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Performance Analysis of Producer Gas Based Diesel Engine

J. P. Yadav
Mechanical Engineering Department, Chandra Shekhar Azad University of Agriculture and Technology,
Campus - Etawah (U.P.) – INDIA; E-mail: jpyadav_caet@yahoo.com

***Abstract* - Producer gas is one out of the alternative fuels used in internal combustion engines. Conventionally, it is made by flowing air and steam through a thick coal or coke bed which ranges in temperature from red hot to low temperature. The oxygen in air burns the carbon to CO_2. This CO_2 gets reduced to CO by contacting with carbon above the combustion zone. The freed oxygen combines with carbon and steam gets dissociated which introduces hydrogen. Producer gas has a high percentage of nitrogen since air is used [1]. Thus, in the present work a gasifier is designed and developed which could gasify any form of biomass. In the present work waste wood chips, bagasse, rice husk, and eucalyptus, etc are used for gasification in a fabricated updraft gasifier to produce producer gas. The producer gas obtained from the developed gasifier is sent along with air into a diesel engine with diesel as the primary fuel and the performance characteristics ie brake thermal efficiency, exhaust gas temperature and brake specific energy consumption of the engine are studied along with economic analysis with and without aid of producer gas.**

***Keywords* – Diesel Engine, Producer Gas.**

I. Introduction

India produces about 600-1000 million tones of agricultural residues comprising of mainly rice husks, paddy straw, bagasse etc. which are not being utilized and are disposed of by burning them in the open fields. These solid fuels can be effectively harnessed by converting them into a gaseous combustible fuel termed as "producer gas" in suitably designed reactors. This producer gas comprises mainly of carbon monoxide and hydrogen can be used for energy generation. Also, the increasing concerns for environment have driven the need to find alternatives to this energy source. Biomass, biogas, solar power, wind power and hydro power are the main sources of renewable energy in India. About 15% of the total power production in India is contributed by renewable energy sources as can be observed from Table 1.

II. Gasification

Gasification is a process that converts organic or fossil based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (>700 ^{O}C), without combustion, with controlled amount of oxygen and/or steam. The resulting gas mixture is known as producer gas and is itself a fuel. The organic matter produced by plants and their derivatives is termed as biomass. The power derived from gasification of biomass and combustion of the resultant gas is considered to be a source of renewable energy [5]. The gasification is done in a gasifier through various complex physical and chemical processes. The biomass gets heated, pyrolysed, partially oxidized and reduced, as it flows through it. The gas that is produced in a gasifier is a clean-burning fuel having heating value of about 950-1200 kcal/ m^3. Hydrogen and carbon monoxide are the main constituents of the gas. A typical composition of the gas obtained from wood gasification on volumetric basis is like Carbon monoxide (18-22%), Hydrogen (13-9%), Methane (1-5%), Heavier hydrocarbons (0.2-0.4%), Carbon dioxide (9-12%), Nitrogen (45 - 55%) and Water vapor (4%) [3]. Gasifiers are classified from medium size to very large size with out put capacity from 10 kW to 300 kW and above. The gas produced can be used either in dual fuel engines or in diesel engines with some modification. Spark ignition system (e.g. petrol engines) can be made to run entirely on producer gas, whereas those using compression ignition systems (e.g. diesel engines) can be made to operate with about 60%-80% fuel oil replacement by the gas. Gasification using wood chips bagasse, rice husk and eucalyptus were obtained from the workshop, juice shop, rice mill and wood shop respectively. These were sun-dried to remove the moisture content in them. Table 2 lists the proximate analysis of wood, bagasse, rice husk and eucalyptus.

