Codigestion of Food Waste with Used Lipids as Substrate Material to Produce Biogas

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Abstract

Anaerobic co-digestion of food wastes process is represents an active technique to enhance the production of biogas as one of the clean energy sources. The effects of adding lipids as substrate material to the food waste mixture for producing biogas by anaerobic co-digestion are experimentally investigated and evaluated at various mixing ratios in the present work. The influence of lipids and food waste (potatoes, tomato, Carrots, Cellulose) mixing ratios, digestion time and other factors on production of the biogas and CH4, CO2 and H2S percent are investigated experimentally. Seven samples of substrate mixtures (used edible oil, waste food, cow dung and water) with various mixing ratios were tested during 32 days as digestion period to investigate the influence of lipids percent compared to food waste on biogas yield. The results show that, average biogas production was in range of 100-160 ml per day and the maximum percent of CH4 and CO2 were 52% and 46% respectively for the produced biogas. Increasing the lipids percent in the substrates mixture could enhanced the biogas and CH4 production. The mixing sample containing 70% lipids and 30% food waste percent was produced significantly higher biogas and CH4 yields compared to the other mixing samples. Best digestion time of the food waste-lipid mixtures was observed in range of 12-16 days for the tested samples. The maximum cumulative biogas was 5120 ml which was produced by substrate mixture (70% lipid and 30% solid waste) during digestion time 32 days.

Keywords: Biogas, Co-digestion, Food Waste, Lipids, Anaerobic

1. Introduction
Renewable energy sources are considered the backbone of the energy system that interrupted during availability of cheap fuels which used for decades in a highly unsustainable method [1]. Biogas represents one of the vital sustainable sources of energy that can be produced from the foods waste and used oils which are available in Iraq. Biogas is produced by the decomposition of organic matters under anaerobic environments with presence of anaerobic bacteria. Moreover, methanogens degrade organic materials and help to transfer the biogas to the environment. In this method, the naturally production of biogas plays a significant role in the biogeochemical cycle of carbon. Biogas is considered a renewable source of energy and has a totally closed-cycle pathway [2]. Biogas is usually produced from anaerobic digestion process of organic waste materials. It is a gas blend of mainly methane (CH₄) and carbon dioxide (CO₂) with minor measures of hydrogen sulfide (H₂S), ammonia (NH₃), nitrogen (N₂), oxygen (O₂) and hydrogen (H₂) [3]. Many factors make biogas distinguished from other type of renewable energies is its importance in collecting and controlling organic waste substances as well as producing water and fertilizer used for agricultural irrigation [4]. Food waste (FW) which is the main source in biogas production can be divided into three broad groups, carbohydrates, proteins and lipids, where the hydrolysis rate or biodegradability of the Proteins is greater than Lipids and less than that for carbohydrates. Further, proteins and carbohydrates are decomposed more rapidly than lipids [5]. Therefore lipids degradation is considered as a rate limiting step for FW anaerobic digestion (AD). Lipids in FW is a mixture of animal fats and vegetable oils and the production of these oils and fats account for about (160x10⁶) tons/year in