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Research Article

Increasing Methane Production by Anaerobic Co-Digestion of Slaughterhouse with Fruit and Vegetable Wastes

Mohammad Taghi Samadi,[1] Mostafa Leili,[1] Hossein Haji Agha Alizadeh,[2] Kazem Godini,[1] and Fatemeh Ahmadi[1,*]

[1]Department of Environmental Health Engineering, Hamadan University of Medical Sciences, Hamadan, Iran
[2]Department of Biosystems Engineering, Faculty of Agriculture, Bu Ali Sina University, Hamedan, Iran

[*]*Corresponding author*: Fatemeh Ahmadi, Department of Environmental Health Engineering, Research Center for Health Sciences, Faculty of Health, Hamadan University of Medical Sciences, Hamadan, IR Iran. Tel: +98-9169598496, E-mail: f.ahmadi8899@gmail.com

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Abstract

Despite fossil fuels, the energy supply from biogas process is of renewable energy resources; this kind of energy can be generated in all parts of the world. Thus, the potential of anaerobic co-digestion for production of methane from wastes of an industrial slaughterhouse and fruit and vegetable center in the Hamadan city, west of Iran, was investigated. The digester was operated under the mesophilic (35 - 37°C) condition for a period of 40 days with 3 different C/N ratios (20/1, 30/1 and 40/1). Before operation of digester, the amounts of C and N in the wastes were measured and during the experiments pH and composition of the biogas were determined. The cumulative amounts of the generated total biogas and methane at the 3 examined C/N ratios 20/1, 30/1 and 40/1 were, respectively 181, 201.7 and 162.5 L and 129.8, 149.2 and 114 L. The results indicated that the highest contents of biogas and methane (201.68 and 149.29 L, respectively) were obtained at C/N of 30 within 31 days.

Keywords: Anaerobic Co-Digestion, Methane Production, Slaughterhouse Wastes, Fruit and Vegetable Wastes

1. Introduction

Nowadays, uncontrolled and increasing generation of solid waste containing large amounts of organic matter, considered as a major environmental challenge. Disposal methods such as damping are not acceptable and even incineration and landfilling are not considered as permanent and suitable procedures (1, 2). The energy recovery from biomass sources such as biogas that produced from solid waste can be a proper alternative to fossil fuels consumption, which consequently reduces the effects of air pollution, such as global warming and acid rains (3). Some advantages of biogas are: reduce greenhouse gas emission as well as prevention of surface and underground water resources contamination. It is a renewable energy resource and improves the economic status of farmers from energy cost-saving (4, 5). The biogas process is the anaerobic digestion of organic matters of the biomass in the absence of oxygen (6). This process is performed in 4 phases: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Methanogens is an obligate anaerobic bacteria growth in anaerobic environment (1, 6).

Slaughterhouse wastes (SHW) contain a huge amount of organic matters: protein and fat that can be digested anaerobically as well (7). These wastes usually have high quantities of BOD and COD, which can create various problems if they are discharged into the environment without enough treatment (8). Digestion of these kinds of waste does not happen well because of the high loads of organic materials and nutrients (9). Therefore, co-digestion of these wastes in concert with other suitable materials can result in a decrease of organic load, nitrogen, and improving biodegradability. Appropriate treatment of SHW is producing a high amount of methane, which is indicative of the theoretical potential of methane from effective decomposition of fats (10).

It has been claimed that the lack of a balance between nutrients, nitrogen, and carbon can break down reactions happening in the biogas process (11). For example, animal bodies wastes contain high quantities of nitrogen and can be declining the C/N ratio. On the other hand, fruit and vegetable wastes (FVW) have high C/N ratios, which make them proper co-substances for anaerobic co-digestion with SHW. Several studies have tried to reach the best C/N ration in co-digestion of SHW and FVW (12). Animal wastes provide sufficient amounts of nitrogen for cell production and carbon decomposition present in the process (13) and, the higher buffer capacity of such wastes may avoid pH loses stemming from the high generation of Volatile Faty Acids (VFAs). As a result, mixing vegetable wastes with animal wastes can lead to a balanced C/N ratio and improving the biodegradability of solid waste mixture (14). Anaerobic bacteria needs carbon and nitrogen to survive; when the ratio of C/N is high, nitrogen runs out sooner than carbon. In this case the residual carbon acidifies the environment and conversely, when the C/N ration is low, the environment is alkalized and extra nitrogen is released as ammonia (15).

