Performance Evaluation of a Low BHP Biogas Run Engine

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***Abstract*- A biogas plant with a capacity of 2 cubic meters was used for production of biogas which was supplied to a 4.5 bhp single cylinder biogas run engine coupled with a single phase alternator to generate electricity upto 2.5 kw. It was found that a 28% diesel was replaced by biogas at 60% load after which problem of black smoke emission and knocking occurred. Moreover the overall thermal efficiency of a diesel run engine and an engine supplied with mixture of biogas and diesel were recorded as 20.50% and 17.99% respectively. The cost economic evaluation was done both from research point of view and that of farmer's use and it was found that for research purpose, the engine worked on no profit-no loss basis whereas for farmer's dairy, it can attain a profit of Rs. 183/month with a pay-back period of 14 years 6 months and 25 days. It can be concluded that diesel being a non-renewable source will have a hike in its price and at that time this technology can be adopted for major profits. Moreover, use of biogas is also an eco friendly approach towards environment and hence need to be adopted at much faster rates. So biogas can be used as an alternate source for electricity generation, domestic chulha and many other purposes.**

Keywords: Bio Gas, thermal efficiency, alternate fuel

I. INTRODUCTION

A. General background

It is a well known fact that the world's conventional energy resources will be depleted within the next several decades. The world is unavoidably facing the crisis of fossil fuel shortage and environmental degradation as a direct result of growth in population, urbanization and industrialization. Most countries find themselves under considerable energy constraints, while the growing demand for domestic energy use is constantly decreasing fuel wood reserves and is increasing deforestation rates, also the foreign exchange earnings have to be spent on imported fuels. The search for alternatives for partially or totally substituting the fossil fuels has, therefore, been intensified in the last decade. Among the many different types of alternative fuels, biogas from anaerobic digestion of animal manure appears to be one of the most promising options as India has a large population of cattles. Biogas technology has been developed steadily over the last 70 years. It originates from the biodegradation of organic materials by bacteria under anaerobic condition and consists of mainly methane and carbon dioxide. The idea of biogas as a diesel fuel substitute is not new, but it is a very attractive alternative, especially in countries rich in agricultural products and poor in petroleum resources. There have been continuing efforts in research, development and demonstration to utilize biogas to provide heat and power agricultural engines in farm within the country for the past several decades. Biogas can be used as an alternative to the partial or total substitution of gasoline and diesel fuels without requiring extensive engine adjustments or modifications. Utilization of biogas will also help in decreasing the farmer's electricity bill and reduce the expenditure of foreign exchange required for imported petroleum products.

Numerous research works have been done on dual fuel engines. These include natural gas, methane and propane, hydrogen, producer gas and biogas. All investigations have concentrated on combustion characteristics, emissions and short term engine performance. Generally, relatively short term test results have confirmed their feasibility as fuels in engines with acceptable performance and emission quality.

B. Justification

Different models of biogas plant have been developed during the past years. Portable type biogas plants have been developed as they are easy to fabricate and can be transported from one place to another where trained masons are not available. No scientific study has been made on this portable type biogas plant designed by Sintex. There is a need to evaluate it so that the necessary modifications can be made, if any and it could be popularised among the small farmers.

As far as engine is concerned, diesel engines can be conveniently converted to a fumigated dual fuel engine which is the most practical and efficient method. Since biogas has a high octane number, it can be employed in a high compression ratio engine to maximize its conversion efficiency. One advantage of this method is that the engine can be switched back to conventional diesel operation mode when the gaseous fuel supply is not available. Hence the present study was undertaken to evaluate the performance of low bhp dual-fuel engine run on biogas.

