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Research Article

Upgrading biogas for utilization as a vehicle fuel

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Abstract: The demand for petroleum products in India has been increasing at a faster rate than the increase in domestic availability, resulting in increased imports. The transport sector is the single largest consumer of petroleum products. Secondly, about 65 % of total air pollution is caused by the emissions of pollutants from the vehicles run on petroleum products. In the wake of this, there is urgent need to introduce alternate fuels as substitutes for diesel and petrol in the transport sector. Biogas, a clean and renewable fuel, has vast potential in India. It can be supplement to petroleum products, if used in compressed form in cylinders. Here a model is conceptualized for bottling of biogas from 120 m^3/day capacity biogas plant and its use as vehicle fuel. It can save petrol worth about 0.66 million Rs. per annum and also generate employment for 12 persons.

Keywords: Biogas, Upgradation, Compression, Bottling, Vehicle Fuel.

Introduction

The rising demand for petroleum products from transport and other sectors together with stagnating domestic production have led to an increased dependence on petroleum imports. Net imports of crude oil and petroleum products in India have more than doubled in the last nine years, from 27 MT in 1990 to 57 MT in 1999 [1].

To reduce import bill and control emission of pollutants from vehicles has compelled the search for alternate fuels. Among the options available is use of combustible gases as fuel. Most commonly used combustible gases in world-wide are Natural Gas, Liquefied Petroleum Gas and Biogas. Among these three, first two are petroleum based, hence non-renewable;

while the later has a renewable source. Natural gas in form of Compressed Natural Gas (CNG) has received a great deal of attention and has already been applied successfully to over a million vehicles in various parts of the world. New Delhi (India) has world's largest fleet of public transport bus service operating on CNG.

However, the feasibility of dispensing CNG in the country as an alternative transport fuel would depend not so much upon the overall natural gas availability in the country, but on the feasibility of lying natural gas pipeline network connecting various cities. Investment in pipelines cost up to Rs.25 0000 millions to cater the demand (between 180 and 230 million standard cubic meter per day) of gas in India in the year 2007 [2]. It is estimated that the demand of LPG would be 11.48 MMT (million metric tonnes) as against supply of 8.10 MMT in the year 2006-07. Thus, LPG will be shortening of 3.38 MMT and this demand-supply gap is projected to widen substantially in near future [3].

Therefore, the third alternative i.e. Biogas is best suited in this context, being clean and renewable fuel. It is produced by anaerobic digestion of bio-wastes, which is generated daily in enormous quantity. An estimate indicates that biogas has a potential of generating 6.38×10^{10} cubic meter of biogas from 980 million tones of cattle dung annually produced in India. The heat value of this gas amounts to 1.3×10^{12} MJ. Besides this, 350 million tones of manure could also produce if this quantity of dung is used for biogas production [4]. It could replace 76 % of natural gas demand of the country. In addition to this, there will be no need of laying pipeline supply network connecting cities, as bio-waste is available plenty in each city and village of the country.

More than 3.5 million family size biogas plants as against a potential of 12 million have been installed in India. These plants are of small capacity ($1\text{-}10m^3$) and mainly used for cooking & other domestic applications [5]. Biogas provides a clean fuel for both SI (petrol) and CI (diesel) engines. Diesel engines required combination of biogas and diesel while petrol engines run fully on biogas. Use of biogas as an engine fuel offers several advantages. Biogas being a clean fuel causes clean combustion and reduced contamination of engine oil. For use of biogas as a vehicle fuel, it is first upgraded by removing impurities like carbon dioxide, hydrogen sulfide and water vapour, then compressed in a three or four stage compressor up to a pressure of 20 MPa and stored in a high pressure gas storage cascade which helps to facilitate quick refueling of storage cylinders.

However, these applications of biogas are restricted to the place where it is produced. To make it a convenient fuel for vehicle use, large quantity of biogas generation has to be ensured. The large quantity of compressed upgraded biogas can significantly replace conventional fuel mainly diesel/petrol. This can be facilitated by bottling of biogas in cylinders. Bottled biogas can be taken at any place for use as a vehicle fuel. Therefore, a decentralized energy source which is independent of the utility system and based on biogas offers a better option in order to meet the vehicle fuel requirements in the country with zero emission. The only criteria are to have large size biogas plants and assurance of supply of bio-waste in large quantity for such plants.

Upgradation & Bottling of Biogas

Biogas consists of methane (55-65%), carbon dioxide (35-40%), hydrogen sulfide (<1%) and traces of water vapour. To have more energy per unit volume of biogas, the carbon dioxide content in the biogas should be removed. Hydrogen sulfide (H_2S) content may deteriorate compression system due to corrosive property.

