



*Int. J. New. Chem.*, 2020, Vol. 7, Issue 4, pp 256-270.

## International Journal of New Chemistry

Published online 2020 in <http://www.ijnc.ir/>.  
Open Access

Print ISSN: 2645-7237

Online ISSN: 2383-188x



### Original Research Article

## Experimental investigation and modeling of parameters affecting biogas production process from food waste by anaerobic digestion method

Milad Shokrollahi<sup>1\*</sup>, Seyyed Abbas Mousavi<sup>2</sup>

<sup>1</sup>Department of Energy Engineering, Sharif University of Technology, Azadi Ave., Tehran, Iran

<sup>2</sup>Department of Chemical and Petroleum Engineering, Sharif University of Technology, Azadi Ave., Tehran, Iran

*Received: 2019-12-01*

*Accepted: 2020-02-15*

*Published: 2020-09-29*

### ABSTRACT

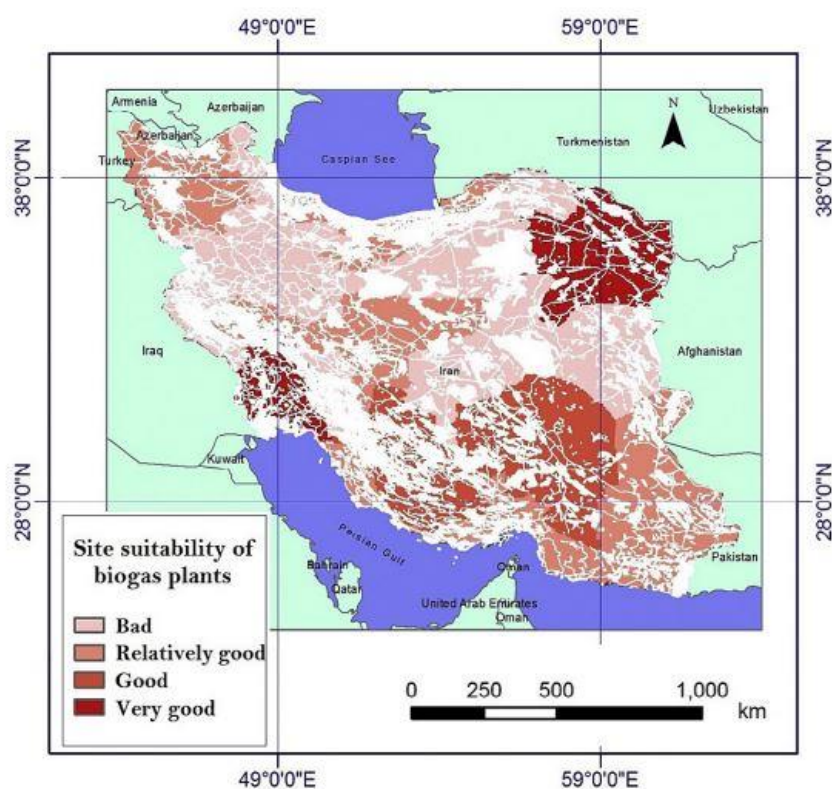
Biogas production among other renewable energy sources is an economical and environmentally friendly way. Since high percentage of human food in the world is converted into food waste, one of the most suitable sources used as a feed for bio-gas production is food waste. One of the most important methods for producing biogas from organic waste is the use of anaerobic digesters. The factors affecting the production of biogas in anaerobic digestion machines are two general types of feed and its characteristics and the effect of process parameters on the amount of biogas production. In this paper, an anaerobic digestion machine was constructed and the effect of the parameters of the input feed type and operating parameters such as temperature and retention time on the operation of this process are examined by applying "Response Surface Methodology" (RSM) technique. Experimental results in this paper show that with increasing temperature and (C/N) and retention time, the amount of gas produced in anaerobic digesters increases. By increasing the temperature parameter to 45 °C and C/N to 40 in the remaining time of one month, the amount of biogas produced reaches 265 mL. RSM Model shows that (C/N) parameters has the greatest impact on the amount of biogas and T-square ( $T^2$ ) term has the least impact on the amount of gas produced. In the following article, the function of the amount of gas produced based on the independent temperature and C/N parameters is expressed as a mathematical relation.