II. LITERATURE REVIEW

Ojolo *et al.* (2007) observed that the amount of solid wastes generated in developing countries such as Nigeria had steadily increased over the last two decades as a result of population explosion and continuous growth of industries and agricultural practices. In agriculture, particularly cattle rearing, large quantities of cow wastes were generated, which could be used as biogas inputs to compliment the fuel usage alternative. In addition, a large number of families generated heavy wastes in the kitchen on a daily basis, which could be converted to economic benefits. In this work, a comparative study of biogas production from poultry droppings, cattle dung, and kitchen wastes was conducted under the same operating conditions. 3kg of each waste was mixed with 9L of water and loaded into the three waste reactors. Biogas production was measured for a period of 40 days and at an average temperature of 30.5°C. Biogas production started on the 7th day, and attained maximum value on the 14th days for reactor 1. Production reached its peak on the 14th day with $85\times10^{-3}dm^3$ of gas produced in reactor 2. For reactor 3, biogas production started on the 8th day and production reached a peak value on the 14th day. The average biogas production from poultry droppings, cow dung and kitchen waste was $0.0318dm^3$/day, $0.0230dm^3$/day and $0.0143dm^3$/day, respectively. It was concluded that the wastes can be managed through conversion into biogas, which is a source of income generation for the society.

Tippawayang *et al.* (2010) studied the effect of long term durability tests using biogas/diesel dual fuel operation on wear characteristics. Steady state tests were performed on a small, single cylinder, naturally aspirated, 4-stroke, direct injection diesel engine at a speed of 1500 rpm, coupled to a generator set to generate electricity for over 3500 hours. Lubricating oil samples were collected during the test run and were subjected to the analysis of various wear metal traces present and the changes in their properties. After completion of the endurance test, the engine was dismantled for physical inspection and wear assessment of vital parts. Formation of carbon deposits on in-cylinder surfaces was not found to be problematic. Injector tip coking did not occur. Surface wear and accumulations of metal debris in crankcase lubricating oil samples were analyzed and found to increase with time, but not at an unusual rate. Properties of used lubricating oils did not alter significantly from their original values. Wear was not significantly different in the test engine fuelled with the biogas/diesel combination. An overall evaluation of the results indicated that the biogas/diesel duel fuel operation could be substituted for diesel fuel in electricity generation and worked satisfactorily under long term engine operation without any major troubles.

Fallahipanah *et al.* (2011) observed that biodiesel is a fuel which due to its environmental friendly and renewability properties has established a proper place among researchers. There have been several researches on this fuel. But it has not been observed in a certain research on biodiesel to demonstrate, by using numerical simulators, the behaviour of this fuel in an engine which performs a specific cycle. The irreversible cycle of biodiesel fuel and its compounds by means of thermodynamics laws and finite time thermodynamics when the biodiesel fuel was applied as the operative fluid inside the cycle were studied. The results from numerical simulation showed that applying biodiesel fuel and its compounds in this cycle proved to have similar or in some cases even better results from the traditional diesel fuel.

Razbani *et al.* (2011) through detailed literature review studied the challenges such as lower flame speed and biogas impurities and also investigated the combustion characteristics of biogas in reciprocating engines. Many new things such as advancing the spark timing, increasing compression ratio, changing the bearing and piston materials and pre-chamber ignition systems were learned.

Muchiri *et al.* (2012) observed that rising global challenges of energy generation, sustainability, cost, environmental concerns among others had triggered immense research on alternative energy sources and technologies in the recent past. Such previous works included research into use of biogas as a substitute fuel in diesel engines. After all these observations a research on how biogas was generated from solid waste and among other uses, was used for power generation, electrical energy was generated from biogas and diesel, using dual fuel (DF) generator was done. Reviewing alternative fuel techniques focussing on biogas properties and local potential, then on how to run internal combustion engines on biogas fuel were also focussed in the research. Stress on methods of modification of ordinary engine to run on dual fuel, considering their applications, performance and cost implications were also laid.

Simio *et al.* (2012) observed that biomass, in form of residues and waste, can be used to produce energy with low environmental impact. It was important to use the feedstock close to the places where waste were available, and with the shortest conversion pathway, to maximize the process efficiency. In particular waste vegetable oil and the organic fraction of municipal solid waste represented a good source for fuel production in urban areas. Dual fuel engines could be taken into consideration for an efficient management of these wastes. In fact, the dual fuel technology can achieve overall efficiencies typical of diesel engines with a cleaner exhaust emission. Study about the feasibility of a cogeneration system fuelled with waste vegetable oil and biogas and reported the evaluation of performance and emissions on the base of experimental activities on dual fuel heavy duty engine in comparison with diesel and spark ignition engines was also done. The ratio of biogas potential from MSW and biodiesel potential from waste vegetable oil was estimated and it resulted suitable for dual fuel fuelling. An electric power installation of 70 kW every 10,000 people could be achieved.

