DESIGN AND DEVELOPMENT OF CROW OPTIMIZATION MODEL FOR BIOGAS POWERGENERATION SYSTEM

ASHWINI NIKOSE¹ & DR. RAJEEV ARYA²

¹Scholar, Department of Energy Technology, Truba Group of Institutes College, Bhopal, Madhya Pradesh, India

²Director, Department of Mechanical Engineering, Truba Group of Institutes College, Bhopal, Madhya Pradesh, India

ABSTRACT

Biogas power generation is renewable energy made from biological materials. Biogas power production is technology which helps in development of sustainable energy supply systems. Anaerobic digestion (AD) technology has become popular and is widely used due to its ability to produce renewable energy from wastes. The bioenergy produced in anaerobic digesters could be directly used as fuel, thereby reducing the release of biogas to the atmosphere. This research work is focused for designing of crow optimization model for Biogas electrical power generation. The production is done using co-digestion system of waste products (dung or municipal waste) under the process of anaerobic digestion. The optimization model results in increase of generated power.

KEYWORDS: *Biogas, Anaerobic Digestion, CH₄, CO₂, Energy Production & Optimization*

Received: Aug 09, 2020; **Accepted:** Aug 29, 2020; **Published:** Sep 11, 2020; **Paper Id.:** IJMPERDAUG202022

1. INTRODUCTION

India is the world's third largest producer and third largest consumer of electricity. The national electric grid in India has an installed capacity of 368.79 GW as of 31 December 2019 [1]. Renewable power plants, which also include large hydroelectric plants, constitute 34.86% of India's total installed capacity. During the 2018-19 fiscal year, the gross electricity generated by utilities in India was 1,372 TWh and the total electricity generation (utilities and non utilities) in the country was 1,547 TWh. The gross electricity consumption in 2018-19 was 1,181 kWh per capita. In 2015-16, electric energy consumption in agriculture was recorded as being the highest (17.89%) worldwide [2].

Coal	Large Hydro	Small Hydro	Wind	Solar	Biomass and other Renewable Resources	Nuclear	Gas
74.50%	9.80%	0.60%	4.50%	2.90%	1.20%	2.70%	3.60%

Figure 1: Electricity Generation by Sources in India [3].

India has recorded rapid growth in electricity generation since 1985, increasing from 179 TW-hr in 1985 to 1,057 TW-hr in 2012.[4] The majority of the increase came from coal-fired plants and non-conventional renewable energy sources (RES), with the contribution from natural gas, oil, and hydro plants decreasing in 2012-2017. The gross utility electricity generation (excluding imports from Bhutan) was 1,372 billion kWh in 2018-19, representing 5.53% annual growth compared to 2017-2018[5]. The contribution from renewable energy sources was nearly 17% of the total. In the year 2018-19, more than 50% is contributed by the renewable energy sources to the total incremental electricity generation. Fig 2 shows the total power generation capacity year-wise. The total installed power generation capacity is the sum of utility capacity, captive power capacity, and other non-utilities.

Figure 2: Total Installed Power Generation Capacity [3].

The continuing use of fossil fuels and the effect of greenhouse gases (GHGs) on the environment have initiated research efforts into the production of alternative fuels from bioresources. The amount of GHG emissions in the atmosphere is rising, with carbon dioxide (CO₂) being the main contributor. In addition, the global energy demand is increasing rapidly, with approximately 88% of the energy produced at the present time being based on fossil fuels [6][7].

Moreover, the security of the energy supply is a crucial challenge because most natural energy resources (i.e., oil and gas reserves) are found in politically unstable regions. In this context, biogas from waste and residues can play a critical role in the energy future. Biogas is a multilateral renewable energy source that can replace conventional fuels to produce heat and power; it can also be used as gaseous fuel in automotive applications. Biomethane can also substitute for natural gas in chemicals production.

