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Modelling and optimization of thermophilic anaerobic digestion using biowaste

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Abstract

Biowaste generation is considerably increasing multiple times recently due to various social and environmental changes like population growth, economic prosperity, globalisation etc. they contain different composition and generated at different stages of their life cycle. Though studies reported for recycle, reproduce and reuse of them, this investigation is unique by focussing to investigate the ideal circumstances for the production of biogas and methane from anaerobic digestion of vegetable waste using response surface methods and artificial neural networks with thermophilic temperature range. Thermophilic temperature of 20.78, organic loading rate of 0.2, pH of 8.81, agitation time of 5.8 and hydro retention time of 3 are the ideal input parameter values for the generation of biogas 3.03 m3 and methane% 186.08 with a desirability of 1. The Response surface model was surpassed by the Artificial Neural Network model.

Introduction

Nowadays, bio-waste is one of the important disposal issues all over the world. Due to its significance as a technique for waste treatment and resource recovery, the production of biogas from the microbial conversion of biogenic organic wastes under anaerobic conditions has gained attention on a global scale (Vijayan et al., 2021). Under (Sathish et al., 2018a, Sathish et al., 2018b) weak or no oxygen conditions, anaerobic digestion (AD), a biological process, creates biogas from biodegradable wastes by bacteria. An alternative technique of waste treatment and energy recovery is anaerobic digestion (Neto et al., 2021). Methane and carbon dioxide make up the majority of the biogas produced, which can be used as a sustainable energy source. The goal of today's waste minimization is to recycle organic materials and plant nutrients back into the soil while reducing the amount of garbage that ends up in landfills (Parthiban et al., 2021a, Parthiban et al., 2021b). In addition to producing biogas for energy usage, the process also eliminates pathogens and creates stabilised material that may be applied to the ground as organic compost. Anaerobic treatment has been the subject of extensive study to improve biogas output. The floating drum anaerobic digestion facility is one of the more efficient kinds of biogas plants when (Sathish and Vivekanandan, 2016) compared to other kinds of biogas plants. The production of biogas is influenced by a number of (Kumaraswamy et al., 2022) variables, including the inoculum, digester temperature, pressure, pH, stirring duration, pretreatment of feedstock, co-digestion, loading rate, volatile matter, carbon nitrogen ratio, and hydro retention period, among others. Generally thermophilic temperature operating condition range is 34°C–55°C.

The (Martí-Herrero et al., 2019) major factor influencing the actions, survival, and growth of the microorganisms engaged in the production of biogas is temperature, among other variables. Different temperature ranges enable the operation of anaerobic digestion (Vivekanandan and Sathish, 2015). Thermophilic digestion removes any pathogenic microorganisms that might grow as a result of the process's high operating temperature. Given that the digestion is occurring more quickly, the substrate's hydraulic retention period in the digesters is minimal. Furthermore (Parthiban et al., 2021a, Parthiban et al., 2021b), at thermophilic temperatures, interspecies hydrogen transfer is expedited, microorganism growth rates are raised, and solids are destroyed more quickly (Sathish et al., 2020), thus increasing the yields of bio methane at shorter retention times. To provide sufficient contact between bacteria and substrates and to aid in the extraction of gas from the liquid, mixing is essential in anaerobic fermentation. The reduction of scum development, which reduces the digester's overall capacity, is another argument for such blending (Abebe, 2017). A large-scale, single-stage continuous fermentation system that uses vegetable waste produces biogas at a sustainable, consistent rate. One of the key parameters affecting the continuous generation of biogas is the hydro retention time because it may be controlled to prevent the biogas from being used by biomass-consumers

like methanogens (Shaisundaram et al., 2020). While mixing is essential to all anaerobic digestion systems, continuous systems depend on pumps to maintain continuous operation. Changes within those two variables had an impact on the microbial population and different fermentation types in addition to the ability to generate anaerobic methane (Harish et al., 2022). one of the key parameters affecting the continuous generation of biogas is the hydro retention time because it may be controlled to prevent the biogas from being used by biomass-consumers like methanogens (Phetyim et al., 2015). the amount of carbon dioxide in biogas has a big impact on the pH of an anaerobic system. Higher organic loading rates might result in smaller digesters with lower construction costs. However (Muhammad and Chandra, 2021), adequate time should be allowed for retention so that the microbes can decompose the organic substance and turn it into biogas (Sathish et al., 2019). The loading and unloading of effluents does not interrupt the production of biogas in continuous reactors. Large commercial biogas plants might be a better fit for it (Parthiban et al., 2006). The digesting contents must be agitated in order to ensure direct contact between bacteria and substrate concentration, which leads to an improved digestion process (Sridhar et al., 2020). Anaerobic fermentation techniques have been applied in several industrial sectors recently to estimate the interaction and individual impacts in the biochemical conversion process using ANN and RSM (Jishuchandran et al., 2020; Ambrose et al., 2020). the current work is aimed to develop a predictive model for both individual and interacting effects of biogas yield using RSM and ANN (Anil et al., 2022; Bernard et al., 2020; Onu et al., 2022a, 2022b; Karikalan et al., 2020). in the anaerobic process, where the degradability of the feedstock changes and subsequently the optimum condition varies with the variety of the feedstock's composition, the substrate composition is critical. Based on the feedstock, an anaerobic digester's retention period is determined. Throughout the digestion process, the output of biogas varies (Okwu et al., 2021; Sathish et al., 2017, 2018; Kannan et al., 2022).

