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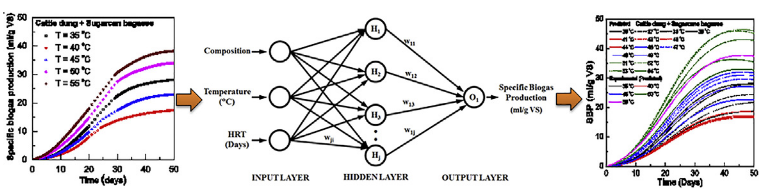
Full Length Article

Artificial neural network model to predict behavior of biogas production curve from mixed lignocellulosic co-substrates

Manjula Das Ghatak[a], Amitava Ghatak[b,*]

[a] Department of Mechanical Engineering, National Institute of Technology, Yupia, Papumpare, Arunachal Pradesh 791112, India
[b] Department of Mechanical Engineering, Techno India University, Salt Lake, Kolkata, West Bengal 700091, India

GRAPHICAL ABSTRACT



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ABSTRACT

Depletion of fossil fuels and increase in global pollution at an alarming rate has encouraged the researchers to look for environmental friendly and cost effective alternative sources of energy. Biogas production using co-digestion of lignocellulosic biomass with cattle dung is receiving a lot of attention due to its plenty of availability and relatively easy energy conversion technique. Artificial neural network (ANN) is one of the most recent modeling tools, used to solve and predict complicated problems that cannot be explained by conventional methods. The paper demonstrates the modeling and optimization by ANN for prediction of specific biogas production using cattle dung as co-substrates, separately with bamboo dust, sugar-cane bagasse and saw dust in mesophilic as well as in thermophilic condition. In this study, the effect of biogas production parameters such as composition, temperature, and time are considered. Specific biogas production data of 99.7% might be predicted using ANN model within a precision of ± 10% deviation from the experimental values. The ANN model was used to predict specific biogas production for the substrates at various temperatures. The optimal biogas production was obtained for the mixture of cattle dung and sugar-cane bagasse.

1. Introduction

The limitation and consequential hike in price of fossil fuels and increase in global pollution at an alarming rate has brought worldwide attention to renewable energy resources for researchers. Among various environmental friendly and cost effective alternative energy sources, biomass is found to be better potential energy source due to its plenty of availability worldwide. However, the technology related to production of biogas from lignocellulosic biomass has been found to be little rudimentary. To encounter the global pollution by reducing the emission of oxides of carbon and nitrogen from use of fossil fuel, co-digestion of biomass with cattle dung is a promising method among various technologies adopted for biogas production.

Anaerobic digestion is a process in which microorganisms degrade the biodegradable part of the organic material in the absence of oxygen to produce biogas mainly of methane and carbon dioxide. The digestion mainly takes place either at mesophilic (30–45 °C) or thermophilic temperatures (50–60 °C) [1]. Thermophilic stabilization of biogas digesters at 55 °C is truly economical as it produces more quantity of biogas [2]. But anaerobic digestion in mesophilic condition is more

* Corresponding author.
E-mail address: agmechanical@technoindiauniversity.ac.in (A. Ghatak).

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common as compared to that in thermophilic condition due to the reduction in process stability, dewatering properties and requirement of large amount of energy for heating the substrate inside the digester. Formerly, to improve the biogas production from cattle dung using co-digestion, has been studied briefly by researchers [3–5]. Hence, temperature of the feed stock during anaerobic co-digestion is a significant parameter which controls the rate of digestion. Optimum yield of biogas was obtained at 50 °C followed by 60 and 40 °C from cow dung and water mixture [3]. Mahanta et al. [6,7] investigated the optimum temperature environment for higher rate of biogas production from anaerobic digestion of cattle dung-water mixture. They found that the gas production rate was the maximum at 35 °C followed by 45, 30 and 40 °C. A few researchers had reported on biogas production at thermophilic condition with *Laminaria digitata* (seaweed), waste water and food waste [8,9]. However, a systematic study regarding the effect of temperature on anaerobic digestion of lignocellulosic biomass in mesophilic as well as thermophilic condition has not yet been reported.

Other than temperature, various parameters also affect the operation of anaerobic digestion process for biogas production and thereby, the best combination of biomass substrate which can maximize the biogas production is selected. Several kinetic models, such as logistic growth curve, exponential rise to maximum, modified Gompertz equation have been generated to explain and predict anaerobic biogas production [10,11]. Among these, modified Gompertz equation [12,13] is commonly used by researchers to simulate methane and hydrogen gas production. However, these models require large number of experimental data. Since, biogas production takes long time; researchers perform limited experiments and use these data to simulate parameters of the above explained kinetic models. Hence, these traditional physics based techniques may not be appropriate for modeling highly complex non-linear behavior with great accuracy.