III. MATERIALS AND METHOD

A. Materials

1. Cattle Dung: Fresh cattle dung was collected from the Gausala, Ladwa, Hisar.
2. Portable Type Biogas Plant: A floating dome type portable biogas plant with capacity of 2 cu. m, manufactured by Sintex as shown in Figure 3.1 was installed in the Rudra Intitute, Hisar.

Various components of the portable type biogas plant are as: -

Inlet: - A 70’ (178 cm) long pipe of diameter 4’(10.16 cm) was used as inlet for feeding the slurry.

Hopper: - The slurry was fed into the digester with the help of a hopper put on the top of pipe.

Outlet: - A 118’ (300 cm) long pipe of diameter 10.16 cm (4 inch) was used for outlet purpose.

Digester: - Sintex water tank of 2000 l capacity was used for digester purpose.

Floating Drum: - Another drum inscribed in the digester was used for collecting the biogas.

Supporting Frame:- An iron frame was provided on the top of the digester periphery for supporting the upward and downward movement of the floating drum.

Compression Ring: - A ring which was compressed when the drum started floating was provided in the middle of the floating drum for guiding the upward and downward movement of the drum after the production and release of biogas.

Fig. 1: Portable Type Biogas Plant

B. Dual Fuel Engine

A 4.5 bhp (Prakash Diesel Engine PV-1) dual fuel engine was used in the present study. Setup of the experimental engine is illustrated in Fig. 2 and its specifications are listed in Table 1.

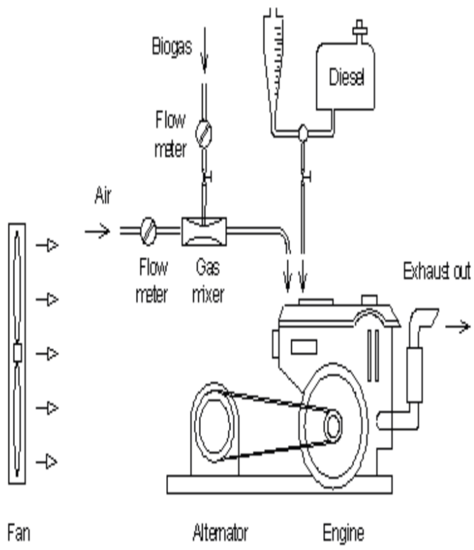

Fig. 2: Setup of the Engine Test Rig

Table 1: Specifications of the Engine Used in this Project

Engine	Prakash Diesel Engine PV-1
Combustion	Internal Combustion
Number of Cylinders	1
Rated Power	3.3 kw/4.5 bhp
Rated Speed	1500 rpm
Fuel	H.S. Diesel
Lubrication Oil Grade	SAE 30/40

C. Alternator

A turbo power alternator for diesel engines and generating sets was coupled with the engine. The specifications of the alternator are listed in Table 2.

Table 2**:** Description of alternator

Number of Phases	Single phase
Amperes	20
Volts	230
Speed	1500 rpm
Frequency	50 Hz
CosØ	0.8

IV. METHODS

A. Installations & Commissioning of Biogas Plant

Portable type biogas plant was installed on a levelled ground and all the components of the biogas plant were connected. The site selection criteria for installation of the plant were availability of water, levelled ground, direct solar radiations without obstructions and no vegetation in the nearby locality. A pit was also dug in order to dispose off the digested slurry removed from the outlet. Biogas digester was filled with 2000 litre of cattle dung slurry in 1:1 ratio (Cattle dung: water = 1:1) and the gas so prepared was disposed off for complete one month.