Generally (Devi et al., 2022; Jaysingpure and Khobragade, 2023); the predominant reason for the creation of biogas is the presence of methanogens bacteria and other microbes in vegetable biowaste and also vegetable waste have high Carbon/Nitrogen ratio, easily degradation during the digestion this one for the reason for researcher chosen the feedstock. Main research gap of the work is previous literature only used to optimize the biogas production using taquci method only. The primary goal of this work is to implement Central Composite Design-based Response Surface and Neural Networks to optimize process parameters like pH, thermophilic temperature (T), Organic loading rate (OLR), and Agitation time that affect biogas generation under anaerobic digestion of vegetable waste (biowaste). The ANN model is useful for developing bioprocess designs, and it is entirely data-based The ANN model is a multilayer architecture used to create approximations of

nonlinear interactions that currently exist between input variables and output dependent variables. This study is to use response surface methodology and artificial neural networks with thermophilic temperature range to examine the optimal conditions of biogas and methane from anaerobic digestion of vegetable waste.

A floating drum type biogas plant with a 1-cubic-meter bio-digester capacity is used in this experimental project. This experimental investigation is being conducted to investigate the impact of vegetable waste's thermophilic temperature. The one external heating device (heater) is used to heat the digester slurry for thermophilic condition. Cow dung is used as the experiment's inoculums after vegetable waste and water are mixed in a ratio of 1:2 to make slurry. The pH of the digester's inflow and outflow slurry is tested daily using a digital pH probe (pH redox meter), and the temperature of the digester is determined in each case with the assistance of a thermocouple with K-type nickel chromium-nickel temperature sensor is used. The range of the temperature sensor is maximum 30°C–650°C with K-type. Other approaches, such as total solids and preparation solids concentration, are used to calculate the Carbon Nitrogen Ratio C/N ratio. According to ease.inc. The central composite design (CCD) and Response surface methodology (RSM) were introduced using design expert version 9.0.Thermophilic temperature (T), pH, Organic loading rate (OLR), and agitation time are the four important parameters taken into consideration in this study Agitation Time (AT). Independent variable values, both actual and coded, and experimental ranges based on some preliminary experimental research, each independent variable was altered at experimental ranges over five levels between −2 and +2. Fig. 1. Shows the photo graphic view of the floating drum digester and various parts of the digester is mentioned in Fig. 1.

The percentage of methane from the biogas measured using gas chromatography with a flame ionization detector (FID) is a scientific instrument that measures analyses in a gas stream. The digested slurry is agitated using pneumatic automatic stirrer and hydraulic type of agitator. Digestion period is calculated using Hydro retention time (HRT) in this period's gas formation is calculated from initial stage to end stage of the digestion process. For full 30 days of the experimental phase, biogas production and methane percentage were measured. During the phases of digestion, the pH of the vegetable wastes in the digester is measured. At the point where the feedstock is charged, this type of experiment is run continuously. Every day during the experimentation periods in both phases, the temperature is recorded between 11 and 2 p.m. The gas sample is air bags taken from the digester, examined, and tested. Fig. 2 depicts the experimental setup from a photographic perspective (see Fig. 3).

Empirical models are developed using a set of statistical and mathematical techniques known as response surface methodology (RSM) with Design-Expert version 13 is used (Onu et al., 2022a). The box-behnken design can be used to fit second-order models. When a first order model is unable to correct for the interaction between the variables and the surface curvature, a second order model can significantly improve the optimization process (Aung et al., 2022). A second-order model in general is represented by equation (1).
$y = a_0 + \sum_{i=1}^{n} a_i\, x_i + \sum_{i=1}^{n} a_{ij}\, x_{ij} + \sum_{i=1}^{n} \sum_{i=1}^{n} a_{ij}\, x_i\, x_j$where y stands for the response, xi and xj stand for the design variables, and a stand for the parameters. Since the constructed model's statistical significance is examined using analysis of variance (ANOVA), utilising the model's values for regression and mean square residual error, the coefficients of determination were utilised to gauge the model's quality (R^2). On biological neural networks, ANNs are based (Stojanović et al., 2022). Through the use of an activation function, this method converts the weighted sum of the inputs that are received by each neuron into an output signal. A bias input is added to the weighted sum in order to modify the net input to the activation function. The connections between processing units and the network architecture have a big impact on the functions (Simsek et al., 2022). The output neurons are BIOGAS and CH_4, while the input neurons are the mass fraction of the Thermophilic Temperature, Organic Loading Rate OLR, pH, Agitation Time, and Hydro Retention Time HRT (Gupta et al., 2022). Thirty experimental data sets are employed together with the back-propagation technique to train and validate the input and output values (Reza and Chen, 2022; Selvakumar et al., 2022).

Section snippets

Result and discussion

The output neurons are BIOGAS and CH_4, and the input neurons are Thermophilic Temperature, Organic Loading Rate OLR, pH, Agitation Time, and Hydro Retention Time HRT. Using the back-propagation method, the input and output values are trained and validated (Ogedjo et al., 2022a). Along with 30 experimental data sets and Table 2. Represents the ANOVA (see Table 3).

The F-value for the model, 4.33, indicates that it is significant. Only 0.46% of the time might noise be the source of a high Model…

Conclusion

In order to anticipate BIOGAS and CH_4 in the BIOGAS Production Plant, the current study compares and optimises response surface methodology and artificial neural network modelling approaches. Five input parameters are used in the trials, and two responses are used to create the RSM and ANN-based models. The accuracy of BIOGAS and CH_4 predictions was used to compare the two models' performance. From the findings of this current research project, the following conclusions are drawn:

- For both the…

…

Author contributions

A.Parthiban: Collected the data (Data collected from various sources). S.Sathish: Other contributions (Facilitating consumable and non-consumable resources for experimentations). R.Suthan: Contributed data or analysis tools (software, validation, formal analysis). T. Sathish: Wrote the paper (writing—original draft preparation, writing—review and editing). M. Rajasimman: Conceived and designed the analysis (Project administration). V. Vijayan: Conceived and designed the analysis…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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