There are many methods for carbon dioxide (CO_2) removal i.e. absorption in water, absorption using chemicals, pressure swing adsorption and membrane separation. However, absorption of CO_2 in water is simple, cost effective, eco-friendly and practical method for CO_2 removal from biogas in rural areas. It is a continuous process and simultaneously removes H2S also. This method is most popular in sewage sludge based biogas plants in Czech Republic, France, Sweden, New Zealand and USA. High purity biogas (> 95% methane content) can be obtained using this technology [6]. G.B. Pant University of Agriculture & Technology, Pantnagar (India) has reported 87.6 % CO_2 removal from the raw biogas using a 6000 mm high scrubbing tower [7]. When biogas is produced from cattle dung, hydrogen sulfide content is usually less than one per cent. The concentration of hydrogen sulfide more than this level should be removed before use in engines [8].

A scrubber is designed and developed at Indian Institute of Technology, New Delhi for removal of CO_2 from biogas. The scrubber is 150 mm in diameter and 4500 mm height with 3500 mm packed bed height. It has been designed to enrich methane content of biogas from 60 % to 95 %. Pressurized water from top and pressurized raw biogas from bottom is sent in the scrubber in counter- current direction through packing material (Resching rings), so that maximum absorption of carbon dioxide in water takes place. Enriched biogas is stored in a pressure vessel for further compression up to 20 MPa pressure using a three stage gas compressor and filled in cylinders.

Approach

Based on above, a model bottling plant has been conceptualized for a 120 m^3/day capacity biogas plant as a village enterprise. The required quantity i.e. 3000 kg dung will be purchased from village or from near by area using auto rickshaw. Approximately 300 square metre land is required for this activity. A well to ensure sufficient water supply is also dug in the premise. The bottling plant has three components (i) upgrading unit for removal of CO_2 and other impurities from raw biogas, (ii) a compression unit for compression of enrich biogas upto 20 MPa pressure for filling in cylinders and (iii) a power unit consist of a generator coupled with biogas operated SI engine for production of electricity to run compressors and water pump.

Considering 80 % plant efficiency (account of seasonal and other factors) the average raw gas availability will be 96 m^3/ day. Energy available from the biogas plant is 1958 MJ /day. The energy analysis of the whole process is given in Table1. It s estimated that 489 MJ /day energy in form of enrich gas will be consumed in operating the engine for upgrading and compression operation which is 24 % of the total energy generated per day. The net gas available per day for bottling will be 43.2 m^3 having energy value of 1469 MJ.This gas will be stored at 20 MPa pressure in eight cylinders, each of 21.5 litre water capacity and have 5.4 m^3 enriched biogas [9].

Table 1 Energy analysis on upgradation & compression of biogas

A	**Assumptions**		
	Capacity of plant	120	m^3/day
	Plant efficiency	80	%
	Generated gas	96	m^3/day
	Upgraded gas consumption for running S I engine	0.36	m^3/kW
	Calorific value of upgraded biogas	34	MJ/m^3
	Gas capacity for 0.0215 m^3 water capacity cylinder	5.4	m^3
	Gas flow rate for 8 hours of working in a day	12	m^3/h
	Heat rate of raw gas	245	MJ/h
	Total energy available in one day from biogas plant	1958	MJ
B	**Energy required for upgradation**		
1	For pumping and pressurizing water at 1.2 MPa	1.5	kW
2	For pressurizing raw gas at 1.0 MPa.	1.3	kW
C	**for compression**	2.2	kW
D	**Total energy required per day (B+C)**	5	kW
E	**Process plant energy (B+C) met by upgraded gas driven engine**		
	Rated power of gas engine	5	kW
	Upgraded gas consumption	1.8	m^3/h
	Gas energy consumed /day	489	MJ
F	**Net upgraded gas available for compression and storing in cylinders**	5.4	m^3/h
	Net heat rate available for storing in cylinder	183.6	MJ/h
	Total upgraded gas available per day	43.2	m^3/day
	Net energy of upgraded gas available in cylinders	1469	MJ
G	**Estimation of cylinders filled with compressed gas**		
	Total upgraded gas available	43.2	m^3/day
	Number of cylinders filled in one day	8	cylinders
	Weight of gas in one filled cylinder	3.8	kg
	Energy value per cylinder	183.6	MJ

The economics of biogas bottling plant is calculated and shown in Table 2. It is worth to establish biogas bottling as an enterprise, since it give a profit of 0.136 million Rupees per annum and also provide direct employment to 4 persons. (1 US $ = Rs.45)