worldwide, about 80% are used for human consumption. Food waste in many countries in the Middle East are rich in salinity and oil content. They are described by high percent of organic materials, protein (15-29%), lipids (22-32%) and carbohydrate materials [6] [7]. Therefore, food waste can be combined and co-digested with animal manures or sewage sludge, for resource recovery and energy, because of high lipid content of used oil waste coupled with the high protein and organic carbon content in food waste. Many studies had indicated that, the organic wastes including fats, was notify that about 50% increasing in biogas production at a full scale digester using fats, oils and grease as a co-substrate. Experimental study to produce biogas (CH₄) from Kitchen food waste by anaerobic digestion using small scale reactor (20L) capacity at 37°C was conducted by Ziauddin and Rajesh [8]. It can be concluded from the results of this work that, 650 lit of biogas can be produced daily using 1000L reactor under ideal conditions. Thanikal et. al. [9], studied the anaerobic digestion of a mixture of fruit and cooked oil using anaerobic sequencing batch reactors operated at mesophilic temperature. Biodegradability study was carried out for both vegetable and oil substrates individually. Creco et. al.[10], assessed the effect of mild alkaline pretreatment on the anaerobic biodegradability of tomato processing waste (TPW). Experiments were carried out in duplicate Biochemical methane potential BMP bottles using a pretreatment contact time of 4 and 24 h and a 1% and 5% NaOH dosage. The average methane production for all runs was 320 NmL/g VS. Based on first order kinetic modeling, the alkaline pretreatment was found to slow down the rate of methanogenesis. Many researchers [11], [12], [13] investigated the production of biogas from animals dung, fruit waste and kitchen wastes at different retention times and biogas yield. Gubara et. al. [14], investigated the synthesis of biogas from vegetable wastes through anaerobic digestion in batch reactors. The maximum methane percent produced in this work was noted to be as 60.32 percent during the second week of biomethanation. Sandriaty et. al. [15], determined the effect of fat, oil and grease (FOG) waste in the co-digestion process of food waste to produce biogas. The results showed that FOG waste combined with FW has a methane yield that may reach to about 485 mL CH₄/g VS. Kurade et. al. [16], assessed the shifts in the microbial community during anaerobic co-digestion of fats, oil and grease to understand relationships between substrate
digestion and microbial adaptations. Excessive addition of FOG inhibited the methanogenic activity during initial phase and enhanced the ultimate methane production by 217% compared to the control. Yeqing Li et al. [17], conducted anaerobic mono- and co-digestion of kitchen waste, corn Stover, and chicken manure under mesophilic 37 °C conditions in batch mode to investigate the biomethane potential (BMP), biodegradability, methane production performance, and stability of the process. The kitchen waste had the highest biodegradability of 94% as compared with corn Stover 45% or 47% of chicken manure. In present work, the effects of adding lipids as substrate material to the food waste mixture for producing biogas by anaerobic co-digestion are investigated and evaluated at various mixing ratios. The influence of lipids and food waste mixing ratios, digestion time and other factors on production of the biogas and contents percentages of CH₄, CO₂ and H₂S are investigated experimentally.

