Design, a Study of Laboratory-scale Experimentation and Economic Analysis of Biogas Plant for Phuentsholing Area

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Abstract

The project focuses on designing the biogas plant considering the normal temperature of Phuentsholing area and carrying out the laboratory experiment for the different feedstock. Factors like temperature (ambient temperature), pH value of leachate, pressure, and the ratio of the feedstock to water has been considered. The paper also presents the amount of gas produced by the different feedstock. The three different feedstocks used are rice water, brewery waste, and the cow dung. The total solid suspended (TSS) test for each feedstock was performed to ensure the minimum content of 20,000 mg/l. For hydraulic retention time (HRT) of 10 and 21 days, the readings were recorded from the laboratory scale experimental setup. For measurement of the gas volume, the U-tube manometer is used. The volumes of gas produced per kg are 0.1411 cm^3/kg, 0.0641 cm^3/kg, and 0.1026 cm^3/kg for cow dung, brewery waste, and rice water respectively in 10 days. Besides, the result of the experiment, the volume of gas produced is integrated for real-time quantities of the feedstock. Based upon the result of the experiment, the design of the plant was made, whereby the digester volume is calculated theoretically, and the cost involved in building the plant is also estimated. The energy content of biogas produced is also calculated and compared with two other energy sources, which are electricity and liquified petroleum gas (LPG).

Key Words: *Feedstocks, Total solid suspended (TSS) test, Biogas, Energy, Leachate.*

1. INTRODUCTION

These kinds of energy sources such as petroleum and nuclear increase greenhouse gas and lead to environmental degradation which is one of the world's concerns that had driven interest in renewable energy generation. The use of renewable energy sources like solar, wind, tidal, and biogas was adopted by many environmental organizations, as it is eco-friendly. The initial cost involved in building the infrastructure for renewable energy is costlier, however, in the long run, it gives positive sides on the economic and energy background.

Anaerobic digestion converts the waste into a valuable energy source (Achinas, Jan and Euverink, 2016). Production of biogas is anaerobic digestion and it is one of the renewable energies that have started gaining its popularity in the world. It is an alternative energy source that can meet the growing demand in rural areas and developing countries. Its expenditure is less than other renewable energy sources. The work to be done in the biogas is simple and required less time.

Although Bhutan is almost electrified, biogas plays a vital role in rural areas. It has become important to the farmer who cannot afford LPG and to those who own livestock and those who brew locally produced alcohols can take advantage of it. The government had also encouraged the farmers to use the biogas. In some of the rural areas in Bhutan, the use of LPG was replaced by biogas. Therefore, the use of LPG has reduced in some of the rural areas.

The project was targeted for designing the biogas plant for Phuentsholing area by considering the temperature and humidity of the place. As it is difficult to control these two parameters, therefore they are not controlled unlike in many cases.

2. LITERATURE REVIEW

Group of biogas microbes (bacteria) are methane-producing and non-methane producing (fermentative and hydrogen-producing acetogenic bacteria). Groups of microbes involved in the three stages of biogas fermentation. First stage: fermentative bacteria (it produces volatile acids, hydrogen, and carbon dioxide). Second stage: hydrogen-producing acetogenic bacteria (acetic acid, hydrogen, and carbon dioxide). 3rd stage: methane-producing bacteria (produces methane and carbon dioxide) (Center (BTC), n.d.).

Maximum generating capacity = 4 m^3 at the temperature (35-40 ºC). The biogas plant was operating on the surrounding temperature (27 ºC). pH is one of the important factors in the production of biogas. Thus, it was maintained to 7 by adding sodium hydroxide to leachate before it goes to the methanation tank (Khandu, Pema., Zangmo, Sonam., & Peljor, 2018).

The introduction of biogas technology in Bhutan began in the 1980s as one of the clean and renewable sources of energy but due to poor technical design and scarcity of spare parts, most of the biogas technologies are uninhibited (Subba, 2017). As the composition of microorganism's populations and the intensity of their operation are predetermined by temperature as the temperature is one of the important factors determining the rate of biogas production (Nagel 2001).