III. Experimental Setup

The gasifier is designed and fabricated by suitable process and the experimental setup is arranged by connecting the gas outlet to the inlet of the engine. The output from the alternator of the engine was connected to the load testing panel to provide various load conditions. Load testing panel is equipment for varying load on the engine. It consists of ten 500 Watt heater rods, two rods connected to a MCB such that there are 5 MCBs designated 20 % load each. It also has display unit which shows the voltage and the current developed by the alternator coupled with the engine. During testing, the engine is started and the MCBs are raised according to the load to be provided, i.e. for 0% load all MCBs are down, for 20% load one MCB is lifted and likewise. A 5 kW alternator is coupled with engine. Generally a 5 kW alternator supplies a maximum of about 3.5 kW. So the readings up to 60% of the load are taken. The various components of gasifier manufactured are as the specification laid down below. The air supply is given by a blower and regulated by a valve. The arrangement of the experimental setup is shown in figure 1. After assembling the gasifier unit with the blower and the diesel engine, the experiments are conducted further. Different biomasses like wood chips, bagasse, rice husk and eucalyptus seeds are used to produce producer gas in the gasifier fabricated. The producer gas from different biomasses was sent to the engine and comparison is done on the performance of the diesel engine without and with aid of producer gas from different biomasses. In the gasification, these biomasses were used as the feed stock or the raw material. They are sun-dried to get rid of excess moisture. The ignition temperature was produced by auxiliary burners. Air was injected into the gasifier from the bottom side with the help of blower. The producer gas is released from the top of the gasifier. The gas coming out from the gasifier is allowed to cool and is directed to the heat engine. Initially the biomass fuel is ignited in the reaction chamber with the help of auxiliary source. The gas is allowed to come out through the pipe opening at the atmosphere. After a continuous supply of white gas is observed coming out, the top most valve is closed and the gas outlet valve directed towards the engine is opened. The diesel engine is started and air along with the gas is sent to the engine. Various parameters are noted further by varying the load.

IV. Performance Characteristics

Internal combustion engines are found to operate within a certain range of speed. The power output varies within the useful range at each speed and it has a maximum usable value. The ratio of the power developed to the maximum usable power at the same speed is called the load. The specific fuel consumption varies with load and speed. The relationship between power developed, specific fuel consumption and speed is crucial and determines the performance of the engine. The useful mechanical energy available at the shaft is termed the brake power of the engine [1]. A load testing panel was attached to the alternator of the engine to provide the different load conditions. Rate of the fuel entering is measured using the flow meter. Thermocouple measures the exhaust gas temperature. The Table 4 shows the readings obtained during the experimentation and Table 5 shows the readings to denote the performance characteristics of the engine when diesel was used as the fuel and when producer gas was sent along with air. These readings were used to obtain the plots of performance characteristics as shown in figure 2, 3, 4, 5 and 6.

Brake Thermal Efficiency: It is the ratio of energy in the brake power, BP, to the input fuel energy in appropriate units. The brake thermal efficiency gives an indication of the output generated by the engine as compared to the heat supplied to the engine. This heat is derived from burning of the fuel.

$$\eta_{bth} = \frac{B.P.}{((\text{Mass of fuel}/\text{sec}) \times \text{Calorific value of fuel})}$$

where, η_{bth} is the brake thermal efficiency. [1]

The variation of brake thermal efficiency with different fuel combinations at different load condition is shown at Table 5.

The figure 3 gives a comparison between the brake thermal efficiencies of the engine when only diesel is used as the fuel and when both diesel and producer gas are used. The brake thermal efficiency is plotted as a function of brake power. When producer gas is used along with fuel a notable increase in efficiency can be observed at the different power outputs. This might be due to the fact that the producer gas adds energy to the air stream that is injected into the diesel engine. The efficiency of the engine with producer gas from different biomasses is plotted against brake power, it can be seen that the efficiency is highest in case of eucalyptus and minimum in case of the bagasse at full load condition.

Exhaust Gas Temperature: It is an indication of how effectively the input energy is converted to work. When the exhaust gas temperature is high, the mixture is supposed to be leaner [1]. Table 6 shows variation of brake thermal efficiency with different fuel combinations at different load condition.

The figure 4 shows the variation of exhaust gas temperature with brake power for both diesel as the fuel and diesel along with producer gas from different biomasses. It is observed that there is not much variation in the exhaust gas temperature when diesel and diesel along with producer gas are used separately from different biomasses at all power outputs. The higher exhaust gas temperature is an indication of the increase in NO_x emissions.

Brake Specific Energy Consumption: Brake specific fuel consumption (bsfc) is the fuel consumed per unit brake power. bsfc=M_f/BP, where, M_f is the mass of fuel consumed per unit time and BP is the brake power. Brake specific energy consumption (bsec) is the energy consumption per unit brake power.

bsec = bsfc x q_{cv} where q_{cv} is the calorific value of the fuel.[1]

The figure 5 shows the variation of brake specific fuel consumption with brake power while diesel and producer gas is used as a fuel along with air from different biomasses. The specific energy consumption is found to decrease at all power outputs when diesel along with producer gas is used which is an indication of good combustion efficiency. The use of producer gas reduces the consumption of diesel fuel at all power outputs. At 60 % load it is found that brake specific energy consumption for producer gas from eucalyptus is least.

