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Design and development of portable household biogas plant

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■ **ABSTRACT :** Energy is one of the prerequisites for the growth of agriculture and industry. The growing global awareness of the energy crises has brought us to the beginning of what might be called as the "recycle revolution". Biogas as an alternative source of energy has been widely recognized in a number of countries of the various alternative sources of energy. Biogas energy assumes a major role with special reference to the rural sector. Biogas is generated by anaerobic digestion using cow dung, methane content of the gas produced from the digestion of the cattle varied from 60 to 72 per cent, the remaining being carbon-dioxide. The feed material cow dung and kitchen waste selected for experimental study was analyzed for physical and chemical characteristics using standard procedure. A cylindrical shaped floating drum type biogas plant which gives constant gas pressure, less scum problem, higher gas production per cubic meter of digester volume and less leakage over fixed dome type plant. The biogas digesters work safely up to a pressure range of 0.05 kg/ cm^2 (50 m bar). Hence, the pilot size biogas plant designed will operate safely. The pressure developed inside the gas holder was measured by using the Borden type pressure gauge (0-2 kg/cm^2). The temperature of gas was measured by handheld thermometer (0-110^0 C). The cow dung, kitchen waste and water is mixed in definite proportions on weight basis to bring the total solid. The amount of gas produced in 24 hours was measured daily from gas holder till 40 days of experiment. The experimental result indicated that 6 to 8 per cent of digester volume added with inoculums before feeding the material increased the biogas production. It was noted that combination gas production from slurry combination was 350.99 liters in 2.08 size digester at the end of retention period of 56 days

■ **KEY WORDS :** Biogas, Kitchen waste, Cow dung, Energy, Portable

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Energy is one of the prerequisites for the growth of agriculture and industry. The energy requirements are mainly met through commercial energy sources like oil and coal. In recent years, the prices of fuels, oil and coal have increased sharply and there is a continuous depletion of these scarce resources. Hence, there is an urgent need to develop and exploit the alternative sources of energy. There are several renewable energy sources like solar, wind, tidal and biomass which are now being considered as alternative to conventional energy sources. The strength of India's biomass resources mostly lies in the agricultural sector. A large quantity of crop residue biomass is generated in India. However, burning of cattle dung, agricultural residues and other non-commercial fuels in Indian villages has been a traditional practice, because of the non-availability of cheaper alternative fuels. Incomplete combustion of such fuel leaves a pale of smokes which pollutes the atmosphere and adversely affect the health of the people. Therefore to meet the energy requirement we need the alternate sources of renewable energy like biogas, solar energy etc. The anaerobic digestion of agricultural wastes produces biogas, a valuable energy resource. Anaerobic digestion is a microbial process for production of biogas, which consists of primarily methane (CH_4) and carbon dioxide (CO_2) 650 lit of biogas daily in 1000 lit reactor, under ideal conditions (Ziauddin and Rajesh, 2015). But with increased demand for renewable energy in the rural area, cattle dung alone will not form enough substrate material to meet the growing demand of biogas plants, so the potentiality of using various agricultural and animal wastes for biogas production is one of the alternatives. Biogas produced from the decomposition of food waste has a mixture of 76 per cent methane and 24 per cent carbon dioxide (Mohan and Jagadeesa (2013). Keeping this point in view research project were undertaken to analyze the biogas production potential of the animal and kitchen waste.

■ METHODOLOGY

The feed material, cow dung selected for experimental study was analyzed for physical and chemical characteristics using standard procedure.

Determination of moisture content and total solids of samples :

A known quantity of material of each substrate were kept in aluminum boxes and placed in an oven at 65^{0}C for 7 to 8 hrs till the constant reading of weight was obtained. Initial weight of the box with the sample before placing in the oven and the weight after drying was determined using a precision electrical balance with an accuracy of 0.1 g.

From the observed value of moisture content of samples as explained in pervious section the total solids presents in each test sample was determined using the following formula:

Total solids = Weight of test sample – Weight of water content in the sample.

Standardization of the solid content of feed material to 10 per cent level:

After determining the moisture content and total solids of each of the sample, the solid content of the sample was maintained at 10 per cent. In order to bring the total solid content of each feed material to 10 per cent level, the following procedure was followed.

