Biogas Purification and Bottling into CNG Cylinders: Producing Bio-CNG from Biomass for Rural Automotive Applications

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Abstract: *The paper presents development of biogas scrubbing and bottling system for production of Bio-CNG to substitute compressed natural gas used in automobile and transport applications. Biogas can be used in automobiles after its purification (removing CO_2, H_2S and vapour present in it). A CO_2 scrubbing and bottling technology has been designed and developed at Indian Institute of Technology Delhi based on physical absorption of CO_2 in water at elevated pressure. The developed scrubbing system is able to remove CO_2 from raw biogas when pressurized raw biogas was fed into the packed bed scrubbing column and pressurized water is sprayed from top in counter-current action. The enriched biogas was compressed up to 20 MPa pressure using a three stage compressor after moisture removal and filled in special high pressure steel cylinders (as used in CNG filling). The enriched biogas filled CNG cylinders were tested in a vehicle. Biogas enrichment and compression system can be recommended for large size biogas plants as there is sufficient biogas available for bottling, thus make it an economical venture of methane farming. The technology ensures sustainable development and energy security with employment generation in rural areas using cattle dung and biomass.*

Keywords: Biogas, Water Scrubbing, Bio-methane, Bottling, CNG, Automobiles

1. INTRODUCTION

Gaseous fuels like Natural gas, Biogas has been explored as an alternative to petrol and diesel to lighten the import burden. Natural gas in compressed form is already being used successfully as vehicle fuel in many European countries like Argentina, Pakistan, India etc.. New Delhi, the capital of India has the world's largest fleet of public buses run on compressed natural gas (CNG).

Natural gas has 75-98 % methane with small percentages of ethane, butane, propane while biogas has about 60 % methane and 40 % carbon dioxide. It is possible to improve the quality of biogas by enriching its methane content up to the natural gas level. After methane enrichment and compression it can be used as vehicle fuel just like CNG. Over and above, it has lower emission than natural gas and diesel as shown in Table 1 [4].

Table 1 Comparison of gaseous emissions for heavy vehicles (bus)

g/km	CO	HC	NO_X	CO_2	Particulates
Diesel	0.20	0.40	9.73	1053	0.100
Natural gas	0.40	0.60	1.10	524	0.022
Biogas	0.08	0.35	5.44	223	0.015

Source: A report on biogas technology and biogas use in Sweden, Traffic and Public Transport Authority, City of Gothenburg, November 2000.

An estimate indicates that India has a potential of generating 6.38×10^{10} m^3 of biogas from 980 million tons of cattle dung produced annually. The heat value of this gas amounts to 1.3×10^{12} MJ. In addition, 350 million tons of compost would also be produced [5].

If other available organic wastes such as sewage, municipal solid waste, industrial effluent, distilleries etc. are also be taken as feedstock for gas production, the total biogas potential would increase further. Different categories of urban municipal and industrial organic wastes and their estimated quantity available in India are shown in Table 2 [6].

Table 2 Organic wastes and their estimated availability in India

Type of waste available	Estimated quantity
Municipal solid waste	30 million tons/year
Municipal liquid waste	12000 million litres/day*
Distillery (243 units)	8057 kilolitres/day
Press mud	9 million tons/year
Food and fruit processing wastes	4.5 million tons/year
Willow dust	30000 tons/year
Dairy industry waste	50-60 million litres/day
Paper and pulp industry waste (300 mills)	1600 m^3 /day
Tannery (2000 units)	52500 m^3 waste water /day

*212 class I and II cities

Source: Ministry of Non-conventional Energy Sources Report, Renewable energy in India and business opportunities, MNES, Govt. of India, New Delhi, 2001.

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Biogas has the potential to replace a substantial level of gaseous fossil fuel and chemical fertilizer consumption in India. This can be better understood by following example. In the year 2001-02, 22.7 billion cubic meters of natural gas (excluding gas for LPG shrinkage) and 7.3 million tons of LPG were consumed [7]. In terms of heat energy, this amount to 1.08 x 10^{12} MJ per year, against the potential heat value of 1.3 x 10^{12} MJ/year available from biogas produced annually from the cattle dung [5]. Similarly, against the chemical fertilizer consumption of 19.4 million tons in 2001-02 [7], 350 million tons of compost can be produced by biomethanation of cattle dung annually [5].

