Biogas Purification using Chemical Absorption

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Abstarct - **Biogas is a developing alternative energy source produced from the anaerobic digestion of organic matter by bacteria. It is composed of methane and carbon dioxide (CO_2) with trace amounts of hydrogen sulfide (H_2S). The presence of CO_2 decreases the energy yield from the combustion of biogas. Past studies on biogas purification have used expensive and environmentally harmful chemicals to purify biogas. This study will involve the construction of a biogas purification system that utilizes sodalime to remove carbon dioxide from biogas by absorbing in it through chemical reaction. This method has the distinct advantage of being simple and easy to use in rural areas. It is expected to purify biogas to a degree similar to that of the most commonly used chemical methods while increasing cost-efficiency by this method.**

Keywords: Biogas, anaerobic digestion, biogas purification, chemical reaction, sodalime.

I. INTRODUCTION

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. Being a 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 [1].So, 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. It provides a clean fuel for both SI (petrol) and CI (diesel) engine. Diesel engines require mixture of biogas and diesel whereas petrol engine can run fully on biogas. 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. The purified biogas could be a decentralized source of fuel with uninterrupted supply using cheap and locally available resources. It will generate sufficient opportunities for employment too in rural areas.

Several researchers have used different techniques to remove carbon dioxide from biogas. Some widely used techniques are water scrubbing, membrane separation, cryogenic separation under varying conditions [2]. As observed from the literatures, water scrubbing is a simple, eco-friendly and practical method for carbon dioxide removal from biogas. But it requires a lot of water for this process which makes it impractical for areas with water scarcity. In chemical absorption method, methane concentration at the output decreases rapidly and to maintain high methane concentration frequent replacement of absorbent is needed which makes the operating cost high. Pressure swing adsorption process is very expensive compared to the other methods. If this process is followed, it is essential to remove hydrogen sulphide before removing carbon dioxide which makes it complicated. Membrane separation method has higher operating pressure (25-40 bar), lower methane yield and higher membrane cost. Operating temperature and pressure of cryogenic separation method is observed to be -100°C and 40 bar, respectively which is very difficult to achieve. The capital as well as operating cost is also very high in this process [3].

Therefore, there is great need for an alternative method of biogas purification. In this study an attempt has been made to purify biogas using chemical absorption method where sodalime s used as the medium of carbon dioxide absorption.

II. DESIGN AND DEVELOPMENT OF EXPERIMENTAL SET-UP

The experimental set up consists of an air compressor to compress raw biogas, a rotameter to measure the flow rate of the compressed biogas before entering into the scrubber, a scrubber made of acrylicfor absorbing carbon dioxide from the compressed biogas and a water displacement system to measure the amount of biogas coming out of the scrubber. Design of the scrubber is done based on the design of canister of carbon dioxide scrubber used in gas mask. The design data are collected from the literature [4].

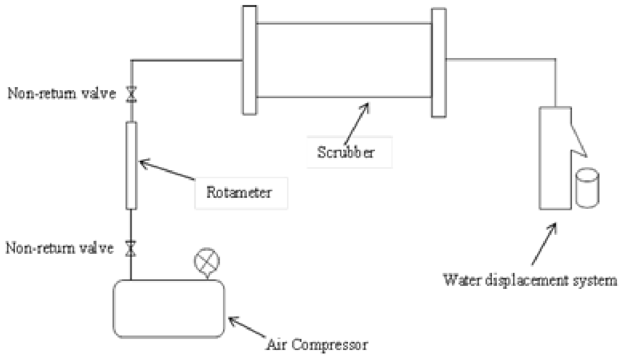

Fig. 1. Schematic diagram of the biogas purification system

Sodalime is used as the absorbent in the designed scrubber to absorb carbon dioxide from biogas. The particle diameter of sodalime granules are measured using electron microscope [make: carl zeiss] and its mean value is found to be 3.75 mm. The design parameters of the scrubber shown in Table 1 are calculated using design guidelines for carbon dioxide scrubbers [4].

TABLE 1. Design parameters of the scrubber

Design Parameters	Value
Inner diameter of scrubber (D)	120 mm
Length of the scrubber (L)	200 mm
Gas flow rate in the scrubber (Q)	3.28 lpm

III. MATERIALS AND METHODS

It is observed from the literature that the chemical absorption method uses aqueous chemical solution (NaOH solution, amine solution etc.) as the absorbent. However it is difficult to handle because of their corrosive nature. The precipitates of aqueous chemical solution formed at the bottom of the scrubber reduce the performance of the system. Hence it is necessary to use the chemical in dry state to avoid the difficulty faced in this method by aqueous solution. So, it is proposed to use dry chemical in chemical absorption method for purification of biogas. It is supposed to make the system simple and easy to use while avoiding the disadvantages of using aqueous solution of chemicals. Hence sodalime is used as absorbent in chemical absorption method. It is a mixture of chemicals such as $Ca(OH)_2$, NaOH, KOH and some moisture. It is used worldwide in various applications like anesthesia, respiratory care, hyperbaric chambers, military and tourist submarines, underwater diving gear, fire safety apparatus, mine rescue equipment, etc. [4].The most important thing about this chemical is that it is available in the form of pellet, which makes it convenient for easy recharging/discharging. Table 2 presents the typical composition of sodalime.