Recent evaluations indicate that biogas produced via anaerobic digestion (AD) provides significant advantages over other forms of bioenergy because AD is an energy-efficient and environmentally friendly technology [8][9].

In comparison with fossil fuels, AD technology can reduce GHG emissions by utilizing locally available sources. In addition, the by-product of this technology, called digestate, is a high-value fertilizer for crop cultivation and can replace common mineral fertilizers.

2. BIOGAS GENERATION

Biogas is a process in which livestock manure is converted to methane gas [9] via anaerobic digestion, that is odorless [10] and can be utilized as fertilizer [11]. So being a valuable fuel biogas can be utilized in variety of applications like domestic, industrial, heating, as a Compressed Natural Gas (CNG) (by scrubbing process) [12] and for electricity generation.

One major advantage of biogas is its utilization as a substitute of coal in power generation, which helps in minimizing greenhouse gases, as coal is the primary cause of carbon dioxide emission. These renewable energy resources

not only help in mitigation of the energy crisis but also create new employment opportunities with positive impact on environment. Therefore, India should encourage renewable energy resources like biogas to fulfill its energy demand to a significant level. India is an agricultural country. Therefore, it is rich in biogas resources. Biomass contains carbohydrates, proteins, fats, cellulose, and hemicellulose, which can be used as feedstocks for biogas production. In current practice, co-substrates are usually added to increase the organic content and thus achieve a higher gas yield. Typical co-substrates include organic wastes from agriculture-related industries, food waste, and/or collected municipal biowaste from house-holds. The composition and yield of biogas depend on the feedstock and co-substrate type. Even though carbohydrates and proteins show faster conversion rates than fats, it is reported that the latter provide a higher biogas yield. A comparative analysis of biogas yield with respect to energy generation is listed in Table. 1.

Table 1: Comparison of Biogas Yield and Electricity Produced from Different Potential Substrates [13]

Type	Biogas Yield Per Ton Fresh Matter (M ³)	Electricity Produced per Ton Fresh Matter (kW-h)
Cattle Dung	55–68	122.5
Chicken Dung	126	257.3
Fat	826–1200	1687.4
Food Waste	110	224.6
Fruit Waste	74	151.6
Horse Manure	56	114.3
Maize Silage	200/220	409.6
Municipal Solid Waste	101.5	207.2
Pig Slurry	11–25	23.5
Sewage Sludge	47	96

The production of biogas includes technical and economic parameters such as microorganism species, pre-treatment and purification technologies, substrate properties, and optimal reactor conditions. Optimizing the combination of these parameters is the key to cost-effective biogas production. Research can play a catalytic role in filling the gap between engineering and biology/biotechnology (Table 2) in order to provide innovative and sustainable technological alternatives for the biogas sector.

Table 2: Current Issues and its Focus for R&D [13]

Issues	Focus for R&D
Use of Enzymes/catalyst	High cost
Utility requirements	Power Consumption Release of oxygen and hydrogen High pressure and generation of heat
Technology	Pre treatment Micro technology
Fuel	Methane gas production

3. LITERATURE REVIEW

The treatment methods for food waste include mechanical crushing, sanitary landfill, composting, feed utilization and anaerobic digestion. Anaerobic digestion (AD) is a biological process that breaks down biodegradable material in the absence of oxygen and produces biogas and digestate [10]. The environmental advantages are more obvious and the input and output efficiency is higher. The use of this technology to deal with food waste can produce clean energy-biogas, which can be used for heating and power generation; and biogas slurry can be used as high-quality organic fertilizer, which can be applied to farmland to improve soil quality [11]. Anaerobic digestion is a continuous and dynamic process. According to the different ways of feeding, it can be divided into three kinds of technologies: continuous digestion process, semicontiguous digestion

process and batch digestion process [12]. It is reported that semi-continuous digestion process is currently applied in most of the large and medium-sized biogas project. It is necessary to set the digestion process parameters reasonably and try to reach the maximum biogas production based on the semi-continuous feeding method. Many contributions for academic research on biogas production modelling have been published in the past years. Due to the limited knowledge on the different process disturbances and microbial composition that are vital for the efficient operation of AD systems, models and control strategies with respect to external influences are needed without wasting time and resources. Different simple and complex mechanistic and data-driven modeling approaches have been developed to describe the processes taking place in the AD system. Microbial activities have been incorporated in some of these models to serve as a predictive tool in biological processes. The flexibility and power of computational intelligence as direct search algorithms to solve multi-objective problem.

