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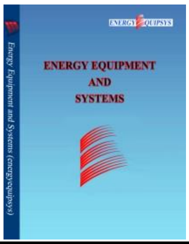

The development and evaluation of a portable polyethylene biogas reactor

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ABSTRACT

Several factors can influence the process of biogas production. The type of reactor is one of the key factors that influence biogas production. Therefore, the aim of this study was to construct a portable horizontal polyethylene-based biogas reactor. In addition, the performance of the developed biogas reactor was tested through digestion of cow manure. The experiments were carried out in Mashhad, Iran, during June–July 2016. Biogas production was studied over a span of 58 days' hydraulic retention time. Artificial neural network (ANN) models were used to predict the production of biogas based on temperature and pH. The Levenberg–Marquardt learning algorithm was employed to develop the best model. The obtained biogas productivity was 0.27 m^3 $kgVS^{-1}$, indicating that the developed biogas reactor was optimum to convert the substrate into biogas. The ANN results highlighted that the best developed model consisted of an input layer with two input variables, one hidden layer with 15 neurons, and one output layer with the correlation coefficient of 0.90. Overall, it was concluded that the ANN models can be employed to prognosticate biogas production using a portable polyethylene biogas reactor.

Keywords: Artificial Neural Network, Horizontal Reactor, Modeling.

1. Introduction

Biogas accounts for a remarkable share of renewable energy consumption in the world [5]. Boasting 8,726 bioreactor plants, Germany is the greatest producer of biogas in Europe [9]. Italy is the second-largest producer of biogas in Europe with 1,700 bioreactor plants [3, 25]. There are approximately 27 and 4 million biogas plants in China and India, respectively [4]. In Austria, about 400 agricultural bioreactor plants are currently used [20].

Numerous factors may influence the process of biogas production. The type of reactor is one of the key factors affecting biogas production [18]. So far, several biogas reactors have been developed in different parts of the world [7]. Table 1 demonstrates the summary of the literature on the development of biogas reactors. Polyethylene-based biogas reactors are considered to be efficient for the construction of biogas reactors [35]. Low cost and economic viability are the main advantages of polyethylene-based biogas reactors [22,28]. Moreover, tubular polyethylene is available in most countries.

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It is concluded that making the depth of slurry larger than the width does not allow a large enough fermenting liquid surface for the biogas to escape and also inhibits biogas production by exerting too much pressure on the liquid at the bottom of the bio-reactor [14]. Therefore, horizontal biogas reactors can contribute to reducing the depth of the slurry in the tank, thus providing enough liquid surface for the released gas [2].

In some cases, there is a need to develop a biogas reactor for a limited period of time in a certain region, which can be conveniently reinstalled at a new location [24]. Many researchers have reported the possible and successful application of portable biogas reactors [39]. The advantages of portable reactors are that they are easy to install, easy to transport and operate, and can also be moved from location to location as required, increasing their operational lifetime [41].

A review of the related literature indicates that the construction of portable horizontal polyethylene-based biogas reactors has not yet been investigated. Therefore, the aim of this research is to construct a portable horizontal polyethylene biogas reactor. In addition, the developed biogas reactor's performance was tested through the digestion of cow manure. Finally, artificial neural network (ANN) models were used to predict the biogas production based on temperature and pH.

2. Materials and Methods

2.1. Development of the Biogas Reactor

Figure 1 demonstrates the schematic sketch of the developed biogas reactor. The reactor had an inlet to feed the reactor, an outlet to take out the digested substrate, a gas line to determine the amount of generated biogas, and an opener to empty its contents. The total volume of the reactor was 400 L. The diameter of the inlet and outlet tubes was 7.62 cm. A circulation pump was used to provide efficient mixing [6]. No heating system was used during the experiments. The reactor was filled with air and water to check for any possible leakage [28].