**Keywords:** Biogas, Anaerobic digester, Food waste, RSM model

## Introduction

The energy demand is increasing in the world every day, and this results in higher fossil fuel consumption and emissions. It is therefore essential to provide energy from renewable energy sources. Replacing fossil fuels with renewable sources certainly has a huge impact on reducing greenhouse gas emissions [1-3]. There are many sources of renewable solar energy, geothermal energy, and wind energy that currently provide a significant portion of the human energy needed. But each of these resources is not available in all areas and requires high technology [4]. Biogas is one of the renewable resources that has very few environmental problem [5, 6]. Thra'n et al. reports 28 of EU and the European succession states of the former Soviet Union can produce up to 250 billion cubic meters of bio methane of digester by 2020 [7]. Most of the gases contained in this gas mix are methane and carbon dioxide. Of course, there are very few water vapor ( $H_2O$ ), hydrogen sulfide ( $H_2S$ ), and hydrogen ( $H_2$ ) in this gas mix [8]. Unprocessed biogas can be converted into electrical and thermal energy at the same site. Iran is one of the countries with good potential for biogas production. Figure 1 shows potential of biogas production in different regions of Iran. Biogas is produced by the process of anaerobic digestion and in the energy crisis of 1970 its technology grew up tremendously [9, 10]. The anaerobic digestion process is a good way to produce biogas. Among the benefits of this approach are the reduction of greenhouse gas emissions, use in agriculture, small footprint production and high quality renewable fuel production [11]. Granado et al. (2017) have reported that concept of anaerobic digestive system was introduced in 1870 and the first anaerobic digestion plant in the United States was built to feed municipal solid waste in 1939. The feed for production of biogas is organic compounds with complex microbial reactions [12]. Due to the high volume of organic matter present in food waste as well as the abundance and availability of wastes of fruits and vegetables, these wastes are one of the most important organic compounds used as digesters [13]. Due to economic and population growth, more and more sources of food waste are produced every day. According to the FAO (Food and Agriculture Organization of the United Nations) in 2019, more than 30 percent of the world's food is converted into food waste [14]. Baroutian et al has shown that more than 160-295 kg of food waste is produced per person per year in the world in the food supply chain [15, 16]. Mr Magnet (2018) has been reported food waste produced in Australia, Japan, Germany, India, and China is 361, 157, 154, 51, 44 kg per person respectively. Management of produced biogas is important because methane and carbon dioxide are one of the factors contributing to global warming. On the other hand, in the study of Papargyropoulou et al., it was reported that agricultural producers with 22% and livestock

producers with 18% of greenhouse gas emissions produce a large amount of greenhouse gas [17]. There are other ways to use food waste that include the use of waste incineration and landfill but the use of digestion is more economically and environmentally friendly [18]. Bong et al. examined the effect of lipid and cellulose on the amount of gas produced [19]. Fisgativa et al. has tested various samples of food waste and they identified the parameters affecting on biogas production [20]. In this paper the effect of parameters of the input feed type and operating parameters of temperature and the remaining time of the process are investigated. On the other hand, the most important innovation of this paper is RSM numerical modeling to predict anaerobic digesters' process behavior for different types of food waste. Since the potential gas production of different types of feed is usually done experimentally and this is a very time-consuming and costly method. By presenting this mathematical model without the need for experimental experiments the potential of gas production at different temperatures and feed types can be checked.

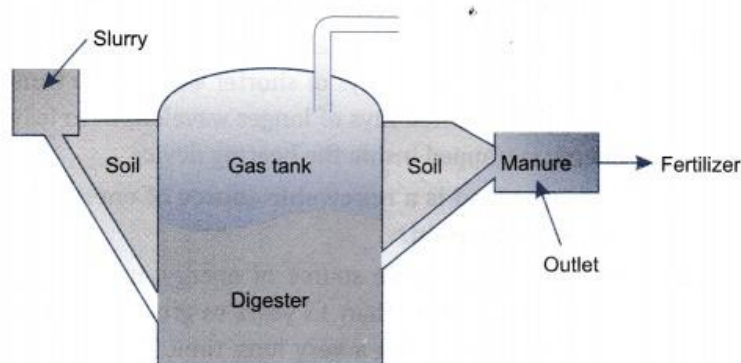


**Figure 1.** Map of suitable areas to build biogas plants in Iran[21].

## Material and Methods

### Biogas plant

Biogas production facilities include an inlet and outlet pond, a fermentation tank and a gas storage tank. In all of these devices the water and raw materials are mixed in the inlet pond and then dumped into the fermentation tank. After fermentation and production of gas they are directed to the outlet pond. It should be noted that conditions such as climate, culture, economics and technology have caused various forms and various models of digestion [22, 23]. Figure 2 shows a schematic of the biogas production process.