Achinas et al. [13] provided an overview of biogas production from lignocellulosic waste, thus providing information toward crucial issues in the biogas economy.

Timothy et al. [14] used genetic algorithm optimization model for electricity generation. The Amount of methane gas in Biogas production will affect Thermal rotating shaft of Biogas Electrical Plant. The Result showed that biogas electrical power generated without and with Genetic Algorithm Optimization were 5KW and 11.18KW respectively. The biogas power generation was increased by 6.18KW, which is 38.2% increase after Genetic Algorithm optimization.

Wang et al. [15] proposed PSO-BP neural network-based algorithm to build biogas production prediction model. The biogas power generation was increased by 17%

Qdais et al. [16] proposed modeling and optimization of biogas production from a waste digester using artificial neural network and genetic algorithm. The optimal amount of methane was converged to be 77%, which is greater than the maximum value obtained from the plant records of 70.1%.

Enitan et al. [17] adopted computational intelligence methods such as neural networks, FL, GA, PSO, CPMDE, and other EAs for biogas optimization from AD processes. The optimization of plant parameters, efficiency, biogas quantity and quality, as well as substrates using EAs was shown to offer many important advantages to biogas plants.

Selvankumar et al. [18] found that Coffee pulp with an optimum proportion of cow dung can be used a substrate with a high potential for biogas generation by anaerobic digestion. The coffee pulp and cow dung co-digestion at 1:3 ratios of mixture had showed maximum biogas yield 144 mL/kg water displaced after 96 h. The biodegradability percentage of CP: CD (1:3) = 15.30. The maximum yield of biogas was obtained at pH 8.0 and also at the temperature of 40°C.

Singh et al. [19] proposed a model for production of biogas using kitchen wastes, therefore there is a requirement of an anaerobic digester which will digest and utilize food waste from kitchen to generate biogas. The quantity of waste produced was found enough in amount to produce sufficient biogas for the purpose of power generation.

Suslov et al. [20] developed an experimental setup with a bioreactor of 5 litres to study the biogas production process. A series of full-scale experiments on the effect of the composition of the initial substrate on the qualitative and quantitative composition of biogas was carried out. As the substrate used: corn silage, poultry manure, pig manure and manure of cattle. Dependences of the volume of biogas and methane content on the type of substrate being processed and the temperature of the process are obtained. It has been established that the greatest amount of biogas is released during fermentation of corn silage and avian manure, and the smallest of pig manure drains. The greatest content of methane is observed when processing bird droppings - 64%, and the smallest of corn silage - 50%.

Sanchez et al. [21] developed an alternative technology to obtain biogas used for the management of organic media are used for the use of media.

4. METHODOLOGY

Large-scale production of lignocellulose as biogas has considerable potential and research efforts have already been made to develop it further. These methods generally pose technical problems based on a poor understanding of optimal reactor operation. AD technology also requires services such as electricity and heating. Optimal utilization of utilities is a technical problem that can be improved in pilot plants and can change process efficiency [30].

An unfortunate downside to biogas today is that the systems used to produce biogas are inefficient. There are still no new technologies to simplify the process and make it abundant and inexpensive. Like other renewable energy sources, biogas production is also affected by weather conditions. The optimum temperature needed for bacteria to digest waste is 37°C. In cold climates, fermenters need thermal energy to maintain a constant supply of biogas.

Following steps are to be followed for optimized biogas energy production.

