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Investigation of Performance and Emission Characteristics of a Dual Fuel Compression Ignition Engine Using Sugarcane Bagasse and Carpentry Waste – Producer Gas as an Induced Fuel

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Abstract—*Due to ever increasing use of fixed heavy duty diesel engines, for various electrical and mechanical energy needs, the concentrations of GHGs and air pollutants such as NOx, etc. are increasing at a high rate. These emission characteristics usually deteriorate with the increase in the operational hours. When these engines are fired with a waste derived gas called as producer gas, obtained by the gasification of the carbonaceous dry biomass, a significant reduction in the concentrations of the pollutants such as NOx, SOx, etc. is observed. Such an investigation was carried out, in which the producer gas was prepared in a downdraft gasifier at a flowrate of 5.07Nm^3/Hr. A venturi type spray tower was used to remove the tar from the gas followed by two charcoal filters to ensure an ultra pure gas supply. A 3.5 kW, single cylinder, modified dual fuel compression ignition engine was fired with blends of diesel and the producer gas derived from sugarcane bagasse and carpentry waste at a constant speed of 1500±5 RPM. The investigation was carried out at a constant compression ratio of 16.The modified dual fuel compression ignition engine showed a smooth working at all load values in dual fuel as well as pilot fuel mode. In the investigation, it was observed that on dual fuel mode, a maximum of 51% of diesel was replaced by the producer gas, with a slight reduction in the net power output. This power loss to a great extent was compensated by the significant improvement in the emission characteristics of the engine. There was a maximum reduction of ~71% in the NOx emissions. A significant reduction in the exhaust gas temperature has also been reported in the present work.*

1. INTRODUCTION

At present, the world as a whole is facing a threat of depletion of the conventional fuels. These fuels due to their high heating values are used in almost all small and large scale industries in various forms. Instead of their high heating values, these fuels are also associated with numerous harmful effects in the form of high carbon footprints and deadly air, soil and water pollutants. The pollutants include GHGs (Green House Gases) such as CO, CO_2, CH_4 etc., ash, particulates, etc. In order to overcome the threat of depletion of these conventional fuel resources, the world is now fastly turning on to some advanced renewable energy resources such as solar energy, wind energy, hydel energy, etc. In such case, biomass appears to be a promising renewable energy resource, which is available in a large amount in most of the agriculture based countries at an exceptionally low cost in comparison to the conventional fuels [1]. Farmers in such countries are day by day getting aware of the energy potential of biomass and most of the use the biomass efficiently and effectively without producing any carbon footprint or air pollution. There are various "biomass to energy" conversion techniques, which produce various more compatible products such as Bio-oil from pyrolysis, producer gas from gasification, bio-diesel from esterification, Bio-gas from anaerobic digestion, Bio-ethanol from fermentation. The carbon conversion efficiency of these processes ranges from 70% to even 90%. [2] Talking about the present work progress in the gasification area, though most the investigations are carried out using wood and other abundantly materials as raw materials, yet not much work is reported on the use of sugarcane bagasse as a raw material.

Most of the villages and the regions located far from the electric grid in the developing countries such as India, experience the shortage of electric energy due to the heavy losses associated with the transmission of electricity to a far off distance. [3] In such regions, to meet the energy needs, rural electrification by means of various small energy generating devices serves a good purpose. For electricity generation in such regions, fixed heavy diesel engines are used. These engines are quite robust and also consume a high quantity of conventional fuel. [4] After long hours of operation, these engines show a significant polluting characteristics such as a large increase in the NOx levels than the normal specified limit. Apart from NOx, other pollutants such as soot particles, CO, HC etc also tend to increase with the time of operation of these engines. Out of all the pollutants, NOx are the most important and the least bothered one. NOx emissions are responsible for various deadly effects in human beings and other living organisms. The various oxides of nitrogen are washed down to the earth in the form of poisonous acids called as acid rain. [5]