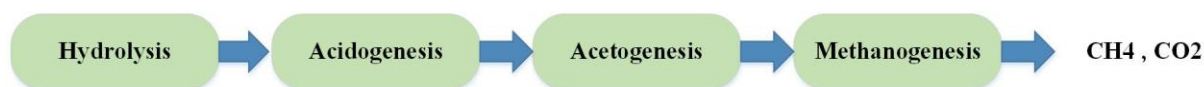


**Figure 2.** Scheme of the biogas production process

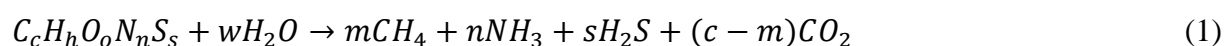
### Anaerobic digestion method

Anaerobic digestion is a biological process and the lack of oxygen decomposes complex organic matter into simpler components. In the anaerobic method, kinds of bacteria break down organic matter in a multiphase manner in parallel reactions. This process involves four general steps. The first step is hydrolysis, in this stage complex organic molecules break down by adding hydroxyl group to simple sugars, amino acids and fatty acids. It is noteworthy that hydrolysis is a relatively slow step and thus can limit the speed of the anaerobic digestion process [24]. In the second step, acidification, the molecules are broken down, and they are converted to fatty acids and adjuvants such as ammonia, carbon dioxide and hydrogen sulfide. In the third stage, acetogenesis, with more digestible residues, acetic acid is produced. The final stage is methanogenesis, in this stage acetic acid, hydrogen, and carbon dioxide are used to produce methane gas [25]. This stage is the most important stage in the production of biogas

and the setting of operating parameters has a significant effect on the performance of this stage [26-28]. Figure 3 illustrates the stages of biogas production. The most important general reaction of converting organic matter to biogas is shown in Equation 1 [5].



**Figure 3.** Biogas production steps



$$\text{Where. } m = 1/8(4c - h - 2o + 3n + 3s)$$

$$\text{and } w = 1/4(4c - h - 2o + 3n + 3s)$$

Much of the biodegradable food waste includes carbohydrates ( $C_6H_{12}O_6$ ), proteins ( $C_{13}H_{25}O_7N_3S$ ) and lipids ( $C_{12}H_{24}O_6$ ).

### Characteristics of the Feed waste

There are various types of food waste such as fruit and vegetable waste, household waste, and restaurant waste [29]. The digestive feed in this article is a waste of food and fruit. This feed contains carbohydrates, lipids and proteins. Reports indicate that lipids are less degradable compared to carbohydrates and proteins and their hydrolysis is slower. Therefore, fat-rich food waste and fast-decomposing carbohydrates produce more methane [30]. Reports show that fruits and vegetables are low in fat but high in cellulose, while food waste is high in fat due to its oil and animal fat content [19]. Y. Li et al. (2017a) have reported that food waste such as kitchen waste has a higher lipid percentage and produces more methane than waste containing a higher percentage of carbohydrates and proteins [25]. One of the most important indicators in determining the type of compounds in the waste is the "ratio of carbon to nitrogen (C / N)". In this study the effect of this parameter on the produced gas is examined. Three different samples were sampled with a combination of various food waste and fruits and vegetables which is shown in Table 1 of these compounds. The following elemental analysis was carried out for each of the samples which is reported in Table 2

**Table 1.** Mass fraction of food and fruit and vegetable waste

| Sample | Mass fraction of fruit and vegetable waste | Mass fraction of food waste |
|--------|--|-----------------------------|
| 2      | 75   | 25                          |
| 1      | 25   | 75                          |
| 3      | 0  | 100                         |

**Table 2.** Elemental analysis of samples

| Parameter | Sample 1 | Sample 2 | Sample 3 |
|-----------|----------|----------|----------|
| Carbon    | 8.21     | 5.1      | 9        |
| Nitrogen  | 0.27     | 0.39     | 0.2      |
| Hydrogen  | 10.1     | 5.7      | 7.5      |
| Sulfur    | 0.014    | 0.0013   | 0.01     |
| C/N       | 30.4     | 13.07    | 45       |

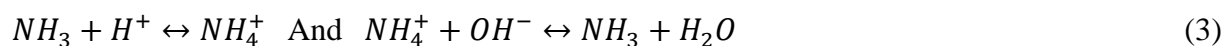
## Types of microorganisms in the digestive process

The methane production stage is carried out by two groups of thermophilic and mesophilic microorganisms with temperature range of 55-70 ° C and 35-45 ° C respectively. It should be noted that the feed temperature does not fluctuate. Temperature fluctuations have the most destructive effect on the performance of thermophilic microorganisms. Because microorganisms in this group operate in a small range of temperatures and with high fluctuations this system's performance goes down. Mesophilic microorganisms with less sensitivity to temperature changes are more stable than thermophilic microorganisms [31, 32]. On the other hand thermophilic microorganisms have benefits such as higher digestibility, higher performance processes and less oxygen solubility [14].

## Effect of PH

The optimal PH range is between 6.8 to 8 for bio methane production. In the range of less than 6 or more than 8.5 this process is limited. The accumulation of volatile fatty acids causes the acidification, and accumulation of ammonia causes the feed into the anaerobic digestion to be alkaline. Although the existence of two buffers that are naturally occurring can control the pH range. The buffer that prevents acidification of the feed is a carbonic acid / bicarbonate /

carbonate equilibrium buffer (equation 2). The buffer that prevents alkalinity of the feed is ammonia / ammonium buffer (equation 3) [14, 33]. In this research, the putative pH is set to neutral in all three samples.