2. Materials And Methodology

2.1 Experimental Setup

The digesters system was prepared and fabricated in the present work to produce the biogas which is consisted of seven identical bench-scale anaerobic digesters (glass containers) of 1Litre capacity placed in two water baths as shown in the Figure 1. The water baths with controlled temperature were used to maintain the temperature of lipids and food waste mixture at constant setting value under mesophilic conditions (35 °C) during the retention time. Each digestion container is well sealed and supplied with manual valve for gas accumulation and with necessary measuring sensors. Gas data analyzer of model RASI 700 was used to measure the percent of biogas components, methane, carbon dioxide, oxygen and hydrogen sulphide concentrations produced from the anaerobic digestion system. The measurement functions of this instrument contain standard configuration fitted with O₂, CO₂, H₂S, and CH₄% using infrared technology. Digital pH meter was used to monitor the value of pH for the mixture every day. Thermocouples of K-type (Nickel Chromium, Nickel Aluminum) in the range of -200 °C to 1250 °C with digital readers were used to measure the temperature of the mixture during the digestion time. All measuring devices were properly calibrated to minimize the measurement errors.

2.2 Substrate Samples Preparation

A mixture of food waste, used edible oils (lipids), and cow dung with various mixing ratios are prepared in the current work based on the standard methodology described in many literature [7], [8] to investigate the effect of used lipid ratio as substrate material on biogas and CH₄ yields. The food waste (potatoes, carrots, tomato, cellulose,…) in the mixture was collected from kitchen wastes and prepared in small size pieces in the range of 1- 2 cm and mixed with used lipids and cow dung at different mixing ratios as illustrated in the Table 1. These types of materials were found as an effective feedstock of anaerobic digestion. The small size pieces of food waste and dung improves the mixing efficiency and also increases the area that valid for cells enzymes to raid biomass resulting in faster degradation and reduction in the fermentation time. Due to the presence of higher content of the anaerobic bacteria in the animals dung, thus it was used as inoculum for anaerobic co-digestion in this study. The food waste pieces then properly dried using drying oven and the components of each mixture of the seven mixing ratios illustrated in the Table 1 was weighted using digital balance. After that, the food wastes, dung, lipid, and water for each mixing ratio were mixed and grinded by electrical blender for 10 minutes to form slurry and placed in the 1Litre glass container.
2.3 Experimental Methodology

Each digester was then purged for 5 min (100 mL/min) with inert gas (Argon) to create an anaerobic environment. All digesters were well sealed and placed inside the water bath under constant temperature conditions (35 °C) as illustrated in the Figure 1. The retention time of the digestion process was 32 days. During this period, continuous measurements of pH and biogas (O2, CO2, H2S, CH4%) produced by all digesters were made by amount of downward displaced water. All volumes of biogas given in the present work have been corrected to 1atm pressure and 23 °C. Thus, the total volume of biogas equals to volume of the collector (i.e. volume of cylindrical tube). Biogas produced by the digester was measured using the amount of downward displaced water method and collected using plastic balloons. A brine solution was prepared in order to prevent the biogas dissolution. Sodium chloride (NaCl) was added to water until reaching saturation state. To form acidified brine solution, five drops of sulphuric acid were added. As the biogas production started in the digesters chamber, it was passed to the second chamber (glass tube scale) which contains the brine solution. The pressure in this chamber is build-up provided the driving force for solution displacement due to the insolubility of biogas in this solution. Each 4-5 days, the displaced solution was measured, which represents the amount of biogas produced. A schematic diagram and photograph of the experimental setup is shown in the Figure 2. Gas data Analyzer of model RASI 700 was used to analyze the produced biogas to the components O2, CO2, H2S, and CH4% using infrared technology.

![Figure 1: Digesters system used to conduct the experimental tests.](image)

Table 1 Mixture contents concentrations.

| Sample No. | Mixture Concentration |
|------------|-----------------------|


Table 1: Composition of Substrates

|   | Waste (%) | Lipid (%) | Waste : Lipid (%) | Water (%) | Dung (%) | Total Mass (g) |
|---|-----------|-----------|-------------------|-----------|---------|----------------|
| 1 | Substrate 1 | 66        | ---               | 100:0     | 32      | 800            |
| 2 | Substrate 2 | ---       | 66                | 0:100     | 32      | 800            |
| 3 | Substrate 3 | 33        | 33                | 50:50     | 32      | 800            |
| 4 | Substrate 4 | 27        | 39                | 40:60     | 32      | 800            |
| 5 | Substrate 5 | 20        | 46                | 30:70     | 32      | 800            |
| 6 | Substrate 6 | 39        | 27                | 60:40     | 32      | 800            |
| 7 | Substrate 7 | 46        | 20                | 70:30     | 32      | 800            |

Figure 2: Experimental setup used to measure the biogas using water displacement method, (a) Schematic diagram, (b) photograph.