As discussed earlier, biomass is available in plenty amount in all the agriculture based countries, so due to the high efficiency and low operational cost of biomass gasification, it has become a popular technique used these days. This technique finds its application in fixed or mobile IC engines, furnaces, gas turbines, for the drying of cereals and beverages like tea, coffee, etc., crematories, etc. [6] In IC engines, there is a term called "the dual fuel engine", which is a specifically modified form of an IC engine, so that it could work using blends of two different fuels, at least one of which is gaseous in nature. Previous work done by some researchers has reported that when the engine is run on the on dual fuel mode, the gaseous fuel is able to replace a significant amount of conventional fuel and a maximum replacement of 70% has been reported. On dual fuel mode, there is a slight reduction in the power output of the engine due to the lower heating value of the gas. [7] Although a requisite amount of work can be found in the performance characteristics of the dual fuel engine, but the area of analysis of the emission characteristics of the dual fuel engine is still lagging behind.

Keeping mind the gaps in the previous literature, following objectives were made and are reported in the present work.

- Use of sugarcane bagasse and carpentry waste for producer gas production.
- To use the prepared producer gas as a secondary/induced fuel in the DFCI engine.
- Investigation of performance characteristics of the DFCI engine.
- Investigation of the emission characteristics of the DFCI engine.

The present work reports an investigation of the performance and the emission characteristics of the DFCI engine

2. GASIFICATION – BASICS

Gasification is a thermochemical process in which the carbon content of the raw material gets converted into partially combusted products such as CO, H_2, CH_4, CO_2 etc. along with a mixture of some complex compounds called as tar. In gasification, the raw materials as wood, forestry waste, agricultural residue, sewage sludge, etc. are burned in a very low supply of air, which creates a reducing type atmosphere in the combustion chamber and at the outlet, reduced products are obtained as discussed earlier. This process is carried out at a temperature of ~950^{o}C. It found that, for the best results, the permissible moisture content in the raw material should be <20%. In such case, maximum range of calorific value is 4500-5000 kJ/Nm^3. [8] The gasification process is divided into the following four parts/zones:

2.1 Drying zone:

As the name suggests, it the zone, where excessive moisture gets dried off. The temperature of this zone is ~120^{o}C. Due to this, some of the volatile components such as low boiling hydrocarbons, etc. get evaporated along with the moisture. No chemical reaction takes place in this zone.[9]

2.2 Pyrolysis zone:

It is the necessary step in all the thermochemical processes, in which the carbonaceous matter is converted into some upgraded products. In this zone, some fraction of the raw material gets thermally broken. The temperature of this zone ranges from 220^{o}C to 250^{o}C. The raw material gets converted into volatile components such as CO_2, CH_4, CO and variety of hydrocarbons.[10]

2.3 Combustion zone:

The pyrolyzed raw material now shifts to the combustion zone, where actual combustion takes place, but in a limited supply of air. Partially and fully combusted products such as CO, CO_2, CH_4, along with some hydrocarbons are formed in this zone. The temperature of this zone is 850^{o}C to 900^{o}C. [11]

2.4 Reduction zone:

In this zone, the actual gasification of the biomass takes place. All the compounds such as CO, CO_2, CH_4, etc are reduced to CO, CO_2 and H_2. In this zone, mainly four types of reactions are observed, these are: Boudouard reaction, methanation reaction, steam reforming reaction and water-gas reaction. [12]

3. GASIFIER-ENGINE SETUP

3.1 Fuel Collection

Fuel used for production of producer gas was sugarcane bagasse. It was collected from a local juice bar owner as it was just a waste for him. At the time of collection, a large amount of moisture was present in it. So, it was sun-dried for one week. After drying, it was chopped down into small pieces of size ≤ 15mm. The chopped sample was stored in bags for further use. Another biomass fuel selected was wooden chips. It was collected from a carpenter shop. It had a maximum size of 10mm. It was ready to use. The sugarcane bagasse and the carpentry waste were mixed in a ratio of 2:3.