B. Daily Feeding

Daily feeding was started with 50 litres i.e. mixture of cattle dung and water in 1:1 ratio after 30 days of filling the tank and the slurry was continuously removed from the outlet and was dumped into the pit.

Hydraulic Retention Time (HRT)

$$HRT = \frac{Total\ Capacity}{Daily\ feed} = 40 \text{ days}$$

C. Biogas Production

Biogas produced daily was measured with the help of gas flowmeter.

Running the Engine on Biogas

Biogas was mixed with air prior to entering the combustion chamber. At the end of compression stroke, a pilot amount of diesel fuel was injected to ignite the mixture, as long as proper spray penetration and evaporation were achieved.

Coupling of Engine with the Alternator

The engine was coupled to an alternator acting as a variable load whose specifications are already mentioned above.

Calculations

- $\text{iesel Replacement} = \frac{\text{Diesel with biogas} - \text{Diesel without biogas}}{\text{Diesel without biogas}} \times 100$
- Thermal Efficiency
  - Input energy

For diesel

Density = 0.832 kg/l

Calorific Value = 10500 kcal/kg

Volume of Diesel Consumed = Known from experiment (l)

Mass = density × vol.

Energy (kcal) = Mass (kg) × Calorific Value (kcal/kg)

For Biogas

Calorific Value = 4500 kcal/ m^3

Volume of Biogas Consumed = known from experiment(l)

Energy (kcal) = Vol. (l) × Calorific Value (kcal/m^3)/1000

- Output energy

1 watt = 0.859 kcal/hr

Overall thermal efficiency = Input energy/ Output energy

- Specific Fuel Consumption = fuel consumption (g)/ load (hp) for diesel

1 watt = 1/746 hp

Cost Economics of the Plant

The performance of the whole setup was observed and on the basis of the result following parameters were calculated

1. Profit
2. Payback period

V. RESULT AND DISCUSION

Fuel Consumption with load

The consumption of fuel i.e. biogas and diesel varying with load is shown in Table 4.1. From the table, it is clear that the consumption of fuel increased with increasing load.

Table 3: Fuel consumption at different loads

Load(W)	**Biogas Consumption (litres)**	**Diesel Consumption (litres)**
500	701	0.370
1000	655	0.500
1500	700	0.600
2000	739	0.720
2500	809	0.950

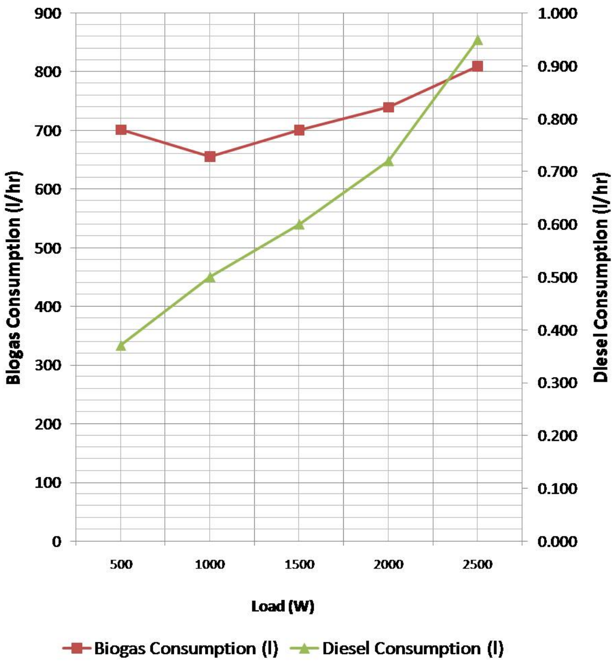

Fig. 3: Fuel consumption with load

D. Diesel Replacement by Biogas:

From Table 3 it is clear that a maximum of 28% diesel was replaced by biogas at 60% load. The diesel replacement varied with the changing of load. After a load of 2.5 kW problem of knocking and black smoke emission was observed. It was due to the speed control mechanism of governor which makes the FIP to inject more fuel into the cylinder. So a sufficient amount of diesel can be saved using Biogas as an alternate fuel.