Table 1. Summary of the literature on the development of biogas reactors

Authors	Material	Fixed or portable	Structure
Anozie et al. (2005)	Mild steel	Portable	Horizontal
Jayakody et al. (2007)	Stainless steel	Fixed	Horizontal
Surendra et al. (2013)	Polyethylene	Fixed	Horizontal
Rajendran et al. (2013)	Textile	Portable	Vertical
Sanaei-Moghadam et al. (2014)	Glass	Portable	Vertical
Current study	**Polyethylene**	**Portable**	**Horizontal**

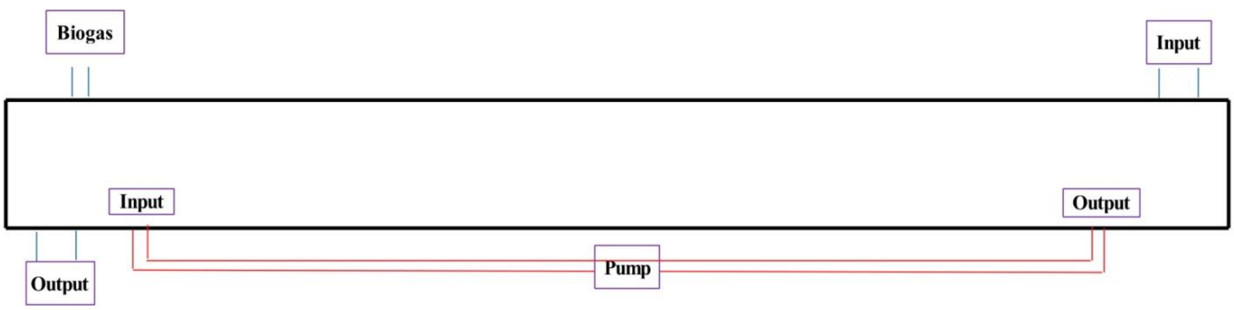

Fig. 1. Schematic sketch of the developed biogas reactor

Fig. 2. Assembled portable polyethylene-based biogas reactor located at the Ferdowsi University of Mashhad, Iran

2.2. Evaluation of the Biogas Reactor

This study was conducted in Mashhad, which is located in the northeast of Iran, within the latitude of 36°14'–36°48' N and longitude of 59°35'–59°74' E in the Khorasan Razavi province [23]. It is considered the second-largest city in Iran and the most important population center in the northeast of the country [11]. The experiments were performed during June–July 2106.

The substrate was provided by the Livestock Company of the Ferdowsi University of Mashhad. Table 2 illustrates the composition of cow manure. The manure was mixed with an equal proportion of water. More particularly, 107.5 kg (wet weight) of substrate was weighed and mixed with water. The total solid (TS) decreased to 7%. Afterward, the substrate was fed into the digester. The substrate volume was 2/3 of the total volume of the reactor. pH, TS, and volatile solids (VS) were determined using the standard methods (APHA, 1992). TS was measured by drying the substrate at 105^{0}C for 24 hours and VS was determined by combusting the substrate at 505^{0}C in a furnace for 8 hours [40, 19]. The acidity of the cow manure was determined by a pH meter (pH-201) [42]. A CHNS-O Elemental Analyzer was used to determine the amounts of carbon and nitrogen (Costech ECS 4010; [1]). The generated biogas was recorded every 12 hours. The volume of water displaced was equivalent to the volume of the generated biogas [2]. Biogas production was studied over 58 days' hydraulic retention time. The measurements were performed during day and night.

Table 2. The composition of cow manure

	Unit	Amount
TS	%	18
VS	%	80
pH	-	6.9
C/N ratio	-	29.16

2.3. Modeling of Biogas Production

To test the normality of the data, the Anderson–Darling normality test was used [8]. In this study, an ANN model was used to predict biogas production based on temperature and pH. In this study, the ANN model called multilayer perceptron (MLP) was selected according to its highest practical importance [31]. It is a feed-forward layered network with an input layer, some hidden layers, and one output layer [30, 12]. In this research, the Levenberg–Marquardt learning algorithm was employed for developing the optimal model. The most widely used method for normalization involves mapping the data linearly over a specified range, whereby each value of a variable x is transformed in the following manner [10]:

$$X_n = \frac{X - X_{min}}{X_{max} - X_{min}} \times \left(r_{max} - r_{min}\right) + r_{min} \quad (1)$$

where x is the original data, x_n is the normalized input or output values, and x_{max} and x_{min} are the maximum and minimum amounts of the concerned variable, respectively. r_{max} and r_{min} correspond to the actual values of the transformed variable range. A range of 0.1–0.9 is an appropriate range for the transformation of the variable into the sensitive range of the sigmoid transfer function [38].