In the study by Rene' Alvarez et al., who worked on semi-continuous co-digestion of solid slaughterhouse waste, manure, and fruit and vegetable wastes, they considered organic loading rate (OLR) (in the range 0.3 - 1.3 of kg VS m^{-3} d^{-1}), pH, total solids, volatile solids, total nitrogen, total organic carbon, total phosphorous, and total potassium as variables of the study. They investigated t10 different compounds. In all experiments, after 60 days of operation, a stable state of biogas production for the mixture was attained in the range of $1.1^{-1}.6$ Ld^{-1}, with a methane content of 50 - 57% (16). The results of the study by Beatriz Molinuevo-Salces, in which the anaerobic digestion of SHW: swine manure, poultry litter, and vegetable processing wastes mixtures was investigated, illustrated that addition of vegetable wastes to animal wastes before the anaerobic digestion enhanced the degradation of VS and CH_4 yield went up from 111 to 244 mL CH_4 g VS^{-1} added, and the VS removal increased from 50 to 86%. Furthermore, in the case of poultry litter-vegetable processing wastes (PL-VPW) co-digestion, CH_4 yield increased from 158 to 223 mL CH4 VS^{-1} added and VS removed from 70 to 92% (17).

The main objective of this study was to investigate the co-digestion of solid wastes (liver, stomach and intestines and serous fluid) from an industrial slaughterhouse with the wastes from a vegetable and fruit center in Hamadan, west of Iran in a lab pilot at temperature of 37°C. Moreover, in order to survey the total biogas production from the wastes, different C/N ratios: 20, 30, and 40 at different times: 20, 30, and 40 days were studied and the best values were determined.

2. Materials and Methods

2.1. Substrates Characteristics

In this study, 2 different substrates were used; SHW from an industrial slaughterhouse and FVW from a fruit and vegetable center in Hamadan city (Iran). The mean numbers of daily slaughter were 45 - 70 cows and 150 - 200 sheep. Table 1 presents the properties of SHW and FVW.

Table 1. Initial Characterizations of Slaughterhouse and Fruit and Vegetable Wastes

Parameters	SHW	FVW
pH	7.1	4.3
VS, %	26.1	89
TS, %	28.2	11.5
Moisture, %	65	70

2.2. Design and Operation of the Pilot

A batch of 50-liter anaerobic digester was made of stainless steel. Different parts of the digester have been shown in Figure 1. The required temperature of the digester was provided by the water heated through an electrical heater installed between the wall layers. Sampling valve was installed at the bottom of the digester to measure the pH. pH values were measured by a pH-meter (Sensoal-HACK-Germany), which its probe was placed in leachate, and, a magnetic stirrer was used to completely mix the materials in the reactor.

2.3. Operation Condition

Since the SHW had a low C/N ratio, the FVW were added to raise it to 20/1, 30/1, and 40/1. The ratios of water loading with materials was: 1:1; the effective volume of the digester was 45 L, including 50% solid waste and 50% water stodied. In this study, 3 ratios of C/N (20/1, 30/1, and 40/1) were examined and the best ratio for producing biogas was determined. Organic solid wastes of the slaughterhouse, which have the ability to generate total biogas (stomach contents, rumen wastes (and plasma were collected, and the wastes were shredded. Then, different kinds of FVW (vegetables, fruits and so on) were added at different ratios. All experiments were conducted at neutral pH (6.5 - 7.5) and room temperature (20 - 25°C). The reactor was filled with the prepared feed and the 3 specific C/N ratios and were under the mesophilic (35 ± 1°C) conditions for 40 days. It must be pointed out that the amounts of generated total biogas and methane were monitored during the anaerobic process.

The amount of total biogas produced in different time intervals in the headspace of the reactor was detected based on a water displacement method. In this method, the generated gas directed the balancing bottle through connective tubes. Water moves to the top of the graduated cylinder because of an increase in pressure. The amount of displaced water volume is equal to the produced gas (18). A gasometric device (ALTAIRIR 5X- MSA American) was used to detect the generated methane. The volume of the generated gas was determined daily and each day the materials inside the reactor was mixed well for 15 minutes.

