DESIGN AND OPTIMIZATION OF DOWNDRAFT GASIFIER FOR OPERATING CI ENGINE ON DUAL FUEL MODE

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ABSTRACT

Gasification is a thermo-chemical process which converts solid biomass into a mixture of combustible gases that can be used in various applications. In this project, a downdraft gasifier was designed and developed for running a single cylinder, 4-stroke, air cooled, direct injection diesel engine developing a power of 4.4 kW, at a rated speed of 1500 rpm on dual fuel mode. Wood chips and mustard oil cake in the ratio of 7:3 was used as a feed stock in the gasifier. An experimental study was also carried out on diesel fuel (DF) and producer gas (PG) on dual fuel mode. The producer gas was introduced in the inlet manifold of engine at 4lpm, 6lpm and 8lpm respectively. The performance and emission characteristics of the engine were studied at different loads for various gas flow rates. A reduction in the consumption of diesel fuel was observed when operated on dual fuel mode though there was a reduction in brake thermal efficiency. NO emission was found to be very low in dual fuel which is a great advantage of dual fuel mode over diesel fuel alone but, CO and HC emission for dual fuel mode was found to be higher than diesel.

Key words: *Biomass, Gasifier, Producer gas, Performance, Emission.*

1. INTRODUCTION

Biomass is the oldest source of energy and currently accounts for approximately 10% of total primary energy consumption. Many of the developing countries has growing their interest in biofuel development and providing greater access to clean liquid fuels while helping to address the issues such as increase in fuel price, energy security and global warming concerns associated with petroleum fuels. Abundant biomass is available throughout the world which can be converted into useful energy. Biomass is considered as a better source of energy because it offers energy security, rural employability and reduced GHG emission. Biomass is traditionally available in the form of solid. Solid biomass include crops residues, forest waste, animal waste, municipal waste, food waste, plant waste and vegetable seeds. This biomass can be converted into heat and power by adopting appropriate method [1].

Gasification is a thermo-chemical process by which carbonaceous (hydrocarbon) materials (coal, petroleum coke, biomass, etc.) can be converted to a synthesis gas (syngas) or producer gas by means of partial oxidation with air, oxygen, and/or steam. The device which performs this work is known as gasifier. Gasifier is a chemical reactor where various complex chemical and physical processes take place. A hydrocarbon feedstock (biomass) is fed into a high-pressure, high temperature chemical reactor (gasifier) containing steam and a limited amount of oxygen. As biomass flows through the reactor it gets dried, heated, pyrolysed, partially oxidized and reduced. Under these “reducing” conditions, the chemical bonds in the feedstock are severed by the extreme heat and pressure and producer gas is formed. The main constituents of producer gas are hydrogen (H_2) and carbon monoxide (CO). In short, the task of gasifier is to pyrolyze the biomass to produce volatile matter, gas and carbon and to convert the volatile matter into permanent gases, CO, H_2 and CH_4 [2].

2. LITERATURE SURVEY

A downdraft gasifier at laboratory scale was developed and tested for the composition of producer [3]. The construction of the gasifier was based on the design proposed by Bhattacharya et al. [4]. The various parts of the gasifier like reaction chamber, fuel hopper, gas outlet and air inlet were designed. The gasifier was ignited by a flame torch and the composition of the producer gas was found in close agreement with the desired composition.

An experimental study [5] was carried out on a 75kW downdraft biomass gasifier system to obtain temperature profile, gas composition, calorific value and trends for pressure drop across the porous gasifier bed, cooling-cleaning train and across the system as a whole in both firing as well as non-firing mode. In the reactor, both gas and biomass feedstock move downward as the reaction proceeds. While biomass flows because of gravity, air was injected with the help of a blower. Experiments were conducted to obtain fluid flow characteristics of the gasifier and also to obtain the temperature profile in the reactive bed, the gas composition and calorific value. For non-firing gasifier, the extinguished bed showed greater pressure drop as compared to a freshly charged gasifier bed. The pressure drop across the porous bed was found to be sensitive with change in flow rate. When used in firing mode, the higher temperature in the bed led to better conversion of non-combustibles component in the resulting gas and thus improved the calorific value of the product gas.

An experimental study was carried out on producer gas generation [6] from wood waste in a downdraft biomass gasifier. They used sesame wood or rose wood as biomass. They observed that biomass consumption rate decreased with an increase in the moisture content and it increased with an increase in the air flow rate. The performance of the biomass gasifier system was evaluated in terms of producer gas composition, the calorific value of producer gas, gas generation rate, zone temperatures and cold gas efficiency. Thermocouples were placed inside the gasifier at different locations to measure the temperature of various zones of gasifier. They found the producer gas composition using gas chromatograph.

Characteristics of hydrogen produced [7] from biomass gasification was studied. They used a self-heated gasifier as the reactor and char as the catalyst. The steady temperatures of the pyrolysis zone, combustion zone and reduction zone were recorded. Equivalence ratio(ER) was defined as the actual oxygen to fuel ratio divided by the stoichiometric oxygen to fuel ratio 14 needed for complete combustion. The temperature of the neck was found to increase with feeding rate for similar ER values. For increasing the production capacity, accelerating the feed rate is essential, but excessively high feeding rate would result in a higher gas yield and a shorter gas residence, thus degrading gas quality. The temperature increased with feeding rate but hydrogen yield decreased with feeding rate.

