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Design and development of biogas cleaning system

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Abstract
The research work focuses on the design and development of a biogas cleaning system for electricity generator to achieve higher efficiency in terms of power production. A raw biogas consists of 60% combustible methane and 39% non-combustible elements containing carbon dioxide (36%), water vapor (0.5%), hydrogen sulfide (1%) and traces of other gases. The system is designed considering the filtration materials like red soil, NaOH solution, silica gel crystals and activated carbon. The biogas cleaning system composes of four stages: stage 1 is the red soil filter intended to remove the hydrogen sulfide; stage 2 is the NaOH solution filter intended to reduce the carbon dioxide; stage 3 is the silica gel crystal filter intended to remove the moisture; stage 4 is the activated carbon filter intended to remove the fine impurities from the raw biogas. The biogas cleaning system is able to purify 50 m^3 day^{-1} of raw biogas.

Keywords: Biogas, cleaning, red soil, NaOH solution, hydrogen sulfide

Introduction

Biogas has emerged as a promising renewable technology to convert agricultural, animal, industrial and municipal wastes into energy. (Mittal *et al*. 2018) [7]. Biogas technology provides an alternative source of energy mainly from organic wastes. Biogas is a combustible mixture of gases mainly composed of methane (CH_4) around 55-65% and carbon dioxide (CO_2) around 30-40% and small quantities of hydrogen, nitrogen, carbon monoxide, oxygen and hydrogen sulphide. The gas can effectively be utilized for generation of power through a biogas-based power-generation system after dewatering and cleaning of the gas. The introduction of advanced methods of purifying biogas to remove carbon dioxide (CO_2) and hydrogen sulfide (H_2S) and enrich its methane content can potentially bring biogas to the quality level of natural gas. This, combined with its compression, enables it to be used as a fuel for vehicles, just like compressed natural gas (CNG). Cost-efficient technology for removing CO_2 and H_2S from biogas makes it a technically and commercially viable fuel. (Shah and Hemant, 2015) [11].

Biogas can be used in the generation of electricity through a biogas-fueled generator. 1 m^3 of biogas is equivalent to 0.5 to 0.6 litres of diesel or 6 kWh. The biogas needs to be dehumidified and purified before use in the electricity generator. Combustion of biogas containing hydrogen sulfide (H_2S) produces sulfur dioxide (SO_2). When SO_2 combines with water vapour, it produces sulfuric acid that corrodes the exhaust pipes of burners, gas lamps and engine parts. Carbon dioxide is present in raw biogas with very high concentrations. This decreases energy content per unit mass/volume and limits its use for low-quality energy applications. The presence of moisture in biogas to be used as fuel may corrode metallic parts of the engine and fuel supply system. The reaction of H_2O (Moisture) with SO_2 (Sulphur dioxide) produces sulfuric acid that corrodes the exhaust pipes of burners, gas lamps and engines. Hence, in order to safeguard engine components and increase engine performance it is a need of an hour to develop a biogas cleaning system. Biogas as a fuel can replace the conventional fuels like LPG, kerosene, coal and wood for producing electricity. Meanwhile the fossil fuels are depleting day by day so that it needs to increase use of renewable energy sources for reducing the dependency on those fuels for our energy needs.

Materials and Methods

The cleaning system for biogas was constructed and designed, incorporating a CO_2 scrubber, an H_2S scrubber, a biogas analyzer, a biogas flow meter, a control valve, a pressure gauge and a frame to support the scrubbers. The biogas cleaning system containing red soil, NaOH solution, activated carbon and silica gel was used for cleaning of raw biogas.

The designed biogas cleaning system has the following components.

1. H_2S scrubber
2. CO_2 scrubber
3. Biogas analyzer
4. Biogas flow-meter
5. Control valve
6. Frame for holding the scrubber

Design of biogas cleaning system

The biogas cleaning system was designed considering the following assumptions give in Table 1.