Table 2 Economics of biogas bottling

A		**Assumptions**		
	1	Capacity of biogas plant	120	m^3 /day
	2	Biogas plant cost	0.4	Million Rs.
	3	Bottling plant cost	0.4	Million Rs.
	4	Cost of well for water supply	0.05	Million Rs.
	5	Cost of land & other infrastructure	0.15	Million Rs.
	6	Cost of 1 auto rickshaw	0.1	Million Rs.
		Total capital cost (2+3+4+5+6)	1.1	Million Rs.
	7	Purchase cost of dung	0.25	Rs./kg
	8	Sale price of digested slurry	2	Rs./kg
	9	Interest rate	5	% / annum
	10	Depreciation (life span 20 years)	5	% / annum
	11	Repair & maintenance	5	% of capital / annum
	12	Market rate of CNG	18	Rs./ kg
	13	Gas filled in a cylinder (size d=0.230m, h=0.695m)	3.8	kg
	14	No. of cylinders filled in a day	8	
B		**Fixed cost**		
	15	Interest on capital cost	0.055	Million Rs./annum
	16	Depreciation	0.055	Million Rs./annum
		Total	0.110	Million Rs./annum
C		**Variable cost**		
	17	Dung cost (3000 kg /day)	0.273	Million Rs./annum
	18	Manpower (2 skilled persons @ Rs 150 /day & 2 unskilled persons@ Rs.100 / day)	0.172	Million Rs./annum
	19	Repair & maintenance	0.055	Million Rs./annum
		Total	0.500	Million Rs./annum
D	20	**Total operational cost** (B + C)	0.610	Million Rs./annum
	21	or	1671	Rs./day
E		**Cost of bottling**		
	22	Income from sale of digested slurry (0.25 x 3000 kg/day x 2 Rs/kg)	1500	Rs. /day
	23	Cost of bottling (21 – 22)	171	Rs. /day
		Upgraded gas available for bottling (8 x 3.8 kg /day)		
	24	so, cost of bottling	5.6	Rs./ kg
G	25	**Profit by sale of bottled upgraded biogas** (12-24)	12.4	Rs./kg
		or	377	Rs./ day
		or	0.136	Million Rs./annum
H	26	**Pay back period**	8	Years

Application of Compressed Upgraded Biogas as Vehicle Fuel

Since 8 cylinders are filled per day with compressed upgraded biogas from 120 m^3 /day capacity biogas cum bottling plant, they are sufficient to fuel a fleet of 8 auto rickshaws traveling 100-120 km distance everyday. The plant will generate employment for 4 persons directly and indirectly it will create a business opportunity for 8 persons who will own /drive the biogas powered auto rickshaws. Since biogas plants based on cattle dung are mostly located in rural areas, these areas will be most benefited by using biogas as fuel for vehicles. Thus, save diesel/ petrol. The annual savings of petrol in auto rickshaws using compressed upgraded biogas as fuel is given in Table 3.

Table 3 Economics on use of compressed upgraded biogas as vehicle fuel

S No.	Vehicle	No. of Vehicles run on compressed biogas daily	Annual savings	
			Petrol litre	Cost Million Rs.
1	Auto rickshaw	8	15768	0.66

It is evident from Table 3 that 15768 litres petrol worth cost 0.66 million Rs. per annum can be saved using compressed upgraded biogas. Besides monetary benefit, use of compressed upgraded biogas reduces emission of polluting gases in environment to a great extent. It can be understand through a citation shown in Table 4.

Table 4 Comparison of emissions from exhaust gases between diesel and biogas driven busses in Vaxjo city

S. No.	Emissions	Fuel used for driven buses	
	Kg / Per annum	Diesel / RME	Biogas
1	NO_x	16200	800
2	SO_x	380	30
3	CO	430	930
4	CO_2	840000	23000
5	N_2O	700	0
6	CH_4	400	16500
7	Particles	250	50

The above citation shows the calculated emissions of the exhaust gases from 16 city-buses in Vaxjo city of Sweden [10]. The comparison shows the situation today and a future situation if the buses could use biogas for fuel instead of diesel. It would reduce the environmental impact in several parameters, but especially the carbon dioxide emissions. Biogas can also be used in petrol cars. Petrol cars have the advantage that they normally have a dual-fuel system, with one tank for biogas and one tank for petrol. The advantage is that the effect due to shortage of biogas is strongly reduced.

Conclusion

Biogas is a potential renewable energy source for rural India. Biogas generation and subsequent bottling will cater the fuel requirement in rural transport, make villages pollution free and supply enriched manure. The bottling system will work as a decentralize source of fuel with uninterrupted supply using local resources, generate ample opportunities for employment in rural areas and income of the people. The model bottling plant will give savings of 15768 liters of petrol worth cost about 0.66 million Rs. per annum. It should be replicated at mass scale to reduce import of petroleum products, save environment and generate employment in the villages. The spirit behind the whole concept is to develop self sustained rural enterprises and decentralized fuel station based on compressed upgraded biogas to make rural areas economically developed and competitive in all respects. The initial financial support required for biogas-cum-bottling plant may be made available through bank or government bodies on soft loan basis.

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