Development of Low Cost Biogas Purification System

K. A. Sahu[*], S. R. Kalbande and V. P. Khambalkar

Department of Renewable Energy Sources, Dr.Panjabrao Deshmukh Krishi Vidyapeeth, Akola (MS) 444104, India

*Corresponding author

A B S T R A C T

Biogas is produced through anaerobic fermentation process of organic matter and it contains CH_4, CO_2, H_2S and other gases. The main combustible gas in biogas is CH_4 and the presence of other gases reduces the calorific value of biogas, hence for obtaining better performance of engine it is essential to remove CO_2 and H_2S present in raw biogas. The dry absorbent based biogas purification system was developed and its performance was evaluated. The major components of the biogas purification system include CO_2 scrubber, H_2S scrubber, biogas analyzer, biogas flow-meter, biogas pump, pressure gauge, control valve and frame for holding the scrubber. The performance of the purification unit was evaluated for purification of biogas at bed heights of 15 cm, 20 cm and 25 cm with maintaining flow rates of 1.2 m^3/h, 1.5 m^3/h and 1.8 m^3/h. The purification unit was therefore observed to performed best at the optimum bed height of 20 cm and flow rate 1.5 m^3/h. The result of the study showed that the purification unit could purify the biogas satisfactorily. The payback period of the investment involved for the biogas purification unit was workout. The total cost of biogas purification system was Rs. 41000 with payback period of the investment of 3 years, 2 months and 13 days.

Introduction

Energy is an essential prerequisite for accelerated economic development and improved quality of life for citizens of any country. Due to rapid industrialization and urbanization in last few decades, there is a huge pressure on depletable crude oil, coal and other fossil fuels. This resulted into need for finding some alternative sources of energy. Biogas is one of the most important renewable sources of energy which may

cope up to cater for heating and power. Biogas generated by the biological degradation of organic compound, has been considered as a valuable energy carrier, and it is now playing a key role in emerging market of renewable energy. Total biogas production in India is 2.07 billion m^3/year (Mittal *et al.,* 2018).

Biogas is a clean renewable energy source for rural India. It mainly consists of methane (55-70%), carbon dioxide (30-45%),

hydrogen sulphide (<1%) and some traces of water vapour. Non-combustible constituent of biogas, carbon dioxide does not contribute to the combustion; in fact it lowers the heating value of biogas and increases the compression and transportation costs.

Hence there is an immense need of removal of carbon dioxide from biogas. Biogas production and subsequent purification will significantly satisfy the fuel requirement in rural as well as urban transport.

For using biogas as vehicle fuel, it has to be purified by removing the impurities like carbon dioxide, hydrogen sulphide and water vapour. These impurities can have detrimental effect on the life cycle and performance of the engine. Removal of carbon dioxide also enhances the calorific value.

Therefore, it is necessary to purify the biogas before using it for combustion. Biogas is a promising renewable fuel and produced by anaerobic digestion of biomass such as cattle dung, vegetable waste, municipal solid waste, poultry droppings, industrial waste water and landfill etc. Main products of the anaerobic digestion are biogas and slurry (Manjula and Mahanta, 2016).

Any low cost technique to remove carbon dioxide and hydrogen sulfide from biogas can make biogas a techno-commercially viable fuel (Shah *et al.,* 2015).

Materials and Methods

Location and site

Akola is located at latitude 20.7° north and longitude 77.07° east. It is at an altitude of 287 m to 316 m above sea level. The experiment was conducted at the Department of Animal Husbandry and Dairy Science, Dr. PDKV Akola.

Development of biogas purification system

This system was mainly consisted of CO_2 scrubber, H_2S scrubber, biogas analyzer, biogas flow meter, control valve, pressure gauge, biogas pump and frame for holding the scrubbers (Fig. 1–5 and Table 1–3).

Sizing of biogas purification scrubber

H_2S and CO_2 scrubbers were used for purification of biogas. The size of scrubber was depended on adsorbents particle size. The size of scrubbers was calculated by following equations.