### Retention time of waste in digestion

One of the most important parameters that affect the production of methane gas is the retention time in the digestion of organic residues. Retention time organic residues in digestion depend on the type of feed intake, temperature and other parameters affecting digestibility. As the time elapses the amount of organic waste inside the digester decreases and the volume of digestion increases. On the other hand by reducing the retention time the volume of digestion becomes smaller and the cost of investment decreases. It should be noted that the minimum amount of retention time feed intake in digestion is between 10-15 days and the average feed time for digestion is between 15-30 days [33, 34].

### Design of experiments (DOEs)

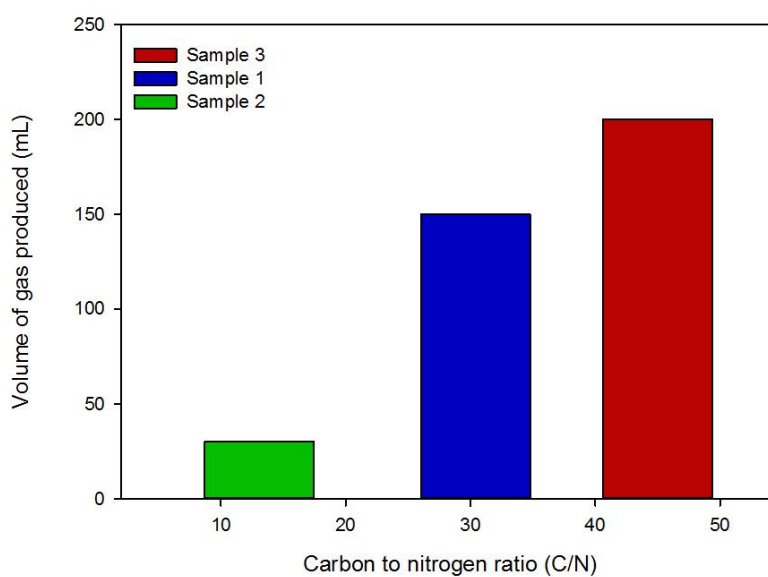
Experimental design method is an advanced method for screening parameters influencing process, modeling and process optimization. In this way, by designing the range of each parameter, the design of the experiment is performed and based on the analysis the of variance of the responses, a suitable model can be developed and finally optimized. There are several methods for modeling the effect of parameters affecting the process by numerical methods. In this paper, the CCD (Central Composite Design) method, which is one of the RSM (response surface method), is used to model the influence of (C/N) and retention time parameters on biogas production.



## Results and discussion

### The effect of organic feed type

An important parameter for investigating substrate characteristics is the carbon to nitrogen ratio. Due to the importance of this parameter, several different food residues were mixed together to obtain samples with different ratios of this parameter. The amount of gas produced in each sample was investigated over a period of 30 days. As shown in Figure 4, in sample 3 with the highest C / N value, the highest amount of produced gas is observed and samples 1 and 2 are in the next ranks because in digester carbon consumption rate is higher than nitrogen. The most important reason for mixing food waste with fruit and vegetable residues is to set the optimum ratio of carbon to nitrogen. Figure 4 shows up if this parameter is out of its optimal range, it will affect the pH parameter and reduce the performance of the process. Increasing carbon content will give rise to more carbon dioxide formation and lower pH, value while high value of nitrogen will enhance production of ammonia gas that could increase the pH to the detriment of the microorganisms.



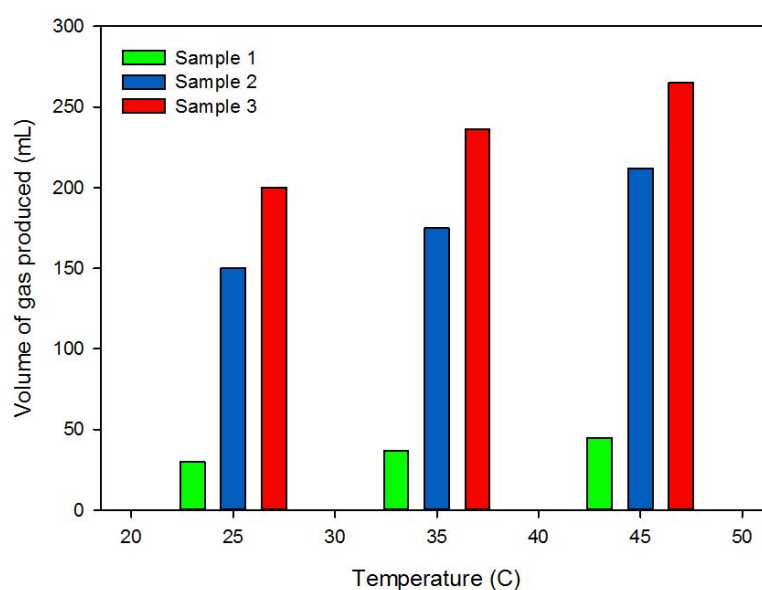
**Figure 4.** Effect of carbon to nitrogen ratio on biogas production