The thermo-chemical reaction in gasification [8] may vary with varying parameters and the size of biomass. For a particle size below 1mm diameter, thermo-chemical reaction shows a sharp increase in the fuel conversion which could be used in conventional entrained flow gasifier. A reduction in the fuel particle size led to an improvement in the gas quality and thus to a higher producer gas heating value. Maximum fuel conversion was obtained for the smallest particle size tested (0.5mm). The thermo-chemical characterization of the char-ash residue showed that as the fuels particle size was reduced, the release of volatile matter during pyrolysis stage along with particle carbonization, gradually increased, which suggest that pyrolysis reaction took place to a great extent. For fuel particle size of 1mm, the reaction of char gasification became more relevant which contribute in the improvement of conversion of fuel and the composition of producer gas.

It is necessary to cool biomass-based producer gas to ambient temperature, and clean it of tar and particulates before it could be used as a fuel [9]. The unit gave a clean gas with tar+dust content below the limit of 150 mg/nm3 as long as the inlet gas tar dust content was below about 600 mg/nm3 . The system was being tested to supply gas to a dual-fuel engine, and solve any operating problems in this application. It was developed further to study its maintenance requirements, and increase the number of hours of continuous use of the sand filter with no operator attention. The system was mainly developed for small scale gasifier–engine system applications. It can be scaled up to larger sizes to provide a compact unit. The scale up can be done by increasing the cross-sectional areas of the various beds and the water flow rate in proportion to the producer gas flow rate.

For prediction of gasification process in downdraft gasifier, an equilibrium modeling [10] was been used. The composition of the producer gas, the calorific value was determined by the modeling. The effects of moisture content in wood and temperature in the gasification zone on 15 the calorific value were investigated. In addition to wood, the prediction were also made for peddy husk, paper and municipal waste and it was found that wood and paper are the two most efficient biomass to produce syngas. It had high CO, H_2, CH_4 content with higher CV. The result of equilibrium modeling showed that the H_2 content in the producer gas increased with moisture content for all the material considered and CO content decreased as the moisture content in the producer gas increases. Methane content in the producer gas increased with increase in moisture content but calorific value of the producer gas also decreased.

3. EXPERIMENTAL SETUP & METHODOLOGY

3.1 Engine specification

A single cylinder, four stroke air-cooled and naturally aspirated DI diesel engine designed to develop a power of 4.4kW at 1500 rpm was used for the experimental study. A detail of engine specification is shown in Table 6.

Table 6. Engine specification

Model	Kirloskar TAF 1
Brake power (kW)	4.4
Rated speed (rpm)	1500
Bore (mm)	87.5
Stroke (mm)	110
Compression ratio	17.5:1
Nozzle opening pressure (bar)	200
Injection timing, (^{o}CA)	23
Cooling system	Air cooled

Diesel was used as a pilot fuel to run the diesel engine in this study. The physical and combustion properties of diesel fuel are shown in Table 7.

Table 7. Physical and Combustion Properties Diesel fuel

S.No.	Properties	Diesel fuel
1.	Formula	$C_{12}H_{26}$
2.	Density, kg/m3 (At 1 atm & 20^{0}C)	840
3.	Auto ignition temp (K)	527
4.	Stoichiometric air fuel ratio, (kg/kg)	14.5
5.	Flammability limits (Volume %)	0.6-5.5
6.	Lower calorific value (kJ/kg)	42,500

The air flow in the intake manifold of engine was measured by a pressure drop across a sharp edge orifice of the air surge chamber and by sensors. Fuel consumption was determined by using calibrated burette with an accuracy of 0.1CC. The pressure time history of cylinder was measured by a pressure transducer, which was mounted on the cylinder head. The crankshaft position was obtained using a crankshaft angle sensor to determine cylinder pressure as a function of the CA. The CA signal was obtained from an angle-generating device mounted on the main shaft. A laptop is provided with data acquisition system to collect the data from all sensors and stored for offline calculations. The exhaust gas constituents CO, CO_2, HC, NO, O_2 were measured by AVL gas analyzer and smoke density can be measure by AVL smoke meter.

3.2 Gasifier unit

Gasifier unit consists of a downdraft gasifier, heat exchanger, cleaning cum cooling kit, drum and a flow meter. Fig. 19 shows the general sketch of gasifier used in present research work.