Design procedure for H_2S and CO_2 scrubber

The H_2S scrubber was designed to remove the H_2S gas from biogas. In the design diameter of scrubber was taken as required and height of scrubber was calculated. The height and diameter of the scrubber was determined by using equation

Cross section area of scrubber

$$\text{Area of section} = \frac{\text{Biogas per second in cm}^3/\text{s}}{\text{Maximum flow rate in chamber in cm}}$$

$$\text{Radius of scrubber} = \sqrt{\frac{\text{Cross sectional area in square centimeter}}{\pi r^2}}$$

Volume of scrubber

$$\text{Volume of the scrubber} = \pi r^2$$

Where: r - Radius of the scrubber, cm
h - Height of the scrubber, cm

Height of the scrubber

The height and cross sectional area of the chamber determine its volume. The volume determines the amount of absorbent that can be filled into the unit. The amount in turn determines the operating time of the chamber between absorbent exchanges.

$$\text{Scrubber height} = \frac{\text{Chamber volume in cubic meter}}{\text{Cross section in Square meter}}$$

Number of intermediate absorbent holding cylinder

The number of intermediate absorbent holding cylinder can be calculated as:

$$\text{No. of cylinder} = \frac{\text{Height of chamber in meter}}{0.30 \text{ m layer depth/Cylinder}}$$

Sieve analysis of absorbents used for purification of biogas

The absorbent was used for the purification of biogas consist of limestone crystal, Iron turning, silica gel, etc. average particle size determined for the effective purification of biogas (Gaikwad, 2017).

Average particle size of the different absorbents was taken on the basis of fineness modulus.

Fineness modulus

$$\frac{\sum \text{Cumulative percentage retained onsieves)}}{100}$$

Average particle size

$$D_{avg} = \frac{b}{\sqrt{a}} \times a^{FM}$$

Where,

a = constant (i.e. a= 2 for India)
b = smallest sieve size in mm.

Economic feasibility of biogas purification system

The economic feasibility of biogas purification system was calculated by using discount rate method. Following different economic indicators were used for economic analysis: Net present worth (NPW) Benefit cost ratio (B/C ratio) Payback period.

Net present worth

The mathematical statement for net present worth can be written as:

$$\text{NPW} = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t}$$

Where,

C_t = Cost in each year
B_t = Benefit in each year
t = 1, 2, 3................n
i = discount rate

Benefit cost ratio

The mathematically benefit-cost ratio can be expressed as:

$$\text{Benefit-cost ratio} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}}$$

Where,

C_t = Cost in each year
B_t = Benefit in each year
t = 1, 2, 3................n (year)
i = discount rate

Table.1 Details of components of biogas purification system

S.No.	Components	Details
1	CO_2 scrubber	The CO_2 scrubber was made up of PVC pipe having height 2400 mm, and diameter 152.4 mm. The CO_2 scrubber consists of PVC pipe with end caps, to hold the limestone crystals
2	H_2S scrubber	The H_2S scrubber was made up of PVC pipe having height 2400 mm, and diameter 152.4 mm. The H_2S scrubber consists of PVC pipe with end caps, to hold the iron turnings
3	Biogas analyzer	The Biogas analyzer is an instrument which was used for analyzing the composition of biogas. It analyzes the biogas and gives the concentrations of methane, carbon dioxide and hydrogen sulphide in the biogas
4	Biogas flow-meter	The biogas flow meter measures the flow of biogas in cubic meter per hour. It was attached to the system. The biogas flow was installed to measures the flow rate of biogas at the inlet to the scrubber and also at the outlet of the scrubber. It also checks the flow of biogas
5	Biogas pump	The biogas pump of 0.5 hp was used to pump the biogas to the purification unit. The biogas pump makes the flow of gas inside the purification unit with a pressure which impacts the gas on the absorbents and helps in proper absorbtion
6	Pressure gauge	The pressure gauges were installed used to measure pressure of biogas at inlet and the outlet of the biogas scrubbing unit. The pressure gauge help in regulating the pressure of the gas thereby maintaining uniform flow of biogas inside the purification unit for optimum absorbtion
7	Control valve	The control valve having size 12.7 mm was attached at the inlet and outlet of the scrubbing unit. It was used to regulate the flow of biogas at the inlet and outlet.
8	Frame for holding the scrubber	The frame was made up of square mild steel pipe of 25×25 mm size and thickness 3 mm. The frame holds the biogas scrubbing unit i.e. the PVC pipes, absorbents, biogas pump, etc
9	Frame for holding absorbent holding cylinder	A frame of 300 mm length was made up of M.S bars of 8 mm diameter and flat spherical plates of 150 mm. The frame was developed for holdings the absorbents holding cylinder inside it
10	Absorbent holding cylinder	The absorbents of diameter 130 mm and height 300 mm was fabricated of M.S 1 mm wire mesh