2. REVIEW ON BIOGAS ENRICHMENT PROCESSES

A lot of processes are available for enrichment of methane content in biogas by removing significant amount of carbon dioxide (CO_2), and hydrogen sulfide (H_2S). Most of these processes have been developed for use in the natural gas, petroleum and petrochemical industries. As a consequence, some of them may not be suited for biogas applications unless high flow rates are involved. Commonly CO_2 removal processes also remove H_2S [8].

1. Absorption into liquid (Physical / Chemical)
2. Adsorption on solid surface
3. Membrane separation
4. Cryogenic separation
5. Chemical conversion

Selection of the appropriate process for a particular application depends on the scale of intended operation, composition of the gas to be treated, degree of purity required and the need for CO_2 recovery. If water is available in the required quantity, water scrubbing is a better option for removal of CO_2 and H_2S [8].

2.1 Water scrubbing

Water scrubbing involves the physical absorption of CO_2 and H_2S in water at high pressures and regeneration takes place by release in pressure with very little change in temperature.

It is simple method involving use of pressurized water as an absorbent. The raw biogas is compressed and fed into a packed bed absorption column from bottom and pressurized water is sprayed from top. The absorption process is, thus a counter-current one. This dissolves CO_2 as well as H_2S in water, which are collected at the bottom of the tower [9 and 11].

The design of water scrubbing system depends on the solubility of carbon dioxide in water as solubility is governed by pressure and temperature as given in Table 3.2 [11]. It is clear from table that as the pressure increases solubility of CO_2 in water increases but decreases as temperature increases.

Table 3 Approximate solubility of CO_2 in water

Pressure (atmospheric)	Solubility, in kg of CO_2 per kg of water at different temperatures.			
	0º C	10º C	20º C	30º C
1	0.40	0.25	0.15	0.10
20	3.15	2.15	1.30	0.90
50	7.70	6.95	6.00	4.80

3. SYSTEM DESIGN AND FABRICATION

A packed bed scrubber was designed for 95 % removal of carbon dioxide from biogas. Thus, initially 40 % carbon dioxide present in raw biogas would be reduced to 2 % by volume in enriched biogas. To increase solubility of carbon dioxide in water, raw biogas was compressed up to 1.0 MPa pressure and pressurized water was used as an absorbent liquid.

A packed bed scrubbing column with 3500 mm packed bed height was designed for absorption of CO_2 at operating pressure of 1.0 MPa of biogas inlet. Ceramic Resching rings were used as packing material. The details of various component involved in the system is described below:

3.1 Biogas enrichment unit

The unit comprise of a scrubber, a water supply system, a gas supply system, a low capacity compressor, a pressure vessel, pipe fittings and various accessories. Schematic diagram of complete biogas enrichment, further its bottling is shown in Figure 1.

3.1.1 Scrubbing column

The diameter of the scrubber and packed bed height were taken as 150 mm and 3500 mm respectively. The scrubber consists of a packed bed absorption column and a supporting frame as described in following sub-sections:
A 10 mm thick Mild Steel (MS) pipe was selected for the column fabrication. The column was fabricated in three sections.

(I) Top section – It has provision for water inlet pipe, water spraying system, gas outlet pipe and a safety valve. Water spraying system was connected with water inlet pipe to provide fine atomized spray of pressurized water inside the absorption column. A safety valve is provided at the upper portion to release the excess pressure as it is a pressurized column.

(II) Middle section – In this section Resching rings of 16 mm diameter have been filled as packing material. Two sieves are fitted at the top and bottom of the section to hold the packing height of column. A view glass, to see the water level inside the column and a dry type pressure gauge, to check column pressure; are also mounted at the upper portion of the middle section.
(III) Bottom section – This section has provision for inlet gas feeding pipe and a view glass at upper side. Lower side has been transformed into truncated cone shape with 50 mm diameter outlet opening. It is fitted with a ball valve to control the outlet water flow. Outlet water is stored in a water collection tank. All the three sections are joined together with flanges, bolts and nuts.