Table 4: Diesel Replacement by Biogas

Load	Diesel with Biogas (litres)	Diesel without Biogas (litres)	% Replacement
500	0.370	0.460	20.00
1000	0.500	0.620	19.36
1500	0.600	0.770	22.00
2000	0.720	1.000	28.00
2500	0.950	1.200	20.90

E. Thermal Efficiency of Biogas Run Engine:

The overall thermal efficiency of biogas run engine was calculated using the calorific values of both the fuels and the consumption of fuel observed during the experiment. The following parameters were used to find out the overall thermal efficiency of biogas run engine.

Input Energy

Output Energy

Thermal efficiency = Input/Output

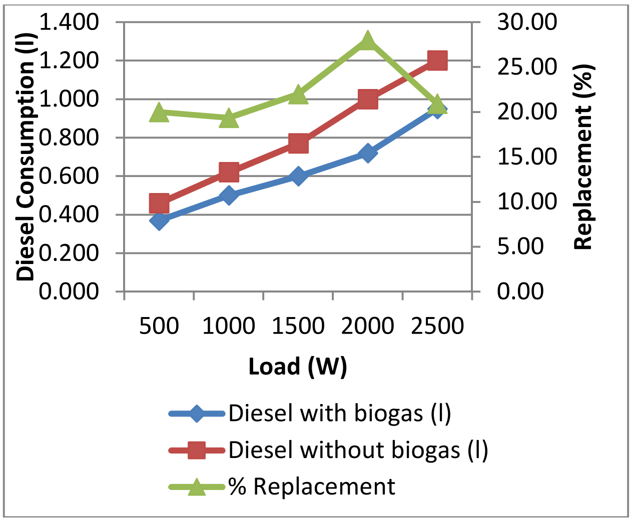

Fig. 4: Diesel consumption and replacement

Table 5: Thermal efficiency of biogas run engine

Load (Watts)	Input Energy (kcal)			Output Energy (kcal)	Efficiency (%)
	Biogas	Diesel	Total		
500	3154.5	3232.32	6386.8	429.50	6.70
1000	2947.5	4368.00	7315.5	859.00	11.70
1500	3150.0	5241.60	8391.6	1288.5	15.35
2000	3325.5	6289.92	9615.4	1718.0	17.86
2500	3640.5	8299.20	11939.	2147.5	17.99

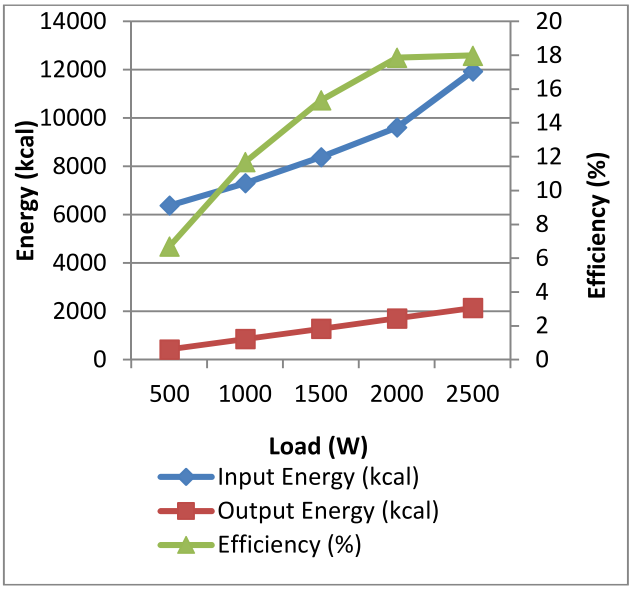

Fig. 5: Thermal efficiency of biogas run engine

Thermal Efficiency of Diesel Run Engine:

During this study, the input energy was supplied to engine by diesel only. The thermal efficiency was calculated as.