TABLE 2. Typical composition of sodalime [5]

Compositions	(%)
$Ca(OH)_2$	94
H_2O	14-19
NaOH	2-4
KOH	1-3%.

The chemical reaction between sodalime and carbon dioxide is an exothermic reaction and it generates humidity [4]. The temperature rise during the exothermic reaction throughout the scrubber is analogous to a moving temperature front. As the gas passes through the scrubber containing sodalime, carbon dioxide is absorbed by the first layer of sodalime granules and once the sodalime get saturated the reaction proceeds to the next layer of sodalime [6].

The reaction between sodalime and CO_2 is a three step exothermic reaction producing water vapour. Equation 1 describes how gaseous CO_2 dissolves in water, which is the first of the three step reaction (7).

$$CO_2 + H_2O \rightleftharpoons CO_2\,(aq) \qquad (1)$$

The second step of the reaction is shown by Eq. 2. This shows that the strong base, NaOH is not consumed here rather it acts as a catalyst in the reaction. Due to the high pH this bicarbonate is formed.

$$CO_2\,(aq) + NaOH \rightleftharpoons NaHCO_3 \quad (2)$$

The third and the final step is shown by Eq. 3. It deals with the production of calcium carbonates.

$$NaHCO_3 + Ca(OH)_2 \rightleftharpoons CaCO_3 + H_2O + NaOH \quad (3)$$

Combining Eq. 1-3, the overall reaction can be shown by Eq.4. Heat release in the reaction is found to be 16.4 kcal/mol of CO_2 [8].

$$CO_2 + Ca(OH)_2 \rightleftharpoons CaCO_3 + H_2O + \Delta H \quad (4)$$

To initiate the CO_2 absorption processes water is required as shown by Eq. 1. However in the second step of the reaction water is produced as a by-product of the chemical reaction that takes place within the scrubber (Eq. 2). The water required to initiate the absorption process may be furnished by the vapour present in the carrier gas stream.

Sodalime absorbent has been used for over sixty years as a carbon dioxide absorbent for various applications as mentioned above [4]. But literature is hardly found regarding the use of sodalime to remove carbon dioxide from biogas. In the present work a carbon dioxide scrubber is designed and developed where sodalime is packed as absorbent.

IV. EXPERIMENTAL PROCEDURE

The raw biogas is compressed and stored in the air compressor and then it is allowed to flow through the scrubber at various inlet gas pressures through the rotameter. Rotameter is a device in which the flow enters the bottom of a vertically placed tapered tube and causes the bob to move upwards. The bob will rise to a point in the tube where the drag force (upward direction) and buoyant force (upward direction) is balanced by the weight of the bob (downward direction). The position of the bob is taken as the indication of the flow rate. It is also called variable area orifice meter as the elevation of the bob is dependent on the annular area between it and the tapered glass tube. Flow rate of the compressed gas passing through the rotameter is controlled with the help of the valves fitted. The gas going out of the scrubber is measured using water displacement system and collected for gas analysis using gas chromatograph (GC).

Raw biogas is first compressed using the single stage air compressor as shown in Fig. 2 and then the compressed biogas is allowed to pass through the scrubber at different inlet gas pressure and inlet gas flow rate. K-type thermocouples were fitted to the scrubber at various locations to detect the temperature rise during chemical reaction as shown in Fig. 3. Fig. 4 shows the water displacement system consisting of brine solution in the solution bottle where the outlet gas is allowed to enter which leads to displacement of the solution. The displaced solution is collected in a beaker. The amount of solution collected directly indicates the amount of gas coming out of the scrubber. The quality of biogas before and after scrubbing was collected in tedler bags and analyzed using gas chromatograph (GC). The gas pressure and flow rate is measured with the help of the pressure gauge and the rotameter fitted to the experimental set-up. Figures 5 show the complete experimental set-up.

Fig. 2 Compression of biogas

Fig. 3 Biogas passed through the scrubber

Fig. 4 Measurement of purified biogas

Fig. 5 Experimental set-up

V. RESULTS AND DSCUSSION

In this experiment raw biogas is compressed and stored in the air compressor. The compressed biogas is allowed to pass through the scrubber by varying the inlet pressure from 1 bar to 5 bar at an interval of 1 bar with the help of the pressure regulator. The gas flow rate of the inlet biogas is also varied from 1 lpm to 5 lpm at a step of 1 lpm with the help of the rotameter. The raw biogas as well as purified gas coming out of the scrubber is tested for composition analysis with the help of Gas Chromatography (GC). The percentage of raw biogas was found to be 41.5%. It is observed from Fig.6 and Table 3 that with increase in inlet pressure, percentage of carbon dioxide at the outlet gas decreases and with increase in inlet gas flow rate, percentage of carbon dioxide at the outlet gas increases in case of vertical scrubber. It is observed that inlet pressure of 1 to 3 bar carbon dioxide percentage in the outlet turns out to be more than 5% irrespective of flow rate. Whereas at inlet pressure of 4 and 5 bar the percentage of carbon dioxide in the outlet is found to be less than 5% at all the above mentioned flow rate.

