Methodology for Biogas Power Production and Optimization

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Abstract
This research work is focused for designing of optimization model for Biogas electrical power generation. The production is done using co-digestion system of waste products (dung or home waste) under the process of anaerobic digestion. In this paper optimization of anaerobic digestion process is performed which leads to improvement of power production at low methane gas release. In this work, artificial butterfly algorithm is proposed with optimization technique and two different scenario was observed. In first case only municipal waste is taken and anaerobic digestion is performed and power is generated with and without optimization condition. In second case along with municipal waste animal dung is also taken and anaerobic digestion is performed and power is generated with and without optimization condition.

Keywords: *Biogas, Anaerobic Digestion, CH4, Rotating Shaft, Energy Production, Optimization*

1. INTRODUCTION

Biogas is a mixture of combustible gases [1]. It is mainly composed of methane (CH4) and carbon dioxide (CO2) and is produced by the anaerobic bacterial decomposition of organic compounds, i.e. H. Without oxygen, formed. The gases formed are the breathing waste products of these decomposing microorganisms and the composition of the gases depends on the substance being decomposed. If the material consists mainly of carbohydrates such as glucose and other simple sugars and high molecular weight compounds (polymers) such as cellulose and hemicellulose, the production of methane is low. However, when the fat content is high, methane production is also high. Methane and any other hydrogen that may be present constitutes the combustible part of the biogas [2]. Methane is a colourless, odourless gas with a boiling point of -162 ° C and burns with a blue flame. Methane is also the main component (77 to 90%) of natural gas. Chemically, methane is one of the alkanes and is the simplest form. At normal temperature and pressure, methane has a density of approximately 0.75 kg/m^3. Due to the slightly higher carbon dioxide, biogas has a slightly higher density of 1.15 kg/m^3. Pure methane has a higher calorific value of 39.8 MJ / m, which corresponds to 11.06 kWh / m3. When biogas is mixed with 10-20% air, explosive air is created. The production and use of biogas from anaerobic digestion has ecological and socio-economic benefits for society as a whole and for the farmers concerned. Using the internal value chain of biogas production improves local economic capacities, secures jobs in rural areas and increases regional purchasing power. It improves the standard of living and contributes to economic and social development. The global interest in renewable energy sources is growing. Biogas production is steadily increasing as more and more people build biogas plants to produce biogas.

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].

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 [3]. 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 [4]-[10]. 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 [11][12]. 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%.

2. METHODOLOGY

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. I.

Table I: 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.

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 4.1, a comparison is given on the production amount and energy potential for the different feedstocks that can be utilized for biogas production. In this research work municipal waste is considered to be as biogas producing material. This is because everyday from each house tons of waste are collected which can be used as biogas production on large scale.
- 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 multi-objective optimization algorithm. 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.

