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Research Article

Assessment of Feasibility for Biodigestion of Cattle Waste in Gwalior City, India

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Different biodegradable waste may indeed be processed by biodigesters to generate biogas, a clean and sustainable source of energy. Different digesters are classified according to their digestive process, which is either aerobic or anaerobic. The rate at which organic waste is loaded, the temperature, the amount of dilution, etc., all affect the size of the digesters. A biodigester typically needs a relatively steady atmosphere as well as ongoing agitation. Additionally, it necessitates a large land area. Although it has numerous advantages, the nature of the feedstock is the main factor on which the potential of biogas production depends, as well as the design of the reactor and operational parameters. Though many authors attempted to establish the effect of various factors on the process of biodigestion of food waste, very few studies on reactor design to achieve maximum biogas production were reported. The current study focuses on the use of a reactor with multiple stages that requires a smaller footprint to increase the rate of gas production from solid substrates. In the study, an experiment was attempted to determine the effect of substrate composition, food waste size, and multiple stages inside the reactor on biogas production. It has been found from the results that agricultural and environmental sustainability associated with livestock waste can reduce pollution risk considerably through biodigestion. It has also been found that stages inside the reactor do have an effect on gas production, which has been increased by up to 30%.

1. Introduction

The global food supply, nutrition, and economic security of a country largely depend on animal agriculture. Ruminants, nonruminants, and aquatic animals largely comprise domestic animal agriculture in several countries. Cattle, poultry, swine, and companion animals are the main examples. Among the several advantages of animal agriculture to the population, a few of these are an increase in the supply of nutrient-dense foods, family income growth, job creation, etc. It can also help in agricultural diversification, improving soil fertility, and transportation, and may also help in asset savings, economic output and taxes, and animal traction [1, 2].

By implementing the Clean Development Mechanism (CDM) and the Kyoto Protocol, the diversification aims to prevent pollution at its source and recycle waste into usable final products in a scientifically and economically viable manner. It also aims to generate sustainable income through the sale of organic manure and electricity generated by the state electricity grid.

Based on the studies and case reports, it can be said that solid waste is produced at a steadily increasing rate around the world, and its disposal is a growing problem. India is an agricultural country, a significant role is played by livestock in the farming system of India. Benefits like availability of milk, meat, and so on can be attributed to livestock, but farm yard manures, wool, and egg can also be provided by it. In addition, they are largely used in agriculture for draught purposes as well as for transport purposes. Countries like America, Europe, Asia, and Africa have contributed significantly to livestock manure globally to the extent of 36%, 22%, 21%, and 17%, respectively [3]. In present times, a requirement has emerged for the removal of nutrients from livestock waste to treat solid and liquid waste from it.

The solid waste components of livestock manure can be treated by biodigestion. This can be achieved either by close vessel or tank mode or active continuous composting treatment [4]. The bioreactors are of different types based on the aerobic and anerobic biodigestion processes. There are several stages involved in the anerobic digestion process: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The efficiency of biogas production in each process depends on the type of material undergoing digestion and many other factors because it is attributed to the dominance of the microorganisms involved in the process. A relative increase in inbound and residual phosphorus forms has been observed with the decrease in the concentration of labile inorganic phosphorous during the digestion process. The loss of nutrients in the digestor is affected by runoff and leaching [5]. Additionally, a significant reduction in total nitrogen (below 10 g/kg) after the biodigestion process has been reported by several researchers [6, 7]. Moreover, factors like carbon to nitrogen ratio (C/N), substrate moisture, nutrient stability, hydraulic retention time (HRT), porosity, particle size, water, and temperature can also influence the biodigestion process. [8] The metabolic process of the microbes is regulated by their microbial activities in the digestion process, which are strongly affected by temperature. It is therefore eliminated by applying heat during cow dung digestion [9]. Thus, the temperature is the most vital parameter inside the digester. The methanogen bacteria are active even at low temperatures like 10–15°C [10–12]. The biogas production can be increased tenfold if the temperature is increased from 10 to 25°C. It has been observed that the biogas produced at high temperatures with low HRT is quite comparable to that produced at low temperatures with high HRT [10]. The anaerobic biodigestion process that produces biogas mainly comprises methane and carbon dioxide with very low quantities of other chemicals such as hydrogen sulfide and nitrogen [13, 14].

