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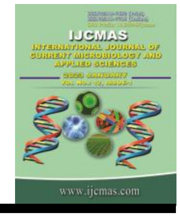

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Design and Performance Evaluation of Community Size Fixed Dome Biogas Plant

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A B S T R A C T

The disposal of cow dung was a great problem in dairy as the dung raises a lot of problems for human health and ecology system. Fossil fuels are depleting day by day there was need to increase the use of renewable energy sources and for reduce the dependency on fossil fuels for our energy needs. At Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, University dairy produces a huge amount of dung everyday which had a problem of disposal of such waste. To handle the waste in an efficient manner large scale modified fixed dome biogas had been constructed. A 50 m^3 fixed dome biogas plant had been constructed to produce biogas. An average percentage of Nitrogen, Phosphorus and Potassium were found 1.13, 0.75, 0.55 and 1.33, 0.90, 0.68 in fresh cow dung and digested slurry, respectively. The biogas production from modified Janta biogas plant was found maximum 49.90 $m^3 day^{-1}$ on 29th May 2021 at 49.90 ^{o}C digester temperature and minimum of 40.00 $m^3 day^{-1}$ on 17th December 2021 at 33.10 ^{o}C digester temperature. Economic indicators i.e. net present worth, benefit-cost ratio, payback period and internal rate of return of the system was found to be Rs. 2143000.40, 1.87, 2 years, 11 months & 3 days and 40 % respectively.

Introduction

The natural resources of energy are being depleted exhaustively and uneconomically in a developing country. India is a developing country; it needs to reorient its different methods of use of energy so that it can be used effectively as well as economically. Biogas is becoming very much useful clean, efficient, economical and pollution free source of energy. Setting up a biogas plant is the best alternative to utilize and handle the waste in efficient manner. Biogas plant stabilizes the waste properly and makes it free from odour. Biogas is not only an excellent alternative source of energy, but also a step towards stopping global warming. (Sooch, 2015; Adesanya, *et al.*, 2016).

Biogas has emerged as a promising renewable technology to convert agricultural, animal, industrial and municipal wastes into energy. Biogas development can be integrated with strategies to improve sanitation as well as reduce indoor air pollution and greenhouse gases. Currently, the total biogas production in India is 2.07 billion m^3/year, which is quite low as compared to its potential, which is estimated to be in the range of 29-48 billion m^3/ year (Anour *et al.*, 2015; Mittala *et al.*, 2018).

India's power generation from renewable energy sources stood at 10.325 billion units (BU) in January 2020, a 9.46 per cent increase from 9.433 BU generated in January 2019 last year, according to provisional data released by the Central Electricity Authority (CEA), an arm of the Power ministry. Total Power generation from conventional and renewable energy sources grew 2.65 per cent to 113.20 BU in January 2020, as compared to 110.280 BU of energy generated in January 2019.

The combined generation from solar, wind, small hydro, biomass, bagasse and other sources stood at 10.647 BU in December 2019, as against 9.083 BU of green energy generation recorded for the December month in 2018. Among renewable sources, wind generated the highest amount of power followed by solar at 3,943 million units (MU) and 3,932 MU, respectively, in December 2019. For the corresponding month in 2018, solar generated more power than wind at 3,182.12 MU and 2789.24 MU, respectively (Ansari and Javed, 2012; Desai *et al.*, 2013).

India installed 2,308 megawatt (MW) of solar and 817 MW of wind energy generation capacity in the fourth quarter of 2019. Around 15 GW of new capacity addition is expected in 2020 including 4 GW of wind installations and 11 GW of utility-scale solar installations. The country's renewable energy sector needs new investment in a range between $500 billion and $700 billion by 2030 to meet its target of 450 gigawatt (GW) of installed capacity, as per Australia-based Institute for Energy Economics and Financial Analysis. India has set itself a target of 175 GW renewable energy capacity by 2022 including 100 GW of solar and 60 GW of wind power capacity (Sooch *et al.*, 2009; Anonymous, 2020). At Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, university dairy has 214 cattle which produces 2000 kg dung every day. The dairy department was facing a problem of disposal of animal waste. They require an electricity for lightning in the evening, pumping water from bore well and heat energy in product making such as paneer, butter etc. In order to recycle the animal waste into energy and to reduce dependence on conventional energy a large scale biogas plant required. Considering the aforesaid facts a large scale modified Janta fixed dome biogas plant was constructed and installed at university dairy farm to mitigate the daily energy needs of Department of Animal Husbandry and Dairy Science under the Department of Unconventional Energy Sources and Electrical Engineering, Dr. PDKV, Akola.