The required quantity of water to be added was calculated using the following equation:

$$Q = X \times \left(\frac{90}{10} \right) - Y$$

where, Q= Quantity of water to be added, fraction
X=Initial total solid content of feed material,
Y=Amount of water content in feed material.

Determination of bulk density of sample :

The test samples were cut into small pieces and filled in a known volume V cc of sample box weighing W_2 g. The weight of box with sample W_1 g was determined using a precision electrical balance with an accuracy of 0.1 g. The procedure was repeated thrice for each sample the bulk density was calculated using the following formula.

$$\text{Bulk density} = \frac{\text{Weight of sample}}{\text{Volume of sample}}$$

Determination of volatile solids (VS) :

The oven dried samples of cow dung and kitchen waste were weighed (W_2) and kept in the muffle furnace at a temperature of (550 $\pm$ 10) ^{0}C for 30 minutes. After drying, the samples were taken out and weighed (W_4). The differences in the weight of each of the samples were noted. The procedure was repeated for three times. The volatile solids were calculated as under:

Determination of carbon content :

The oven dry samples of cow dung and kitchen waste were weighed (W_2) and placed in the crucibles in muffle furnace. These samples were treated at 900 ^{0}C for 6 hours. Then the charred sample were taken out carefully and weighed (W_5) in an electrical balance having an accuracy of 0.1g. The difference in weights of the sample gave the carbon in each sample. The same procedure was for three times and average values were recorded. The carbon content of the sample was determined using the following formula:

$$\text{Carbon content, \%} = \frac{W_2 - W_5}{W_2} \times 100$$

Estimation of nitrogen content :

The total nitrogen content of samples was estimated using the standard procedure suggested by Micirokjeldhal method which is explained below:

For one ml of sample, three ml of 25 per cent $KMnO_4$ was added. Then 10 to 15 ml of diacid (H_2SO_4 : $HClO_3$ = 5:2) was added and digestion was carried out in a Kjel plus digester with 20 to 50 m1 of 40 per cent NaOH in a kjel plus unit and the distillated sample was titrated against 0.01, N H_2SO_4. The procedure was repeated thrice for each sample and the average values have been reported. The C:N ratio of selected samples was calculated by determining the carbon content of sample to the nitrogen content as earlier.

Design and development of digesters :

In order to study the effect of pressure and temperature on biogas production, the design parameters of digesters like depth to diameter ratio and shape were considered.A cylindrical shaped 750 litre capacity digester was chosen for collecting of gas.The dimensions of depth (H) and diameter (D) of digester was calculated as given below:

$$V Z \frac{\pi}{4} x D^2 x H$$

Design and construction of biogas plant:

Site selection :

The site selected for conducting field experiment was located at department of agricultural Engineering, GKVK, UAS, Bangalore. A cylindrical shaped floating drum type biogas plant was considered for the study as it had many advantages like constant gas pressure, less scum problem, higher gas production per cubic meter of digester volume and less leakage over fixed dome type plant.

Estimation of gas requirement :

The proposed biogas plant was designed to meet the cooking gas requirement of a family consisting of two adults and a child. The gas requirement for cooking per adult per day was 0.227 m^3. Hence, the gas requirement per day for the above said family was worked out to be = 0.22 x 2 + 0.12= 0.574 m^3/ day = 0.5 m^3/ day.

Mixing ratio :

The dung was mixed with water in 1:3.16 proportion (dung: water) for bringing down the total solids (TS) present in the slurry to 10 per cent.

Size of digester :

The size of digester was calculated using the following formula:

$$V_D = V_C \text{ x HRT}$$

where, V_D = Digester Volume (m^3)

HRT = Hydraulic retention time, days and

V_C = Volume of daily charge (m^3)

$$Vc Z \frac{W}{B.D.}$$

where, W = Weight of (dung+ water). kg

B.D = Bulk density, kg/ m^3

The height of digester was calculated by using the following formula:

$$V Z \frac{\pi}{4} x D^2 x H$$

where, V = Digester volume, m^3

d = Inside diameter of cement ring, m

H = Depth of digester, m

Size of gas holder :

Most of the floating type biogas plants have cylindrical shaped gas holder (Rai, 1999). Accordingly, cylindrical shaped drum with conical dome was selected as gas holder for collecting the gas. The gas holder was designed for 75 per cent of volume required for daily gas production. Hence, the volume of gas to be collected by the gas holder was worked out to be 0.5 x 0.75 = 0.375 m^3/ day.