### The effect of temperature

In this paper, biogas production has been investigated at the end of a 30-day period at three temperatures 25, 35 and 45 ° C for all three samples. As shown in Figure 5, as the temperature



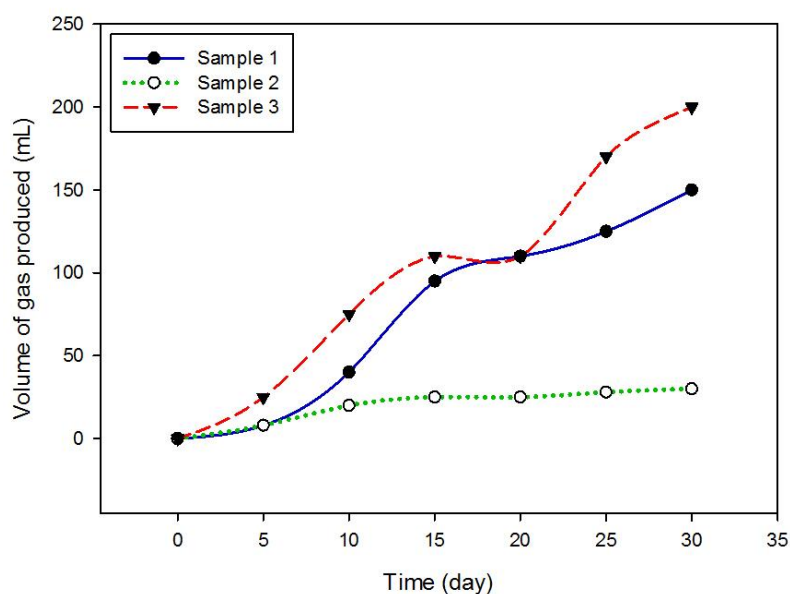
risers the amount of gas produced increases and this indicates that higher digestibility occurs at higher temperatures. By increasing the feed temperature, the activity of microorganisms increases and more gas is produced. The most important reason for increasing the amount of biogas production with increasing temperature is that the microorganisms involved in the biogas production process are mesophilic and thermophilic and as mentioned their temperature range is above 35 ° C. Increasing the temperature in this process improved the performance of the system and produced more gas because of increased activity of these microorganisms.



**Figure 5.** Effect of temperature on biogas production

### The effect of time remaining

In this study, the amount of gas produced in each of the three samples was studied at 25 ° C. As shown in Figure 6, the amount of produced gas increases with increasing the time. As more time passes more of the waste is digested by microorganisms. The most important reason for increasing biogas production over time is to allow enough time for all four steps to take place for biogas production.



**Figure 6.** Effect of retention time on biogas production

### Design of experiments (DOEs)

Experimental results of gas production based on temperature and C/N changes are shown in Table 3. In this paper, first, the influence of different parameters on the amount of the produced gas is investigated. Next, with the same 30-day retention time for all three samples, the effect of various parameters and their interactions on the amount of produced gas using design expert software were modeled. After collecting the statistical data, Table 4 is used to select the best model to determine the amount of biogas produced. As can be seen in Table 4, the p-value for the model is less than 0.05 and p-value for lack of fit is more than 0.05. Consequently, the proposed model is suitable for the mentioned data. On the other hand, given that all p-values for all parameters and their interactions are less than 0.05 then all parameters are important and fit into the mathematical model. Equation 4 shows the model performed to produce biogas and Figure 7 shows effects of two main parameters on biogas production.

**Table 3.** Results of experiments designed by CCD method and obtained results of each experiment

|     |     | Factor 1      | Factor 2 | Response 1 |
|-----|-----|---------------|----------|------------|
| Std | Run | A:Temperature | B:C/N    | R1         |
| 13  | 1   | 35            | 26.5     | 158        |
| 5   | 2   | 25            | 26.5     | 125        |
| 12  | 3   | 35            | 26.5     | 162        |
| 7   | 4   | 35            | 13       | 37         |
| 1   | 5   | 25            | 13       | 30         |
| 11  | 6   | 35            | 26.5     | 163.5      |
| 2   | 7   | 45            | 13       | 45         |
| 9   | 8   | 35            | 26.5     | 157        |
| 3   | 9   | 25            | 40       | 200        |
| 8   | 10  | 35            | 40       | 236        |
| 6   | 11  | 45            | 26.5     | 166        |
| 10  | 12  | 35            | 26.5     | 159        |
| 4   | 13  | 45            | 40       | 265        |