Overall, 80% of the experimental data were used for the training of the model and 20% were used for the validation and testing phases. A computer code was developed in MATLAB2014b software to implement the ANN models.

2.4. Model Performance Evaluation

The performance of the developed models was determined through the coefficient of determination (R^2) and root mean square error (RMSE) as defined in Eqs. (2) and (3) below [37]:

$$R^2 = \frac{\left(\sum_{i=1}^{n}\left(E_{ai}-\overline{E_{ai}}\right)\times\left(E_{pi}-\overline{E_{pi}}\right)\right)^2}{\sum_{i=1}^{n}\left(E_{ai}-\overline{E_{ai}}\right)^2\times\sum_{i=1}^{n}\left(E_{pi}-\overline{E_{pi}}\right)^2} \quad (2)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(E_{ai}-E_{pi}\right)^2}{n}} \quad (3)$$

where E_a and E_p are the actual and predicted biogas production, respectively, and i (1,..., n) represents the number of patterns. The model with the smallest RMSE and the largest R^2 is considered the best [33].

3. Results and Discussion

3.1. Biogas Production

Figure 4 illustrates the daily (24 hours) biogas production rates from the digestion of cow manure in a portable polyethylene biogas reactor. The production of biogas started from the first day of the experiment. The highest amount of daily biogas production rate was obtained on the 34th day of digestion. Overall, the obtained biogas productivity was found to be 0.27 m^3 $kgVS^{-1}$, indicating that the developed reactor is efficient in converting the substrate into biogas.

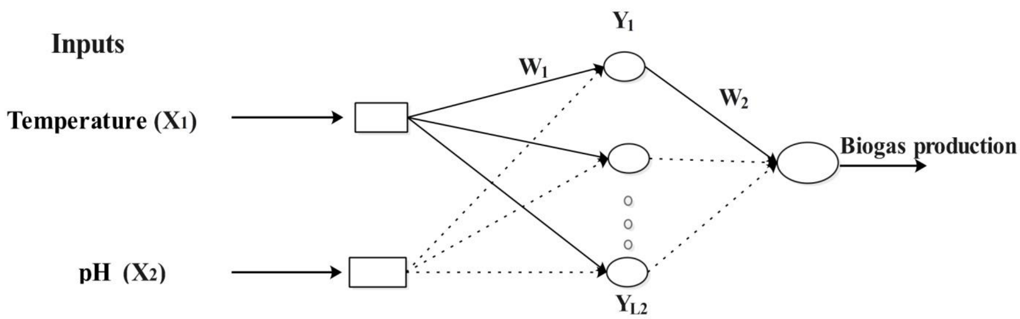

Fig. 3. Application of ANN modeling to predict the biogas production

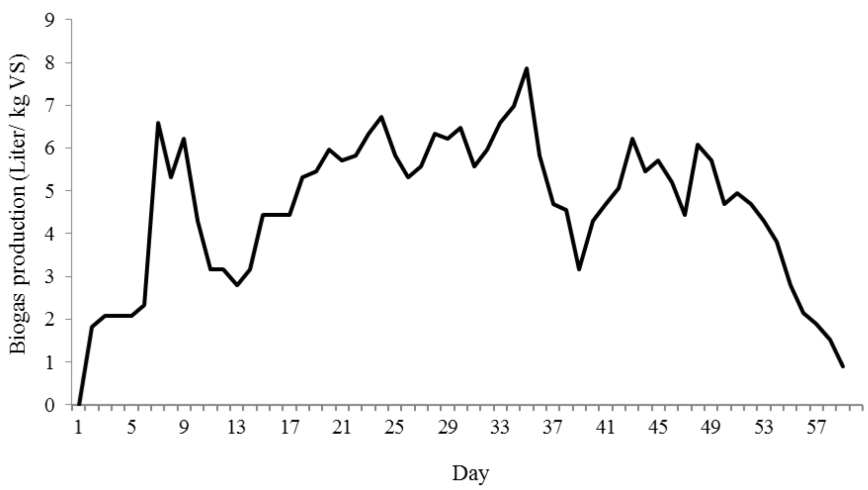

Fig. 4. Daily (24 hours) biogas production rates from digestion of cow manure in the portable polyethylene biogas reactor

