the Effect of Co-digestion with Dairy Cow Manure, *Biores Technol.*, **99**: 8288-8293 (2008).

[15] Mao C., Feng Y., Wang X., Ren G., Review on Research Achievements of Biogas from Anaerobic Digestion, *Renew Sustain Energy Rev.*, **45**: 540-555 (2015).

[16] Houba V.J.G., Novozamski H., Van Eck R., Van Wark W., Soil testing and plant analysis in Western Europe, *Communications in Soil Science and Plant Analysis*, **23(17-20)**: 2029-2051 (1992).

[17] APHA., AWWA., WEF., Standard Methods for the Examination of Water and Wastewater, *23rd Edition, Washington*, DC 20001- 3710 (2017).

[18] Lee D.H., Behera S.K., Kim J.W., Park H.S., Methane Production Potential of Leachate Generated from Korean Food Waste Recycling Facilities: A Lab-scale Study, *Waste Management*, **29(2)**: 876-882 (2009).

[19] Horiuchi J.I., Shimizu T., Kanno T., Kobayashi M., Dynamic Behavior in Response to pH Shift During Anaerobic Acidogenesis with a Chemostat Culture, *Biotech. Tech.*, **13(3)**: 155-157 (1999).

[20] Lemmer A., Merkle W., Baer K., Graf F., Effects of High-Pressure Anaerobic Digestion up to 30 Bar on pH-Value, Production Kinetics and Specific Methane Yield, *Energy*, **138**: 659-667 (2017).

[21] Vongvichiankul C., Deebao J., Khongnakorn W., Relationship Between pH, Oxidation Reduction Potential (ORP) and Biogas Production in Mesophilic Screw Anaerobic Digester, *Energy Procedia*, **138**: 877-882 (2017).

[22] Gedefaw M., Biogas Production from Cow Dung and Food Waste. Glob. J. Pollut. Hazard, *Waste Manage*, **3(1)**: 103-108 (2015).

[23] Rosińska A., Karwowska B., Dynamics of Changes in Coplanar and Indicator PCB in Sewage Sludge During Mesophilic Methane Digestion, *J. Hazard Mater*, **323**: 341-349 (2017).