3.1.2 Supporting frame

Supporting frame comprises of three legs, which is fabricated from MS angle size 55 x 55 x 5 mm. The legs are grouted firmly in ground with cement, sand and stone gravel mixture and fitted with the absorption column in the middle. A staircase, made of MS angle and flats, has also been attached with the absorption column to climb up to the top of the column to check water level and column pressure.

3.1.3 Water supply system

Screw pump is used to pump water from water storage tank into the scrubber. Screw pump is selected to provide pressurize water at low discharge. 25 mm diameter Galvanized Iron (GI) pipe fitting have been used for water supply. The water flow rate is controlled through a flow regulating valve. A rotameter and a dry type pressure gauge are mounted to measure the water flow rate and pressure of water respectively.

3.1.4 Gas supply system

The gas supply system consists of a biogas plant, a single stage compressor, a pressure vessel, pipe fittings and accessories.

3.1.5 Biogas plant

Raw biogas is fed to the scrubber from a cattle dung based floating drum type biogas plant. The raw gas is supplied from the biogas plant, through 25 mm diameter rigid PVC pipeline to a single stage compressor, after removing water condensed in pipeline using a water remover.

3.1.6 Single stage compressor

A single stage Kirloskar make compressor having 1.1 kW power rating and 10.0 m^3/h suction capacity is utilized for initial compression of raw biogas up to 1.0 MPa pressure before sending it to the scrubber.

3.1.7 Pressure vessel

To ensure steady supply of compressed raw biogas to the scrubber, it is first stored in a pressure vessel. It is made from MS sheet and has storage capacity of 1.0 m^3.

3.1.8 Pipe fettlings and accessories

12.5 mm diameter G I pipe line is used to supply gas from compressor to the pressure vessel and then to the scrubber. Between the pressure vessel and the scrubber, a rotameter and a dry type pressure gauge are installed to measure the rate of discharge and pressure of the raw biogas respectively. The gas flow rate is controlled through a valve provided near inlet point of the scrubber.

3.2 Enriched biogas compression unit

It comprises of a three stage compressor for compression of enriched biogas up to 20 MPa pressure, a set of filters for removal of water vapour, storage cylinders for storing highly pressurized biogas and pipe fittings.

3.2.1 Three stage high pressure compressor

A low suction capacity and high pressure developing compressor is utilized in the present investigation. A three stage compressor is used for bottling. It can compress gas up to 34.5 MPa pressure.

3.2.2 Ultra filters

A set of three filters (Pre filter, Micro filter and Sub Micro filter) are employed in the G I pipeline connected with storage pressure vessel (containing enriched biogas) and three stage compressor. They are designed to remove almost all water vapour from the enriched biogas.

3.2.3 Storage cylinders

High pressure steel cylinders (available in the market for CNG storage) are used for final storage of enriched and compressed biogas. These cylinders are shorter in length and larger in diameter than most gas cylinders and had been specifically built for high pressure gas storage.

3.2.4 Pipe fettlings and accessories

12.5 mm diameter G I pipeline is employed to deliver enriched biogas from the scrubber to the storage vessel (0.5 m^3 capacity). From vessel, it is sent to the three stage compressor via ultra filters and rotameter through 12.5 mm diameter G I pipe line. From compressor, compressed & enriched biogas is finally filled in a cylinder. A pressure gauge is mounted in the pipeline near cylinder to check the gas pressure inside the cylinder and provision is made to release the back pressure from the pipeline after cylinder filling.