Table 1: Proximate analysis, calorific value, size and moisture specifications of the raw materials

Component	Sugarcane bagasse	Carpentry waste
Volatile matter (%)	76.58	72.05
Moisture (%)	8.48	9.2
Fixed carbon (%)	12.02	17.71
Ash (%)	2.92	1.04
CV (kJ/kg)	18342.65	18773.60
Size (before processing)	Fibers of length < 2m.	5 – 20 mm
Size (after processing)	1mm to 25mm	5 – 20 mm
Moisture (before sun drying)	>50%	<10%
Moisture (after sun drying)	<9%	<10%

3.2 Gasifier system

In the present investigation, a downdraft biomass gasifier was used. Following are the specifications of the gasifier system in accordance to catalogue the supplied by the manufacturer:

Table 2: Specifications of gasifier system

Parameter	Specification
Gasifier Make	Ankur Scientific Energy Technologies Pvt. Ltd.
Gasifier model	WBG-10
Gasifier Type	Downdraft with a throat.
Number of air inlets	2
Permissible moisture content	<20%
Gas flow rate	25 Nm^3/hr (Maximum)
Thermal output	30.21 kW
Typical gas composition	CO = 19±2%, $CH_4 \leq 4\%$, H_2 = 18±2%, CO_2 = 10±4%, N_2 = 51%
C.V. of the producer gas produced	4393.2 kJ/Nm^3 – 5439.2 kJ/Nm^3
Fuel Consumption	8-10 kg/hr

This downdraft gasifier system was further coupled to a gas cleaning system, which consisted of the following:

- Scrubber: For cleaning and cooling of the producer gas
- Secondary filter: For removal of the soot particles and excessive moisture.
- Safety filter: to ensure the ultra clean supply of the producer gas.

Fig. 1: Downdraft gasifier system coupled to the gas cleaning system

The ultra clean gas was sent into the DFCI engine with the help of a gas carburetor. The schematic diagram of the gas carburetor is shown in Fig. 2.

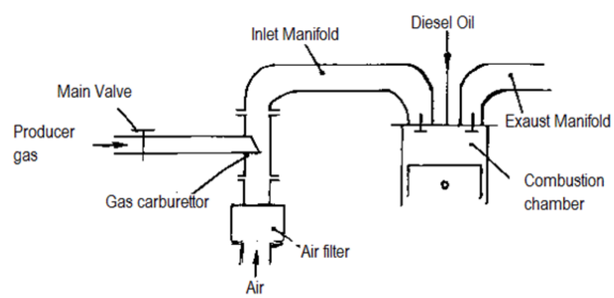

Fig. 2 Schematic diagram of the gas carburetor

3.3 DFCI engine setup

In the experimental investigation, a four stroke, single cylinder engine was used. The complete specifications of the modified DFCI (Dual Fuel Compression Ignition) engine are represented in table 2.

Table 3: Specifications of the DFCI engine setup

Parameter	Specification
Engine make & model	Kirloskar AV-1
Engine type	VCRE (Variable Compression Ratio (CI) Engine)
Cylinders	1
Strokes	4
Capacity of the engine	553 cc
Maximum power	3.5 kW at 1500 RPM
Connecting rod length	234mm
Compression ratio	12 -18
Dynamometer	Eddy current type

The engine was water cooled so the water supply was opened before starting the engine. Water flow rate of 250 LPH and 75 LPH was supplied to the engine water jacket and the calorimeter. The compression ratio of the engine was fixed at 16 and the loads on the engine were varied from 2 kg to 12 kg. Air and gas flow rates were measured using two different flowmeters having an orifice of diameter 20 mm and 15.31 mm. The maximum flow rate of the producer gas for the sustainable engine running was 5.07 Nm^3/hr..

Fig. 3: DFCI engine setup

In this investigation, it was assumed that the volumetric efficiency of the engine remains the same as in the diesel fuel mode operation The engine was tested for performance and emission characteristics on the following two modes:

- Single fuel mode: operation of the engine on diesel as on and the only fuel.
- Dual fuel mode: operation of the engine using diesel as the pilot fuel, whereas the producer gas the induced fuel.