- Step 1: Choosing the more energy producing waste: According to the above-mentioned table 1, a comparison is given on the production amount and energy potential for the different feedstocks that can be utilized for biogas production.
- Step 2: Designing of Biogas Electrical Power Generation Simulink Model. MATLAB platform is used to design Model for biowaste. The biowaste will be fed into the digester through an inlet pipe in the inlet tank and the slurry flow to the digester vessel for digestion. The methane gas produced through fermentation in the digester is collected in the Gas holder. The digested slurry flows to the outlet tank through the main pipe. The slurry then flows through the overflow opening in the outlet tank to the compost pit. The gas is supplied from the gas holder to the gas Compressor which generates output Power.
- Step 3: Optimizing the energy production using different AI techniques: The optimization of generated power in step 2 is done using crow optimization. The Algorithm is designed in such a way that the system will trigger the thermal engine to work with high power at low methane gas. The result will be obtained in order to find the best Biogas Electrical power generation.

Figure 3: Flow Chart of Biogas Production System.

5. MATERIALS AND METHOD

This paper develops a optimization model for biogas production from waste materials such as domestic waste, pig waste and poultry waste. This system was designed and simulated to calculate daily power generated under thermophilic condition. The waste product was mixed with water in the ratio 1:1. Poultry dung was also mixed with water in the ratio 1:1. Similarly, pig dung was also mixed with water in the ratio 1:1. Then both the slurry is mixed in 50:50 ratio. The mixture was fed into the digester through an inlet pipe in the inlet tank and the slurry flow to the digester vessel for digestion. The methane gas produced through fermentation in the digester is collected in the Gas holder. The digested slurry flows to the outlet tank through the main pipe. The slurry then flows through the overflow opening in the outlet tank to the compost pit. The gas is supplied from the gas holder to the gas Compressor which generates output Power. In Fig. 2 shows the flow chart of biogas production and gas flow for power generation. The optimization of power generated is done using crow algorithm.

A.Mathematical Calculation for Biogas Power Generation

For generation of biogas there is required a large quantity of waste. So, mass of waste first of all needed to be calculated. It is calculated as in eqn (i-iii):

$$Mass_{animal\ waste} = N_i M_i \quad (i)$$

$$Mass_{domestic\ waste} = M_i \quad (ii)$$

$$Mass_{total} = Mass_{animal\ waste} + Mass_{domestic\ waste} \quad (iii)$$

Where, N_i = Number of animals

M_i = Solid waste mass per day per kg.

Then from mass volume is calculated which is shown in eqn (iv):

$$V_{biogas} = R * Mass_{total} \quad (iv)$$

Where, M_{total} = Input waste mass

R = Biogas yield per unit dry mass of whole input in (m^3/kg)

Then, volume of fluid in the digester is calculated which is shown in eqn (v):

$$V_{fluid} = \frac{Mass_{total}}{Density} \quad (v)$$

Then, volume of digester is calculated which is shown in eqn (vi):

$$V_{digester} = V_{fluid} * T_r \quad (vi)$$

Where, T_r = Retention time in digester

Then, finally generated energy is calculated which is shown in eqn (vii):

$$Energy = \eta * V_{biogas} * H_c \quad (vii)$$

Where, H_c = Combustion heat per unit volume of biogas

η = Combustion efficiency

Figure 4: MATLAB Simulink Model for Biogas Production without Optimization.

Figure 5: MATLAB Simulink Model for Biogas Production with Optimization.

B. Crow optimization (CO)

The measured data collected from simulated mathematical model for the optimizing power generated. The result obtained from optimization which is implemented in MATLAB. In order to obtain the best solution for maximum power/energy output.