The biodigester is operated on temperature range for psychrophilic below 28 °C, mesospheric at the medium temperature range from 29 °C to 40 °C and thermopile temperature from 50 °C to 55 °C. The retention time is also affecting the biogas production and the slurry prepared with different ratios of biomass and the gas production is found higher when the proportion of waste to water is 1:0.5. The total gas collected is around 0.95 m^3 with a methane content of 85% and the pH value of 7.3 (Das et al., 2017).

3. METHODOLOGY

3.1 Designing of the system

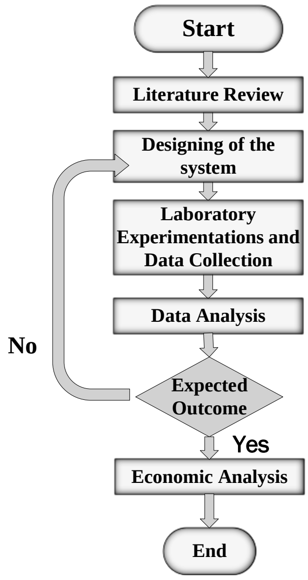

Fig. 1 Methodology flow chart

For experimentation, two setups were made in the process of the project. The earlier one was based on the principle of water displacement method. Due to low pressure of biogas produced from the reactor, the water could not displace. Hence second experimental setup's design was made based on the principle of the U-tube manometer and water displacement method. The operation of the set up follows the aforementioned principles, whereby initially, when there is no digestion in the reactor, the pressure on the surface of liquid remains same and the level of the liquid too.

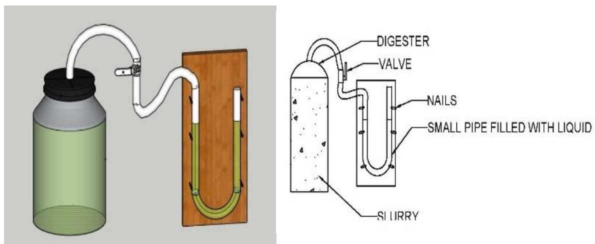

Fig. 2 Design of experimental set up

For the real-time purpose of implementation, the Fixed-Dome Type Plant. It is selected based on its merits and demerits. The Biogas model stands out to be highly promising in the rural areas. Some of the prominent features of the biogas plant are: it is spherical, with a fixed-dome top and concaved bottom. Since it is spherical, the sideways surface area is small with pressure and stresses of load distributed evenly, hence, compact and solid. Moreover, the construction of the model is economical. No dynamic parts and metallic components, except the structural supports.

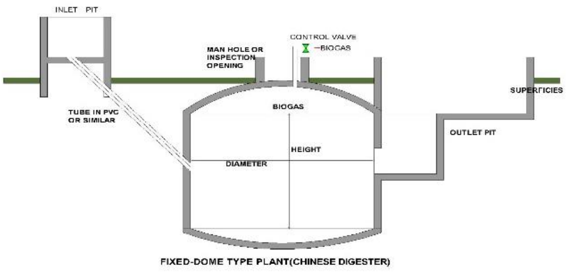

Fig. 3 Fixed-Dome Type Plant

Hence, it is robust, and almost a long-term investment. It is completely constructed underground. Hence, the digester is protected to maintain a high variation in temperature. The digester works on the principle of gravity whereby the input materials flow effortlessly into it, thus the operation is simplified. It has the capability of generating higher gas pressure which is due to an exclusive gas storage mechanism that does not need a floating tank as other designs do. It uses the displacement principle where slurry moves up and down the specially designed outlet compartment as gas volume changes inside the digester.

3.2 Laboratory Experiments

For the laboratory scale experimentation, the feedstock chosen is cow dung, brewery waste, and rice water. The experiment was conducted by maintaining a certain amount of waste to water ratio. Similarly, feedstock to inoculum and hydrogen ion concentration (pH) in the slurry is maintained initially before experimenting.

Total Suspended Solid (TSS) test

Before conducting the experimentation for the production of biogas. It is important to know the solid content of each feedstock. Hence, a TSS test was conducted for every feedstock. The solid content in the slurry determines the retention periods of the plant.