The total volume of gas holder was calculated by using the following formula:

$$V_t = V_{ci} + V_{co}$$

where, Vt = Total volume of gas holder, m^3

Vci = Volume of cylindrical portion of gas holder, m^3

Vco = Volume of conical portion of gas holder, m^3

$$V Z \frac{\pi}{4} x r^2 x h$$

where, r = Inside radius of gas holder, (m)

h = Height of cylindrical portion, (m)

Pressure developed inside the gas holder :

The pressure developed inside the gas holder was calculated and it worked out to 0.0035 kg/ cm^2. The biogas digesters work safely upto a pressure range of 0.05 kg/ cm^2 (50 m bar). Hence, the pilot size biogas plant designed will operate safely.

Leakage tests for gas holder :

Before feeding the material the gas holder was tested for leakage. For this purpose, the gas holder was kept in inverted position and was filled with soap solution. The leakages were noticed by air pockets and bubbles and were rectified. This procedure was repeated for several times until no leakages were observed from joints.

Testing and evaluation of biogas plant :

Preparation of substrate mixing ratio :

The cow dung and water is mixed in 1:3.16 proportions on weight basis to bring the total solid to 10 per cent.

Charging the biogas plant :

Initially, the digester was filled upto 70 per cent of its volume. In order to achieve this level, 250 kg of cow dung and 750 liters of water for maintaining the total solids in the slurry upto 10 per cent.

Measurement of gas :

The volume of gas produced was measured by using standard wet type gas flow meter. The amount of gas produced in 24 hours was measured daily from gas holder till 40 day of experiment.

Measurement of quality of gas :

The percentage of methane and carbon dioxide in the biogas produced under field experiment was analyzed using Orsat apparatus.

Measurement of ambient temperature :

The ambient temperature (maximum and minimum) was recorded daily at GKVK, Bangalore. The readings were taken from the start of the experiment till its completion.

Measurement of pressure and temperature of gas :

The pressure developed inside the gas holder was measured by using the bourden type pressure gauge (0-2 kg/cm^2). The temperature of gas was measured by handheld thermometer (0-110^0 C).

Cost analysis :

The cost analysis of biogas plant was worked out by considering fixed and operating costs of the biogas plant. The fixed cost was worked out by taking into account the depreciation per year at 10 per cent, interest on investment at 12 per cent per year and maintenance cost at 6 per cent per year. The operating cost was worked out by taking into account the cost of initial feeding and daily feeding of cow dung with water and labour charges. The benefits were worked out by considering the slurry output and gas produced annually.

■ RESULTS AND DISCUSSION

The digester was fed with selected substrate namely; kitchen waste like raw and cooked vegetables, cooked food, cow dung etc. The results described are given in Table 1 to 8 and Fig. 1 to 3.

Characteristics of feed substrates and digested slurry :

The result pertaining to different physic-chemical characteristics like moisture content (MC), total solid (TS), volatile solids (VS), bulk density (BD), pH, percentage of carbon (C), percentage of nitrogen (N) and C:N ratio for feed substrates before feeding and after digestion in digesters are presented in Table 1 and 2.

Physical characteristics :

Moisture content (MC) :

The moisture content of feed stock material via, kitchen waste like raw and cooked vegetables, cooked

Table 1 : Physico-chemical characteristics of feed substrate before feeding in to digester

Feed substrate	Moisture content (%)	Total solid (%)	Volatile solid (%)	Bulk density (kg/m^3)	pH	Carbon (%)	Nitrogen (%)	C:N
Cow dung	65.25	34.75	76.26	695.6	7.01	45.20	5.90	7.93

Table 2 : Physico-chemical characteristics of digested slurry in digester (HRT=56 days)

Digested slurry of material	Total solid (%)	Volatile solid (%)	pH	Carbon (%)	Nitrogen (%)	C:N
Cow dung	8.5	62.20	5.54	32.87	2.46	13.36

food etc. and cow dung varied from 51.55 to 83.55 per cent.

Total solids (TS) :

The total solids content of feed substrates varied from 16.45 to 48.45 per cent before feeding the sample in to digester. The percentage of total solids for cow dung was (48.45 %). The total solids of digested slurry varied from 8.1 to 16.7 per cent.