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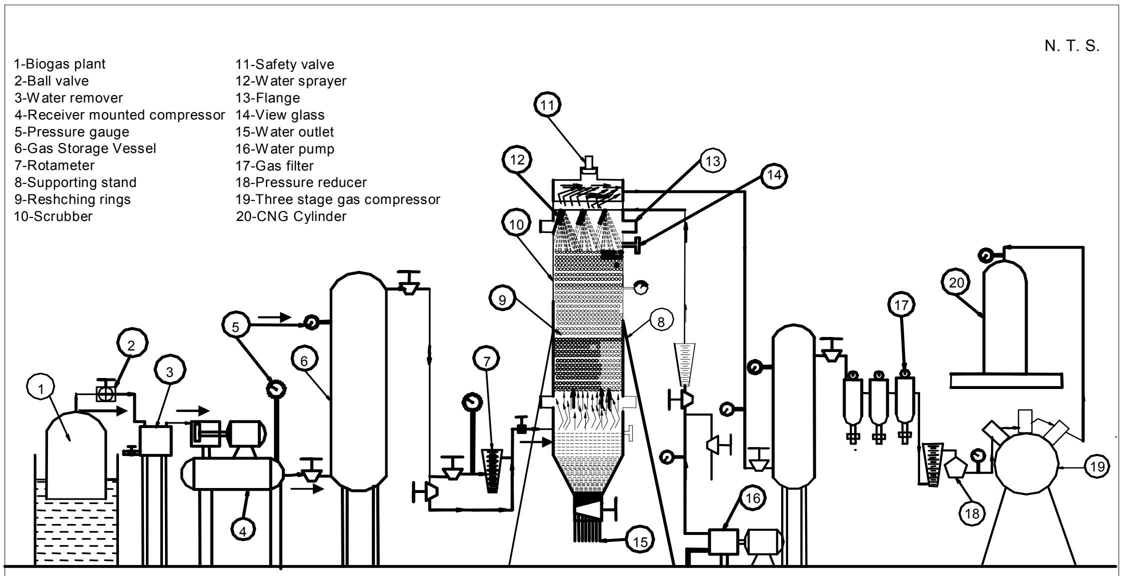

Fig.1 Setup for a biogas purification and bottling plant

4. RESULTS AND DISCUSSION

4.1 Performance of water scrubbing system on removal of CO_2 from biogas

Percentage absorption of carbon dioxide in water was determined in terms of variation in inlet gas flow rates and inlet gas pressures.

The scrubber was designed for 95 % CO_2 absorption from raw biogas in pressurized water for 2.5 m^3/h inlet gas flow rate at 1.0 MPa gas pressure. Accordingly, the variation in inlet gas flow rates from 1.0 - 3.0 m^3/h were studied at 1.0 MPa gas pressure. The values of CO_2 absorption observed were 87.66, 99.00, 83.96, 73.82 and 53.77 % at 1.0, 1.5, 2.0, 2.5 and 3.0 m^3/h gas flow rates respectively.

It was found that the percentage CO_2 absorption from raw biogas has initially increased when gas flow rate vary from 1.0 to 1.5 m^3/h and afterwards it decreased continuously. The highest CO_2 absorption (99 %) was observed at 1.5 m^3/h gas flow rate at 1.0 MPa inlet gas pressure. The best performance of the scrubber was found at 1.5 m^3/h gas flow for maximum CO_2 absorption at 1.8 m^3/h wash water flow rate. The scrubber works perfectly well around 1.8 m^3/h wash water flow rate, above this flow rate, flooding starts. The experimental results confirm the conclusion of Dubey [12], who found that CO_2 absorption in water is influenced by the flow rates of gas and water.

The effect of gas pressure on percentage CO_2 absorption was also determined for all gas flow rates for pressure variation from 0.6 to 1.0 MPa. The percentage CO_2 absorption ranged between 38.34 to 66.03 % at 0.6 MPa pressure and 53.77 to 99.00 % at 1.0 MPa pressure. Again the highest percentage CO_2 absorption is observed for 1.5 m^3/h gas flow rate for all pressure variation i.e. from 0.6 to 1.0 MPa.

It has also been found that, the percentage absorption of carbon dioxide is increased with increase in gas pressure for all gas flow rates. The highest absorption (99 %) was observed at 1.0 MPa gas pressure. This is in agreement with Wellinger & Lindberg [13], who reported that 1.0 MPa pressure for inlet gas can give more than 90 % CH_4 enrichment in biogas.

Table 5 Average test results for the scrubber performance at 1.0 MPa pressure

S. No.	Inlet gas pressure MPa	CO_2 in raw biogas %	Gas flow rate m^3/h	Water flow rate m^3/h	CO_2 remained in enriched biogas %	Performance index (σ)
(1)	1.0	42.4	1.0	1.8	5.4	92.24
(2)	1.0	42.4	1.5	1.8	1.0	98.62
(3)	1.0	42.4	2.0	1.8	6.8	90.08
(4)	1.0	42.4	2.5	1.8	11.1	83.03
(5)	1.0	42.4	3.0	2.0	19.6	66.88

4.2 Automobile vehicle Testing on enriched and bottled biogas

Experiments were conducted on the use of enriched biogas in a car. The results of automotive car testing on compressed & enriched biogas were encouraging. After minor adjustments in air fuel ratio settings, the vehicle started smoothly and showed similar performance as CNG. Enriched biogas contained 85 % methane.