Materials and Methods

Modified Janta biogas plant

The biogas plant includes five main components and working of each component is different in order to produce biogas containing methane, carbon dioxide, hydrogen sulphide and traces of other gases. Dung available at the dairy collected in a cart or trolley is supplied at inlet chamber of biogas plant. At inlet chamber dung and water mixed and poured into the digester with the help of inlet pipe connected to the digester.

Temperature sensor recorded the temperatures of the different part like inlet chamber, digester, outlet chamber and ambient temperature by using temperature sensors. The gas produced collected at hemispherical shaped dome and produced gas exerts pressure on the digested slurry to make its way towards outlet chamber. The digested slurry stored into outlet chamber to be utilized as manure into the agriculture fields.

Components of modified Janta biogas plant

Inlet chamber

It is cylindrical in shape chamber and is used as slurry mixer where water and dung are mixed. It is constructed 300 mm above the ground level.

Inlet pipe (HDPE)

An inlet pipe of High Density Polyethylene material having diameter 300 mm was connected from inlet tank to digester at 900 mm above from the bottom of digester and laid at 75°with horizontal for the smooth feeding of slurry. A HDPE pipe was installed due to its advantages of leak, corrosion, abrasion free, chemically resistant, excellent flow characteristics, lightweight and flexible, lower life cycle costs and reduction in installation costs.

Digester

It is an underground cylindrical wall portion made with bricks, sand and cement. The mixed slurry from the inlet tank is stored into the digester where the anaerobic digestion takes place. In digester thermophiles occupies the area of thermophilic digestive regime and the range of temperature for its operation is between 50°C and 60°C. Cryophiles (psychrophiles) occupies the area of cryophilic digestive regime and the range of temperature for its operation is between 12°C and 24°C. Mesophiles occupies the area of mesophilic digestive regime and the range of temperature for its operation is between 22°C and 40°C (Kamble, 2016).

Dome

It is hemispherical in shape constructed on the digester. The amount of gas produce in the digester gets collected and stored in the dome. The produced biogas exerts pressure on the digested slurry so that it is removed out from the outlet.

Outlet chamber

It is that part of the plant through which digested slurry moves out from digester. The outlet chamber was enlarged to accommodate total volume of the slurry displaced from the digester. The outlet chamber of biogas plant was constructed step type so that the outlet material does not slide back to the digester. These components are shown in Fig.1.

Design considerations for modified Janta biogas plant

To design the modified Janta biogas plant, several assumptions were made. Table no. 1 shows the design assumptions of the different components of modified Janta biogas plant.

Cow dung available at University dairy

At university dairy there are 214 cattle which produces large amount of dung. The daily dung produced at the Department of Animal Husbandry and Dairy Science, Dr. PDKV, Akola is given in the Table No. 2.

Total volume of the digester (V_d)

The volume of the digester depends on the daily dung feed with density of material. It is determined by equation 3.1.

$$V_d = \frac{\text{Daily feed}}{\text{Density}} \text{ x Retention period} \quad \text{...eq.1}$$

$$V_d = \frac{2500}{1080} x\ 30$$

$$V_d = 69.44\ m^3 \approx 70\ m^3$$

Daily feed = 2500 kgday^{-1} (cow dung + water).

Density of input slurry = 1080 kgm^{-3}.

Hydraulic retention time = 30 days.

Volume of gas holder is 40 to 60 % of the capacity of the biogas plant.