Table.2 Absorbents used for biogas purification

S.N.	Name of absorbent	Particle size	Function
1	Iron turning	0.2 – 5 mm	To remove hydrogen sulphide gas
2	Limestone crystal	0.5 – 10 mm	To remove carbon dioxide
3	Silica gel	4 – 20 mm	To remove moisture

Table.3 Result obtained after examination

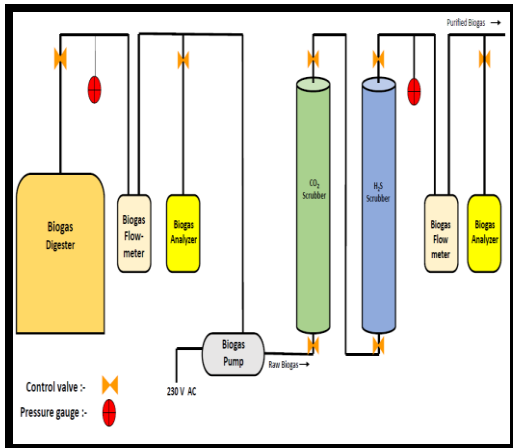| Results obtained after experimentation					
Raw Biogas			Purified Biogas		
CH_4(%)	CO_2(%)	H_2S(ppm)	CH_4(%)	CO_2(%)	H_2S (ppm)
56.15	43.74	0.11	65.37	33.94	0.02

Fig.1 Experimental arrangement of biogas purification system
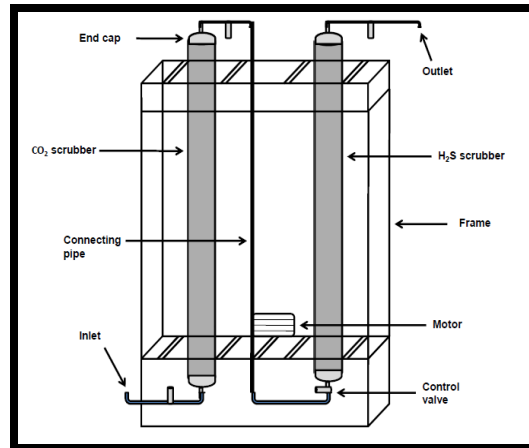

Fig.2 Schematic view of biogas purification system

Fig.3 Developed Biogas purification unit

Fig.4 Absorbents used in biogas purification unit

Fig.5 Sieve Analysis of absorbents Fineness modulus

Payback period

The mathematically payback period can be expressed as:

$$P = \frac{I}{E}$$

Where,
P= Payback period of the project in years,
I = Investment of the project in rupees and
E = Annual net cash revenue in rupees

The performance of biogas purification system was found satisfactory at 20 cm bed height and 1.5 m^3/h flow rate. The estimated cost of the system was Rs.41000 with 12 year payback period and benefit cost ratio was found as 3 years 2 months and 13 days is 1.93. It could be inferred that the biogas purification system was economically feasible.

References

Gaikwad, V. R. and Katti P. K. 2014.Design of biogas scrubbing, compression &storage system. J. of Electrical and Electronics Engineering. 2278: 58-63.

Kamble A. K. (2016). Modified biogas technology for the digestion of fresh undiluted cattle dung for energy generation. International Journal of Research in Engineering, Science and Technology. Vol 1, issue 9: 29-32.

Manjula, D. G. and Mahanta, P. 2016. Biogas purification using chemical absorption .In. J. of Engineering and Technology. 8(3): 0975-4024.

Mittal, S., Ahlgren, E. O. and Shukla, P. F. 2018. Barriers to biogas dissemination in India: A review 112:361-370.

Shah, D. and Hemant, N. 2015. Low cost biogas purification system for application of bio CNG as fuel for automobile engines. In. J. of Innovative Science, Engineering & Technology. 2 (6): 308-312.

Vijay, V.K., Kapdi, S.S. 2006. Biogas purification and bottling into CNG cylinders producing BioCNG from biomass for Rural Automotive Applications. The second joint international conference on "Sustainable Energy and Environment "Bangkok, Thailand. Pp. 22-26.