Some observations:

Cylinder (as used for CNG filling) No.	: MDCL0040
Weight of empty cylinder	: 62.1 kg
Weight of compressed & enriched biogas filled cylinder	: 71.4 kg
Weight of compressed & enriched biogas inside the cylinder	: 9.3 kg
Pressure of the gas inside the cylinder	: 11.5 MPa
Car engine	: Three cylinders, four strokes, 800 cc, 39.5 bhp at 5500 rpm
Total distance traveled during test	: 60.6 km

Initially the car was tested within the campus of Indian Institute of Technology Delhi, after successful run, detailed testing of the car was done for long drive in a busy route from IIT Delhi to Anand Vihar Bus Stand and back to IIT Delhi.

Speed observation on the tested car:

Gear	I	II	III	IV
Max. obtained speed (kmph)	40	60	80	100

Distance traveled during long drive	: 55.1 km
Time taken in long drive	: 1 hour 25 minutes
Gas consumed during long drive	: 6.06 kg
Average fuel consumption	: 55.1 / 6.06 = 9.09 km/ kg of fuel

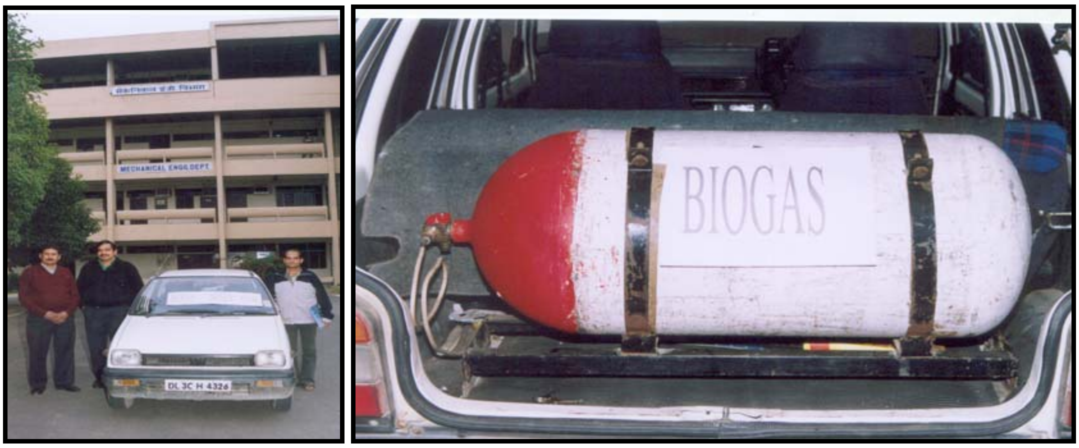

Plate 1. Maruti -800 Car tested on enriched biogas compressed in CNG cylinder

5. CONCLUSION

There is large potential of biogas generation in India to make it an alternate fuel for vehicle.

Biogas produced in large size biogas plants should be enriched before bottling for storage and mobile purpose, as enriched biogas has more calorific value and better fuel quality. Out of several methods of biogas enrichment, water scrubbing is found to be a simple, low-cost and suitable method for enrichment of biogas in rural areas.

I. The designed and fabricated biogas scrubber is able to remove 99 % v/v of carbon dioxide present in raw biogas.

II. To make biogas suitable for automobile application, the enriched biogas was compressed up to 20.0 MPa after moisture removal and filled in special high pressure seamless steel cylinders (as used in CNG filling). The cylinders were tested for vehicle (Maruti -800 car). The test results on performance were observed as good as on CNG operated Maruti -800 car in term of easy & quick starting and smooth running after engine tuning and restriction in air intake.

Overall, the study revealed that biogas enrichment and compression system is a profitable venture for rural areas due to availability of large quantity of cattle dung. The system is recommended to establish rural entrepreneurship for the effective utilization of local biomass resources for production of biogas energy in decentralized manner and sustainable rural development.

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