3. Results and Discussion

The results of the tests conducted on mixtures of food waste, lipids and cow dung with water at various mixing ratios as illustrated in the Table 1 are discussed in this section. Production of biogas from all digesters was not observed through 1-3 days, because at this period the decomposition of multi-substrates takes place inside the digester that proven by dropping pH value caused by accumulation of volatile fatty acids (VFAs). After five days of starting date, the biogas was observed to be produced in range of 100-160 ml per day for the substrates with different mixing ratios which were measured using water displacement method as shown in the Figure 3. During the period 5-10 days of the testing, experiments show that the produced CO₂% was more than CH₄%. This can be resulted from many reasons, the first reason is that, high production of CO₂ occurs in the second stage of the anaerobic co-digestion process by converting the butyrate and propionate to hydrogen, acetate and CO₂. The second
reason is attributed to fact that, the growing of acidogenesis bacteria is faster than methanogenesis bacteria. Variation in production of biogas, Methane CH₄ and carbon dioxide CO₂ with the fermentation time is illustrated in the Figures 4 and 5. Comparison between the results show that, the maximum biogas yield was by substrate 5 which includes more lipid percent compared to food waste percent, where the biogas production was about 160 ml per day, and the maximum percent of Ch4 and CO2 in the produced biogas were 52% and 46% respectively as shown in the Figure 6.

Figure 3. Daily biogas production (ml) by substrates with digestion time (day).
Figure 4. Concentration of CH₄ in the biogas produced by substrates with digestion time (day).

Figure 5. Concentration of CO₂ in the biogas produced by substrates with digestion time (day).
Figure 6. Maximum concentrations of CH$_4$ and CO$_2$ in the biogas produced by substrates.

The effect of Lipids as substrate material is clearly illustrated in Figures 3 and 4 for substrate 5 which produced maximum biogas and CH$_4$ yields, where the percent of lipids in the mixture was 70% compared to 30% of food waste at constant dung and water percentages. Lipids are rich in nutrients such as carbon (C), nitrogen (N) and phosphorus, which are essential nutrients for anaerobic microorganisms [18]. Besides, fatty acids which are the main component in the lipids, arise from the breakdown of lipids (triglycerides). High volatile fatty acids (VFAs) content enhance the biogas production. Results of the seven samples of mixture show that, the best digestion time of the waste-lipid mixtures was in range 12-16 days as shown in the Figures 3 and 4 due to the chemical compositions of the food waste which contains a high percentage of starch particularly in potato, less in carrots and least in tomato as well as cellulose (tomato). The starch helps the transform of the bacteria from decomposition in water to the acid faster, and this leads to accelerate the gas production. Investigating the experimental results show that, the use of organic waste with lipids keeps operation of the anaerobic co-digestion with desired results, particularly the percentages of main gases CH$_4$ and CO$_2$ with low values of Hydrogen Sulphide (H$_2$S) and oxygen, as shown in Figure 7 for Hydrogen Sulphide. The value of pH was observed in range 6.2 for the substrate samples during digestion period which is considered acceptable for the specified digestion conditions, as illustrated in the Figure 8. Among the tested samples of food waste-lipid mixtures, the maximum cumulative production of biogas was 5120 ml by substrate 5 during the period 32 days of digestion time as illustrated in the Figure 9.
Figure 7. Hydrogen sulphide $\text{H}_2\text{S}$ in the biogas produced by substrates with digestion time (day).

Figure 8. Variation of average pH value with digestion time for substrate samples.
4. Conclusions

In current work, the effects of adding lipids as substrate material to the food waste mixture for producing biogas by anaerobic co-digestion are investigated and evaluated at various mixing ratios. The influence of lipids and food waste mixing ratios, digestion time and other factors on production of the biogas and percentages of CH$_4$, CO$_2$ and H$_2$S are investigated experimentally. Seven samples of substrates mixtures with various mixing ratios were tested during 32 days as digestion period to investigate the influence of lipids percent compared to food waste on biogas yield. The average biogas production was in range of 100-160 ml per day and the maximum percent of CH$_4$ and CO$_2$ in the produced biogas were 52% and 46% respectively. Increasing the lipids percent in the substrates mixture could enhanced the biogas and CH$_4$ yields. Mixing sample of (70% lipids and 30% solid waste) was produced significantly higher production of biogas and CH$_4$. The maximum cumulative production of biogas was 5120 ml by during the period 32 days of digestion time. Results show that, the best digestion time of the food waste-lipid mixtures was within 12-16 days for the tested samples.

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