Table 1: Feedstock used

Sl. No	Feedstock	Waste: water	Inoculum	pH
1	Brewery waste	1:1	20 %	6.5
2	Rice Water	2.5:1	20%	7
3	Food waste	2.5:1	20%	7.5

The inoculum to feedstock ratio was taken as 20 % of the amount of each feedstock used. Whereby the pH of the slurry is initially maintained at the range of 6.8 to 7.5 by adding $NaHCO_3$.

Table 2: TSS test results

Feedstock (g)	Ratio (water: waste)	Sample Weight (g)	TSS (mg/l)
Cow dung	1:1.5	4.959	85,760
Rice water	1:1	0.917	9,500
Rice water	1:2	1.27	85,760
Brewery waste	1:2	1.12	99,000

According to Khandu and Peljor (2018), the TSS of every feedstock should be greater than 20,000 mg/l.

The data from the experiment were recorded by measuring the height of the liquid displaced in the U-tube manometer. Thus, calculating the volume of cylindrical displacement, the volume of gas produced will be calculated.

The diameter of connecting pipes = 0.7 cm

The volume of biogas is calculated using the formula, Volume = Area (A) * height (h)

$= Ah = \pi r^2 h$

Therefore, radius (r) = 0.35 cm. Hence, A = 0.3848 cm^2.

The readings recorded are as follows:

Table 3: First reading

Fig. 4 Reading taken from the experiment

Feedstock	Cow Dung	Brewery waste	Rice water
Height of liquid displaced (cm):	1.1	1	0.8

Volume (cm^3):	0.4233	0.3848	0.3078

HRT = 10 days.

Table 4: Second reading

Feedstock:	**Cow dung**	**Brewery waste**	**Rice Water**
Height of liquid displaced (cm):	3.5	4	3.8
Volume (cm^3):	1.3468	1.5392	1.4622

HRT = 21 days.

4. Data Analysis

Gas production per kg or l is calculated using the following formula:

$$\frac{\text{Volume of gas produced } (cm^3)}{\text{Amount of feedstock used (kg or l)}}$$

The unit is cm^3 per kg or cm^3 per liter.

Table 5: Calculation for first reading

Amounts of feedstock used:	3 kg	6 liters	3 liters
Gas production (cm^3/ kg or cm^3/l):	0.141	0.064	0.102

Table 6: Calculation for second reading

Amounts of feedstock used:	3 kg	6 liters	3 liters
Gas production (cm^3/ kg or cm^3/l):	0.448	0.256	0.487

In the second reading, the cow dung has a low height of displacement of liquid inside as compared to other reactors with another feedstock. Due to leakage of the gas from the reactor, thus, it hampered the recording. From the literature review, cow dung is expected to give more gas production

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Fig. 5 Comparison on volume of gas production of reading 1

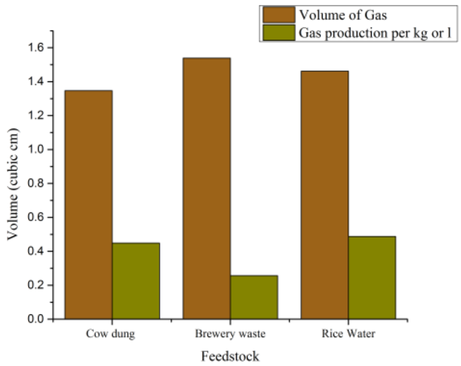
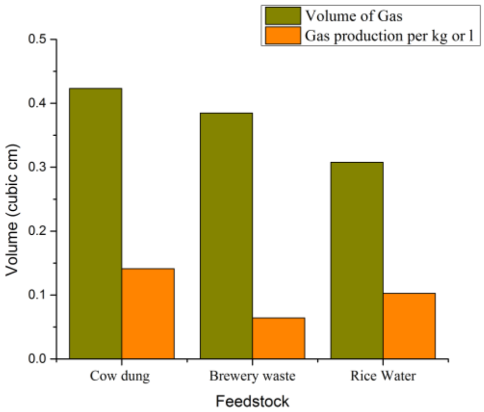


Fig. 6 Comparison on volume of gas production of reading 2



Economic Analysis

Deublein and Steinhauser (2008) have mentioned that 1 m^3 of biogas has a calorific value of 6 to 6.5 kWh. Taking the calorific value of 6 kWh, the following calculations are done:

Table 7: Energy content of each unit weight of feedstock from reading 1.