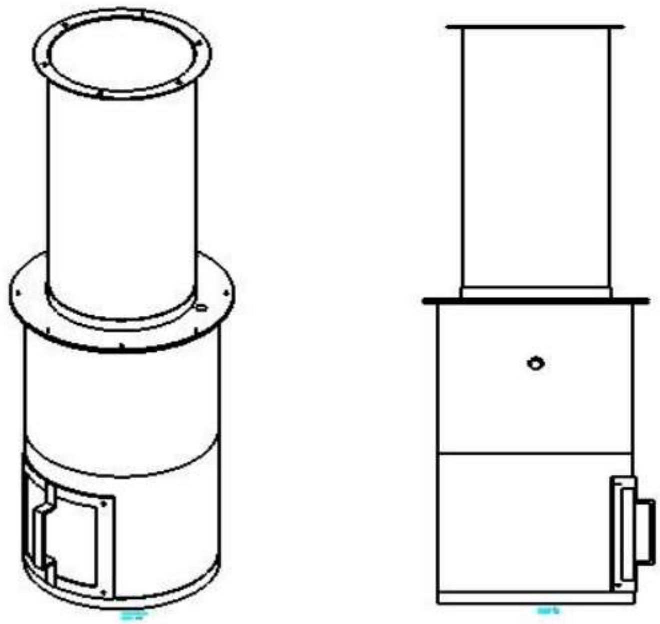

Fig. 19. General sketch of gasifier

Coal was used to initiate the gasification process, 10 – 12 pieces of coal was poured into the gasifier and with the help of oil and dry cow dung, it had been ignited. Air was inducted with the help of blower, the flow of air could be regulated as par the requirement. When coal reaches at its red heat level, a mixture of wood chips and mustard oil cake in the ratio of 7:3 by weight was poured into the hopper and the hopper cover was tightened by nut and bolts. The blower supplied air in such a way that the biomass burnt partially and generates producer gas. This producer gas thus passed through the gap between gasification zone and casing of gasification zone. Here most of the heavier particles get stuck and tar present in producer gas gets creaked. Now this producer gas was allowed to pass through heat exchanger unit so as to reduce the temperature of producer gas. Producer gas from here passed through cleaning cum cooling unit where it was cleaned as well as cooled. The physical and combustible properties of producer gas are shown in Table 8. Before inducting producer gas into the inlet manifold of engine, it was temporarily stored in a drum in order to provide backup to the engine. Between drum and engine intake manifold, a gas flow meter was introduced to meter the volume of flowing producer gas in terms of litre per minute. This flow meter can be regulated as per the requirement of supply. Fig. 20 shows the block diagram of gasifier unit.

Table 8. Physical and Combustion Properties of Producer gas

S.No.	Properties	Producer gas
1.	Density, kg/m3 (At 1 atm & 20^0C)	1.287
2.	Stoichiometric air fuel ratio, (kg/kg)	1.12:1
3.	Flammability Limits	N/A
4.	Lower Calorific Value (kJ/kg)	5000

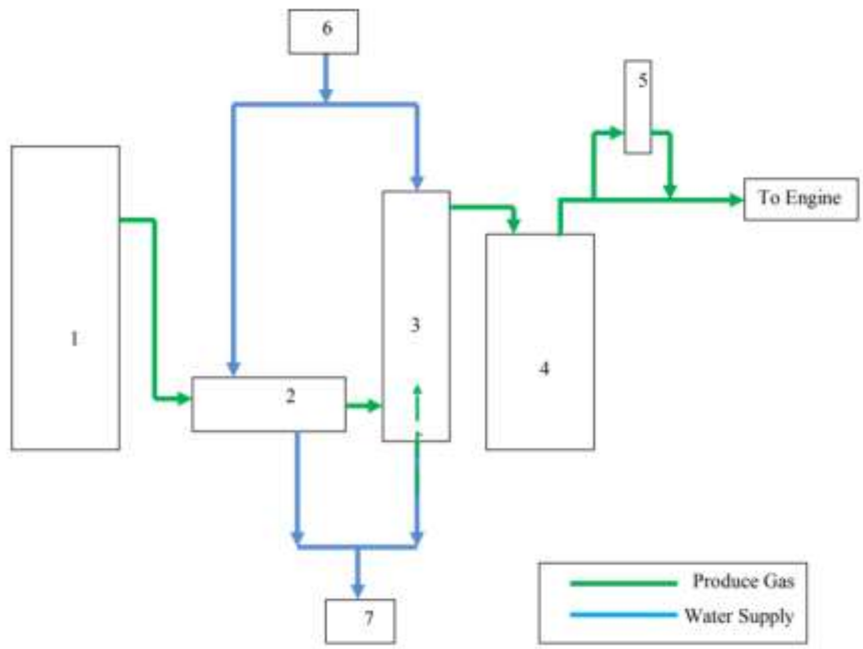

Fig. 20. Block diagram of gasifier unit

Table 9 shows the description of gasifier unit.

Table 9. Description of gasifier unit

Sr. No.	Description	Sr. No.	Description
1.	Gasifier	5.	Gas flow meter
2.	Heat exchanger	6.	Water in
3.	Cleaning cum cooling system	7.	Water out
4.	Drum		

3.3 Engine Coupled with Gasifier

To finalize the experimental setup, engine was coupled with gasifier unit. Fig. 21 shows the block diagram of engine coupled with gasifier. To conduct the experiment, first of all engine was run on diesel fuel only and various readings for emission and performance test were taken at no load, 1kW, 2kW, 3kW and 4.5kW. Now producer gas from gasifier unit was allowed to pass with air in intake manifold of engine. The gas flow meter was maintained at 4 litres per minute (lpm). The engine was allowed to run for a while and after that first load of 1kW was put on electric load cell than 2kW, 3kW and 4.5kW were added on electric load cell and various readings were taken respectively to obtain emission and performance characteristic of engine at diesel and 2lpm of producer gas. Similarly for next experiment, the gas flow meter was maintained at 6lpm and 8lpm and various reading were taken respectively to obtain emission and performance characteristics at varying load. Descriptions of various components of engine coupled with gasifier unit are shown in Table 10.