In order to study the performance of the digester at mesophilic temperature, parameters including: pH and the generated methane volume were measured. Carbon and nitrogen were detected based on the methods: Wakley-Black wet oxidation and Kjeldahl, respectively (19, 20).

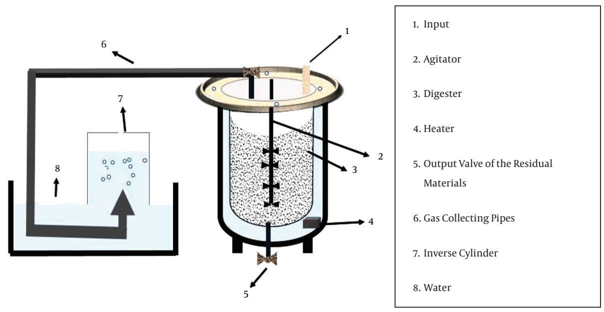

Figure 1. A Schematic Diagram of the Biogas Pilot Used in the Study

3. Results and Discussion

3.1. Methane Yields During the Study Period

The daily production total biogas and methane yield during the 40 day operation period have been presented in Figures 2 and 3. As can be seen, during the first 10 days of the experiments, the contents of the produced total biogas increased up to 14.2, 14.7, and 11.5 L/d, respectively, at C/N ratios of 20/1, 30/1, and 40/1 and then decreased regularly. Accordingly, methane yield enhanced up to 10.7, 11.4 and 8.9 L/d, respectively, at C/N ratios of 20/1, 30/1, and 40/1 and then decreased. Figure 2 shows that during the anaerobic digestion (40 day) the cumulative amounts of the generated total biogas and methane at the 3 examined C/N ratios were, respectively, 181, 201.7, and 162.5 L and 129.8, 149.2 and 114 L. The results illustrate that the highest amounts of total biogas and methane generation obtained at the C/N ratio of 30/1, and were 201.7 and 149.2 L, respectively, which was achieved during 31 days of operation. It has been claimed that the optimal C/N ratio to maximum total biogas generation is in the range of 20/1 - 30/1. Although addition of FVW to SHW increases C/N, when the C/N ratios of 20/1 and 30/1 were examined, these were still in the optimum range for anaerobic digestion. Naturally, C/N = 30/1 produces more biogas and methane.

The ratios between 20 and 30 are suitable for the growth of bacteria in anaerobic systems (21). Naturally, this ratio can be different based on the kind of input materials. For example, in a study it was set at around 15 for co-digestion of onion juice and digested sludge (22). When particulate materials are added to digested sludge, the process of digestion with C/N ratio in the range of 15 - 18 is advised, however, the process is not effective at the ratios more than 21 (23). Other studies have claimed that the best ratio for anaerobic digestion of food wastes is nearly 20 (24, 25).

Although addition of FVW to SHW resulted an increase in C/N (26), as stated above, when the ratios of C/N = 20 and 30 were investigated, it was found that these ratios were appropriate for the anaerobic digestion. Furthermore, it was reprted that the system generated more biogas at the ratio of C/N 30. The study by Molinuevo-Salces et al., who surveyed the anaerobic co-digestion of animal wastes and processed vegetable wastes, concluded that the system operated better at C/N 30 (17).

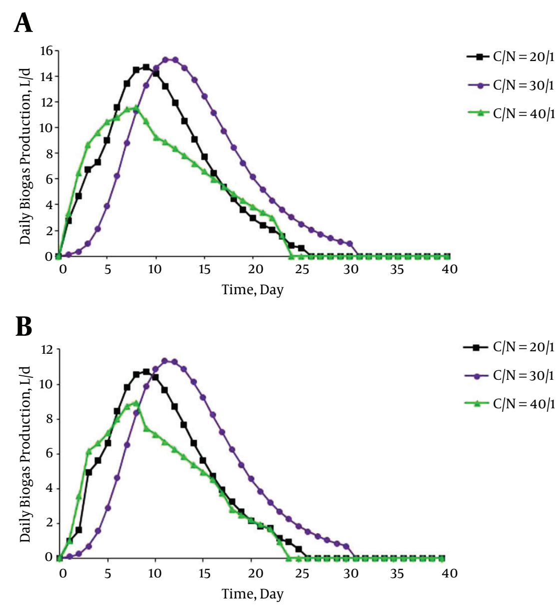

Figure 2. Changes of daily production of (A) biogas and (B) methane at C/N ratios of 20/1, 30/1 and 40/1