At gas flow rate of 1 lpm, percentage of carbon dioxide content is found to be 2.8% at a pressure of 4 bar whereas at 5 bar it become 1.344%. With decrease in inlet pressure the carbon dioxide from 4 to 1 bar, absorption reduces drastically and carbon dioxide percentages in purified biogas increase 2 to 3 times the carbon dioxide percentages at 4 and 5 bar inlet pressure.

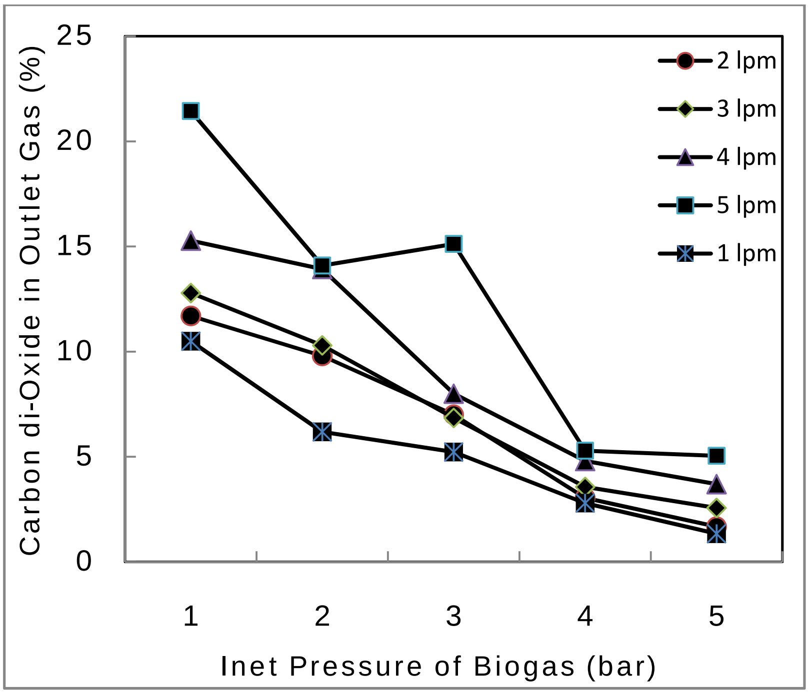

Fig. 6 Percentage of CO_2 in purified biogas

TABLE 3. Percentages of CO_2 in Biogas after purification

Inlet Pressure (bar) \ Flow rate (lpm)	**1**	**2**	**3**	**4**	**5**
1	10.5	11.7	12.79	15.28	21.44
2	6.19	9.8	10.3	13.93	14.1
3	5.23	7.0	6.85	8.0	15.12
4	2.8	3.05	3.57	4.8	5.29
5	1.344	1.68	2.57	3.7	5.05

Max. CO_2 concentratio

Min. CO_2 concentration in outlet biogas

Table 4 presents the results of biogas purification using different methods by various researchers along with the results of present work. It is observed that upto 97.7% methane and 1.34% carbon dioxide can be achieved using the present experimental set-up which is quite comparable with literature. Also this method of biogas purification using dry chemical (sodalime) is found to be very effective in rural areas due to the simple design, easy handling of the chemical, requirement of low pressure and low flow rate of input biogas.

TABLE 4. Comparison of results of biogas purification with literature

Literature	**Method**	**Results**
[2]	Water Scrubbing	99% pure biogas at 1.5 m^3/h gas flow rate and 1.0 MPa gas pressure
[9]		93% pure biogas at1.0 MPa gas pressure
[10]	Chemical Scrubbing (aq. Solution of MEA)	CO_2 content of the biogas was reduced from 40 to 0.5-1.0% by vol.
[11]	Chemical Scrubbing (aq. Solution of NaOH)	95.5% methane and 3.2% CO_2
	Chemical Scrubbing (aq. Solution of $Ca(OH)_2$	95% methane and 4% CO_2
	Chemical Scrubbing (aq. Solution of MEA)	98% methane and 1.3% CO_2
Present study	Dry chemical scrubbing using sodalime	97.7% methane and 1.34% CO_2

VI. CONCLUSIONS

Although there are various methods of biogas purification available, all of them are not quite acceptable in the rural areas. Most of them are costly and are difficult to handle. Among them the chemical absorption is found to the easiest one but due to the use of aqueous solution of chemicals, this method is found to be difficult to handle. That is why the chemical absorption process with dry chemical as carbon dioxide absorber is used in the present study using sodalime as the absorber. Here the minimum carbon dioxide content present in biogas could be reduced to upto 1.34% in the output gas at 5 bar and 1 lpm flow rate of the biogas. The biogas was found to be rich with 97.7% methane.

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