**Table 4.** Analysis of Variance (ANOVA) for biogas production

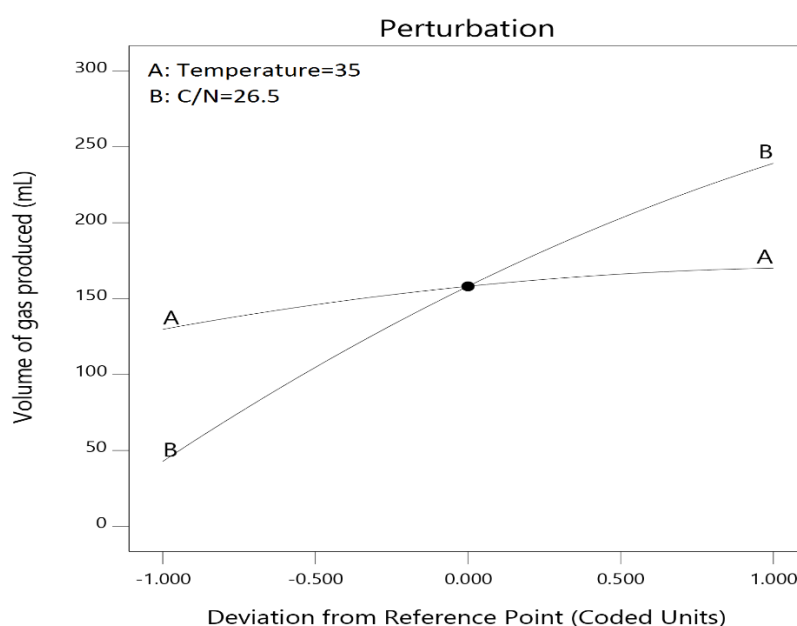
| Source         | Sum of Squares | df | Mean Square | F-value | p-value  |                 |
|----------------|----------------|----|-------------|---------|----------|-----------------|
| Model          | 62399.29       | 5  | 12479.86    | 579.95  | < 0.0001 | significant     |
| A-Temperature  | 2440.17        | 1  | 2440.17     | 113.40  | < 0.0001 |                 |
| B-C/N          | 57820.17       | 1  | 57820.17    | 2686.95 | < 0.0001 |                 |
| AB             | 625.00         | 1  | 625.00      | 29.04   | 0.0010   |                 |
| A <sup>2</sup> | 184.46         | 1  | 184.46      | 8.57    | 0.0221   |                 |
| B <sup>2</sup> | 814.46         | 1  | 814.46      | 37.85   | 0.0005   |                 |
| Residual       | 150.63         | 7  | 21.52       |         |          |                 |
| Lack of Fit    | 120.43         | 3  | 40.14       | 5.32    | 0.0701   | not significant |
| Pure Error     | 30.20          | 4  | 7.55        |         |          |                 |
| Cor Total      | 62549.92       | 12 |             |         |          |                 |

After obtaining the data needed for modeling, the appropriate model to predict the amount of biogas produced based on the temperature and feed type parameters and the interaction of each of these parameters with each other was investigated. Equation 4 shows the effect of these parameters on the amount of biogas produced.

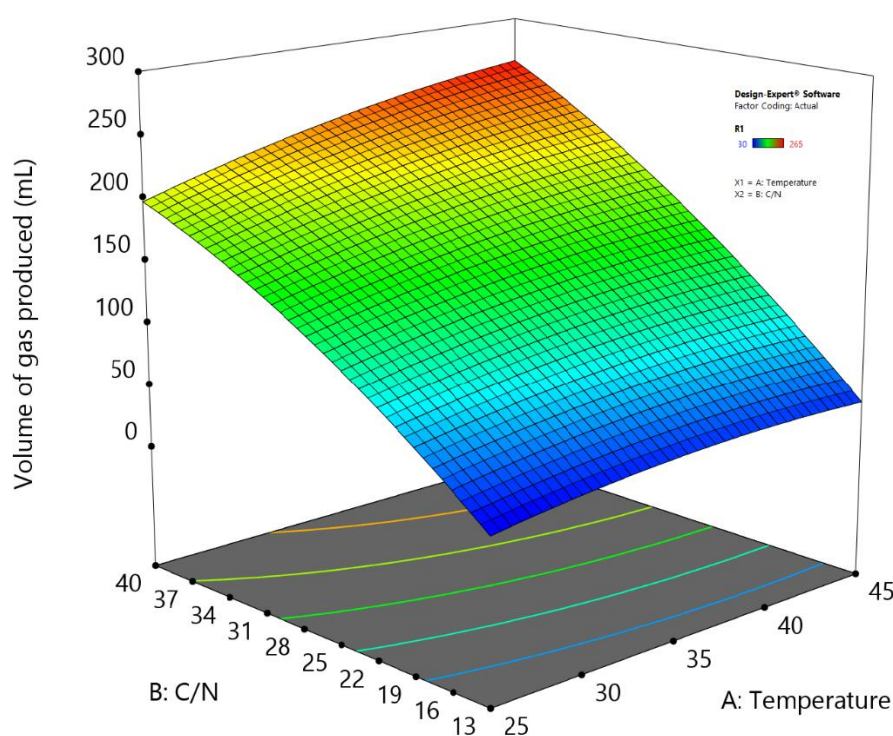
Biogas production (mL)

$$= -185.56176 + 5.28365 T(K) + 9.02476 \frac{C}{N} + 0.092593 T * \frac{C}{N} - 0.081724 T^2 - 0.094224 (C/N)^2 \quad (4)$$