Table 10. Description of engine coupled with gasifier unit

Sr. No.	Description	Sr. No.	Description
1.	Engine	10.	Exhaust gas analyzer
2.	Electric Dynamometer	11.	Gasifier Unit
3.	Fuel tank	12.	Heat exchanger
4.	Air box	13.	Cleaning cum cooling
5.	Data acquisition system	14.	Drum
6.	Data receiver unit	15.	Water in
7.	Electric load cell	16.	Water out
8.	Intake pipe	M.	Gas flow meter
9.	Exhaust pipe		

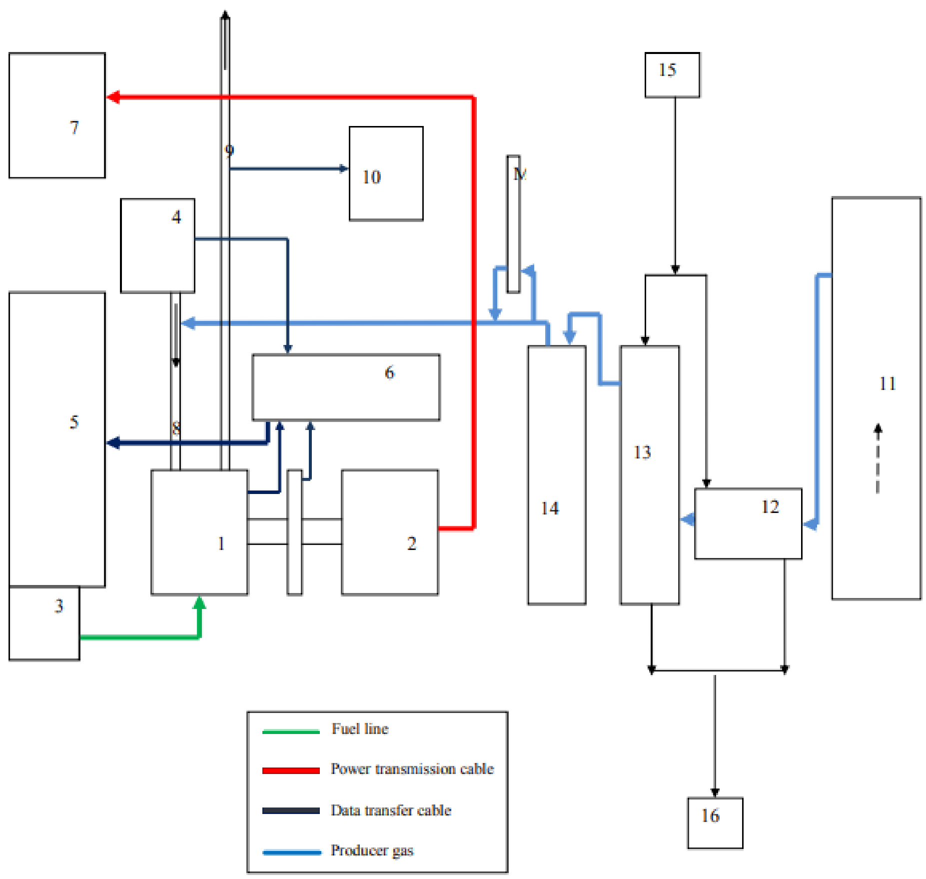

Fig. 21. Block diagram of engine coupled with gasifier

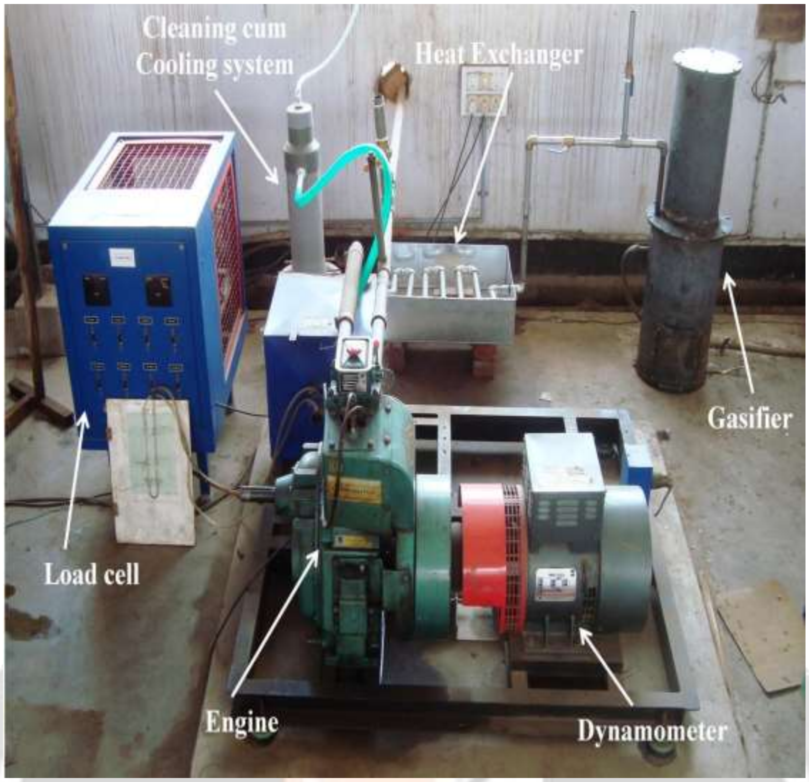

Fig. 22. Complete picture of engine coupled with gasifier unit

4. RESULTS AND DISCUSSIONS

In the present work, the performance and emission tests were conducted on diesel engine at dual fuel mode i.e. diesel (DF) as primary fuel and producer gas (PG) at 4lpm, 6lpm and 8lpm as secondary fuel respectively. The fuel terms are denoted as DF+PG4lpm, DF+PG6plm and DF+PG8plm, where the mass flow rates of producer gas in indicated after PG. The results of the performance and emission test are described below.

4.1 Performance of Diesel Engine in Dual Fuels Mode

Liquid fuel economy is one of the major factors when operating the gasifier CI engine system. The engine performance with diesel (D) and producer gas (PG) is evaluated in terms of brake thermal efficiency (BTE), brake specific fuel consumption (BSEC) and exhaust gas temperature (EGT) along with emission characteristics at no load, 1kW, 2kW, 3kW and 4.5kW of brake power.

