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Production of Biogas from Dairy Manure and Frying Oil in a Continuous Flow Digestion Equipped with an Automatic Control System

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INFO

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ABSTRACT

The increase in global energy demand in the face of the depletion of fossil fuel reserves and on the other hand the harmful environmental effects and global warming caused by the consumption of fossil fuels is one of the problems ahead. Therefore, renewable energy sources such as biogas should be developed. In this study, an automatic control system was developed to control the material's temperature and pressure inside a continuous plug flow digester with an approximate volume of 3600 liters. After installing the control system, in four separate periods, the production of biogas and methane for four different types of substrate including a combination of cow manure and water (slurry) with a ratio of 1: 1(treatment 1), cow manure slurry and 8% used frying oil (treatment 2), co-digestion of manure slurry 10% used frying oil (treatment 3), co-digestion of manure slurry and 12% used frying oil (treatment 4). At each feeding and discharging, a step used the substrate and the outgoing material to determine the pH level, total solids (TS), volatile solids (VS), ammonia, and organic loading (COD). Also, the amount of gas generated at each digester discharge was recorded from a gas flow meter. Data were analyzed in SAS statistical software. The significant difference of each parameter was evaluated with LSD mean comparison. The results showed that the oil increase had a great influence on the production of biogas and increase the methane content. In addition, the mean comparison of LSD showed a significant difference between the average volumes of biogas produced for four different types of substrate.

INTRODUCTION

One of the most important topics is the issues related to energy and its consumption in different parts of the planning of the world countries. Energy, as one of the most important factors of production and the raw material required for final consumption, has significant economic effects and, oil and oil products are still the most important energy suppliers in the world. But in the last 15 years, unprecedented variations have been observed in the consumption of energy resources. Among all of the conventional energy sources, biogas is a clean and renewable source that can be produced in various ways. One method for its production is fermentation and the anaerobic decomposition of organic matter with anaerobic bacteria. In European countries, the anaerobic digestion method has been used for waste recycling and treatment (Ibrahim *et al.*, 2016). The anaerobic digestion process is used to treat many types of waste, such as food waste (Tritt and Schuchardt, 1992), fruit and vegetable waste, household waste (Nosrati *et al.*, 2004), agricultural waste (Badawi *et al.*, 1992), and organic fraction of municipal solid waste (Bolzonella *et al.*, 2006). It is expected that the biogas obtained from the anaerobic digestion will provide about 25% of the future bioenergy from industrial effluents, cow manure, and other organic compounds (Holm-Nielsen *et al.*, 2009). In recent years, many efforts have been made to find ways to improve the performance of anaerobic digesters. One of the investigated options is the combination of several organic materials for simultaneous digestion. With the simultaneous digestion of several substrates, the anaerobic digestion process will be more stable (Braun and Wellinger, 2002). In addition, one of the influencing factors on the ratio of methane to carbon dioxide in biogas is the composition of the substrate. Organic wastes such as fats and oils can increase biogas production from anaerobic digestion and can increase the ratio of methane to carbon dioxide to 70 to 30. So this has increased the motivation to use biogas to produce electrical, thermal, or mechanical energy (Long *et al.*, 2012). However, incorrect decisions regarding substrate type and compound ratio frequently result in a significant reduction in biogas production or even the failure of the anaerobic digestion process (Ibrahim *et al.*, 2016).

Wang et al. (2013) showed that the optimal feed rate is activated in the simultaneous digestion of 20% oil and 80% sludge (Wang *et al.*, 2013). Beer (2013) used consumed fats and oils to increase biogas production as a supplement for wastewater. The results of this research showed that adding oil increases the amount of biogas produced and decreases instability in the pH (Beyer, 2013).

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To properly advance the anaerobic digestion process and reach the optimal amount of biogas, it is necessary to identify new compounds, including edible oil waste, and produce energy from these materials. For this purpose, the main goal of this research is to compare the amount of biogas and methane produced from cow waste in combination with three different levels of restaurant oil waste.