After obtaining the equation for the amount of gas produced, in the figure 7, the effect of temperature and feed type (C/N) parameters is compared. Figure 8 is a three-dimensional diagram of the model presented for anaerobic digestion.



**Figure 7.** Comparison of the effect of feed and temperature



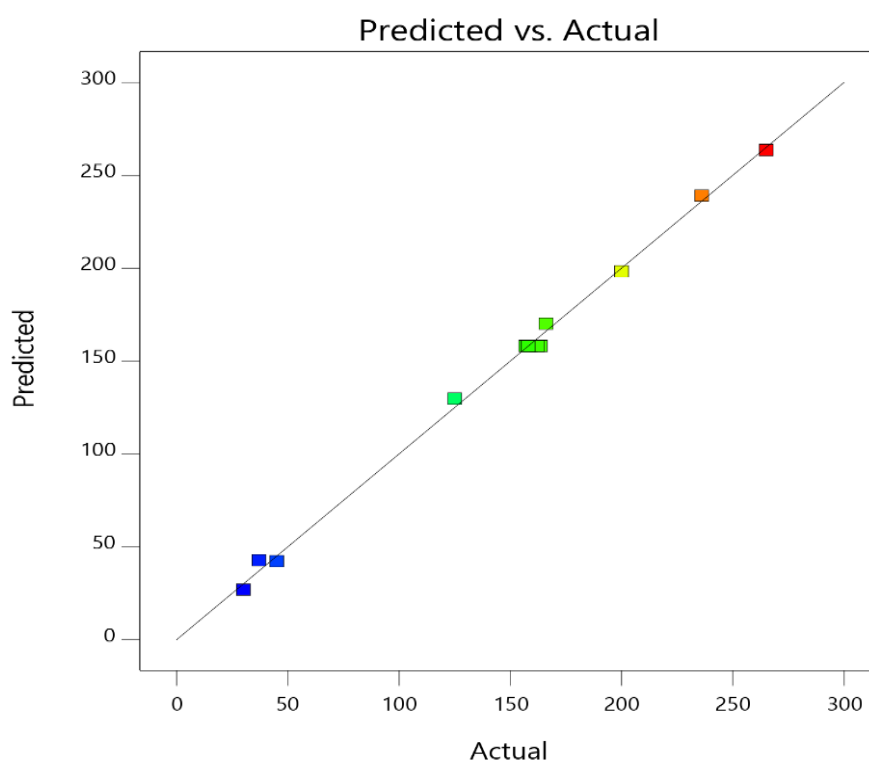
**Figure 8.** Effect of temperature and carbon to nitrogen (C/N) on biogas production

## Evaluation of the module

According to Table 4, to evaluate the model in this paper parameters such as RRESS (Relative Residual Error of Sum of Square), Standard Deviation (SD), Correlation Coefficient (R), Adjusted R-square ( $R_{Adj}$ ), Predicted R-square ( $R_{pred}$ ) and Adequate Precision ( $P_{Adeq}$ ) were used. Considering Table 4, the  $R_{pred}$ ,  $R_{Adj}$ , R values are close to 1 and on the other hand the  $P_{Adeq}$  values is greater than 4. Thus, the presented model is a good model for estimating temperature and C/N parameters on biogas production. Another criterion for evaluating the model presented in the software is the consistency of the actual data and the estimated data. Figure 9 shows well that the actual data obtained from the experiments are in good agreement with the model data.

**Table 4.** Parameters of model Evaluation

|           |        |                          |         |
|-----------|--------|--------------------------|---------|
| Std. Dev. | 4.64   | R <sup>2</sup>           | 0.9976  |
| Mean      | 146.42 | Adjusted R <sup>2</sup>  | 0.9959  |
| C.V. %    | 3.17   | Predicted R <sup>2</sup> | 0.9859  |
|           |        | Adeq Precision           | 75.0971 |

**Figure 9.** Predicted values in the model based on measured values for gas production

## Conclusion

Various parameters affect the performance of biogas production process. In this paper, by making anaerobic digestive devices, effects of temperature, feed type and time remained parameters on the performance of produced biogas was investigated. Results showed that with increasing temperature from 25°C to 45°C the activity of produced microorganism increases and more digestibility is carried out and results in more gas production. With the increase of organic matter and retention time in digestion the amount of gas produced continuously increases. Organic feed type study concluded that food waste with a higher carbon content than

nitrogen had the potential to produce more biogas. "Ratio of carbon to nitrogen (C/N)" should be optimized, because increasing the "ratio of carbon to nitrogen (C/N)" more than 35% reduces the growth rate of biogas production. Then numerical method was modeled to estimate the effect of parameters affecting the amount of biogas produced by quadratic equation. According to the model, the C/N parameter had the greatest impact on the amount of produced gas and the term  $T^2$  had the least effect on the amount of the produced biogas.