Maximize [14]:

$$P = 15X_1 + 3.6X_2 + 11.6X_3 \quad (\text{viii})$$

Where,

P = Generated electric biogas power

X_1 = Mass of the waste

X_2 = Input biogas volume

X_3 = Electric energy generated

Crow optimization works in four steps as:

- Formation of crows flock
- Each crow remembers its hiding places
- Crows follow each other to steal their food
- Crows protect their hiding place from other

Let the flock of crows be n . The position of each crow (C_i) at any time (T_{itr}) in the search space is ($x_{itr}^{C_i} = x_1, x_2, \dots, x_d$). Each crow has its hiding place in memory such that ($m_{itr}^{C_i} = m_1, m_2, \dots, m_d$). This is the best position that C_i has obtained so far. Now at any time T_{itr} , C_j wants to visit its hiding place and at same time C_i decided to follow C_j to see its hiding place. In this situation, two states may happen:

State A: Crow C_j does not realize that it has been followed by C_i

$$x_{itr+1}^{C_i} = x_{itr}^{C_i} + r_{Ci} * F_{itr}^{C_i} * (m_{itr}^{C_j} - x_{itr}^{C_i}) \quad (ix)$$

where r_{Ci} = random number with uniform distribution between 0 and 1.

$F_{itr}^{C_i}$ = Flight length of C_i at time T_{itr} .

State B: Crow C_j realize that it has been followed by C_i and it tries to fool C_i by going to another position in search space

$$x_{itr+1}^{C_i} = x_{itr}^{C_i} + r_{Ci} * F_{itr}^{C_i} * (m_{itr}^{C_j} - x_{itr}^{C_i}), \text{ when } r_{Cj} \geq A_{itr}^{C_i} \quad (x)$$

Otherwise a random position is chosen

where r_{Cj} = random number with uniform distribution between 0 and 1.

$A_{itr}^{C_j}$ = Probability of awareness of C_j .

6. RESULT ANALYSIS

The proposed methodology is simulated using MATLAB platform to carry out calculations to obtain the Power output in the Community. The program automatically calculates the volume of the digester required with optimization and without optimization and calculated power generated. The experiment is performed in two conditions which are discussed as below:

Case I: Pig Slurry and Poultry slurry: In this case only pig dung/slurry is applied and generated power output is shown in below table 3.

Table 3: Power Generation in Case I

No. of Pig	No. of Chicken	Total Mass (in kg)	Total Volume (in m ³)	Power without Optimization (in KW/day)	Power with CO Optimization (in KW/day)
200	300	150	37.8	5	8
200	300	120	29.28	3	6
190	200	90	23.58	1.94	5.94
100	210	60	16.08	0.9	5.89
60	150	30	7.62	0.2	1.2

Figure 6: Power Generated with and without CO Optimization using Pig and Chicken Dung.

Case III: Pig Slurry and Poultry slurry and Municipal waste: In this case only pig dung/slurry is applied and generated power output is shown in below table 4.

Table 4: Power Generation in case III

No. of Pig	No. of Chicken	Municipal Waste (in kg)	Total Mass (in kg)	Total Volume (in m ³)	Power without Optimization (in KW/day)	Power with CO Optimization (in KW/day)
200	200	26	150	40.4	5.71	14.71
150	200	14	120	32	5.35	14.58
100	150	15	90	24.9	2.17	9.17
50	100	16	60	17.8	1.1	9.1
25	50	8	30	8.9	0.27	1.27

Figure 7: Power Generated with and without CO Optimization using Pig Dung, Chicken Dung and Municipal Waste.

7. CONCLUSIONS

Biogas from anaerobic digestion of organic matter is a renewable energy source consisting mainly of CH₄ and CO₂. Since biogas is a clean and renewable energy that could replace the conventional energy source (fossil fuels), the optimization of this type of energy becomes important. Various optimization techniques have been developed in the biogas production process. This paper proposed multi-objective crow optimization techniques which will yields high power at waste products. MATLAB Simulink model is prepared to simulate the scenario. The results show that without optimization power produced is approx. 6KW/day with 150kg of waste whereas with CO optimization technique it will produce approx. 14KW/day which shows approx. 33% improvement over condition without optimization.

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