Economic Analysis: As much ingenuity can go into the financing of a capital project as into its engineering. If a technology is not commercially viable it will never contribute to society's needs, regardless of how ingenious the technology might be. Here, a very simple economic analysis is presented which can be used to give an initial assessment. It was found out that the feed material once fed in the gasifier can produce gas for about 4 hours. The quantity of diesel that was saved by use of gasifier in 4 hours was about 2 litres (on average 200-600 ml/hr) at different load conditions. The quantity of biomass required for feeding of gasifier once is not a very big quantity and is easily available free of cost whereas the diesel costs about Rs. 45 per litre so about Rs 60-70 can be saved per day while diesel engine running 4 hours per day on average at 50 % load.

V. Conclusions

An experimental set up is used consisting of diesel engine retrofitted with compatibly designed and developed gasifier to evaluate performance of diesel engine and based on such parametric analysis the following conclusions are drawn along with future prospective works to be furthered.

a) It is clear from the graphs and tables that with diesel as the main fuel along with producer gas, there is a marginal increase in brake thermal efficiency. The brake thermal efficiency increases by about 4 %.
b) The brake specific energy consumption is found to decrease when producer gas is used along with diesel. The brake specific energy consumption decreases by about 24 %.
c) The quantity of biomass is easily available free of cost whereas the diesel costs about Rs. 45 per litre so about Rs 60-70 is saved per day while diesel engine running 4 hours per day on average at 50 % load.
d) The research can be furthered by studying the properties of the producer gas coming out and compressed well to achieve better results.
e) The emission characteristics also need to be analyzed for each kind of biomass to select the suitable biomass that optimizes both consumption of diesel fuel and produces least emissions.
f) Various producer gas-air ratios can be tried and its effect can be analyzed.
g) The producer gas can be filtered to remove tar and see its effect on engine efficiency.

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Author's Profile

Dr. J. P. Yadav

is a senior Associate Professor of Mechanical Engineering and Dean (Engineering) at a constituent college of Chandra Shekhar Azad University of Agriculture and Technology, campus at Etawah (U.P.) - India. He has a vast industrial experience in the field of Avionics besides teaching experience of more than 16 years at undergraduate level.

Dr. Yadav has large number of research papers in journals and conference proceedings to his credit. His areas of interest include thermal engineering, gas / steam thermal power plant; refrigeration and air-conditioning. He has been undertaking various administrative work of the college at different positions since year 1997. He is also member and life member of the Institution of Engineers (India) and Indian Society of Technical Education (ISTE), respectively.

Table 1 Renewable energy source potential and the present status [4]

Source/System	Estimated potential, MW	Approx. cumulative installed capacity, MW
Wind power	45000	4400
Biomass power	16000	310
Bagasse cogeneration	3500	450
Small hydro(up to 25 MW)	15000	1700
Municipal solid waste	1700	20
Industrial waste	1000	30
Solar photovoltaic power Plants	-	2
Biomass gasifiers	-	75

Table 2: Proximate analysis of wood, bagasse, rice husk and eucalyptus [12]

Wood	Volatile matter, (%)	83.40
	Fixed carbon, (%)	15.40
	Ash, (%)	1.20
Bagasse	Volatile matter, (%)	70.90
	Fixed carbon, (%)	7.00
	Ash, (%)	22.10
Rice Husk	Volatile matter, (%)	72.70
	Fixed carbon, (%)	11.80
	Ash, (%)	15.50
Eucalyptus	Volatile matter, (%)	75.35
	Fixed carbon, (%)	21.30
	Ash, (%)	3.35