Table 1: Assumptions for design of biogas cleaning system

Sr. No.	Parameters	Particulars
1	Biogas available, m^3day^{-1}	50
2	Gas flow rate in chamber, cm^3s^{-1}	1
3	Amount of sulphur bound, gkg^{-1}	3.79
4	Bulk density of red soil, kgl^{-1}	1.6
5	Amount of H_2S in cleaned biogas, g H_2Sm^{-3}	3
6	Percentage of CH_4, in raw biogas	60
7	Percentage of CO_2, in raw biogas	40
8	H_2S, in raw biogas, ppm	1150

Calculation of cross section of the chamber of biogas cleaning system

Cross section of the chamber of biogas cleaning system depends on gas flow rate and it is determined by equation 2.

Available biogas = 50 m^3day^{-1}

Therefore,

Flow rate required = $\frac{50}{24}$ = 2.08 m^3h^{-1} 1

$= \frac{2.08 \times 1000 \times 1000}{3600}$ = 578 cm^3s^{-1}

Or

2.08 × 278 = 578.24 cm^3s^{-1}

The flow rate in the chamber is 1 cms^{-1}.

The area of the cross section is then

$\frac{578 cm^3 gas/s}{1 cm/s}$ = 578cm^2 (cross section of chamber) 2

$\frac{578}{10,000}$ = 0.0578 m^2 (cross section)

Length of chamber side (radius) with a circular cross section

$\sqrt{\frac{578}{3.14}}$ = 13.5 cm (Radius) 3

Amount of absorbent required

Adsorption capacity of red soil

Without regeneration 3.79 g sulphur kg^{-1} absorbent

With regeneration 37 g sulphur kg^{-1} absorbent (Machunda and Pogrebnaya 2020)

50 m^3 biogas per day throughout

Assume 3 gH_2Sm^{-3} in biogas

By considering 60 number of operating days between absorbent exchange or regeneration.

50 m^3× 3.0 × 60 operating days4

= 9000 gH_2Soperating period^{-1}

$= \frac{9000}{37}$ = 243.24 kg absorbent

The amount of absorbent required per operating period considering bulk density of absorbent as 1.6 kgl^{-1}

Amount of absorbent required $= \frac{243}{1.6}$ = 152.02 lit absorbent/operating period

Addition for dead volume (Base, head and intermediate trays): 25%

$\frac{152.02}{0.25}$ = 38.00 l.

Chamber volume

The chamber volume is the addition of amount of absorbent required and dead volume

= Absorbent + Dead 5

= 152.02 + 38.00

= 190.02 liters

$= \frac{190.02}{1000}$ = 0.190 m^3

Chamber height

The chamber height is determined by the chamber volume divided by the chamber cross section and it is calculated by the equation 6.

$= \frac{\text{Chamber Volume } (m^3)}{\text{Crosssection } (m^2)}$ 6

$= \frac{0.190}{0.0578}$

= 3.28 m

H_2S scrubber

The H_2S scrubber, which had a total height of 3280 mm and a diameter of 135 mm, was constructed of mild steel. To facilitate material filling and maintenance, the cylinder was divided into two columns, each of which was divided into four equal parts measuring 410 mm in height and 270 mm in diameter. The H_2S scrubber consisted of a single mild steel cylinder that was used to hold red soil.

CO_2 scrubber

The CO_2 scrubber was constructed using a HDPE pipe with a height of 1830 mm and a diameter of 135 mm. It was designed to hold NaOH solution and was equipped with end caps. The scrubber was designed to accommodate 60 liters of 2.25 molar NaOH solution.

Frame for holding the cleaning system

The frame supporting the biogas scrubbing unit, which includes mild steel cylinders, HDPE pipe, and absorbents, was constructed using 25 × 25 mm square mild steel pipes with a thickness of 3 mm. To withstand the weight of the absorbents and the vibrations that occur during gas flow, the frame was well-braced and able to mount and support other parts of the unit. The experimental arrangement of biogas cleaning system is shown in Fig 1.

