RESEARCH PAPER | International Journal of Agricultural Engineering | Volume 5 | Issue 1 | April, 2012 | 16 – 20

Anaerobic digestion of cattle dung at higher solid concentration in modified Janata Biogas Plant

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Received : 15.09.2011; Revised : 27.10.2011; Accepted : 25.01.2012

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Abstract **:** The biomass as renewable source can be utilized for production of biogas which can be produced through anaerobic digestion of animal excreta and other agricultural wastes. The main raw material used for biogas production is cattle dung and most of the biogas plants installed in India are operated at 10 per cent total solids concentration. To achieve this, equal quantity of water should be added with dung and this large quantity of water required for operation of biogas plants is an important constraint in propagation of biogas technology in rural areas, particularly in water scarce regions of the country. To overcome the above said problems, an investigation was undertaken to study the anaerobic digestion of cattle dung at higher solid concentration in modified Janata biogas plant. The results indicated that on an average 203 litres of biogas / kg dry matter was produced from cattle dung at total solid concentration of 15 per cent in modified Janata biogas plant with an average methane content of 60 per cent. It was also observed that the nitrogen, phosphorus and potassium contents of digested slurry (cattle dung after digestion) were 1.50, 1.40 and 0.48 per cent, respectively as compared to that of 1.26, 1.20 and 0.40 per cent, respectively for fresh cattle dung, which indicated that digestion of cattle dung at higher solid concentration also results in rich nutrient fertilizer.

Key words **:** Anaerobic digestion, Total solids, Modified Janata biogas plant, Biogas, Cattle dung

How to cite this paper **:** Palled, Vijaykumar, Lokesh and Shirwal, Sunil (2012). Anaerobic digestion of cattle dung at higher solid concentration in modified Janata Biogas Plant. *Internat. J. Agric. Engg.*, **5**(1) : 16-20.

In India, the firewood is the main source of fuel in rural areas that leads to air pollution after combustion. Due to deforestation, the availability of firewood is decreasing day by day and the price of fossils fuels like coal, natural gas, kerosene etc. are increasing. On the other hand, the biomass as renewable source can be utilized for production of biogas, which is a combustible gas. This gas can be used for cooking, heating etc. there by reducing the consumption of other fuels. The main raw material used for biogas production is cattle dung and the most of the biogas plants installed in India are based on cattle dung and operated at 10 per cent total solids (TS) concentration. To achieve this, equal quantity of water is to be added with dung. The large quantity of water required for operation of a biogas plant is an important constraint in the propagation of the biogas technology, particularly in water scarce regions of the country. The solid state anaerobic digestion process could be used as an effective tool for solving the above problem. By using solid state digestion technology, loading rate could be increased to the optimized level, the output rate of gas per unit digester volume could be increased, additional water requirement could be minimized and the digested sludge handling problem could be eliminated to a greater extent and can be easily handled and directly transported to the field.

Ranade *et al.* (1987) studied the production of biogas at different total solids content in cattle dung. They recommended a dung water mixture having 14 per cent TS for water scarcity areas. Shyam (2001) reported that the modified biogas plants for solid state digestion of cattle dung required very little or no water for mixing with the cattle dung and generated 50 per cent higher gas as compared to common biogas plants. He also reported that solid-state digestion makes handling of input slurry and digested slurry much easier than the conventional plants. It has been reported that average biogas production in modified Janata biogas plant was 204.30 litres per kg of dry matter at 16 per cent total solids and at 10 per cent solid content it was 176.54 litres per kg of dry matter which showed 15.72 per cent increase in gas production at 16 per cent total solids Anonymous (2002 a).

Several researchers have done considerable research work on the various aspects of anaerobic digestion and few designs like modified Janata biogas plant have been evolved in various regions of the country. But no research work on anaerobic digestion of cattle dung at higher solid concentration has been carried out in Raichur region. Hence, a study was undertaken to evaluate the performance of cattle dung at higher solid concentration in modified Janata biogas plant in Raichur region.

■ METHODOLOGY

Design of modified Janata biogas plant:

The modified Janata biogas plant of 2 m^3 capacity was designed by Anonymous[6] (2002 b), the details are given below.