Energy	**Cow Dung**	**Brewery waste**	**Rice Water**
Energy (Wh/kg or Wh/l):	$8.466 * 10^{-4}$	$3.846 * 10^{-4}$	$6.156 * 10^{-4}$

Table 8: Energy content of each unit weight of feedstock from reading 2

Energy	**Cow Dung**	**Brewery waste**	**Rice Water**
Energy (Wh/kg or Wh/l):	$2.693 * 10^{-3}$	$1.539 * 10^{-3}$	$2.9244 * 10^{-3}$

Since the production of biogas is more in cow dung, similarly the energy generation is also more in it. Thus, one can conclude that cow dung has experimentally higher calorific value and more biogas production than the other two feedstocks experimented.

Taking the second reading:

Table 9: Energy of Real-Time Quantity using second reading

	The energy of Real-Time Quantity (Wh)		
	100 kg	**200 kg**	**500 kg**
Cow Dung	0.2693	0.5386	1.3465
Brewery Waste	0.1539	0.3078	0.7695
Rice Water	0.2924	0.5848	1.4622

As per the launching of Non-subsidized LPG in 2018, it cost Nu. 50.8451 per kg and similarly, Nu. 37.32 per kg for subsidized LPG, where the cost of electricity for LV block-I is Nu. 1.28 per unit.

Hahn (2019) has mentioned that 1 kg of LPG gives 13.6 kWh of energy.

If it is converted into electrical energy, the cost of energy will be Nu. 17.408. Similarly, if the 1 m^3 of biogas can produce 6 - 6.5 kWh, to get the same energy that of 1 kg of LPG:

13.6 / 6 = 2.67 m^3 of biogas is required.

The experimental result says that the usage of a biogas plant as the source of energy substituting the other two sources is not efficient.

Determination of Plant Size

Hidayati and Maktub (2019) have calculated that a kg of cow dung will give 0.04 m^3 of biogas.

Taking HRT = 10 days and considering the daily supply of 100 kg.

The ratio of waste to water is maintained as 1:2

Thus, the amount of slurry used will be:
= 1*100 + 2*100 = 300 kg = 0.3 m^3

The volume of Digester (VD) = Daily Supply (S_d) * Retention Time (RT)

= 300 * 10 = 3 m^3

Total volume of the unit will be:

3 m^3 slurry + 25 % of 3 m^3 (as gas holder) = 3 + 0.75 = 3.75 m^3

Daily gas production is found to be 0.7596 m^3 /day. The estimation of cost to build the biogas plant is approximately Nu. 23,141.

It is theoretically found that the annual gas production of the plant is 277.25 m^3, thus, annual cost saving is Nu. 2,149.12.

Where the Simple Payback Period is at 10.76 years.

4. CONCLUSION

Non-renewable energy leads to environmental degradation, which is one of the world's concerns that had attracted interest in renewable energy generation. Therefore, the biogas plays important roles in renewable energy and it has been adopted as one of the clean and green energy sources by the environmental organization. Biogas is a future energy and technology growth is expanding at an ever-greater rate. Also, the biogas plant is simple and easy to control.

The experiment was conducted for different feedstock maintaining certain parameters. The feedstocks used are cow dung, rice water, and brewery waste. The average ambient temperature for Phuentsholing during the experimentation was 23.1 °C, the average humidity was 72.1 % and the pH was maintained constant at 7.5 by adding sodium bicarbonate ($NaHCO_3$). From the experiment conducted, the cow dung (2:3 ratio) produced 0.4489 cm^3/ kg, rice water (1:2) 0.4874 cm^3/ kg and brewery (1:2) 0.2565 cm^3/ kg of biogas. The cow dung gave the highest biogas production amongst three feedstocks. For the Phuentsholing area, for a real-time scale, the amount of feedstock considered is 100 kg, 200 kg, and 300 kg for all the feedstock used in the experiment. The reading recorded from the experiment is taken as a reference for the real time scale, the fixed-dome type plant is selected based on its merits and demerits. The result shows that cow dung is one of the feedstocks, efficient for the production, then rice water, and lastly the brewery waste.

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