2. Study Area

Gwalior is a town in the Madhya Pradesh State of India, and its relative proximity to Delhi gave it its status as a “countermagnet” in the National Capital Region. As per Census 2011, population of Gwalior city was 10,69,276. The reported number of cattle in Gwalior city are 35,787, as per the Gwalior Municipal Corporation (GMC), which contributes about 319.6 MT of livestock waste. For treatment of livestock waste by biodigestion, it is necessary to assess the factors affecting digestion. Therefore, an attempt has been made in the present study to assess the feasibility of biodigestion of cattle waste.

3. Material and Methods

In order to assess the feasibility of biodigestion or composting, the characterisation of livestock waste is required. The information about the waste has to be determined under the following heads:

(1) Physical parameters, including electrical conductivity (EC), particle size, porosity, nonvolatile solids, and temperature.

(2) Chemical parameters required to analyse as carbon-to-nitrogen ratio (C/N), nutrient stability (NPK), pH, moisture content, and calorific value.

Waste samples were obtained from several cattle owners in the Karounda Nala, Imaliya, Pariyat, Kandrakheda, and Gour regions in order to ascertain the characteristics of cattle waste. The GMC authorities in charge of waste management in Gwalior City and those involved with site operation were consulted for determining the sample locations. Samples were taken for one day at each location, during which all of the cow dung generated that day was collected and combined. Each location collected and mixed around 70 kg of sample, which was then placed in double plastic bags and labelled as detailed in Table 1. The samples taken to the laboratory are processed by the quartering method to prepare a representative sample for each of the four slots (slots are classified according to the location of the sample collected) that can be handled for testing parameters in the laboratory. Following Figure 1, explain the quartering method used for preparing the representative sample, which was analysed in the laboratory.

The analysis of representative samples was done in the laboratory for determining pH (of 1 : 10 water extract), electrical conductivity ($dS \cdot m^{-1}$) and moisture content (at 105°C). Polythene sheets were used to air dry the samples by spreading them. Then, the samples were analysed for density, total nitrogen ($g \cdot kg^{-1}$), total phosphorous ($g \cdot kg^{-1}$), and total potassium ($g \cdot kg^{-1}$). In addition, organic carbon (C) and nonvolatile solids at 550°C were also determined. The results are provided in Table 2.

Before the solution is transported to the reactor, it is completely mixed by stirring. In four distinct reactors, 100 ml of substrate (combined as 1 : 2) was dissolved in 250 ml, 500 ml, 750 ml, and 1000 ml, respectively, to assess the impact of substrate size. An incubator was used to incubate the solution in the reactor at 35°C. The rate of biogas generation is anticipated to go through many phases. It may be explained by the lower mass transfer resistance provided by the substantial amount of suspension. Four samples totalling 250, 500, 750, and 1000 ml were utilised to evaluate the impact of utilising stages or layers inside the reactor. The findings were compared. The amount of gas produced is recorded for all the samples. The gas chromatograph was used to measure the quantity of gas produced in ml during digestion for each day up to 12 days. The amount of gas is measured by injecting the samples inside the gas chromatograph, and readings were recorded for further data processing. The obtained data are reported in the form of tables and graphs. The obtained results are discussed in subsequent text.

Table 1: Quantity of samples collected for analysis.

Sample	Location	Weight (kg)	Total weight (kg)
Occupant 1	Karounda nala	10.36	70.34
Occupant 2		4.78	
Occupant 3		5.12	
Occupant 4		6.39	
Occupant 5		8.25	
Occupant 6		7.14	
Occupant 7		7.65	
Occupant 8		6.84	
Occupant 9		6.14	
Occupant 10		7.67	
Occupant 1	Imaliya	9.65	69.71
Occupant 2		5.99	
Occupant 3		4.19	
Occupant 4		6.69	
Occupant 5		6.32	
Occupant 6		6.67	
Occupant 7		7.02	
Occupant 8		7.37	
Occupant 9		7.72	
Occupant 10		8.07	
Occupant 1	Pariyat & Kandrakheda	8.11	80.23
Occupant 2		9.65	
Occupant 3		9.15	
Occupant 4		10.12	
Occupant 5		6.65	
Occupant 6		7.89	
Occupant 7		8.78	
Occupant 8		8.26	
Occupant 9		4.87	
Occupant 10		6.75	
Occupant 1	Gour area	4.69	69.58
Occupant 2		8.45	
Occupant 3		7.15	
Occupant 4		7.66	
Occupant 5		8.98	
Occupant 6		6.67	
Occupant 7		7.27	
Occupant 8		7.09	
Occupant 9		4.87	
Occupant 10		6.75	