4.1.1. Brake Thermal Efficiency (BTE)

Fig. 23 shows the effect of brake power at brake thermal efficiency at varying load condition. The BTE of the dual fuel mode for engine is lower than that of diesel. A considerable reduction in brake thermal efficiency is observed in dual fuel mode as compared to DF mode at all loads. The maximum efficiency achieved by diesel fuel was 27.5% where as in dual fuel mode maximum efficiency achieved was 26%, 25% and 24.5% for D+PG4plm, D+PG6plm and D+PG9plm respectively. The reduction in BTE is due to the lower calorific value of producer gas, which contains more combusted mixture that enters into the engine. Producer gas evolved from the engine is at higher temperature and therefore density of producer gas is reduced, which in turn reduces the mass flow rate of producer gas and air required for combustion, resulting in lowering the oxygen level required for combustion. This insufficient oxygen in the combustion chamber is the cause of incomplete combustion [11].

4.1.2 Brake Specific Energy Consumption (SEC)

Fig. 24 shows the variation between specific energy consumption and brake power. Brake specific fuel consumption is not a very reliable parameter to compare the two fuels having different calorific values and density, hence brake specific energy consumption is preferred to compare the performance of CI engine. The specific energy consumption in dual fuel mode is calculated from the fuel consumption and calorific value of diesel and producer gas. Specific 51 energy consumption in dual fuel mode was found to be higher than that of diesel mode at all load conditions. BSEC is inversely proportional to BTE hence as the brake thermal efficiency is reducing by using of producer gas with air, the BSEC will decrease with corresponding flow rate of producer gas.

