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Modeling and Experimental Design and Evaluation of Highly Efficient Biogas Production Using Animal Waste

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ABSTRACT

In this study, an efficient method is presented for biogas formation from animal waste. Gas production is a critical issue in today's world and there is a big challenge to obtain it from reproducible sources. A comprehensive study is presented on the production of methane in biogas from animal wastes. For this purpose, a reactor was designed and animal wastes were used as feed of the reactor for biogas production. For supplying the moisture during the gas formation, the feed was mixed with distilled water in a 1:1 ratio. The mean cell residence time was set at 25 days. The results showed an intense sensitivity of the microorganism to the pH of the reactor. In acidic media, the produced biogas was much lower than in neutral and slightly basic media. In addition, the percentage of methane in the biogas showed to be increased by increasing pH from 6.8-7.2. In addition, the temperature should be maintained between 30-70 °C to get the optimal yield of the gas production.

Keywords: *biogas production; gas reactor; animal waste; reproducible energy.*

Introduction

Today, there is a significant issue for human's life and that is the energy issue. Several traditional sources, such as oil and cock are not reproducible and lead to environmental pollutions (Kazmerski , 2016; Fataei and Seiied Safavian, 2017) . Scientists believe that the consumption of the mentioned energy sources has caused the earth's warming in recent decades (Sahoo, 2016). Regarding the significance of energy supply for human consumption on the one hand, and environmental worries on the other hand, several efforts have been focused on the production of energy from renewable sources (Huzta, et al., 2008) . Due to environmental pollution and global warming caused by fossil fuels, it is necessary to use fuel sources compatible with nature (Yahyaei et al.;2021; Amirfazli et all,2019; Fataei et al., 2006). In this regard, a very interesting approach is the production of biogas from urban waste (Zamorano., et al., 2007 &. Curry., 2012 ; Samadi Khadem et al.,2020). This approach has been regarded as an interesting way for gas produc tion and has been subjected for several studies in various countries (Moretto., et al., 2020. & Tran., et al ,. 2020 &Loghavi., et al ,. 2020) .

Anaerobic digestion (AD) process, is an efficient process for biogas generation from various organic compounds (Yu., et al., 2019; Seiied Safavian and Fataei, 2012) .anaerobic digestion could be a effective method for solve organic waste problems (Heydarian et al.,2023; Mohammad Alipour et al.,2022; Fataei et al.,2012) In this process, bacteria break down the organic molecules to smaller molecules in an anaerobic, which is performed with no need to oxygen(Bong., et al., 2018). The main product in this process is methane gas, which is used as fuel and an energy source (Jabbari., et al., 20220 &Dehghani., et al., 2020) . Application of AD in the gas production is of high interest due to its both benefits, biogas and energy production, and waste management(Bong., et al., 2018;Seiied Safavian et al., 2014; Fataei et al.,2004). The production of biogas from food waste by AD process is an efficient approach, and therefore have attracted interest in research and industry (Deepanraj., et al., 2017 & Zhang., et al., 2014. & Klass., and Ghosh., 1982 &Paton,. 1985. & Ghamipoor., et al., 2020) . The residual of the biogas, which is produced by AD process is nitrogen rich fertilizer and is widely used in agricultural industries (Magrí., et al., 2017 . &Grando., et al., 2017 . &Bharathiraja., et al., 2021). These advantages have made AD process efficient and therefore of high interest for waste management and biogas production (Eskandarpour et al., 2023; Hemmati et al., 2019; Aydın., and İlkılıç,. 2012) . The production of biogas has been classified into some general categories, active and passive. Each of the gas production methods has benefits and drawbacks, and should be selected based on several factors including pH, waste properties, waste moisture, and etc.(Kharrat Sadeghi and maleki, 2022; Alikhan., et al., 2021; Shoary Bavil Oliaei and Fataei, 2016) .