4. Results and Discussion

The representative samples were analysed for pH and moisture content, reporting average of four representative samples as 8.9 and moisture content of waste sample was 38%. These indicate that for the degradation of cow dung, additional water content is required to bring the moisture content level to 65–75%. The effect of using stages/layer inside the reactor was studied. For this, different volume sizes (viz., 250, 500, 750, and 1000 ml) were considered for comparison. The gas production was found to fluctuate from day zero to day 12, as indicated in Figure 2, which can be attributed to the change of stages during anaerobic digestion. The hydrolysis and acidogenesis stages are reflected in the gas production in the reactor from first four days to six, while days six to twelve can be evidence of the methanogenesis process. The rate of cumulative gas production inside the reactor is shown in Figure 3. It can be observed that cumulative gas production goes on increasing per 100 ml substrate as the sample size is increased, viz., 29.91% higher from 250 ml to 500 ml sample, 38.37% higher from 500 ml to 750 ml sample, and 38.93% higher from 750 ml to 1000 ml sample. It can be concluded that the cumulative gas production inside the reactor stabilised as the sample size increased.

The results indicate the effect of the ratio of substrate mixed with water. The layer distance that the gas travels before being discharged to the surface shows that the mass transfer resistance increases as the liquid height in the reactor rises. The conventional reactor design (no layer or stages) can be improved by creating several stages (liquid layer) inside the reactor so as to obtain the desired increased gas production rate.

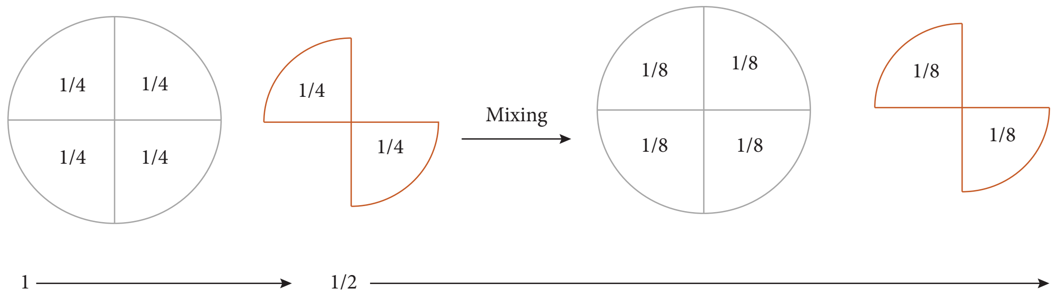

FIGURE 1: Schematic diagram of quartering and the coning method.

TABLE 2: Initial physicochemical characterisation of cattle manure used in the biodigestion process.

Parameters	Sample 1	Sample 2	Sample 3	Sample 4
pH	8.0 ± 0.1	7.2 ± 0.1	6.6 ± 0.1	8.8 ± 0.1
Electrical conductivity ($dS \cdot m^{-1}$)	1.1 ± 0.1	2.3 ± 0.1	1.7 ± 0.1	1.8 ± 0.1
Total organic carbon (%)	46.8 ± 0.5	46.8 ± 0.5	38.1 ± 1.3	31.2 ± 1.0
Total nitrogen ($g \cdot kg^{-1}$)	20.8 ± 0.1	22.4 ± 0.7	25.6 ± 1.0	21.8 ± 0.7
Total phosphorous ($g \cdot kg^{-1}$)	7.7 ± 0.2	6.3 ± 0.2	9.9 ± 0.2	8.7 ± 0.2
Total potassium ($g \cdot kg^{-1}$)	8.1 ± 0.1	9.3 ± 0.1	8.8 ± 0.1	9.6 ± 0.1
Moisture content (%)	36.4 ± 0.5	30.9 ± 0.5	37.8 ± 0.5	39.1 ± 0.5