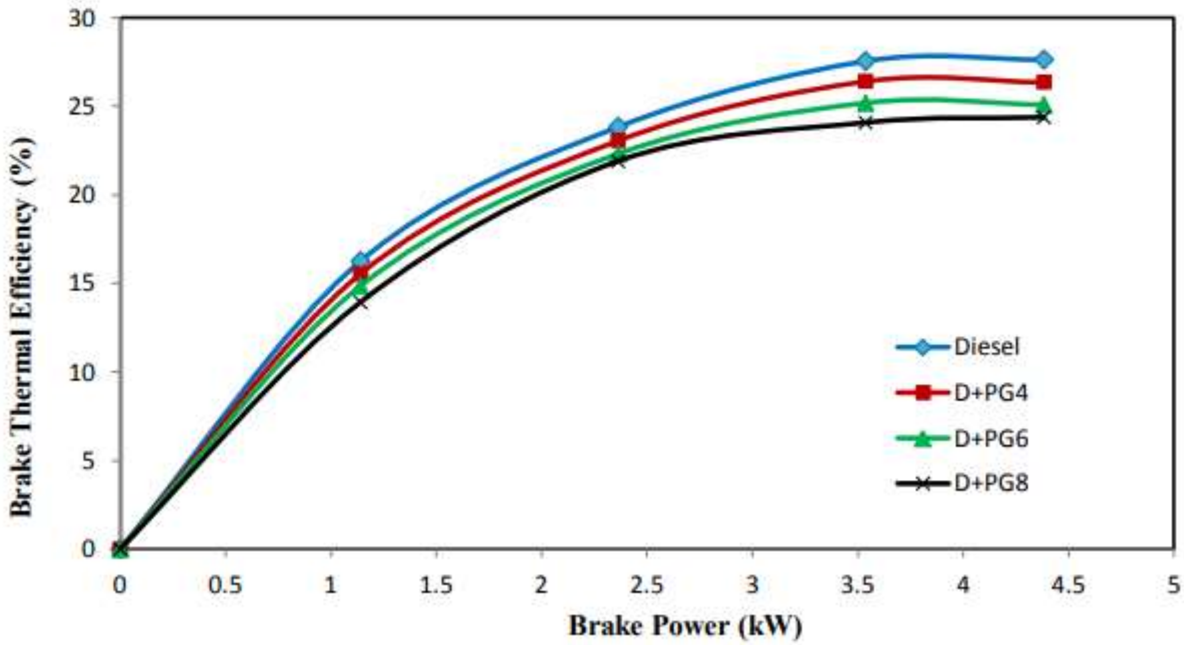

Fig. 23. Effect of brake power on brake thermal efficiency in dual fuel mode

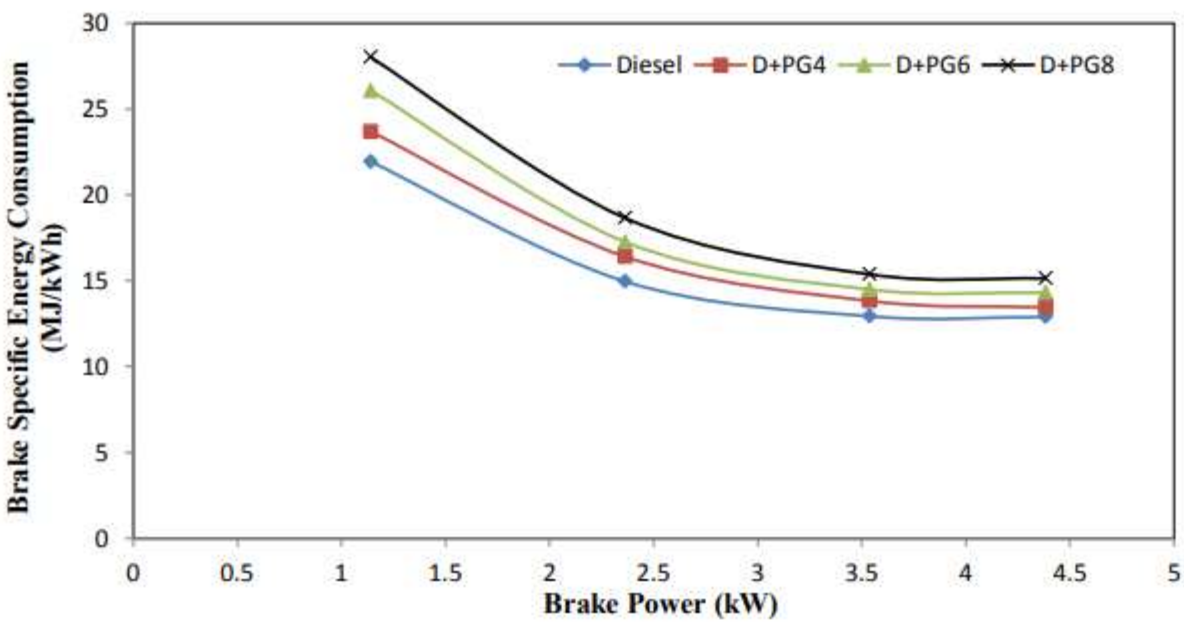

Fig. 24. Effect of brake power on specific energy consumption in dual fuel mode

4.1.3 Exhaust Gas Temperature

The variation of exhaust gas temperature with brake power is shown in Fig. 25. The exhaust gas temperature of diesel at full load is found to be 330°C while the exhaust gas temperature at full load for D+PG4, D+PG6 and

D+PG8 are found to be 365, 378 and 388°C respectively. EGT for dual fuel mode is always higher than DF, this is due to the excess energy supplied to the engine [12]. The EGT can be reduced by increasing the density of fuel mixture for combustion in engine. Higher the exhaust gas temperature in the combustion chamber is an indication of increase in NOx emission because at temperature more than 1100°C, nitrogen reacts with oxygen to produce NOx.

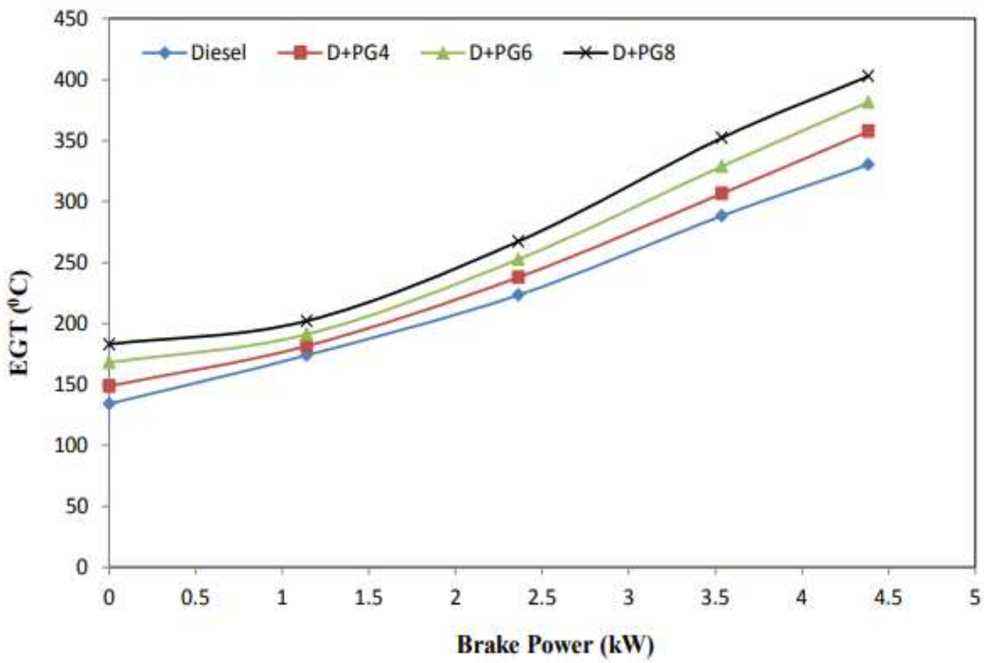

Fig. 25. Effect of brake power on exhaust gas temperature in dual fuel mode

4.2 Emission Characteristics of diesel engine in Dual Fuel Mode

Emission from the engine reflects the quality of combustion takes place inside the engine. The different emission parameters measured during diesel and dual fuel (D+PG) mode operation are discussed as follows.

4.2.1 Carbon monoxide (CO) emission

There are two major cause of formation of CO emission, the first one is the incomplete combustion due to insufficient amount of oxygen supplied in combustion chamber and the second one is the insufficient time in the cycle for completion of combustion. The variation of CO emission of the engine with DF and dual fuel mode is depicted in Fig. 26. With increase in load, an increase in CO emission was observed. Much higher values of CO emission are recorded in dual fuel mode as compared to diesel fuel mode. The higher concentration of CO emission in the dual fuel mode is due to incomplete combustion. The mixture of high temperature PG and air flow to the engine reduces the amount of oxygen required for complete combustion. This creates incomplete combustion and increases the CO emission.