MATERIALS AND METHODS

The reactor used in this research was a piston-type digester that was continuously fed (Fig. 1). First, 2700 liters of the tank were filled with a mixture of fertilizer and water in a ratio of 1:1. To reach a stable state, the system was kept in the same state for twenty days, and after that, taking into account the 15 days left, according to the volume of the tank, and using formula (1), the tank was loaded. Loading was done in the middle of the day for 180 liters, and the same amount was taken out of the tank each time. Sampling and tests related to parameters were carried out during four periods. The first period is a mixture of fertilizer and water with a ratio of 1:1 ; the second period is fertilizer and water with a ratio of 1:1 and 8% oil ; the third period is fertilizer and water with a ratio of 1:1 and 10% oil ; and the fourth period is fertilizer and water with a 1:1 ratio and 12% oil.

$$Daily\ feeding = \frac{Occupied\ volume\ of\ digester\ tank}{Time\ left} \tag{1}$$

In the first period, in each stage of loading, 180 liters of material equivalent to 90 liters of water and 90 liters of fresh cow manure with a density of 990 kg/m^3 (Nita et al., 2010) were entered into the tank from the storage pit for cattle manure. On the last sampling day of the first period, 8% of the occupied volume of the digester tank (that is, 8% of the 2700 liters of fertilizer and water mixture) was replaced by approximately 235 liters of restaurant oil with a density of 918.8 kg/m^3 (Nita et al., 2010). In the same way, at the end of the second period, the experiments related to the third and fourth periods were conducted. In each period of tests, the tank was kept intact for ten days under controlled conditions, and after that, for twelve days, the mixture was entered into the tank with the determined ratio in each period, and the same amount was taken out.

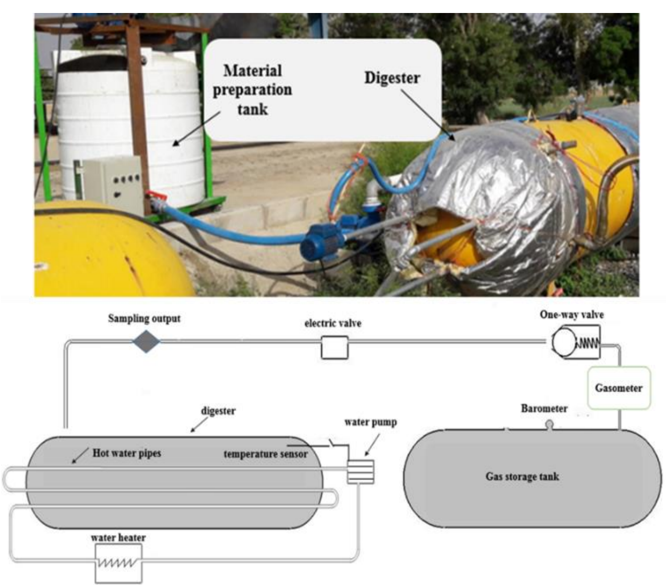

Fig 1. Continuous flow digester for production of biogas

Analyzing methods of digester liquid and produced gas:

Total solids, volatile suspended solids, ammonia, acidity, and organic loading rate (COD) were measured based on standard methods (Wang *et al.*, 2010). Analyzing the produced biogas and determining the percentage of methane and carbon dioxide was done using a gas chromatograph equipped with a TCD detector and a Porapak Q column. The device was equipped with Peak ABC software, which was used to analyze the graphs obtained from the injection of samples.

RESULTS AND DISCUSSION

According to the results of the ANOVA test, there is a significant difference between the average volume of biogas produced in the three tests of the combination of fertilizer and water, fertilizer and water and oil 8%, and fertilizer and water and oil 10%. Also, the LSD test showed that at a significance level of 0.05, the difference in the average volume of biogas produced between the combination of 8% fertilizer, water, and oil and 10% fertilizer, water, and oil is not significant. But there is a significant difference between the two treatments of fertilizer and oil combination and the treatment of fertilizer and water combination. Anyway, the results show that the maximum production of biogas was obtained by the simultaneous digestion of fertilizer and oil compounds. Table 1 shows the results of the variance analysis of biogas volume during the experiments.

Table 1. The results of variance analysis of biogas volume during the experiment

Source of variation	Degree of freedom	Sum of squares	Average of squares	F	Coefficient of variation	R^2
Gas volume	3	3642985	1214328	9.74*	27.07	0.65
Error	16	1994748	124671			
Total error	19	5637733				

* Probability at 5% level

The input parameters measured for each of the treatments are shown in Table 2.

Table 2. Values of input parameters for each treatment

parameters	PH	%TS	%VS	%VS/TS	COD(mg/L)
Fertilizer, water and oil 8%	4.9	20.31	16.66	82	41000
Fertilizer, water and oil 10%	4.6	17.96	16.64	92.7	41200
Fertilizer, water and oil 12%	4.3	24.05	22.99	95.6	39048
Fertilizer and water with a ratio of 1:1	7	5.14	3.6	70	45383

The first test (loading with a combination of fertilizer and water)

The values of the output parameters on different days in this phase of the experiment are presented in Table 3.