4. RESULTS

Performance characteristics

Brake Power

Fig. 4 shows the respective increase in brake power with respect to increase in the load on the engine.

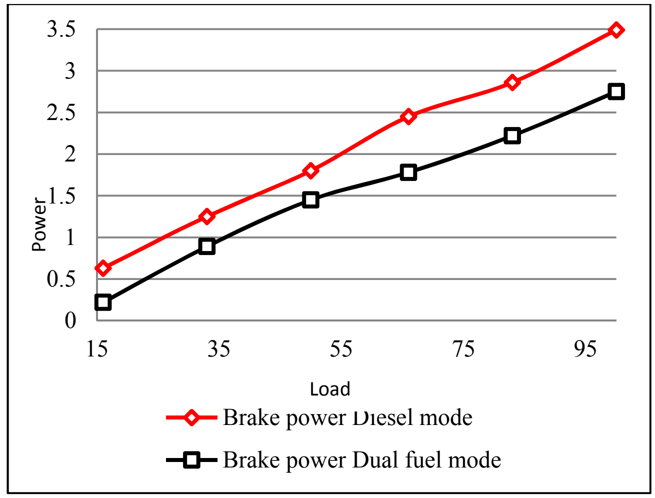

Fig. 4: Variation of brake power with respect to load

It is observed that there is an almost linear increase in the brake power with an increase in percentage of load. Due to the low C.V. of the gas, there was a slight reduction in the brake power of the engine. At medium values of load, there was the least reduction in the brake power. The maximum brake power produced by the engine was 2.75 kW at the dual fuel mode where as at pilot fuel mode, the maximum brake power of 3.49 kW was produced.

Fuel consumption

Fig. 5 shows the corresponding replacement of the diesel fuel with the introduction of mixture of producer gas and air.

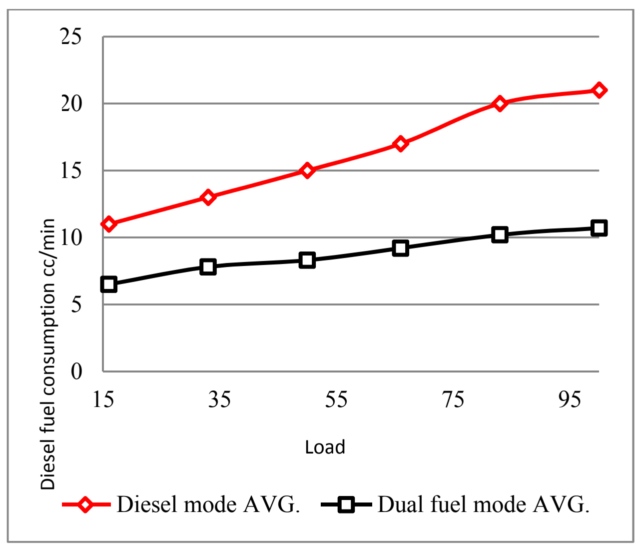

Fig. 5 Fuel consumption variation with respect to load

There is a significant decrease in the conventional fuel consumption due to the use of producer gas. In diesel mode, the fuel consumption shows a linear trend. In dual fuel mode, at lower loads, a lesser replacement of the conventional fuel is noted, in comparison to the higher loads. There is an increase in the gaseous fuel consumption due to the relatively lower CV of the gaseous fuel. A maximum of 51% of the conventional fuel replacement is reported on the dual fuel mode.

Specific fuel consumption

Fig. 6 shows the BSFC of the engine with respect to the load variations. A decreasing trend of BSFC is observed on both the modes of operation. A sudden decrease in the BSFC at ≤33% load was observed on dual fuel mode operation, whereas a regular decreasing trend is followed at the higher loads.