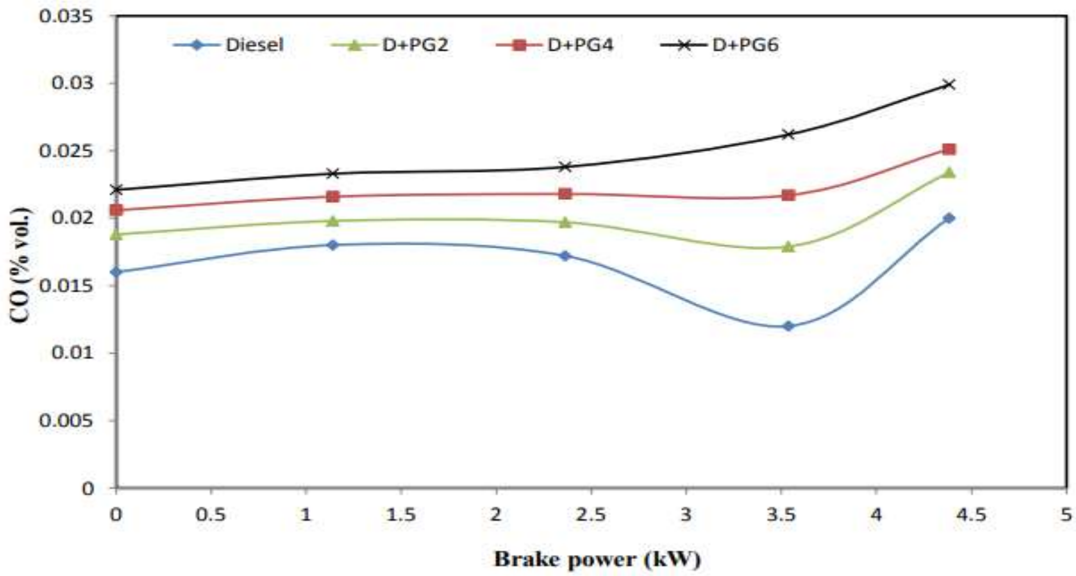

Fig. 26. Effect of brake power on CO emission at varying load in dual fuel mode

4.2.2 Hydro carbon (HC) emission

As shown in Fig. 27, there is always an increase in hydrogen carbon (HC) emission when there is an increment in loads. Unburnt hydrocarbon emissions are the direct result of incomplete combustion. The unburned hydrocarbons and their derivatives that readily vaporize are termed as volatile organic compounds (VOCs). The VOCs react with oxides of nitrogen in the presence of sunlight to form oxidants and photochemical smog [13]. This emission arises when a part of the fuel inducted into the engine escapes combustion. During ignition delay period, fuel air mixtures becomes too rich to ignite and combust contribute to HC emissions.

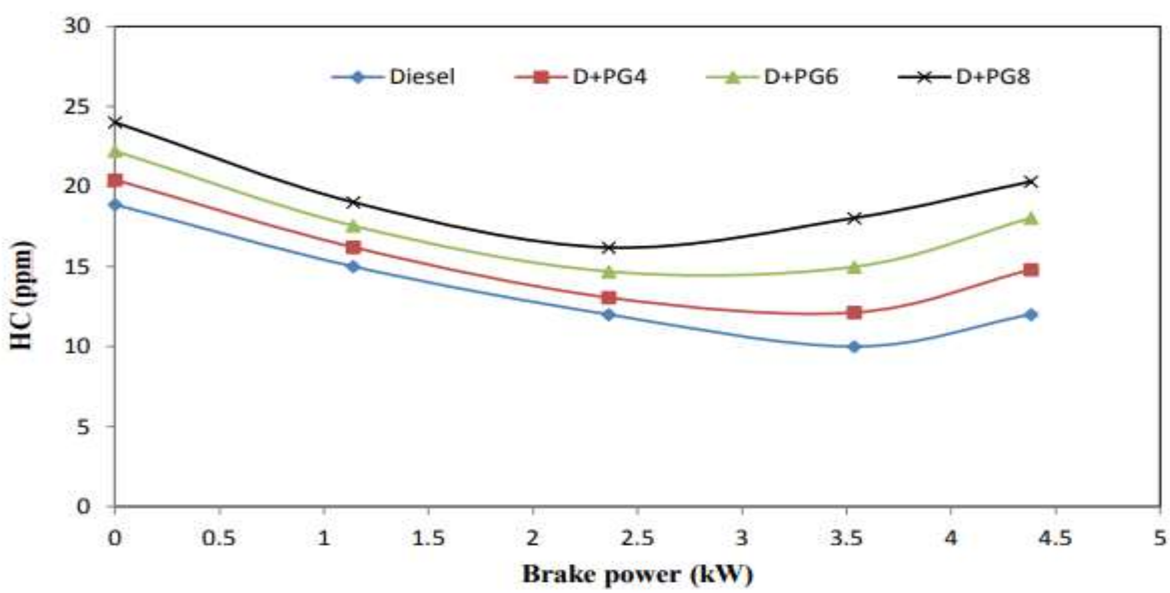

Fig. 27. Effect of brake power on HC emission at varying load in dual fuel mode

4.2.3 Nitric oxide (NO) emission

Higher temperature and availability of oxygen are the two main reasons for the formation of NOx. Nitrogen is inert at low temperature, but at temperature higher than 1100°C nitrogen reacts with oxygen and form oxides of nitrogen [14]. Thus NO emission depends upon combustion chamber temperature which in turn depends on the applied load.

From the Fig. 28, it was observed that the NO emission increases with increase in load for all the fuels i.e. diesel and D+PG fuel. This is due to the high temperature in combustion chamber obtained at high load thus reacting nitrogen with oxygen to form NOx. At low brake power, insignificant difference in NO emission was recorded while operating the engine on diesel fuel mode and dual fuel mode but, as brake power increases the variation of NO emission increases between Diesel and D+PG fuel. NO emission was higher in diesel fuel mode than dual fuel mode, which is an excellent advantage of dual fuel mode. Also organic nitrogen from the air causes NOx formation. Producer gas do not have organic nitrogen, it has only atmospheric nitrogen, which inorganic nitrogen [35].