Volume of digester (V_d)

Volume of digester is essentially the product of feed rate and detention period. It is determined by equation 3.2.

$$(V_d) = \frac{\pi D^2 H}{4}$$ ….eq. 2

Where,

D = Diameter of digester

H = Height of digester

Assume D = H (For large capacity fixed dome biogas plant, diameter height ratio is 1:1)

Diameter of digester

The diameter of digester is determined by the equation 3.3

$$D = \sqrt[3]{\frac{V_d \times 4}{\pi}}$$ ….eq. 3

Where,

V_d = Total volume of digester

$$D = \sqrt[3]{\frac{70 \times 4}{\pi}}$$

D = 4.46 m

Height of digester

The height of digester is determined by the equation 3.4

$$H = \frac{\text{Total volume of digester} \times 4}{\pi \times D^2}$$ … eq. 4

$$H = \frac{70 \times 4}{\pi \times (4.46)^2}$$

$H = 69.67 \approx 70\ m^3$

Volume of Dome (V_g)

The volume of gas dome is determined by equation 3.5

$$V_g = \frac{2\pi r^3}{3}$$ ….eq. 5

Where,

r = Radius of digester

$$V_g = \frac{2 \times \pi \times (2.23)^3}{3}$$

$V_g = 23.22\ m^3 \approx 24\ m^3$

Total volume of plant

Total volume of biogas plant is the addition of volume of digester and dome.

$V = V_{digester} + V_{dome}$

V = 70+24

$V = 94\ m^3$

Results and Discussion

Proximate analysis of fresh cow dung and digested slurry

The biogas production is directly affected by the chemical composition of cow dung. The chemical property of feedstock material influences the biogas production to a great extent. The details of the characteristics of feed material like moisture content, total solid content, volatile matter, ash content and fixed carbon were determined. The proximate analysis of the digested slurry was carried out after 35 days of HRT.

Table.1 Design assumptions for 50 m^3 capacity modified Janta biogas plant

S. No.	Parameters	Particulars
1	Dung produces by small cow, $kgday^{-1}$	08
2	Dung produces by small buffalo, $kgday^{-1}$	10
3	Dung produces by big cow, $kgday^{-1}$	10
4	Dung produces by big buffalo, $kgday^{-1}$	15
5	Biogas produce from one kg cattle dung, m^3	0.04
6	Dung required for production of one cubic meter biogas, kg	25
7	Assume losses	10%
8	Total cow dung available, $kgday^{-1}$	1747
9	Dung required by existing biogas (plant capacity 20 m^3day^{-1}), $kgday^{-1}$	500
10	Available cow dung, $kgday^{-1}$	1247
11	Capacity of biogas plant, $kgday^{-1}$	49.88 ≈ 50
12	Dung water mixing ratio	1:1
13	Cow dung required for 50 m^3 biogas, $kgday^{-1}$	1250

Table.2 Dung production per day (kg) at university dairy

Sr. No.	Animals	No. of animals	Dung Production, $kgday^{-1}$
1	Calves	143	1186
2	Cow	62	620
3	Buffalo	09	135
Total		214	1941

Table.3 Dimensions of 50 m^3 modified Janta fixed dome biogas plant (All dimensions are in mm)

Sr. No.	Particulars	Dimensions
1	Diameter of digester (D)	4460
2	Inner radius of digester (R)	2230
3	Height of digester (H)	4460
4	Height of outlet opening (H_1)	920
5	Height of smaller portion of outlet chamber (H_2)	2175
6	Length of bigger portion of outlet chamber (M)	5180
7	Width of bigger portion of outlet chamber (N)	4300
8	Diameter of mixing tank (R)	1050
9	Height of mixing tank (P)	600

Table.4 Proximate analysis of fresh cow dung and digested slurry

S.N.	Material	Average moisture content, % (w.b.)	Total solid, %	Volatile matter, %	Ash content, %	Fixed carbon, %
1	Fresh cow dung	79.70	20.31	15.83	3.60	1.06
2	Digested slurry	89.12	11.05	7.83	2.19	1.03

Table.5 Carbon, Hydrogen, nitrogen and oxygen content in fresh cow dung and digested slurry

S.N.	Element	Carbon, (%)	Hydrogen, (%)	Nitrogen, (%)	Oxygen, (%)
1	Cow dung	27.51	13.44	1.78	53.76
2	Digested slurry	32.09	6.82	1.94	56.95

Table.6 pH of cow dung and digested slurry

Days	Cattle dung	Digested slurry
1	6.79	7.19
7	6.72	7.14
14	6.77	7.12
21	6.76	7.18
28	6.79	7.17
35	6.79	7.18