Regarding the benefits of AD on one hand, and the management of vegetable and fruit waste on the other hand, in this paper, we report the advantageous results of the use of AD process for biogas production from vegetable and fruit waste. For this purpose, the impact of several variables on the efficiency of biogas production is studied.

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Materials and Methods

General remarks

All the chemicals and reagents were purchased from Merck, Germany, and Sigma, USA.

The animal waste samples were collected and dried in an oven at 105 °C for 24h. After the drying process, the samples were cooled to room temperature, weighted, and stored in a dry chamber.

Reactor setup

The feed of the reactor was evaluated in a 5 L reactor. The feed was added to the reactor in 4 steps in 160 g portions. The same amount of water was added in every step of the addition of the feed to the reactor. The reactor was shaken 3 times a day to have a more uniform reaction mixture and avoid phase separation. The amount of the produced gas was measured and the methane content was measured using a gas analysis, equipped with a methane sensor.

The feed parameters measurement

The density of the feed is obtained from equation 1, in which M id the weight and V is the volume of the samples.

$$\rho = \frac{M}{V} \qquad \text{Equation 1}$$

$$(w.b) = \frac{(W_0 - W_1)}{W_0} \times 100 \qquad \text{Equation 2}$$

Nitrogen content was measured by the Kjeldahl method. The measurements were performed using a Kjeltec Analyzer unit 2300 instrument. For this purpose, 5 g of the dry sample was added to a digestion tube and 5g of 1M NaOH solution in water was added. The samples were heated to 400 °C and then cooled and 100 mL of water and 50 mL of 2% (w/v) boric acid was added. Then 3 droplets of methylene red were added to the samples and titrated by 0.1N sulfuric acid until the yellow color was observed.

Measurement of carbon content was performed by combustion method. To do this, 5g of the samples was dried in an oven for 24h and then transferred to a furnace in 550 °C. The carbon content was measured by equation 3.

$$O.M\% = \frac{A - B}{A} \times 100 \qquad \text{Equation 3}$$

pH control of the reactor

pH of the samples was measured using a pH meter Orion 230A and maintained by the addition of 1M sodium bicarbonate solution and 1M sodium hydroxide solution, where needed.

Feeding to the reactor

The feed was added portion-wise to the 5L reactor. The first portion involved 330 mL of the feed that was mixed with water in 1:1 ratio. Then, four portions of 165 mL were added to the reaction in 4 days.

Methane gas collection

The produced gas was collected every 3 days in 11 steps.

Methane gas measurement

Methane content was measured using a methane sensor, which was inserted in the reactor and remained until the measured value was established. The methane content was read from the sensor after it was stable. For gas production, a reactor was designed and animal wastes were used as feed of the reactor for biogas production. For supplying the moisture during the gas formation, the feed was mixed with distilled water in a 1:1 ratio(Ojaghi et al.,2021; Alayi et al., 2020).

Results and Discussion

In this paper, animal waste is used as the feed for the biogas production. For this purpose, a reactor is designed and used for the biogas production. Several factors affect the biogas production yield. Among the various factors, temperature was shown to have a critical effect of the yield of the production of biogas from animal waste. The results showed that below 30°C and above 70 °C the gas production yield intensely decreases, these results also obtained by other researchers (Oyewole O. A., 2010). Therefore, the temperature should be maintained in this range. In addition, pH is another factor that affects the yield of the gas production. The studies showed that 6.8-7.2 is the optimal pH for biogas production, it is consistent with other results (Cerón-Vivas et al.,2019). Low pH leads to damage to the microorganisms that produce biogas and therefore, pH should be controlled not to become acidic. Increased the high value of pH could disrupt anaerobic digestion (Cerón-Vivas et al.,2019).The amount of moisture content could affect gas production (khedher et al.,2022).In some research, the amount of 50% moisture could enhance gas production(Budiyono et al.,2014). The effect of pH and the relation between pH and biogas production is presented in Figure 1.