## References

- [1] A. Kumer, et al. *Int. j. New Chem.*, 6, 236 (2019)
- [2] M.S. Zolfaghari. *Int. j. New Chem.*, 5, 558 (2018)
- [3] E. Darouneh, and M. Zargan, *Int. j. New Chem.*, 5, 493 (2018)
- [4] S.A.Khan, et al. *Renewable Sustainable Energy Rev.*, 13, 2361 (2009)
- [5] Deublein, D. and A. Steinhauser, Biogas from waste and renewable resources: an introduction. 2011: John Wiley & Sons.
- [6] Priyadarshi, D., Biodiesel Production From Waste Materials: Process Development and Performance Evaluation (2019).
- [7] Gomez, C.D.C., Biogas as an energy option: an overview, in *The Biogas Handbook*. 2013, Elsevier. p. 1-16
- [8] E. Valijanlian, et al., Biogas production systems, in *Biogas.*, Springer 95-116 (2018)
- [9] R.L.Grando, et al., *Renewable Sustainable Energy Rev.*, 80, 44 (2017)
- [10] B.Deepanraj, V. Sivasubramanian, and S. Jayaraj,. *Res. J. Chem. Environ.* 18, 5 (2014)
- [11] J. Ariunbaatar, et al., *Appl. Energy.*, 123, 143 (2014)
- [12] M.A. Rajaeifar., et al. *Renewable Sustainable Energy Rev.*, 79, 414 (2017)
- [13] R. Campuzano., and S. González-Martínez,. *J. waste Manage.*, 54, 3 (2016)
- [14] S. Mirmohamadsadeghi, et al. *Bioresource Technology Reports.*, 7, 100202 (2019)
- [15] M. Aghbashlo, et al. *Energy J.*, 149, 623 (2018)
- [16] S. Baroutian, et al. *J. waste Manage.*, 71, 494 (2018)
- [17] E. Papargyropoulou, et al. *J. Cleaner Prod.*, 76, 106 (2014)
- [18] T. Sprangers, et al. *J. Sci. Food Agric.*, 97, 2594 (2017)
- [19] C.P.C.Bong, et al. *J. Cleaner Prod.*, 172, 1545 (2018)
- [20] H.Fisgativa, , A. Tremier, and P. Dabert. *J. waste Manage.*, 50, 264 (2016)
- [21] S. Zareei. *Renew. Energy.*, 118, 351 (2018)
- [22] A.C.Wilkie,Treatment, Handling, and Community Relations., 301, 312 (2005)
- [23] Hobson, P.N. and A.D. Wheatley, *Anaerobic digestion: modern theory and practice*. 1993: Elsevier applied science London, UK.



- [24] R. Kothari, et al. *Renewable Sustainable Energy Rev.*, 39, 174 (2014)
- [25] D.Y. Leung, and J. Wang. *Int. J. Green Energy.*, 13, 119 (2016)
- [26] W. Gujer, and A.J. Zehnder. *Water sci. technol.*, 15, 127 (1983)
- [27] J.B. Holm-Nielsen. T. Al Seadi, and P. Oleskowicz-Popiel. *Bioresour. technol.*, 100, 5478 (2009)
- [28] J. Mata-Alvarez, S. Mace, and P. Llabres. *Bioresour. technol.*, 74, 3 (2000)
- [29] F. Xu, et al. *Bioresour. technol.*, 247, 1047 (2018)
- [30] Y. Meng, et al. *Bioresour. technol.*, 185, 7 (2015)
- [31] C. Gou, et al. *Chemosphere.*, 105, 146 (2014)
- [32] C. Zhang, et al. *Renewable Sustainable Energy Rev.*, 38, 383 (2014)
- [33] P.C. Pullammanappallil, et al. *Bioresour. technol.*, 78, 165 (2001)
- [34] C. Mao, et al. *Renewable Sustainable Energy Rev.*, 45, 540 (2015)

#### HOW TO CITE THIS ARTICLE

Milad Shokrollahi, Seyyed Abbas Mousavi, “Experimental investigation and modeling of parameters affecting biogas production process from food waste by anaerobic digestion method” *International Journal of New Chemistry.*, 2020; 7(4), 256-270. DOI: 10.22034/ijnc.2020.119439.1085.