Table.7 Nutrients in cow dung and digested slurry

S. N.	Nutrients	Nitrogen N	Phosphorous P	Potassium K
1	Fresh cattle dung	1.13	0.75	0.55
2	Digested slurry	1.33	0.90	0.68

Fig.1 Schematic views of 50 m^3 capacity modified Janta fixed dome biogas plant

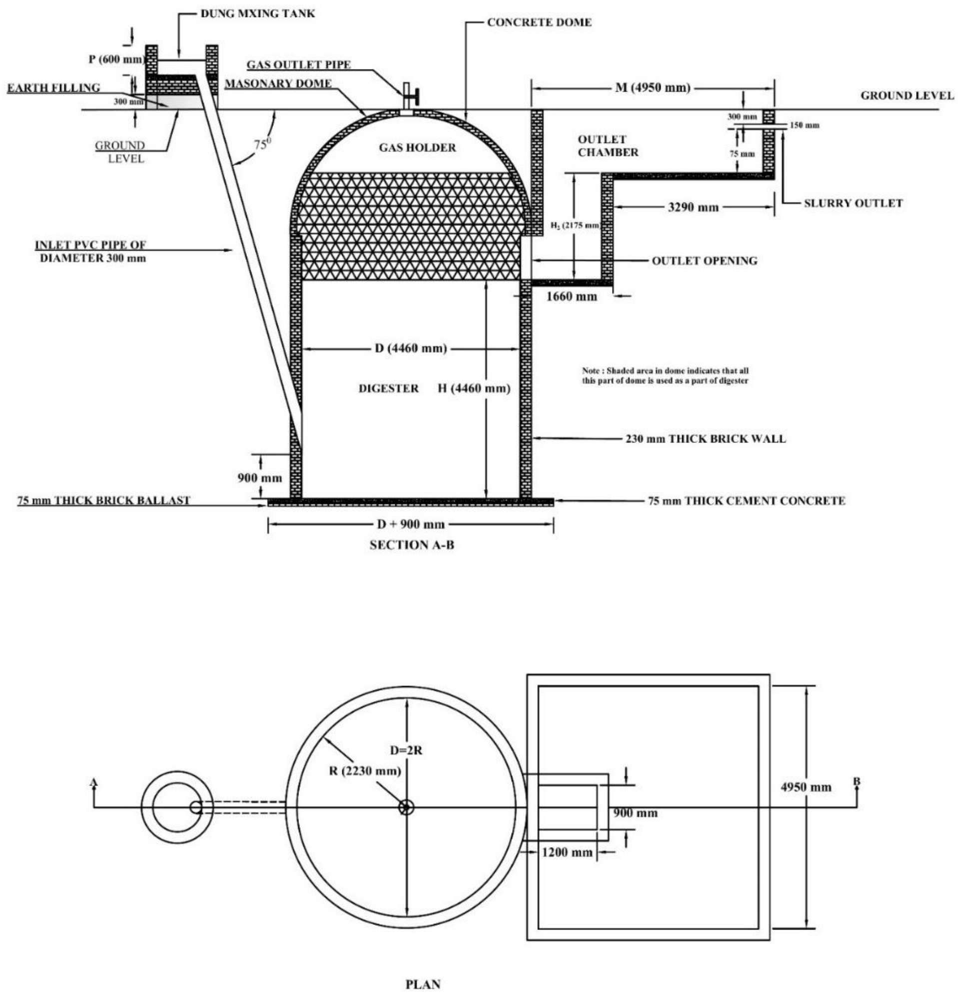


Fig.2 Top view of 50 m^3 capacity modified Janta fixed dome biogas plant

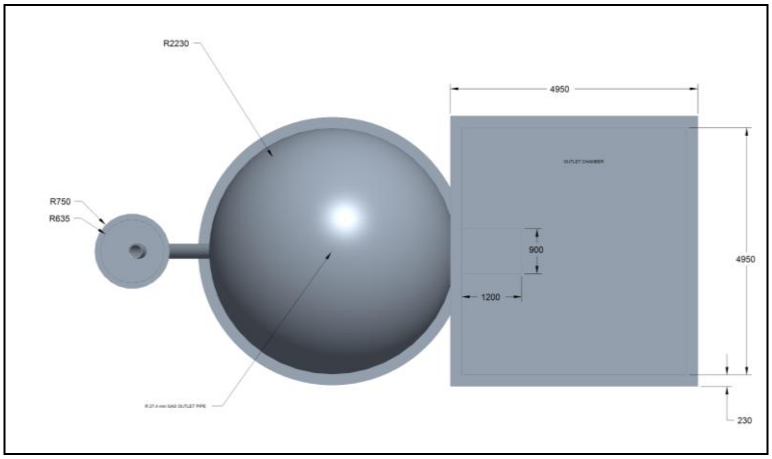


Fig.3 Side view of 50 m^3 capacity modified Janta fixed dome biogas plant