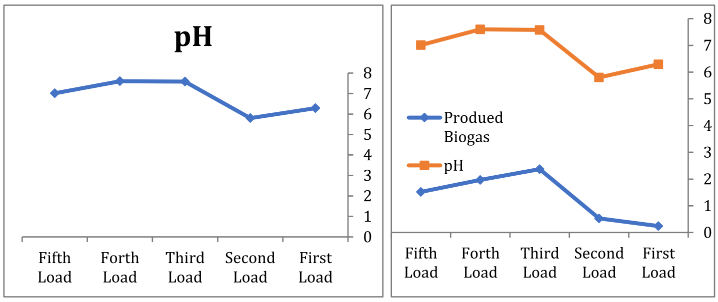

Figure 1. (a) The effect of pH and (b) the relation between pH and biogas production.

Non-aerobic bacteria need carbon as the energy source for growth and nitrogen for the fabrication of the cell wall. The carbon consumption is about 30-35 times faster than that of nitrogen and therefore, C/N ratio should be controlled during the biogas production process. C/N ratio is an important parameter in methane productions (Cerón-Vivas et al.,2019). If C/N ratio is low, the presence of ammonia in the digester limits methane-producing bacteria(Li et al.;2019). The excess of carbon makes the environment acidic, while nitrogen leads to a basic medium. The effect of carbon content on biogas production is presented in Figure 2. In addition, the methane percentage in each loading is presented in Figure 2b. it could be observed that by increasing the loading to the third loading the gas production is increased. On the other hand, after the third loading, the gas production is decreased, which could be due to the increase in the feed volume in the reactor.

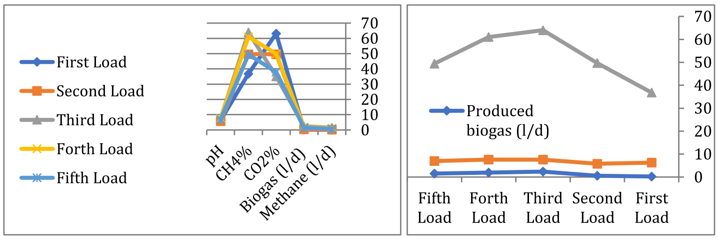

Figure 2.The effect of carbon content on biogas production and (b) methane percentage in each loading

Water content should be more than 90% of the weight of the feed. In addition, the optimal content of the bacteria is 7-9% of the solid content. Modeling and identifying variables improve biogas production and reduce pollution load.

To answer this hypothesis, first in the first part using the regression method, a regression model of biogas production is presented, then in the second part, using the fuzzy AHP method, the variables are examined and their effectiveness in improving biogas production will be prioritized. According to Table 1, it can be seen that the value of R^2 is equal to 0.216, which is an acceptable value. Therefore, it could be concluded that the model under study is a good model.

Simple Linear Regression Model

Table 1. Model details

Model	R	R^2	Corrected R^2	SD
Model 1	0.465	0.216	-0.568	1.14697

Therefore, according to the coefficients in the table, the coefficients of the studied variables are determined.

Table 2. the regression coefficients

Model	Non-standard coefficients		Standardized coefficients	t	The significance level (p)
	B	standard error			
Value	43.229	166.584		0.260	0.820
Average moisture content	-0.464	1.828	-0.254	- 0.254	0.000
The amount of solid waste input	0.515	.023	0.634	0.635	0.000
Percentage of organic solid waste by volume of digestion	0.197	0.133	0.147	0.625	0.014
Wet waste load	0.188	0.467	0.374	0.372	0.016
Percentage of wet waste to digest volume	0.173	0.421	0.312	0.402	0.019
Time left - days	0.015	0.035	0.103	0.164	0.416