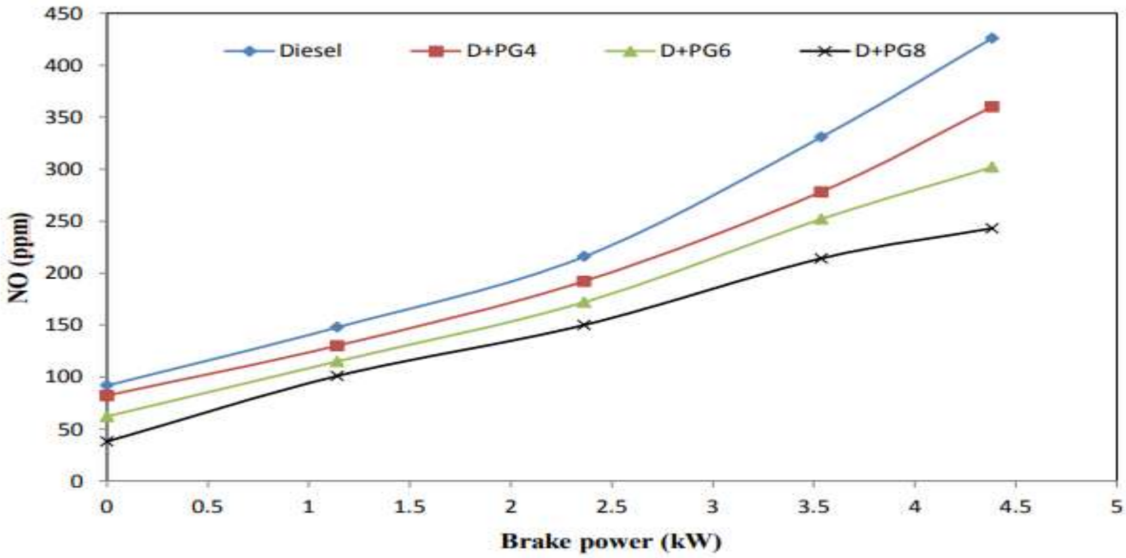

Fig. 28. Effect of brake power on NO emission at varying load in dual fuel mode

4.2.4 Smoke density

Smoke density increases as the brake power increases, it is applicable for all types of fuel used in diesel engine. The cause of smoke is incomplete combustion which may be due to incorrect airfuel ratio or may be due to improper mixing of fuel with air. As shown in Fig. 29, significant difference is observed between smoke density of various fuels at no load and full load, but the change was very insignificant when first load was given to engine. This is due to the lake of oxygen at no load and full load than the oxygen available at first load. In diesel fuel mode operation the smoke density attained a maximum value of 25% where as it is 32% in dual fuel mode for D+PG8 at full load. In dual fuel mode of operation, the smoke density is observed to be higher than that of the DF for all combination of PG.

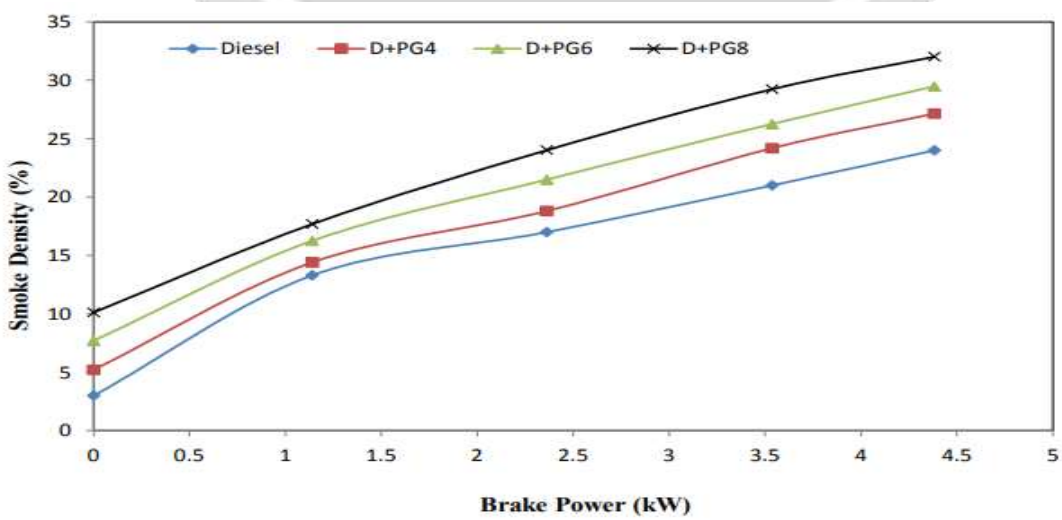

Fig. 29. Effect of brake power on smoke density at varying load in dual fuel mode

5. CONCLUSION

The performance and exhaust emission characteristics were investigated experimentally in a single cylinder, 4-stroke air cooled DI diesel engine operating with gasifier on a dual fuel mode and following conclusion were made on the basis of present work.

- Higher amount of diesel fuel can be saved by replacing diesel with producer gas although there would be a reduction in brake thermal efficiency which is due to lower heating value of producer gas and insufficient amount of oxygen supply.
- NO emission was found to be very low in dual fuel which is a great advantage of dual fuel mode over diesel fuel alone.
- CO and HC emission was observed very high in dual fuel mode which gives an indication of insufficient oxygen in combustion chamber.

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