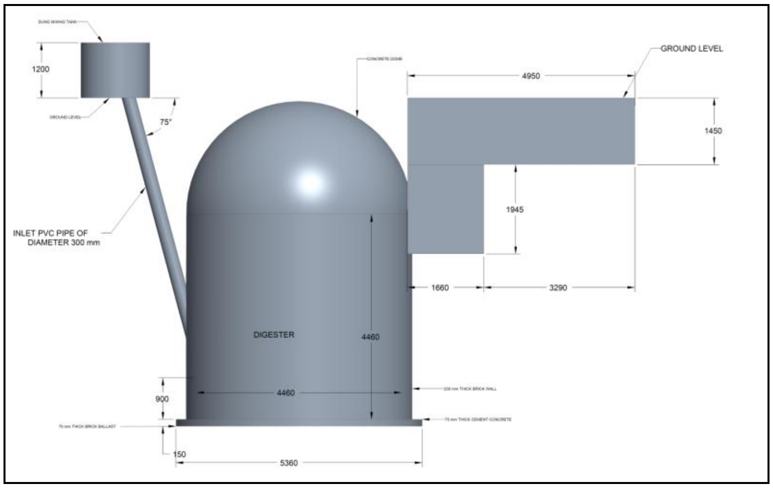


Fig.4 Installed 50 m^3 modified Janta fixed dome biogas plant

Fig.5 Nutrients in cattle dung and digested slurry

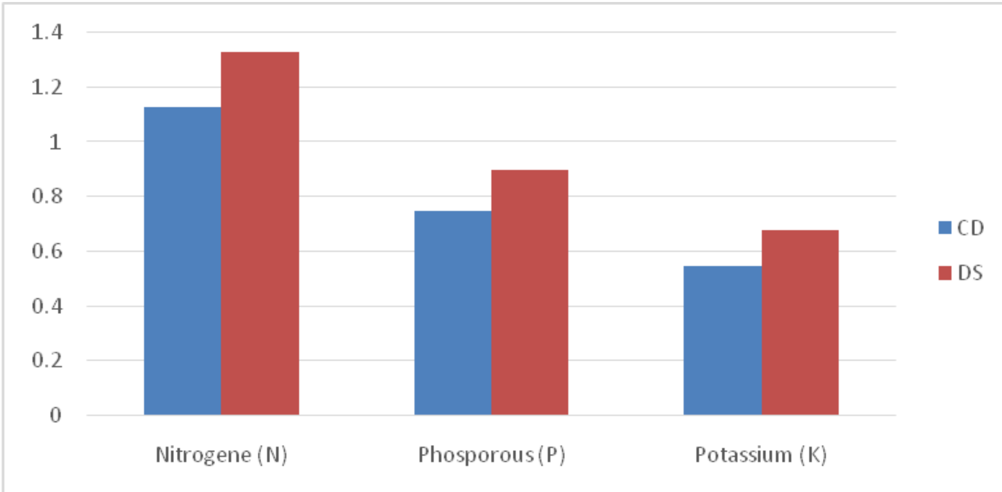


Fig.6 Average daily biogas production in m^3/day

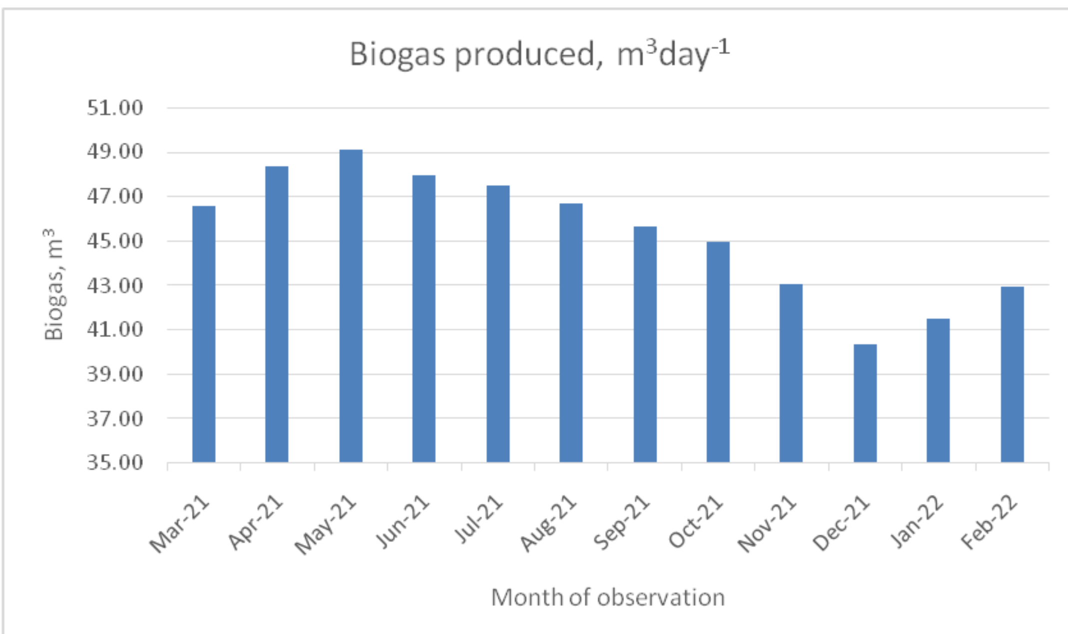


Fig.7 Temperature profile of biogas production

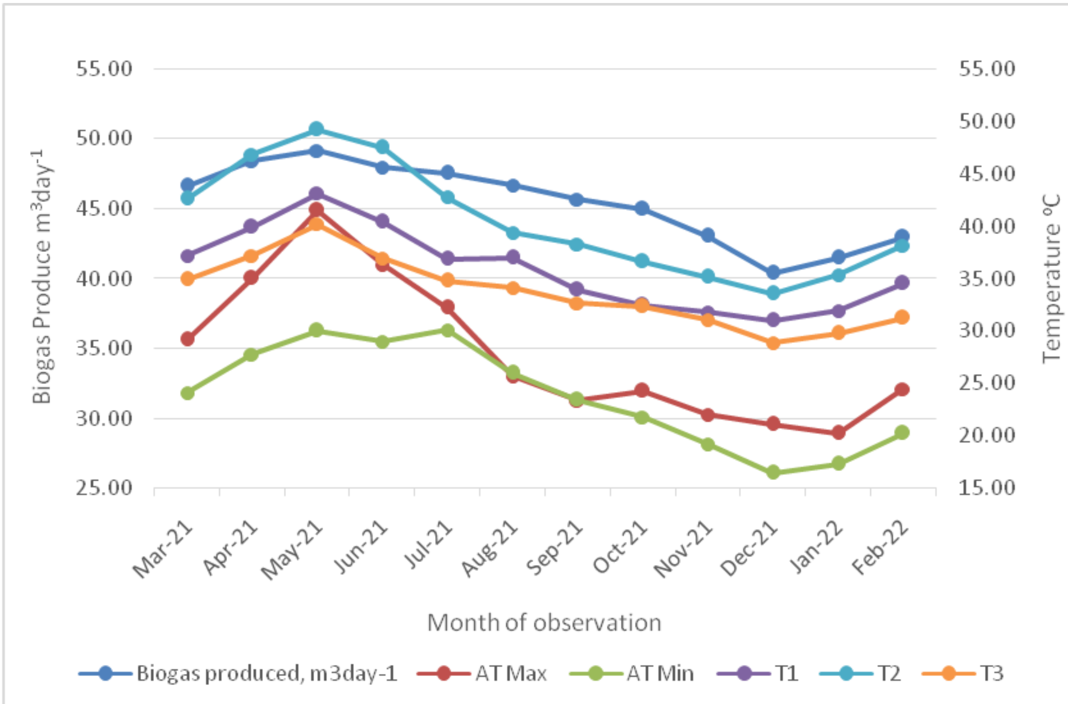
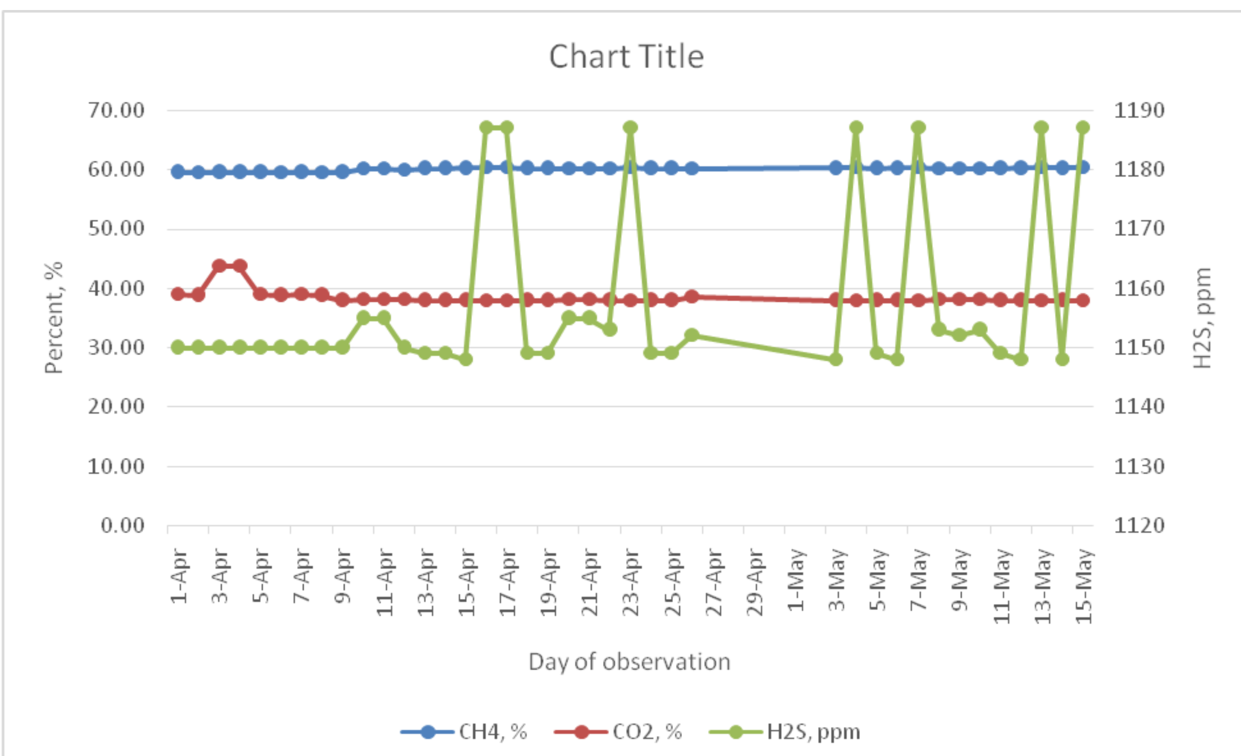


Fig.8 Composition of biogas in months of April and May, 2022



The details of the average moisture content fresh cow dung and digested slurry is given in Table 5.1. The average moisture content depicted in fresh cow dung was 79.70 percent and after digestion 89.12 percent during on field experiment. The detail of proximate analysis of fresh cow dung and digested slurry is given in Table 5.1.the fixed carbon recorded in both fresh cow dung and digested slurry was 1.06 % and 1.03 % respectively

Ultimate analysis of fresh cow dung and digested slurry

In the Table 5.2 ultimate analysis of fresh cow dung and digested slurry was carried out. Elemental analysis is important for calculation of carbon, hydrogen, nitrogen and oxygen contents in fresh cow dung and digested slurry. The table 5.2 depicted that carbon, nitrogen and oxygen content found to a great extent in digested slurry rather than the fresh cow dung. It was found that hydrogen content was reduced in digested slurry rather than fresh cow dung.