Theoretical analysis

Gas production (g):

The gas production from a semi-continuos (daily) fed biogas plant is given by:

$$g = W_f \times G \quad \ldots(2)$$

where,

W_f = Weight of feed material, kg/day

G = Rate of gas production, m^3/kg , G = 0.04 m^3/kg, (for cattle dung)

$$g = W \times 0.04 \quad \text{or} \quad W = g / 0.04 \quad \ldots(3)$$

The minimum active slurry inside the biogas plant is that volume which is generally retained inside the biogas plant and contributes for continuous gas production.

Size of the digester:

The volume of the digester was calculated using the following formula.

$$V_d = HRT \times W / B\,D \quad \ldots(4)$$

where,

HRT = Hydraulic retention time, days

W = Weight of (dung + water), kg

B D = Bulk density, kg /m^3

Generally diameter (d) to depth (h) ratio of digester is kept in the range of 1.2 to 2. In this case, it was taken as :

$$d = 1.2\,h \quad \ldots(5)$$

The dimensions of diameter (d) and depth (h) of digester were calculated using the following formula:

Hence, $V_d = (\Pi/4) \times d^2 \times h = (\Pi/4) \times (1.2h)^2 \times h \quad \ldots(6)$

Dome size:

With the removal of gas, more and more slurry from inlet and outlet tanks enters inside the biogas plant and thus contributes for gas generation. Hence, dome size was designed based on the gas use pattern and the volume of slurry displacement.

Generally, the cooking is done twice within 24 hours. Therefore, minimum 50 per cent of gas generated in 24 hours (*i.e.*, gas generated in 12 hours) was stored in the dome. As period of cooking once prolongs to 1.5 to 3 hours, the volume of gas produced in 3 hours was taken as 3/24 g (as 'g' is the total gas generated in 24 hours) and this quantity was deleted from the actual volume of the dome.

The slurry displacement volume (V_{sd}) calculated by:

$$V_{sd} = (0.5 - 3/24)\,g = (1/2-1/8)\,g = 3/8\,g \quad \ldots(7)$$

Hence, the variable gas storage volume (V_{gs}) inside the dome was determined based on slurry displacement volume (V_{sd}) as:

$$(V_{gs}) = V_{sd} = 3g/8 \quad \ldots(8)$$

since, $V_{sd} = (\Pi\, d^2/4) \times D \quad \ldots(9)$

where, D is the slurry displacement inside the digester, m

So, $3g/8 = (\Pi\, d^2/4)\, D \quad \ldots(10)$

since, $g = V_d/2 = \Pi\, d^2 \times h / (4\times2) = \Pi\, d^2 \times h/8 \quad \ldots(11)$

hence, $D = 3/16\, h \quad \ldots(12)$

The displacement of slurry in the tank (H) was determined by considering the total pressure of gas inside the dome. For proper circulation, the sustainable pressure of gas inside the dome was kept at 90 cm of water column.

So, $H + D = 0.9 \quad \ldots(13)$

or $H = 0.9 - D = 0.9 - (3/16) \times h \quad \ldots(14)$

Thus, H (relates to outlet of the digested slurry) is placed at a height of 10 cm minimum below the lower level of the dome.

Inlet pipe and outlet tank:

Inlet pipe of 30 cm diameter was used for feeding the slurry instead of wide opening. Hence, the volume of inlet was reduced and this reduction in volume was compensated by the outlet volume. To accommodate the displaced digested slurry inside the inlet pipe and the outlet tank the size was calculated as:

$$V_{sd} = l \times b \times H + \Pi\,(0.3)^2\,H/4$$
$$= l \times b \times H + 0.071\,H \quad \ldots(15)$$
So, $$3\,g / 8 = l \times b \times H + 0.071H \quad \ldots(16)$$

Keeping this in view, the area of outlet was kept about one and half times more to accommodate the displaced digested slurry.

For fixing the length and width of outlet tank,

l = 1.5 b was considered.

where,

l = length of outlet tank, m

b= width of outlet tank, m

By incorporating the value of g and H in the equation 3.23, the values of b and l were calculated.