Table 3: Specifications used for design and fabrication of Experimental set up

Diesel Engine	Diesel engine under consideration	Prakash diesel engine 6.5 hp, vertical, 4-stroke single cylinder, direct injection and water cooled engine coupled 5 kW alternator
	Speed of the engine	1500 rpm
	Bore and stroke	80 mm and 110 mm
	Injection at TDC	Injection occurs 23^O before TDC
Gasifier (updraft)	Volume of feed material	11946.17 cm^3
	Volume of producer gas	28829.63 cm^3
(i) Reaction chamber	Outside wall thickness	2 mm mild steel sheet
	Outside dimension	16" × 16" × 19"
	Bottom plate dimension	16" × 16";
	Inside dimension	9" × 9" × 9"
	The grate height on top	9"
	Feeding door to the gasifier	4" × 3"
	The grate made of steel bar	Bars of ⅓" having 1 cm spacing in between
	Dimensions of the door	7½" × 7½".
	Top plate	Dimension 16"×16" with hole diameter 8"
(ii) Air inlet	Mild steel material	2" diameter
(iii) Fuel hopper	Made of mild steel sheet	Height 35" and diameter 8"
(iv) Gas outlet	Mild steel pipe	Dia ½ ", Elbow 2½ "
Blower	Operating range	220 V 50/60 Hz
	Discharge	2.8 m^3/min
	Rpm	16000

Table 4: Approximate diesel consumption at different conditions

Load (%)	Brake Power, BP (kW)	Air + Diesel (ml/hr)	Air + Diesel + Producer Gas (Wood Chips) (ml/hr)	Air + Diesel + Producer Gas (Bagasse) (ml/hr)	Air + Diesel + Producer Gas (Rice Husk) (ml/hr)	Air + Diesel + Producer Gas (Eucalyptus) (ml/hr)
0	0	1440	1200	1320	1080	780
20	1	1200	880	1020	1200	900
40	2	1920	1540	1800	1680	1320
60	3	2640	2040	2280	2160	1860

Table 5: Variation of Brake thermal efficiency with load

Load (%)	Brake Power, BP (kW)	Brake Thermal Efficiency, BTE (%)				
		Air + Diesel	Air + Diesel + Producer Gas (Wood Chips)	Air + Diesel + Producer Gas (Bagasse)	Air + Diesel + Producer Gas (Rice Husk)	Air + Diesel + Producer Gas (Eucalyptus)
0	0	0	0	0	0	0
20	1	8.59	11.71	10.10	8.59	11.45
40	2	10.73	13.38	11.45	12.26	15.61
60	3	11.71	15.15	13.56	14.31	16.62

Table 6: Variation of exhaust gas temperature with load

Load (%)	Brake Power, BP (kW)	Exhaust Gas Temperature, EGT (^{O}C)				
		Air + Diesel	Air + Diesel + Producer Gas (Wood Chips)	Air + Diesel + Producer Gas (Bagasse)	Air + Diesel + Producer Gas (Rice Husk)	Air + Diesel + Producer Gas (Eucalyptus)
0	0	242	240	240	248	237
20	1	303	290	299	298	308

40	2	509	495	500	507	513
60	3	625	600	620	615	634

Table 7: Variation of brake specific energy consumption with load

Load (%)	Brake Power, BP (kW)	Brake Specific Energy Consumption, bsec (MJ/kWh)				
		Air + Diesel	Air + Diesel + Producer Gas (Wood Chips)	Air + Diesel + Producer Gas (Bagasse)	Air + Diesel + Producer Gas (Rice Husk)	Air + Diesel + Producer Gas (Eucalyptus)
0	0	∞	∞	∞	∞	∞
20	1	41.93	30.75	35.64	41.93	31.45
40	2	33.55	26.91	31.45	29.35	23.06
60	3	30.75	23.76	26.56	25.16	21.67