According to Table 2, because the constant value is positive (22.446), there is a direct relationship and the regression relationship is as follows: If A is the average percentage of moisture, B is the amount of input solid waste, C is the percentage of organic solid waste to the volume of digestion, D is the percentage of wet waste, E is the percentage of wet waste to the volume of digestion. The regression relationship between them is as follows:
$Y = 43.229 - 0.464 \times A + 0.515 \times B + 0.197 \times C + 0.188 \times D + 0.173 \times E + 0.015 \times F$
Given that the value of the significance level of the constant-coefficient and the variable of time remained - the day is more than 5650, these two variables are removed from the model and we have:
$Y = 0.464 \times A + 0.515 \times B + 0.197 \times C + 0.188 \times D + 0.173$
Part II: To prioritize the fuzzy AHP method, we first obtain the weight of each variable using the entropy method.

Entropy Method

Step 1: First we form the decision matrix. To form this matrix, it is enough to decide if the criteria are qualitative, to evaluate each option in relation to each criterion from the verbal expressions, and if the criteria are small, to put the real number of that evaluation. Step 2: We scale the resulting matrix, to scale the decision matrix we do the following: If the criterion is positive: we divide each of the numbers in that column by the largest number. If the criterion is negative: the minimum of that column is divided by each number. Step 3: Calculate the entropy of each index: The entropy of Ej is calculated as follows and k as a constant value keeps the value of Ej between 5 and 1. Step 4: Next, the value of dj (degree of deviation (calculated, which states the relevant index) dj (how much useful information for decision making provides the decision-maker.Step 5: Then the weight value of Wj is calculated.The normalized final weight is our standard weight, which is then used to use different decision methods and is presented in Table 3.

Table 3. normalized final weight

	VS	M	pH	VS/TS	CT/NT	CT	N/T	COD	TS	P%	N%
Final Normalized Weight	0.14	0.08	0.15	0.07	0.02	0.02	0.17	0.06	0.05	0.10	0.15

Response by AHP Method

After identifying the evaluation criteria, in order to use all the variables studied in the research, AHP has been used. By the verbal variables listed in Table 4, the decision variables are compared with each other in pairs.

Table 4. AHP results

Language variable	Value	Corresponding fuzzy number scale
Equal importance	1	(1 ،1 ،1)
Intermediate	2	(4 ،2 ،1)
A little more important	4	(4 ،4 ،2)
Intermediate	4	(0 ،4 ،4)
more important	0	(0،0 ،4)
Intermediate	0	(1 ،0،0)
very important	1	(0 ،1 ،0)
Intermediate	0	(0،0 ،1)
significantly important	0	(0،0،0)

The designed system has good efficiency for biogas production from camp wastewater. Analysis of variance (ANOVA) is used for this purpose.

Table 5. Bilateral analysis of variance

Variable	The significance level (p)	F	Average squares	Degrees of freedom	Total squares
Regression	.784	.275	.362	2	.724
left over			1.316	2	2.631
Total				4	3.355

According to the table above, the significance level is less than 5650, so the regression model can significantly predict the changes in the dependent variable. Therefore, the designed system has a good efficiency for biogas production from camp wastewater.

The process of anaerobic fermentation of human effluent by a system designed to reduce the COD of wastewater. For this purpose, a one-group mean test (t test) is used.

Table 6. Single group mean test table

	T test for equality of means					
	t	Degrees of freedom	The significance level	Average difference	95% difference in confidence interval	
					high	low
COD	0.469	7	0.003	750.000	-3028.91	-4528.91

Conclusion

In conclusion, the production of biogas could be performed using animal waste. Biogas production is a way to reduce the amount of organic waste and produce energy. Temperature, pH, and the feed properties intensely affect the gas production yield. The effect of carbon content on biogas production on each loading has been investigated, the carbon consumption is about 30-35 times faster than that of nitrogen. By measuring the acidity and temperature in different stages, it was determined that the best pH for biogas production is 6.8-7.2 and the optimal temperature is 30-70 °C.

Conflict of interest declaration

The authors declare no conflict of interest.

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