Figure 5 illustrates the biogas production during day and night. While the total biogas production during daytime stood at 0.19 m^3 $kgVS^{-1}$, the total biogas production during nighttime was 0.08 m^3 $kgVS^{-1}$. The results indicated that the biogases produced during day and night were different at the 5% significance level.

3.2. Artificial Neural Network Modeling

Figure 6 shows the normal distribution test for biogas production data. The normality of the output data was analyzed using the Anderson–Darling normality test. The results of the test indicated that the data are in fact normal (level of significance at 5%).

Table 3 shows the effect of variations of neurons in the hidden layer on the performance of ANN models. The results highlighted that the optimally developed model consisted of an input layer with two input variables, one hidden layer with 15 neurons, and one output layer (2–15–1 topology). The calculated coefficient of determination (R2) illustrated that the estimated ANN model could explain 90% of the variance of biogas production. Ozkaya et al. [26] used pH, sulfate, conductivity, chemical oxygen demand, chloride, alkalinity, and waste temperature as inputs for the prediction of methane fraction in landfill gas through ANN.

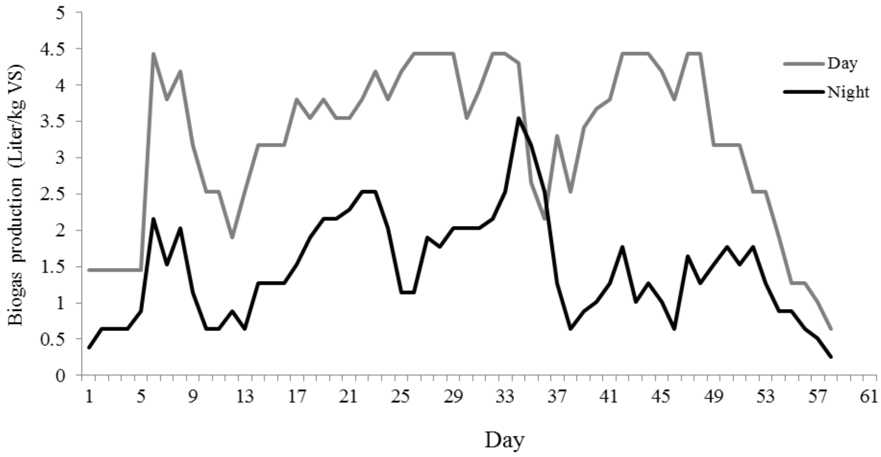

Fig. 5. Biogas production during daytime and nighttime

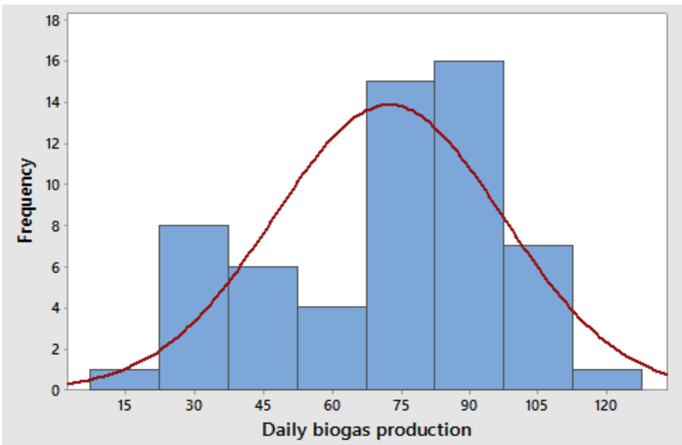

Fig. 6. Normal distribution test for biogas production data

Table 3. Effects of variations of neurons in the hidden layer on the performance of ANN models