Recently, Artificial Intelligence (AI) tools like Artificial Neural Network (ANN), Genetic Algorithm (GA), Fuzzy Logic (FL) have been found suitable and accurate to solve engineering problems. Among these tools, ANN modeling is found to be more popular due to its ability to solve complicated problems. Its accuracy depends on the availability of sufficient input-output data sets. Researchers have used ANN technique as a powerful tool to control and predict the biogas production of anaerobic digestion system [14–18], digester start up and recovery for biogas production [19], and explain presence of trace gases in the product [20]. Dahunsi et al. [21] predicted biogas yield using ANN, considering temperature, retention time, total solids, pH & volatile solids as input parameters. ANN model was constructed to predict methane production from anaerobic digestion of lignocellulosic biomass as a function of pH, chemical oxygen demand, volatile fatty acid concentration, volatile suspended solids, potential gas, gas composition and methane production rate [14]. Yetilmezsoy et al. [22] simulated ANN model to predict biogas and methane production rate, considering volumetric organic loading rate (OLR), influent and effluent pH, operating temperature, influent and effluent alkalinity, effluent chemical oxygen demand (COD), and volatile fatty acid (VFA) concentrations as input parameters. Kana et al. [23] modeled and optimized biogas production from mixed substrates of saw dust, cow dung, banana stem, rice bran and paper waste using ANN coupling GA, considering concentration of the substrates as an input parameters. Behra et al. [24] developed a neural network model to predict methane percentage as a function of landfill gas extraction rate and landfill leachate: food waste leachate ratio. ANN model has also been successfully used to predict methane fraction, biogas volume and outlet volatile solid level, considering five input parameters viz. amount of pineapple peel, inlet pH level, inlet chemical oxygen demand level, inlet volatile fatty acids and inlet volatile solid level [25]. Yusof et al. [26] optimized the amount of methane gas yield for co-digestion of poultry manure and food waste using response surface methodology and ANN. The amount of methane gas yield was considered as a function of pH, temperature and, poultry manure: food waste ratio. ANN and GA model was used to predict and optimize biogas production from mixture of Karanja seed cake and cattle dung using pH, digestion time and C/N ratio as input parameters [27]. Nonlinear Autoregressive Exogenous (NARX) model has been developed to predict daily biogas production rate of anaerobic digester [28]. ANN has also been used to evaluate biogas yield from food waste [29,30] and agricultural waste [31,32] by considering various input parameters. Neural network technique has also been used to predict the methane production during anaerobic digestion [33–35].

Reported literatures indicate that the artificial neural network technique is an effective methodology to predict biogas production by anaerobic digestion of biomass either in mesophilic or thermophilic condition. Since, biogas is a product of fermented biomass; hence, production rate can be enhanced by optimizing the parameters which are favorable to the bacteria involved in the digestion process. The behavior of biogas production data with time is non-linear in nature. Until now, scientists were not being able to predict the behavior of biogas production curve with time and optimize the temperature for a particular lignocellulosic biomass substrate from limited experimental data. Prediction of gas production with a sensible precision would be a major achievement. Hence, the present work demonstrates the application of ANN technique to address this issue of accurate prediction of biogas production from anaerobic digestion of lignocellulosic biomass co-digested with cattle dung in mesophilic as well as in thermophilic condition using experimental data. The simulated data can be further utilized to specify the anaerobic temperature for maximum biogas production.

2. Materials and methods

2.1. Experimental materials and procedure

Cattle dung (CD) was collected from a local dairy farm in Guwahati, India. The lignocellulosic co-substrates of bamboo dust (BD), sugar-cane bagasse (SB) and saw dust (SD) were obtained from an agricultural farm in Guwahati, India. Table 1 shows the composition of substrates.

Bamboo dust, sugar-cane bagasse and saw dust were cleaned and dried for 6 h to remove the apparent moisture. Consequently, these three substrates were dried in the hot air oven for 24 h. After drying, the sugar-cane bagasse was chopped to make 2–3 mm in length. The substrates were ball milled separately in a planetary ball mill and strained

Table 1
Composition of substrates.

Biomass type	Present work			Lower heating value (MJ/kg)	Literature data			Lower heating value (MJ/kg)	Literatures
	Fixed carbon (%)	Ash content (%)	Volatile matter (%)		Fixed carbon (%)	Ash content (%)	Volatile matter (%)		
Cattle dung	21.45	12.35	66.2	14.676	19.3	19.3	46.4	11.4	[40]
Bamboo dust	12.7	3.79	84.24	16.75	9.3	16.5	74.2	16.2	[41,42]
Sugar-cane bagasse	12.19	1.68	84.17	18.46	13.15	3.2	83.66	13.48	[43,44]
Saw dust	19.98	3.51	82.79	14.33	14.04	1.49	76.23	20.18	[45,46]