Fig.1. The Experimental Set Up

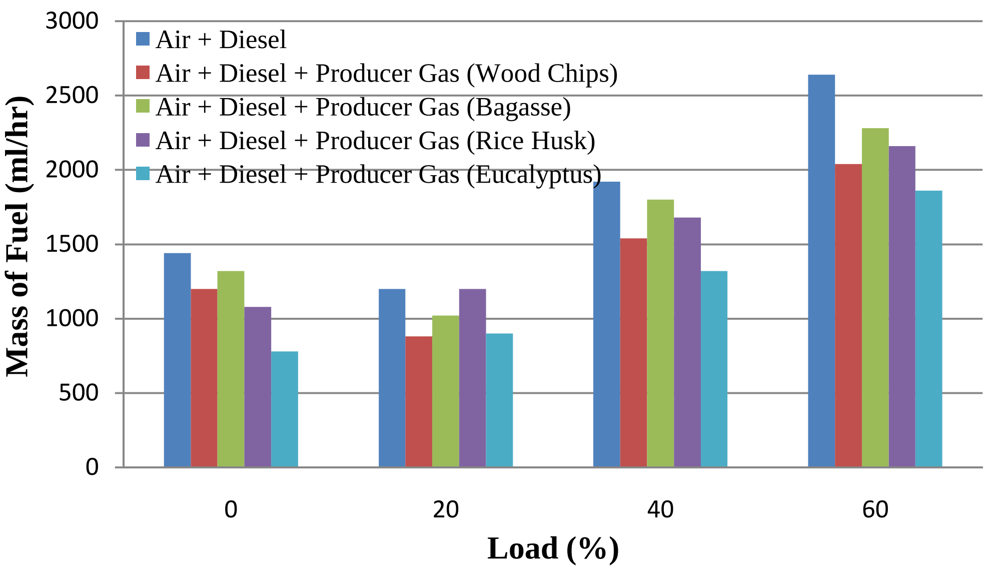


Fig.2. Variation of fuel consumption with different fuel combination at different load