According to the results recorded in this test, an average of 292 liters of gas were produced daily. Also, according to the initial values in Table 2 for TS, VS and the average values recorded for these two parameters in Table 3, TS has decreased by 61.48% and VS by 57.89%. According to these results, the highest biogas production and the highest percentage of methane were obtained for the last sample, which had the highest reduction in VS and COD. This is a possible reason to justify the significant difference between the volume of gas produced in the first sample and the last sample.

Table 3. The measured values of the first experiment (loading with a combination of fertilizer and water)

Time	Temperature (˚C)	pH	TS (g/g)	VS (g/g)	COD (mg/L)	NH3 (mg/L)	Volume of biogas (L)
First day	35	6.8	2.39	2.15	52900	690	180
Third day	35	6.7	2.59	1.65	45545	424	170
Fifth day	37	6.6	2.06	1.44	43383	862	270
Seventh day	37	6.8	2.20	1.29	58416	782	850
Ninth day	37	6.8	1.16	1.05	42666	590	1457

The second experiment (loading with fertilizer, water, and 8% oil)

Table 4 shows the values of output parameters measured on different days. According to the results obtained in this experiment, 753 liters of gas were produced on average daily, which is significantly different compared to the mixture of fertilizer and water. Adding oil to the digester has increased the production of biogas, decreased the pH level and caused instability in it. According to the recorded results and by calculating the reduction rate of VS for each sample, it was concluded that with the increase in the rate of degradation of VS, the amount of biogas production has increased, and this is in line with the results of the studies of Aji et al. (2012) on the effect of increasing degradation on biogas production. Also, compared to the combination of fertilizer and water, according to the results shown with the addition of 8% oil, the organic load has increased by an average of 22%, and this is consistent with the results obtained by Lipp and Smith (Lipp and Schmit, 2014). Also, according to the average values recorded for TS and VS, TS has decreased by 70.75% and VS by 71.18%.

Table 4. The measured values of the second experiment (loading with a combination of fertilizer, water, and 8% oil)

Time	Temperature (˚C)	pH	TS (g/g)	VS (g/g)	Percentage reduction vs	COD (mg/L)	NH3 (mg/L)	Volume of biogas (L)
First Day	36	6.1	4.10	3.17	80.91	52900	690	1645
Third day	35	6	7.23	6.01	63.81	45545	424	1389
Fifth day	41	6.2	3.78	2.55	84.66	43383	862	1802
Seventh day	40	6.1	4.58	3.54	78.68	58416	782	1546
Ninth day	37	6.1	6.75	5.65	65.98	42666	590	1430
Eleventh day	37	6	9.23	7.88	52.51	57133	780	1224

The third test (loading with fertilizer, water, and 10% oil)

Table 5 shows the results of the measured parameters of the digester output and gas output. According to the results obtained in this stage of the experiment, due to the increase in the amount of oil in the input feed, the pH decreased more than in the previous stage. Comparing the results of Tables 1 and 4 shows that TS has decreased by 73% and VS by 78%, and the VS/TS ratio has decreased by 24.56. In this experiment, the amount of organic load has increased by 22.49%, which is the reason for the lack of appreciable difference in this increase compared to 8% oil, further diluting the mixture of fertilizer and water, and therefore, the amount of TS and VS decreased in the third experiment compared to the second experiment. From the comparison of the second and third experiments, it can be concluded that, despite the closeness of the decreased values in TS and VS and the increased values in COD, the reason for the increase in biogas produced in the third experiment compared to the second experiment is the higher amount of the decrease in VS/TS ratio in the third experiment.

The fourth experiment (loading with fertilizer, water, and 12% oil)

To raise the pH level, the lime solution was injected into the digester from the beginning of this experiment, and hence the pH value increased slightly, but the continued instability in the pH value decreased the amount of biogas production. Table 6 shows the volume days. The findings show that at this stage of the test, TS has decreased by 61.46%, VS by 68.25%, and the VS/TS ratio by 92.34%

Table 5. The measured values of the second experiment (loading with a combination of fertilizer, water, and 8% oil)