Other dimensions :

Other dimensions such as thickness of digester wall kept as 22.5 cm and outlet chamber 11.2 cm, respectively. To protect the digester from leakage, crack and settlement in black soils the outer surface (gap between digester wall and soil) was packed using mixture of red soil, water and sand to 30 cm thickness around the wall and compacted properly.

Construction of modified Janata biogas plant:

The modified Janata biogas plant of 2 m^3 capacity was constructed as suggested by Anonymous (2002 b) as given below.

A cylindrical shaped digester was selected for the digester well. Initially, the site was cleaned and made free of weeds, stones etc. The diameter of the pit excavated was equal to the base diameter plus width of the bricks / stones used for lining. A 3 m diameter circle was marked on the site using lime powder and the excavation was carried out. The soil was dug up to a depth of 3.8 m till the hard pan of soil was noticed. A 15 cm thick cement concrete bed of 1:3:6 proportion was laid out. The digester was constructed using cement and bricks. The bottom and digester sides were properly plastered using 1:6 cement mortar. The dome was constructed using cement brick masonry. The inside of the dome was plastered with 1:2 water proof cement and sand plaster for providing an additional safety against gas leakage.

A RCC pipe of 30 cm diameter was fixed as inlet tank at an angle of more than 75 degrees with horizontal. The pipe was projected 90 cm above the dome of the plant and provided with a collar on the top for easy feeding of cattle dung into the digester.

The exit from the digester to the outlet tank was provided for smooth flow of digested slurry. The outlet tank was constructed using cement brick masonry as per the dimensions of length and breadth.

Performance evaluation of biogas plant:

The different physico-chemical properties like moisture content, total solids, volatile solids, bulk density, pH, carbon, nitrogen, phosphorus and potassium contents of cattle dung were determined using standard procedures.

Initially, the foreign and other debris materials like stones, straw etc. were removed from dung and cleaned. Then the plant was charged with cattle dung at 8-10 per cent total solids up to 75 per cent of its volume with a hydraulic retention time of 45 days. In order to achieve this level, 3590 kg of cattle dung was collected. A homogenous mixture of dung with water in the ratio of 1:1 was prepared by mixing equal quantity of water to the dung in order to bring the total solids to 10 per cent. After stabilization (20 to 30 days), 50 kg of cattle dung was fed daily at total solid concentration of 15 per cent.

The volume of gas produced was measured using a wet type gas flow meter. Initially, the gas flow meter was filled with distilled water to the indicated level. A 6.2 mm diameter pipe was connected to draw the gas from inlet pipe of biogas plant to gas flow meter. The quality of biogas was measured in terms of percentage of methane content and carbon dioxide by following standard procedure using Orsat apparatus.

The total nitrogen content of cattle dung (before digestion) and digested slurry (after digestion) were estimated by using Microkjeldhal method as suggested by Mahimairaja *et al.* (1990) and the phosphorus and potassium contents were estimated using standard procedure as suggested by Jackson (1967).

The cost analysis of the biogas plant was worked out by considering fixed and operating costs of the biogas plant. The fixed cost was worked out by accounting 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 fed material and labour charges. The benefit from the biogas plant was worked out by considering the slurry output and the gas produced annually.

■ RESULTS AND DISCUSSION

The different physico-chemical properties of cattle dung are presented in Table 1. It was observed that the moisture content, total solids, volatile solids and bulk density of cattle dung were 80.6 per cent, 19.4 per cent, 78.6 per cent and 1.05, respectively. While pH, carbon content, nitrogen content, C:N ratio, phosphorus content and potassium content of cattle dung were 7.2, 39.98 per cent, 1.26 per cent, 31.73, 1.20 per cent and 0.40 per cent, respectively.

The average monthly biogas production and percentage of methane content present in the biogas produced in modified Janata biogas plant was analysed and presented in Table 2. A maximum gas production of 216 litres per kg dry matter (DM) was recorded during the month of May and a minimum of 191 litres per kg dry matter (DM) during the month of December.