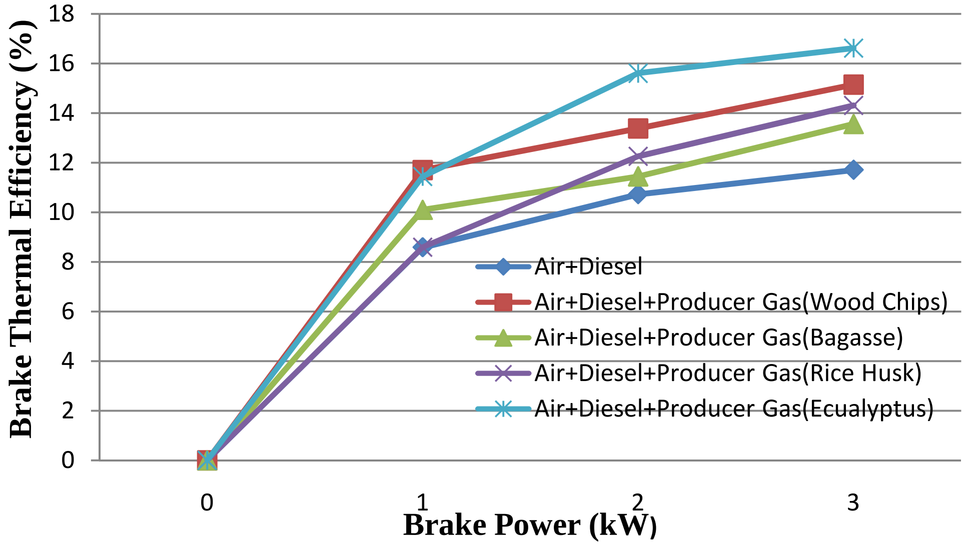


Fig.3. Variation of brake thermal efficiency with brake power

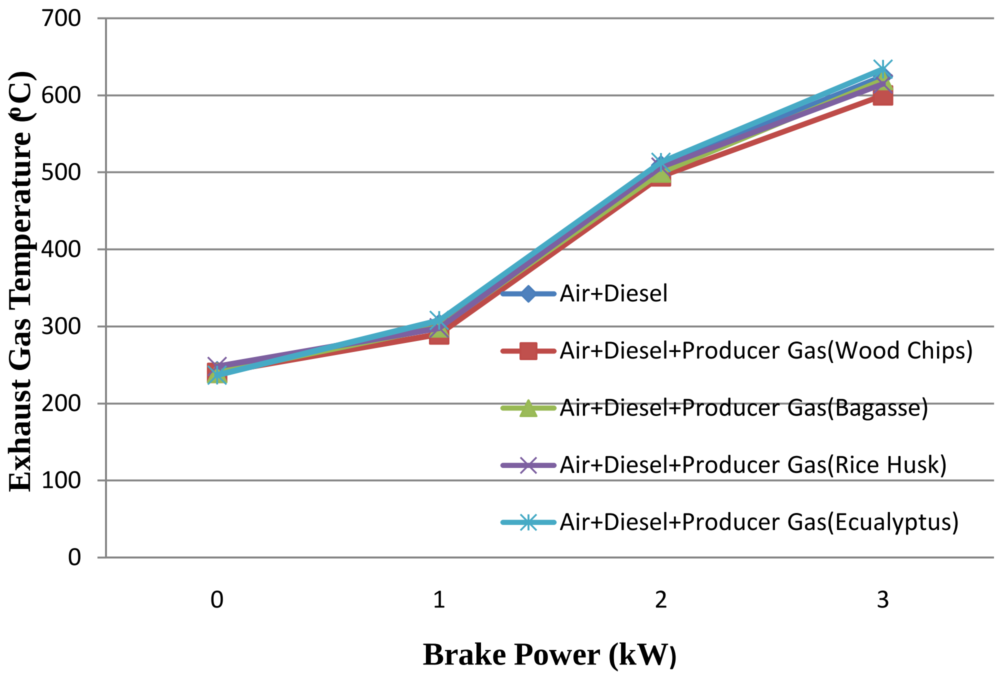


Fig.4. Variation of exhaust gas temperature with brake power

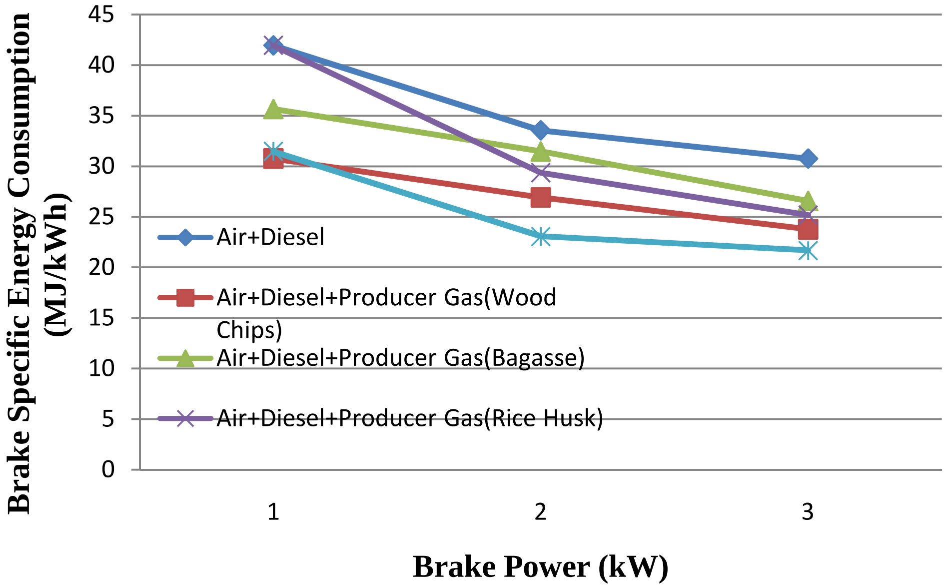
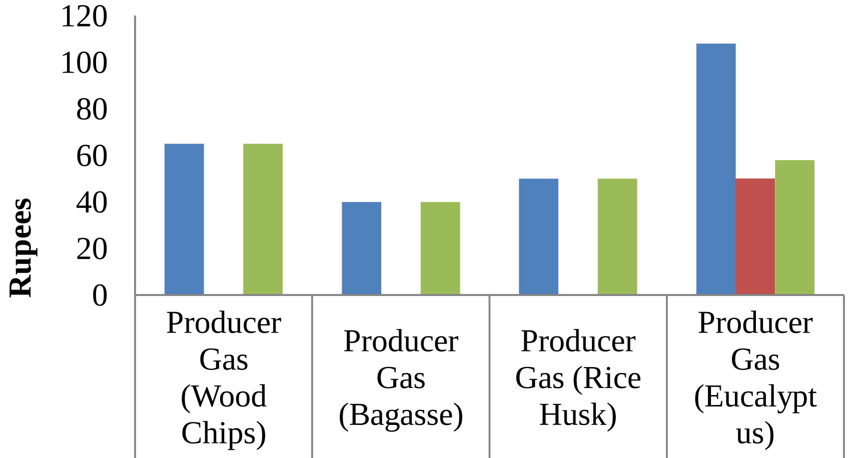


Fig.5. Variation of Brake specific energy consumption with brake power



	Producer Gas (Wood Chips)	Producer Gas (Bagasse)	Producer Gas (Rice Husk)	Producer Gas (Eucalyptus)
Cost of Diesel saved at about 50 % load in 4 hrs (approx.)	65	40	50	108
Cost of biomass feed required for 4 hrs (in Rs.)	0	0	0	50
Profit made (approx.)	65	40	50	58

Fig.6. Profits by use of producer gas from different biomasses