Working of biogas cleaning system

The raw biogas was obtained from a modified Janta fixed dome biogas plant with a capacity of 50 cubic meters. The biogas then entered the first and second cleaning chambers where it reacted with red soil while flowing vertically upward through the unit. Next, it was directed to the third cleaning chamber which contained an absorbent holding cylinder filled with NaOH solution. The biogas flowed vertically downward in this chamber and reacted with the NaOH solution. From there, it was passed to the fourth cleaning chamber where it passed through silica gel crystals to remove moisture and activated carbon to remove fine impurities. The flow rate of the purified biogas was measured by a biogas flow meter installed at the outlet of the cleaning unit. Finally, the purified biogas was analyzed using the biogas analyzer. An absorbents used for biogas cleaning system are given in Table 2 and Plate 1. Schematic view of biogas cleaning system is shown in Fig. 4.3. The technical specifications of biogas system are depicted in Table 4.3.

Table 2: Absorbents used for biogas cleaning system

Sr. No.	Name of absorbent	Particle size (as per literature cited)	Quantity of absorbent	Function
1	Red soil	0.2 – 5 mm	80 kg	To remove hydrogen sulphide
2	Activated carbon	0.5 – 10 mm	7.2 kg	To remove H_2S and carbon dioxide
3	NaOH	2.25 Molar	60 l	To remove carbon dioxide
4	Silica gel	4 – 20 mm	7.5 kg	To remove moisture