Table 6: Thermal efficiency of diesel run engine

Load (W)	Input Energy (kcal)	Output Energy (kcal)	Efficiency (%)
500	4018.56	425.50	10.67
1000	5416.32	859.00	15.85
1500	6726.72	1288.50	19.15
2000	8376.00	1718.00	20.50
2500	10483.20	2147.50	20.48

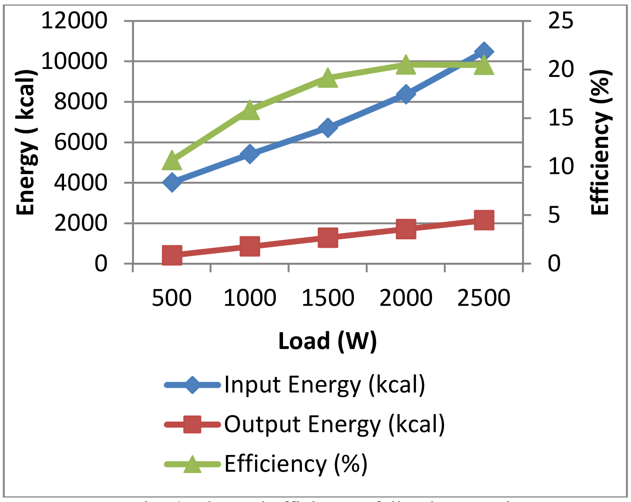

Fig. 6: Thermal efficiency of diesel run engine

Specific Fuel Consumption of Biogas Run Engine:

The specific fuel consumption (SFC) was calculated using the following method:

SFC = fuel consumption (g)/ load (hp) for diesel

= fuel consumption (litre)/ load (hp) for biogas

1 Watt = 1/746 hp

Table 7: Specific fuel consumption of biogas run engine

Load (Watts)	Biogas Consumption (litres)	SFC Biogas (litres/hp)	Diesel Consumption (litres)	SFC Diesel (g/hp)
500	701	1044.40	0.370	459.0
1000	655	488.630	0.590	366.0
1500	700	348.130	0.600	248.6
2000	739	275.647	0.720	223.4
2500	809	241.400	0.950	235.5

Specific Fuel Consumption of Diesel Run Engine:

Table 8: Specific fuel consumption of diesel run engine

Load (W)	Diesel (l)	SFC (g/hp)
500	0.460	571.0
1000	0.620	384.0
1500	0.770	318.0
2000	1.000	310.0
2500	1.200	297.9

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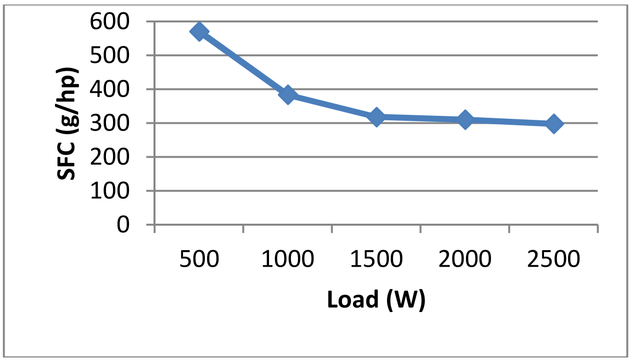

Fig. 7: Specific fuel consumption of diesel run engine

Table 8: Cost Economics

Fixed Cost	Rs.
Depreciation	237
Variable Cost	
Labour	750
Diesel	1080
Total(with labour)	2067
Total (without labour)	1317

Diesel consumption of Engine when run on diesel only = 30 l/month

Total expenditure = Rs. 1500/month

Profit = Rs. 183/month

Payback period = 14.57 years (i.e. 14 years 6 months 25 days)

Breakeven Point = 93.58%

Thus, from the present experimental study it was found that use of biogas as an alternate source of fuel to generate electricity can be beneficial keeping in view the present scenario shortage and depletion of non-renewable sources. From the results it was clear that electricity generation using biogas can decrease the expenses of farmers owning small dairies. On the other hand, easy availability of cattle dung for biogas production is an added advantage. So it can be concluded that biogas can be used as an alternate source of energy for generating electricity as well as for many other purposes.

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