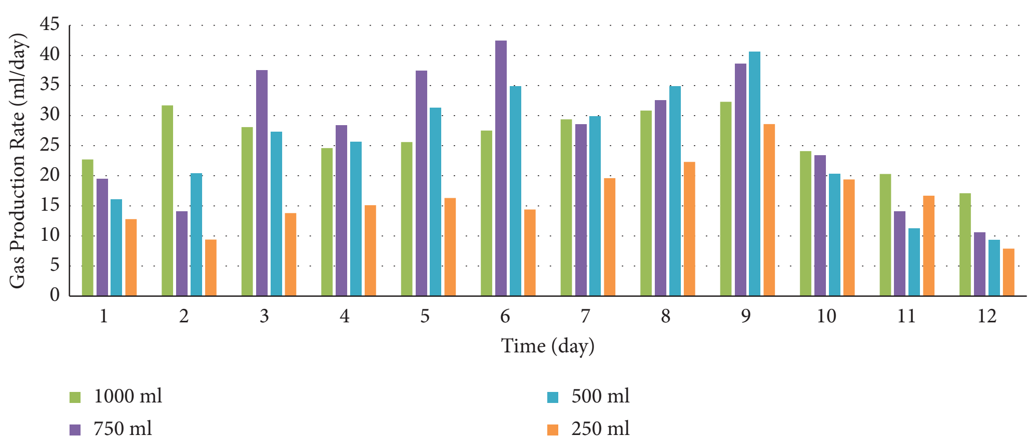

FIGURE 2: Daily gas production rate.

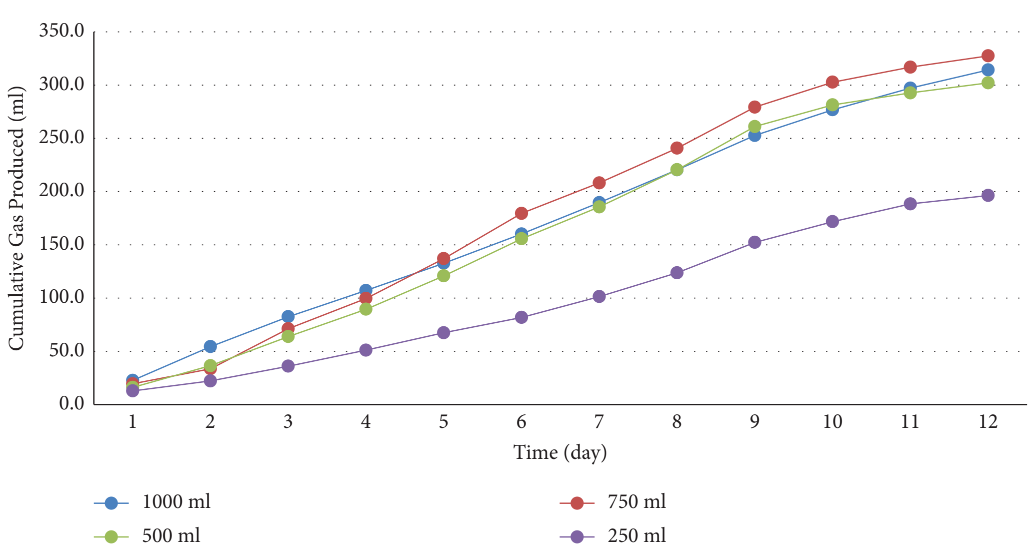

FIGURE 3: Cumulative gas production rate.

5. Conclusions

The following major conclusions can be made on the basis of the results derived:

(1) A multistage anaerobic biodigester is recommended in the study for the treatment of cattle waste in Gwalior town.

(2) The findings of the study could provide the feasibility of using cow dung as feedstock for a proposed biodigester based on the results of samples collected and analysed for the parameters that affect the biodigestion process.

(3) As per the findings of the present study, the digester design should include multiple stages of a liquid layer to improve the efficiency of biogas production, which ultimately benefits the authority operating the biodigester.

(4) Providing biodigester will be efficient and sustainable as a result of biogas production, which can be further utilised for power generation by several means. The gas can also be further fractionated to produce a pure form of methane (CH_4).

(5) The graph in Figure 3 shows that the rate of gas production can be improved by using feedstock with a multilayered digestion process in a biodigestor.

The results indicate the effect of the ratio of substrate mixed with water. The layer distance that the gas travels before being discharged to the surface is shown.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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