Time	Temperature (˚C)	pH	TS (g/g)	VS (g/g)	VS/TS (%)	COD (mg/L)	NH3 (mg/L)	Pressure	Volume of biogas (L)
First day	41	5.9	7.22	5.95	82.4	56833	915	155	2108
Third day	37	5.9	3.84	2.97	77.4	52275	925	93	1736
Fifth day	38	5.8	6.53	5.87	90	43600	920	91	1514
Seventh day	35	5.9	5.42	4.72	87.1	64550	900	72	1140
Ninth day	44	5.9	3.03	1.05	34.6	43333	920	152	2077
Eleventh day	44	6.1	3.07	1.48	48.1	42200	940	127	1905

Table 6. The measured values of the second experiment (loading with a combination of fertilizer, water, and 8% oil)

Time	Temperature (˚C)	pH	TS (g/g)	VS (g/g)	VS/TS (%)	COD (mg/L)	NH3 (mg/L)	Pressure	Volume of biogas (L)
First day	42	6	5.27	4.54	86.15	69000	900	82	1355
Third day	42	6	9.99	8.78	87.9	55966	580	87	1382
Fifth day	43	6.1	12.06	8.91	73.8	54200	600	97	1605
Seventh day	43	6	3.75	2.33	62.2	60000	400	90	1434
Ninth day	42	6.2	15.02	9.24	61.5	75000	450	66	1198
Eleventh day	42	6.2	13.75	10.02	74.2	73101	440	58	900

Fig. 2 shows one of the peaks obtained from the sample taken from the combination of fertilizer, water, and 12% oil in Peak ABC software. By performing calculations, the results of the volume and percentage of methane and carbon dioxide are shown in Table 7. Fig. 2 shows the comparison between methane percentage and carbon dioxide percentage on different days for this experiment. According to these results, the increase in methane was associated with a decrease in carbon dioxide. Also, in this experiment, despite the decrease in biogas production, the percentage of methane production was higher than in the previous three experiments. In other words, with the increase in the amount of oil, the quantity of gas production has decreased, but the quality of the gas produced, which is the same as the high percentage of methane, has increased.

The results of the studies of Aji et al. (2012) in a digester with an operating volume of 3 L showed that a thoroughly stirred mixture causes more destruction of VS and increases the amount of methane production by 7.5%. These findings suggest that the continuous mixing of the materials inside the digester may have contributed to the increase in methane levels in the fourth experiment.

Table 7. The results of variance analysis of biogas volume during the experiment

Time	Volume of CH_4 (L)	CH_4 (%)	Volume of CO_2 (L)	CO_2 (%)
First day	824.24	60.83	364.87	26.93
Third day	842.78	60.98	387.08	28
Fifth day	955.63	59.54	368.80	22.98
Seventh day	816.10	56.91	364.02	25.39
Ninth day	689.93	57.59	226.07	18.87

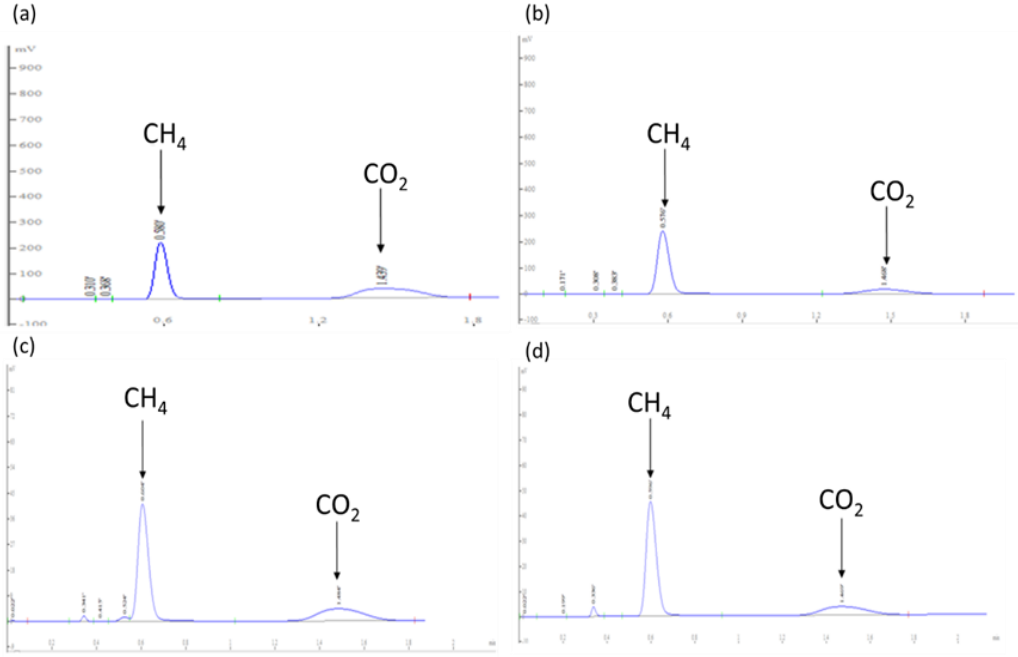

Fig 2. The peak obtained from the sample taken from a) fertilizer and water b) fertilizer, water, and 8% oil c) fertilizer, water, and 10% oil; and d) fertilizer, water, and 12% oil in Peak ABC software