Volatile solids (VS) :

The volatile solids of feed substrates before charging the digester varied from 72.14 to 85.63 per cent. While, it ranged from 62.20 to 67.90 per cent in digester slurry.

Bulk density (BD) :

The bulk density of substrates varied from 573.3 to 896.5 kg/m^3 before feeding the digester. It was observed that the bulk density was in cow dung (896.5 kg/m^3).

Chemical characteristics :

The pH the substrates before changing the digester are presented in Table 1. The pH of digested slurry after 56 days of hydraulic retention time (HRT) are presented in Table 2. It was observed that the pH of substrates before feeding varied from 4.57 to 7.01(Table 1). The pH of digested slurry varied from 5.15 to 5.93 after digestion in the digester (Table 2).

Carbon content (C) :

The carbon content of feed substrates before charging ranged from 33.30 to 55.30 per cent (Table 1). The carbon content in substrates varied from 32.87 to 43.04 per cent after the digestion.

Nitrogen content (C) :

The percentage of nitrogen in the substrates before charging the digester varied from 1.85 to 5.90 per cent. The percentage of nitrogen content in the digested slurry varied from 2.05 to 2.46 per cent.

C: N ratio :

It was observed that the C:N ratio of the substrates ranged from 7.93 to 26.1 **.**The C:N ratio of digested slurry varied from 13.36 to 20.11

Performance evaluation of digesters :

The test results of digesters of 2.08 (H/D ratio) sizes are presented. This digester was fed with feed substrate of cow dung at a proportion of 3:1 (cow dung substrate) The studies conducted for a retention period of 56 days during the first stage of experiment are presented under the following headings:

– Effect of size and environmental factors on gas production

– Analysis of composition of gas in different substrates of digesters.

Effect of size environmental factors on biogas production from cow dung :

From Table 3, it was noted that combination gas production from slurry combination was 350.99 litres in 2.08 size digester at the end of retention period of 56 days. Also, Table 3 indicated that the weekly gas production fluctuated marginally from first to fifth week thereafter, decreased gradually till the retention period of eight weeks in all three digesters.

Table 3 : Weekly and cumulative gas production from cow dung (HRT=56 days)

Weeks	Weekly	Cumulative
1	35.45	35.45
2	37.29	72.74
3	48.65	121.39
4	45.43	166.82
5	54.25	221.07
6	52.15	273.22
7	48.61	321.28
8	29.61	350.99

Analysis of gas composition in feed substrates :

The percentage of methane, carbon dioxide and

Table 4 : Gas constituents in cow dung biogas

Sr. No.	Gas constituents (%)	Retention period, week							
		I	II	III	IV	V	VI	VII	VIII
1.	Methane	37.2	40.9	45.3	48.6	51.7	60.5	56.4	56.3
2.	Carbon di oxide	58.5	53.6	50.5	45.3	41.6	30.8	35.9	39.2
3.	Other gases	4.3	5.5	5.2	6.1	6.7	8.7	7.7	4.5

other gas constituents of biogas have been analyzed weekly. The weekly gas analysis done for the substrates at the digesters is given in Table 4.

Performance evaluation of biogas plant :

The results of pilot size biogas plant feed with substrate studied for a retention period of 42 days during the second age of experiments are studied

Nutrient analysis :

The percentage of nitrogen (N), phosphorus (P) and potassium (K) content of digested slurry are presented in Table 5. The percentage of nitrogen, phosphorus and potassium varied from 2.40 to 2.43 per cent, 0.84 to 0.85 per cent and 0.69 to 0.72 per cent, respectively (Table 5).

The maximum nitrogen of 2.43 per cent phosphorus of 0.85 per cent and potassium 0.72 per cent were observed, respectively during forty second day of retention period followed by thirty fifty day of retention period (2.42%, 0.84% and 0.70 %) and 2.40, 0.84 and 0.69 per cent during twenty eighth day of retention period.

Statistical analysis :

Statistical analysis of digesters :

In order to study the independent and combined effect of ambient temperature and pressure on biogas production in prototype digester during the retention period of 56 days in the substrate cow dung, a regression analysis was carried out. The regression co-efficients obtained are represented in Table 6 to 8.

Specimen regression models developed for cow dung is given as under.