pH of fresh cow dung and digested slurry

The table 5.3 depicted the results of pH weekly in month of May, 2021 before and after digestion of cow dung. The pH of the feeding material plays an important role in producing biogas as it directly affects the methanogenic bacteria which are very sensitive to changes in pH during the production of biogas. The optimum range of pH for satisfactory biogas production lies between 6.5 -7.5. The pH value was increased after digestion with fresh cow dung. Average pH of fresh cattle dung was observed 6.77 and average pH of digested slurry was 7.16 as depicted in Table 5.3.

Nutrients analysis of fresh cow dung and digested slurry

The fresh cattle dung and digested slurry was analyzed weekly in month of May, 2021 for nutrients like nitrogen, phosphorus and potassium. Significant differences in N, P and K content of cattle dung before and after digestion were observed. Average percentage of N, P and K were found to be 1.13, 0.75, 0.55 and 1.33, 0.90 and 0.68 in fresh cow dung and digested slurry respectively. The observations are graphically represented in Fig 5.1.

Biogas production from modified Janta fixed dome biogas plant

The biogas production from installed 50 cubic meter capacity modified Janta biogas plant was measured daily after stabilization of methanogenic conditions. The data for daily biogas production was taken for a whole year from 1st March, 2021 to 28th February, 2022. Average ambient minimum and maximum temperature was recorded daily with the help of thermocouples. Digester temperature at bottom, middle and upper side was measured.

The daily average biogas composition having Methane in percentage, Carbon-dioxide in percentage and Hydrogen sulphide in ppm were recorded. The cattle dung and water were fed into the digester in 2:1 proportion.

Biogas production from fixed dome biogas plant varied from 40 to 49.50 m^3day^{-1}.Observation of biogas production monthly from1st March, 2021 to 28th February, 2022 are shown in Fig. 6. Average biogas production from fixed dome biogas plant was found 45.39 m^3day^{-1}.

Effect of ambient and digester temperature on biogas production

Ambient temperature is directly affecting the biogas production, during study it was observed that biogas production decreases according to decrease in ambient temperature. It was also observed that the digester temperature at top, middle and bottom influences the biogas production. Observation was taken for a whole year from 1st March, 2021 to 28th February, 2022. During study period in a particular day of 29th May 2021 it was found that maximum and minimum ambient temperature were 46.90 and

30.90 ^{0}C respectively. The maximum biogas production of 49.90 $m^3day^{-1}$was observed on 29th May 2021 and minimum biogas production of 40.10 m^3day^{-1} was observed on 16th December 2021 respectively. The average monthly biogas production is shown in Fig 5.2.

Composition of biogas

The methane content in biogas is an indicator of fuel quality. It depends on characteristics of substrate, process environmental conditions as well as growth of methanogens during anaerobic digestion. The percent of carbon dioxide content was initially higher in the produced gas due to unstabilization of methanogenic process. After stabilization of process of biomethanation methane and carbon di-oxide contents of generated biogas were measured. Methane and carbon dioxide contents in produced biogas were measured every day by using a Siya Instruments- portable Biogas Analyzer.

The average methane content as shown Fig. 8 in biogas production of 5 weeks was 60.09 percent and carbon dioxide were 38.48 percent. The maximum methane content in the biogas production was found 62 percent.

In the year to come the need for energy will increase manifold which the reserve of conventional energy will deplete in rapid pace. To meet the growing demand of energy harnessing of nonconventional or renewable energy is necessity and an attempt was made in this investigation to suggest alternatives for energy generation by using biogas. A 50 m^3 capacity modified Janta fixed dome biogas plant was designed for generation of biogas.

An average percentage of Nitrogen, Phosphorus and Potassium were found 1.13, 0.75, 0.55 and 1.33, 0.90, 0.68 in fresh cow dung and digested slurry, respectively. The biogas production from modified Janta biogas plant was found maximum 49.90 m^3day^{-1} on 29th May 2021 at 49.90 ^{o}C digester temperature and minimum of 40.00 m^3day^{-1} on 17th December 2021 at 33.10 ^{o}C digester temperature.

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