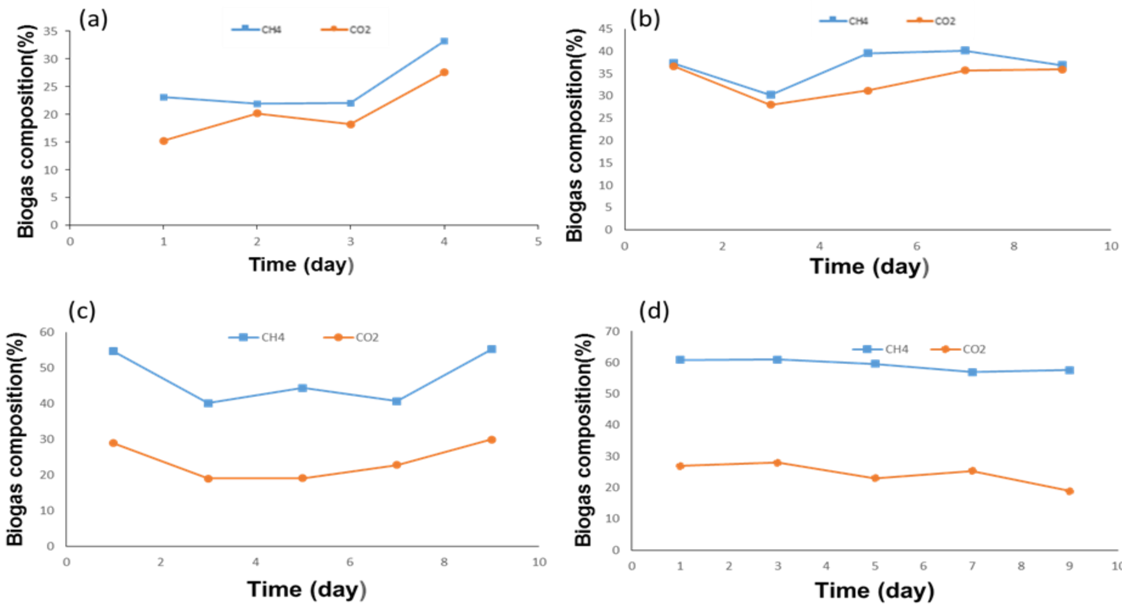

Fig 3. Comparison of the percentage of methane and carbon dioxide in the test of the combination of a)fertilizer and water b) fertilizer, water, and 8% oil c)fertilizer, water, and 10% oil; and d)fertilizer, water, and 12% oil.

Specific performance of methane

The results recorded in Table 8 show the volume of methane produced per kilogram of organic load entering the tank at each stage of the experiment. According to these results, on average, the highest methane production for the combination of fertilizer, water, and oil was 12% and 117.48 liters of methane per kilogram of organic load entered into the tank.

Table 8. The results of variance analysis of biogas volume during the experiment

Time	Volume of CH_4 (L)	CH_4 (%)	Volume of CO_2 (L)
First test	45383	122.54	22.20
Second test	41000	110.70	78.44
Third test	41200	111.24	106.67
Fourth test	39048	105.43	117.48

CONCLUSIONS

Adding restaurant oil as one of the waste materials with a low pH and a high concentration of COD increased the methane production, so the results showed that by adding 12% oil to the mixture of fertilizer and water, the most methane production was obtained at 48.117 Liters of methane per kilogram of organic load entered into the tank. Although the amount of methane production increased with the addition of restaurant oil to the mixture of fresh cow manure and water, the addition of oil to the materials entering the digester caused an increase in the organic load of the materials exiting the digester. Since the introduction of materials with a high organic load is not suitable for human health or the environment, increasing the percentage of oil to increase methane is not a good solution. Unless the loading speed of the material is reduced and the material is given more time to perform the digestion process.

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