At C/N of 40, the production of biogas stopped after 21 days. This was confirmed by the reported results by Perma Vismanath et al., who studied the co-digestion of vegetable and food wastes for biogas production. They concluded that the production of biogas occurred before 5 days (26). It should be known that the most important negative point of anaerobic digestion with FVW is creation of a low-pH environment, which negatively influences the methanogen phase.

The findings of a study showed that degradation of organic matters stopped because of low pH (nearly 4) and, in turn, the production of methane stopped (27). Digestion capability reduces due to the generation of lignocellulose and lignin. Therefore, the amount of nitrogenous materials and energy consumption decreases, which is owing to lower numbers of active microorganisms in digestion (28). Reduction of the proportion of methane in biogas is indicative of an increase in CO_2 production, illustrating that the amidogen bacteria are predominant in system. As a result, the pH and alkalinity of the system decline. All these results in a lower production of methane (29).

3.2. pH Variations During the Study Period

pH variations of the digester were measured daily. As can be seen in Figure 4, pH value was 6.5 at the start of the experiments and then slowly increased, which reached 7.9 on the last day. Furthermore, at the C/N ratio of 30/1, pH increased from 6.3 to 8.1. However, at C/N = 40/1 pH remained on the acidic conditions (4.9 - 5.9).

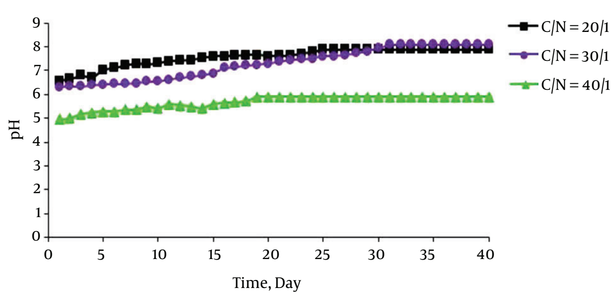

Figure 3. Cumulative Amounts of (A) Total Biogas and (B) Methane Generation at C/N Ratios of 20/1, 30/1 and 40/1

The results of several studies have described that the pH values in the range of 6.4 - 7.2 are suitable for methanogens bacteria (28, 30, 31) and any variation in pH influences the gas production efficiency. A decrease in pH stops methane production. Since methanogens bacteria are highly sensitive to the pH of the digester, pH should be kept in the range of between 5.7 and 7.7. If pH declines to under 5.5, these bacteria will be inactivated. If pH remains constant in the acidic conditions, it is probable that methanogens bacteria will be activated. A sudden change in pH value causes stopping of the fermentation and, subsequently, the production of biogas will be stopped (31-33).

As can be seen in Figure 4, at the C/N ratios of 20/1 and 30/1 the pH variation was in the appropriate range for methane production and the variations can be ignored. At

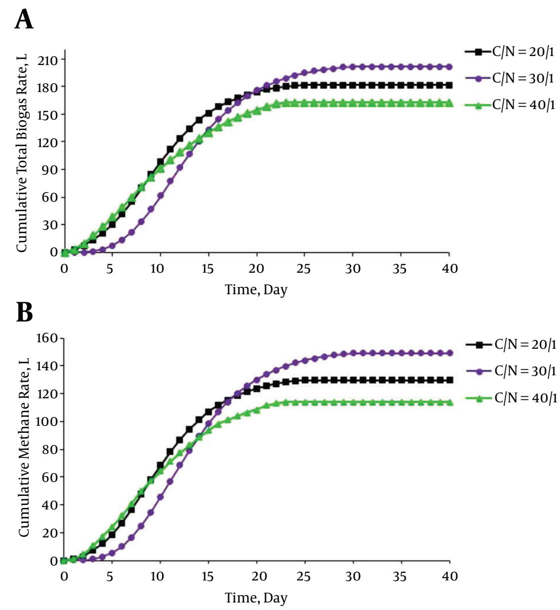

Figure 4. pH Variations at C/N Ratios of 20/1, 30/1 and 40/1

C/N 20/1, pH was 4.9 on the first day and increased to 5.9 on the last day. The rapid decrease of pH can be attributed to addition of FVW containing high amounts of lignocellulose. As a result, low digestibility was associated with high contents of lignocellulosic materials (28).