Table 1: Physico-chemical properties of fresh cattle dung	
Physical properties	
Moisture content (MC), %	80.60
Total solids (TS), %	19.40
Volatile solids (VS), %	78.60
Bulk density (BD), g/cc	1.05
Chemical properties	
pH	7.20
Carbon (C), %	39.98
Nitrogen (N), %	1.26
Carbon to nitrogen ratio (C:N)	31.73
Phosphorous (P_2O_5), %	1.20
Potassium (K_2O), %	0.40

The fluctuation in monthly gas production may be due to the fluctuations in the environmental conditions like temperature, RH etc and the stage of digestion. On an average 203.53 litres of biogas / kg dry matter (DM) was produced in modified Janata biogas plant with an average methane content of 59.97 per cent.

Table 2 : Average monthly biogas production and methane content in biogas

Months	Temperature (°C)		Quantity of gas (l / kg DM)	Methane content (%)
	Max.	Min.		
Jan.-06	34.50	13.50	198.40	60.12
Feb.-06	37.00	16.50	208.30	61.40
Mar.-06	39.50	21.00	212.50	60.80
Apr.–06	41.00	27.00	214.80	61.20
May–06	43.00	28.50	216.00	60.60
Jun.–06	37.50	22.00	207.60	58.40
Jul.–06	36.00	18.50	205.50	60.35
Aug.-06	35.50	17.00	204.00	59.25
Sep.-06	33.50	15.50	196.80	60.35
Oct.-06	32.50	14.50	194.00	59.00
Nov.-06	32.00	14.00	193.50	59.50
Dec.-06	31.00	13.50	191.00	58.70
Average	36.00	18.50	203.53	59.97

The percentage of nitrogen (N), phosphorus (P) and potassium (K) content of fresh cattle dung and digested slurry are presented in Table 3. The average percentage of nitrogen (N), phosphorus (P) and potassium (K) content of fresh cattle dung were 1.26, 1.20 and 0.40 per cent, respectively while these values in digested slurry (cattle dung after digestion) were 1.50, 1.40 and 0.48 per cent, respectively which indicted that the nutrient contents of digested slurry were higher than that of fresh cattle dung.

Table 3 : Nutrient composition of cattle dung (before digestion) and digested slurry (after digestion) in modified Janata biogas plant

Nutrient content, %	Cattle dung (before digestion)	Digested slurry (after digestion)
Nitrogen (N)	1.26	1.50
Phosphorous (P)	1.20	1.40
Potassium (K)	0.40	0.48

The cost economics of modified Janata biogas plant is presented in Table 4. The cost of construction of 2 m^3 capacity modified Janata biogas plant was Rs. 14,600. The total cost (fixed and operating cost) of biogas plant worked out to be Rs. 32,677.78. While the total benefit obtained from the plant was Rs. 47,015. The benefit cost ratio of 2 m^3 capacity modified Janata biogas plant was calculated to be as 1.44:1.

Table 4 : Cost economics of modified Janata biogas plant

Sr. No.	Particulars	Amount (Rs.)
1.	Cost of construction of biogas plant	14,600.00
2.	Fixed cost	
	Depreciation @ 10 % for 20 years	656.90
	Interest @ 12 %	1751.88
	Maintenance cost @ 6 %	399.00
	Total fixed cost	2807.78
3.	Operating cost	
	Initial feeding (3590 kg cattle dung @ Rs. 1 /kg)	3590.00
	Annual feeding (18250 kg cattle dung @ Rs. 1 /kg)	18250.00
	Labour charges (for 365 days @ Rs. 22 /day)	8030.00
	Total operating cost	29870.00
4.	Total Cost (Total fixed cost + Total operating cost)	32677.78
5.	Benefit	
	Returns from gas	7700.00
	[Qty. of gas 730 m^3 per year which is equivalent to 313.90 kg of LPG (1 m^3 of biogas = 0.43 kg of LPG). This is equal to 22 cylinders @ Rs. 350 / cylinder)	
	Returns from digested slurry	39315.00
	[Annual slurry produced 31452 kg with cost @ Rs. 1.25 / kg]	
6.	Total benefit	47015.00
7.	Benefit cost ratio	1:44

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