Effect of temperature on gas production :

$$Y = 2.544 + 0.117\ X$$

where, Y= Gas production, litres/ day and
X= Temperature, ºC

Effect of pressure on gas production :

$$Y = 2.189 + 24.42\ X$$

where, Y = Gas production, litres/ day and

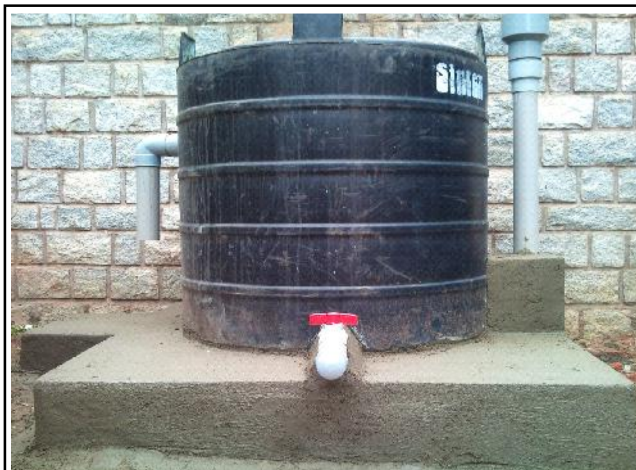

Fig. 1 : Complete installation of biogas plant

Table 5 : Nutrient composition of digested slurry for three different hydraulic retention period

Hydraulic retention time (days)	N (%)	P (%)	K (%)
28	2.40	0.85	0.69
35	2.42	0.84	0.70
42	2.43	0.85	0.72

Table 6 : Statistical parameters of temperature on gas production in biogas plant

Feed material	A	B	R^2	Multiple R
Cow dung	12.24	-183.24	0.437	0.662

Table 7 : Statistical parameters of pressure on gas production in biogas plant

Feed material	A	B	R^2	Multiple R
Cow dung	1794.62	27.51	0.978	0.998

Table 8 : Statistical parameters of pressure and temperature on gas production in biogas plant

Feed material	A	b	b_2	R^2	Multiple R
Cow dung	28.414	-0.0311	1796.71	0.974	0.98

Fig. 2: Feeding in biogas plant

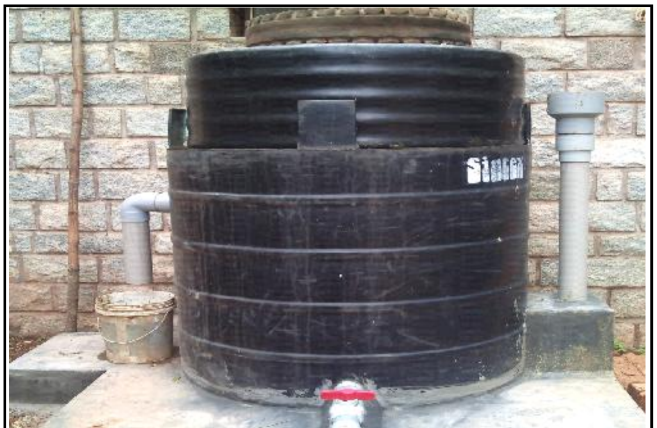

Fig. 3 : Rising of digester due to gas

X = Pressure, kg/cm²

Effect of temperature and pressure on gas production:

$Y = 2.412-0.008 X_1 + 24.52 X_2$

where, Y = Gas production, litres/ day

X_1 = Temperature, °C and

X_2 = Pressure, kg/cm²

Regression models for other two substrates and donkey dung are given in Table 6 to 8.

Conclusion :

A cylindrical shaped floating drum portable type biogas plant which gives constant gas pressure, less scum problem, higher gas production per cubic meter of digester volume and less leakage over fixed dome type plant was developed . The biogas digesters work safely up to a pressure range of 0.05 kg/ cm^2 (50 m bar). Hence, the pilot size biogas plant designed will operate safely. The pressure developed inside the gas holder was measured by using the Borden type pressure gauge (0-2 kg/cm^2). The temperature of gas was measured by handheld thermometer (0-110^0 C). The cow dung, kitchen waste and water is mixed in definite proportions on weight basis to bring the total solid. The amount of gas produced in 24 hours was measured daily from gas holder till 40 days of experiment. The experimental result indicated that 6 to 8 per cent of digester volume added with inoculums before feeding the material increased the biogas production. It was noted that combination gas production from slurry combination was 350.99 liters in 2.08 size digester at the end of retention period of 56 days

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