In this study, the production of methane and total biogas increased at the first days of the experiments, which is due to solid compounds were easily available to anaerobic bacteria. However, over time, organic dissolved materials concentration in leachate was less, which decreased the amount of available organic matters, and consequently decreased the biogas and methane production. The production of total biogas and methane leveled off showed that the process has been completed (Figures 2 and 3).

3.3. Relationship Between Biogas and Methane Production at the C/N of 20, 30 and 40

Figure 5A, B and C shows the trend of pH with biogas and methane production. As can be clearly seen, pH declined on first days of loading, however, it then increased as it became at the suitable range for the methanogen bacteria. At the second stage of the experiments, a decline in pH was not seen. However, the value of pH had more fluctuation, which was not suitable. The decrease of pH on the 12th day may be due to the destruction of complicated organic materials (not fast biodegradable materials) in reactor. Due to the fact that the used beds were of plant origin, the pH of the third stage was lower than the neutral range (34).

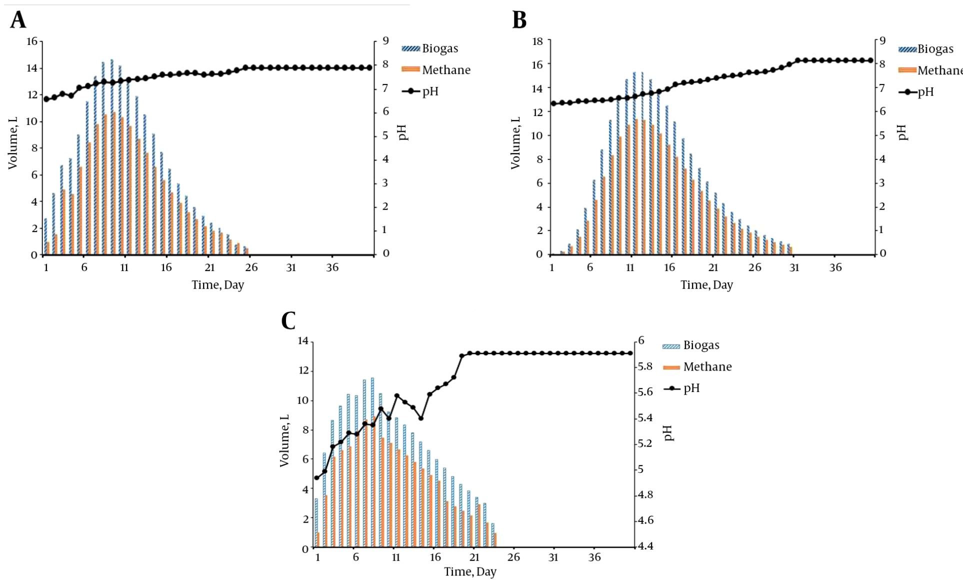

Figure 5. Relationship Between pH, Methane, and Biogas Production at the C/N ratio of (A) 20, (B) 30, and (C) 40

4. Conclusion

In this study, it was found that C/N = 30/1 resulted in the highest amounts of biogas and methane production. It should be noted that at this ratio there were suitable amounts of C and N available for growth of bacteria. The findings showed that an optimum ratio of C/N can be attained by mixing FVW containing more carbon than SHW containing more nitrogen. Therefore, the developed process is an efficient and promising technique for the co-digestion of slaughterhouse, fruit and vegetable wastes. Of course, more studies should be done at full scale to industrial application of the developed reactor. In conclusion, the results showed that this method is suitable for controlling the wastes of slaughterhouses as well as vegetable and food centers; the energy produced can be used to meet slaughterhouses' needs and the generated compost can be applied for agricultural goals.

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