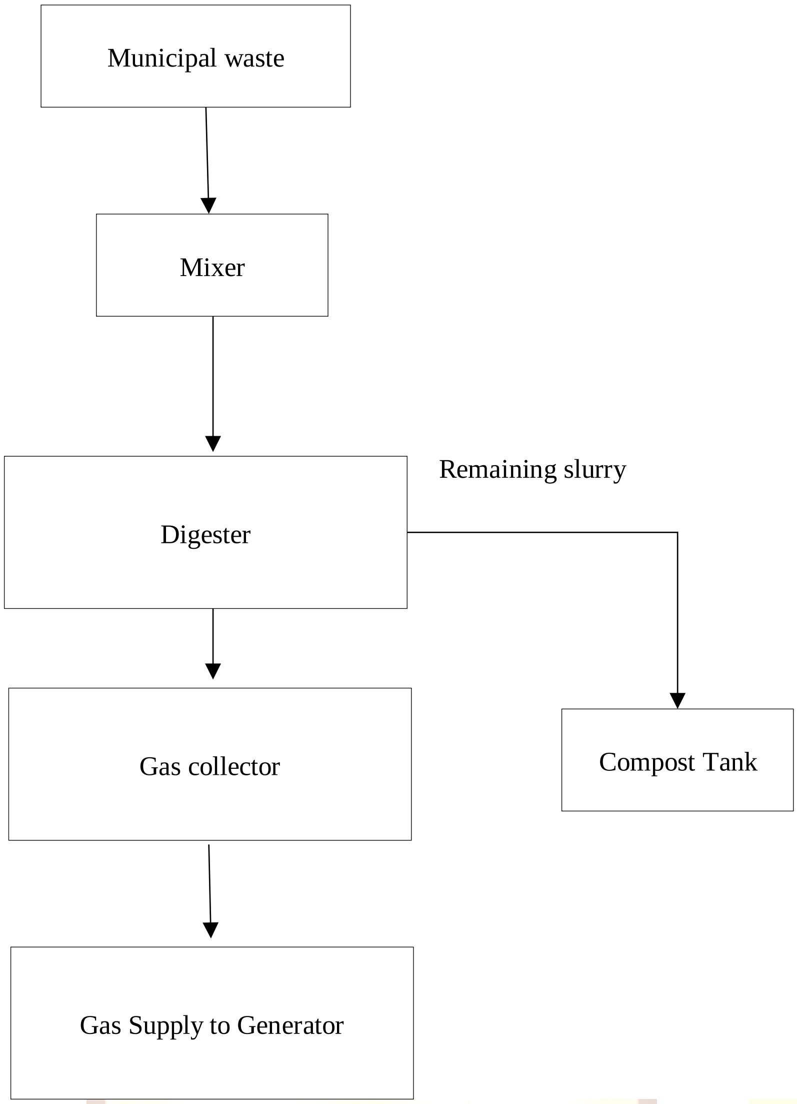

Figure 1: Flow chart of biogas production system

Materials and Method

This research work develops an optimization model for biogas production from waste materials such as domestic waste or municipal 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. 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. 1 shows the flow chart of biogas production and gas flow for power generation. The optimization of power generated is done using multi-objective artificial butterfly algorithm.

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 (1):

$$Mass_{total} = M_i \qquad (1)$$

M_i= Solid waste mass per day per kg.
Then from mass volume is calculated which is shown in eqn (2):

$$V_{biogas} = R * Mass_{total} \qquad (2)$$

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 (3):

$$V_{fluid} = \frac{Mass_{total}}{Density} \qquad (3)$$

Then, volume of digester is calculated which is shown in eqn (4):

$$V_{digester} = V_{fluid} * T_r \qquad (4)$$

Where, T_r= Retention time in digester
Then, finally generated energy is calculated which is shown in eqn (5):

$$Energy = \eta * V_{biogas} * H_c \qquad (5)$$

Where, H_c= Combustion heat per unit volume of biogas
η =Combustion efficiency

Artificial Butterfly Algorithm (ABA)

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]:

$$P = 15X_1 + 3.6X_2 + 11.6X_3 \qquad (6)$$

Where,
P = Generated electric biogas power
X_1 = Mass of the waste
X_2 = Input biogas volume
X_3 = Electric energy generated

Inspired on the mate-finding strategy of speckled woods, Qi et al. [16] proposed a new meta-heuristic algorithm called Artificial Butterfly Optimization. The speckled woods prefer to live on the borders of woodlands where the sun shines on trees and create lots of sunspot. The butterfly population is sorted and divided into two groups according to their fitness. Butterflies with better fitness form the sunspot butterflies and the rest form canopy butterflies, and a different flight strategy is applied to each group. Two modes compose the ABO algorithm:
Sunspot mode
Canopy mode
Some rules of butterflies in ABO algorithm are stated as below:

- In order to increase the likeliness of encountering female butterflies, all male butterflies attempt to fly toward a better location called a sunspot
- To occupy a better sunspot, each sunspot butterfly always attempts to fly to its neighbor's sunspot.
- Each canopy butterfly continually flies toward any sunspot butterfly to contend for the sunspot.

Let P = {p_1 , p_2 , . . . , p_m} = Population of butterflies.
The following strategy is used for the sunspot mode or the canopy mode. Each butterfly flies toward a randomly selected butterfly as follows:

$$P_i^{n+1} = (P_i^n - P_k^n)\beta \qquad (7)$$

Where, i= ith butterfly
n = iteration
β = random generated number between [1, −1]
k = randomly selected butterfly (k≠i)