	Train phase		Validation phase		Test phase	
Neurons	R^2	RMSE (liter)	R^2	RMSE (liter)	R^2	RMSE (liter)
5	0.85	14.69	0.92	9.86	0.95	7.81
10	0.82	22.29	0.91	13.54	0.95	18.46
15	0.92	10.23	0.98	10.28	0.89	14.91
20	0.80	17.97	0.95	17.49	0.90	10.01

The authors claimed that the ANN models could be used to forecast the methane fraction in landfill gas. Holubar et al. [13] employed different ANNs for methane production modeling of anaerobic continuously stirred tank biogas reactors that ran under various organic loading rates. The authors claimed that the developed models could effectively predict the degree of methane production. ANNs were used to produce methane from the digester of Russaifah biogas plant in Jordan based on temperature, TS, VS, and pH. The authors stated that an ANN model with 4-25-25-1 structure, i.e. a network having an input layer with four neurons and two hidden layers each having 25 neurons, was the best model to predict methane production with a correlation coefficient of 0.87 [27]. Mahanty et al. [21] modeled biogas production on the co-digestion of industrial sludges using ANN and statistical regression models. They concluded that the modeling and predictability of ANN were superior to the regression model.

Figure 7 shows the comparison between the actual and predicted values obtained through the optimally developed ANN model. It was concluded that the ANN models may be used to prognosticate the amount of biogas production from portable polyethylene biogas reactor. This finding is in agreement with Kanat and Saral [17], Qdais [27], and Kana et al. [16], who suggested that ANN is a powerful model for serving as a functional and dynamic field of investigation in the realm of biogas production modeling.

4. Concluding Remarks

In this study, the rate of biogas production was modeled and predicted in a portable polyethylene biogas reactor. ANN models were used to predict the biogas production rate based on temperature and pH. The total biogas production stood at 0.27 m^3 $kgVS^{-1}$, while the total biogas production was 0.08 m^3 $kgVS^{-1}$ during nighttime and 0.19 m^3 $kgVS^{-1}$ during daytime. The produced biogases during day and night were significantly different at the 5% significance level. To conclude, ANN models can be efficiently used to prognosticate biogas production in a portable polyethylene biogas reactor.

Acknowledgment

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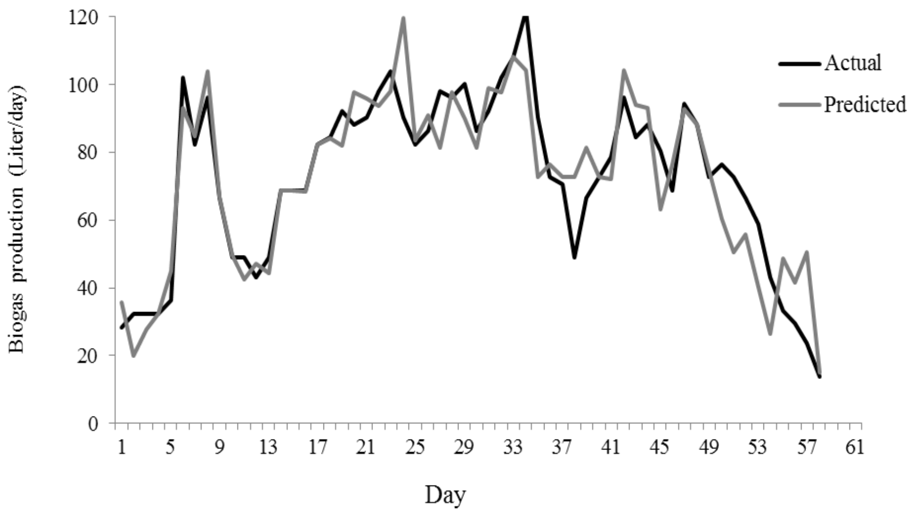

Fig. 7. Comparison between actual and predicted values by the ANN model

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