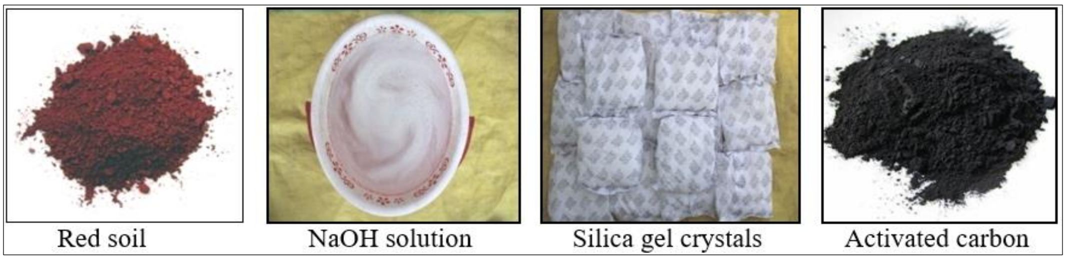

Plate 1: Absorbents used for biogas cleaning

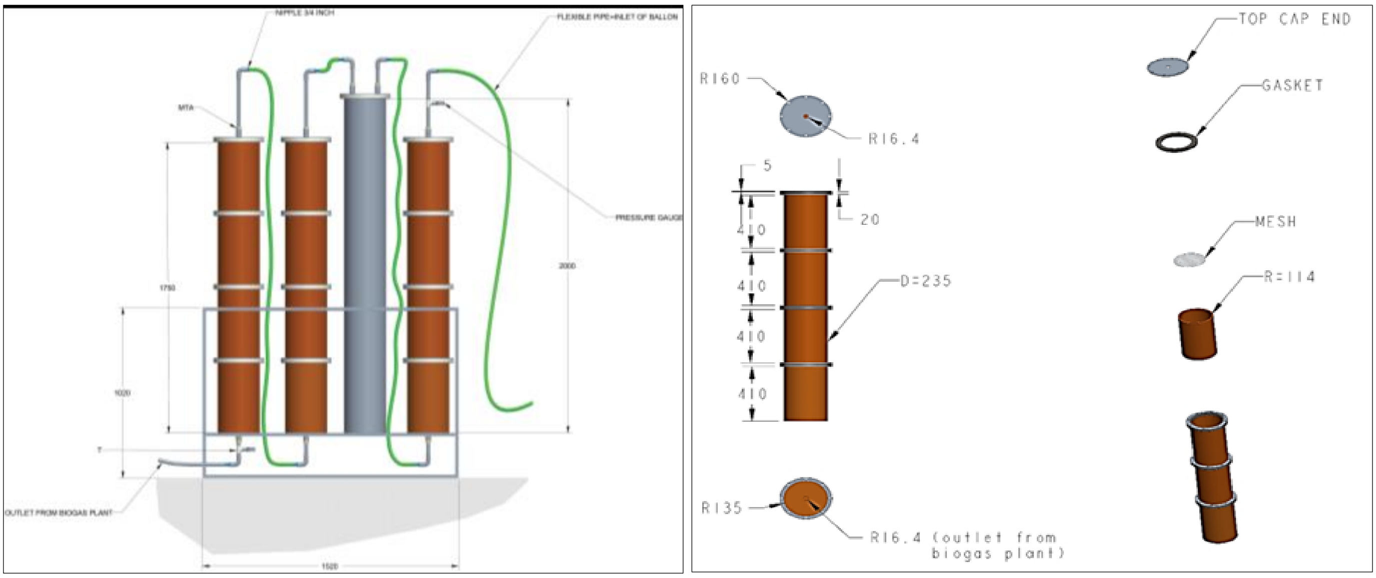

Fig 2: Schematic view of biogas cleaning system

Results and Discussions

The designed biogas cleaning system was developed for the cleaning of raw biogas. A 50 $m^3 day^{-1}$ raw biogas can be purified by using the developed biogas cleaning system. The detailed specifications of biogas cleaning system is given in Table 3.

Table 3: Technical specifications of biogas cleaning system

Sr. No.	Particular	Specification	Quantity	Material
1	Main frame	1520 mm x 420 mm x 1020 mm	1	Mild steel
2	H_2S scrubber 1st& 2nd column	Ø:270 mm, h: 1640 mm	2	Mild steel
3	CO_2 scrubber, 3rd column	Ø: 270 mm, h: 2000 mm	1	HDPE
4	Fine impurities, 4th column	Ø: 270 mm, h: 1640 mm	1	Mild steel
5	Flange	Ø: 300 mm, t: 5 mm	21	Mild steel
6	Hose nipple	Ø: 20 mm	8	GI
7	Control valve	Ø: 20 mm	2	Brass
8	Pressure gauge	100 mm	2	Copper alloy
8	Sieve	177 micro meters	9	Stainless steel
9	Pipe	Ø:19.05 mm, l: 4500 mm	1	CPVC
10	Suction hose pipe	Ø:19.05 mm, l: 4500 mm	1	PVC

The materials used for the fabrication of biogas cleaning system were readily available in the market to verify that the designed structure is low-cost and efficient. Table 4 illustrates the cost of components of biogas cleaning system of the total cost consumed in the construction of the designed biogas cleaning system. The total amount consumed in the design and construction of the filtration system, making use of all materials available like the mild steel sheet, HDPE pipe, mild steel square pipes was Rs. 23200/-. The cost of absorbent material, connecting pipe, flow control valve pressure gauge and fabrication charges were Rs. 17800/-. The total cost clearly shows that the developed cleaning system is low cost as compared with other developed system available in the market as depicted in Table 5.

Table 4: Cost of components of biogas cleaning system

Sr. No.	Particular	Cost (Rs.)
1.	Main frame	4000
2.	**Cleaning chamber**	
	I) Cleaning chamber for red soil	5400
	II) Cleaning chamber for activated charcoal	5400
	III) Cleaning chamber for NaOH	5400
	IV) Cleaning chamber for silica gel	3000
3.	**Absorbent material**	
	I) Red soil	300
	II) Activated Charcoal	500
	III) NaOH	1000
	IV) Silica gel	1000
4.	Connecting pipe	5000
5.	Flow control valve	1500
6.	Pressure gauge	1500
7.	Fabrication charge	7000
	Total Rs	41000

Table 5: Cost analysis of biogas cleaning systems

Sr. No.	Cleaning system	Actual Price (Rs.)
1.	Developed biogas cleaning system	41000/-
2.	Biogas cleaning system developed by Natfrenz Technologies Private Limited	10,00,000/-
3.	Biogas purification system developed by Organic121 Scientific Private Limited	1,00,000/-
4.	Biogas purification plant developed by Jai Krishi Udhyog, New Delhi.	2,50,000/-

Conclusions

Traces of impurities (such as water vapor, CO_2 and H_2S) is to be removed prior to using as fuel for various applications. We have established the biogas cleaning system required for the purification of raw biogas. The developed biogas cleaning system has 50 m^3 day^{-1} capacity of purifying raw biogas.

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