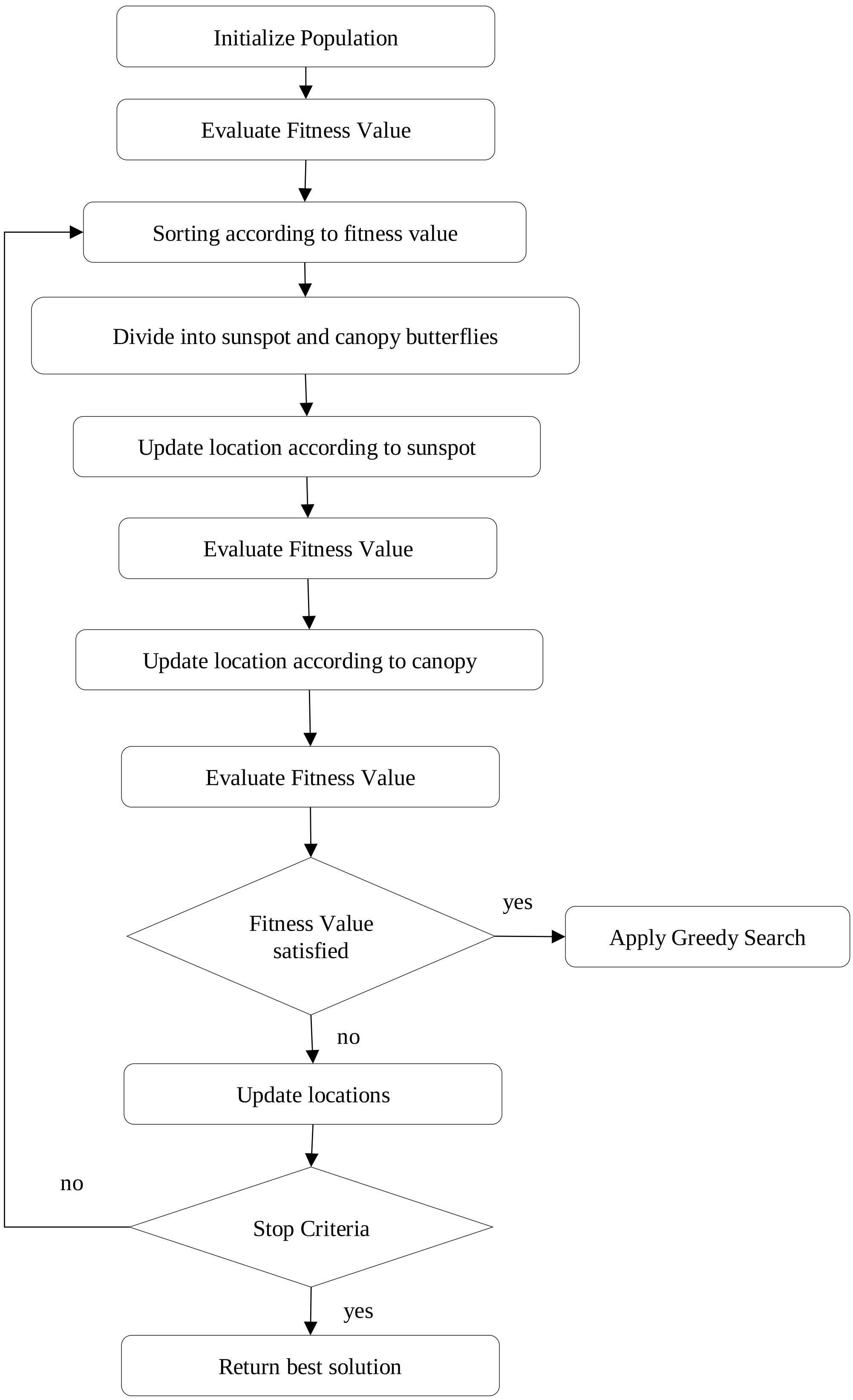

Figure 2: Algorithm for Artificial Butterfly Optimization

Each butterfly flies toward a randomly selected sunspot butterfly as follows:

$$P_i^{n+1} = P_i^n + \frac{P_k^n - P_i^n}{x_k^n - P_i^n})(Ub - Lb)s\beta \tag{8}$$

Where, Ub= upper bound

Lb= Lowe bound

The s parameter decreases linearly from 1 to s_e , as follows:

$$s = 1 = (1 - S_e)\frac{n}{N} \tag{9}$$

where N = Max iteration

3. CONCLUSION

Considering the biogas is a clean and renewable form of energy that could well substitute the conventional source of energy (fossil fuels), the optimization of this type of energy becomes substantial. Various optimization techniques in biogas production process had been developed, including pretreatment, biotechnological approaches, co-digestion as well as the use of serial digester. This work focuses on different techniques to optimize the anaerobic digestion process which results in production of methane gas which rotate the shaft of turbine and more power will be produced at low methane gas production. This research work proposed multi-objective artificial butterfly optimization techniques which will yields high power at low waste products. MATLAB Simulink model is prepared to simulate the scenario.

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