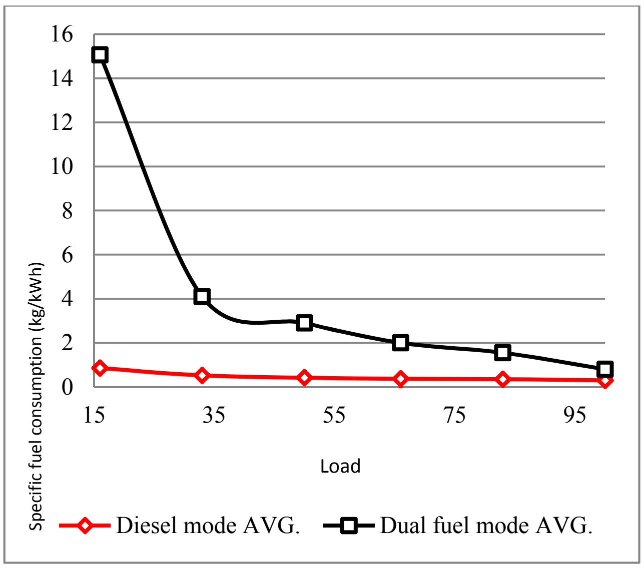

Fig. 6: Trends for SFC with respect to load

When the load on the engine increases, there is a corresponding increase in the brake power output of the engine, due to which the SFC shows a decreasing trend with load increase. The BSFC at the dual fuel mode is higher in comparison to the diesel mode due to the low C.V. of the producer gas.

Emission Characteristics

Exhaust gas temperature

The exhaust gas temperature shows an increasing trend in both the cases. This due to the reason that at higher loads, more fuel is injected into the cylinder, which produces a more amount of heat and hence the exhaust gas becomes hotter with an increase in the load on the engine. On dual fuel mode, relatively lower exhaust gas temperature is observed at all load values in comparison to the pilot fuel mode. Two reasons support this trend.

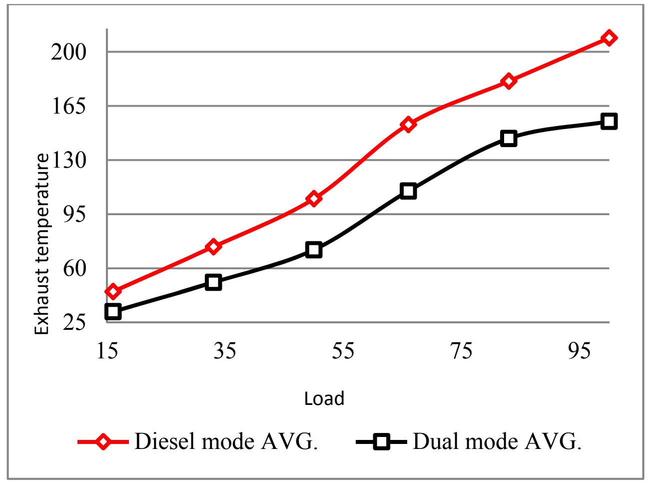

Fig. 7 Variation of Exhaust gas temperature with load variation

The first one is that due to the air deficient atmosphere, lesser amount of fuel gets actually burnt, due to this lesser heat is generated, so the exhaust gas is less hotter in comparison to the exhaust gas in the pilot fuel mode. The second reason is that the producer gas is a low C.V. gas, due to which relatively low heat is generated, which cause the exhaust gas to get less hotter.

NOx emissions

The NOx emissions show an almost linear trend and the NOx concentration in exhaust increases in both the cases but with different slopes. In case of pilot fuel mode, it is observed that the engine emits a greater amount of NOx as compared to the dual fuel mode. The above stated reasons are responsible for this trend also. The concentration of NOx emissions depends on the temperature of the combustion chamber. As discussed earlier, lesser amount of heat is generated in the combustion chamber, so lesser concentrations of NOx are found in the exhaust gas. The present work reports, a maximum reduction of 71% in the NOx emission.

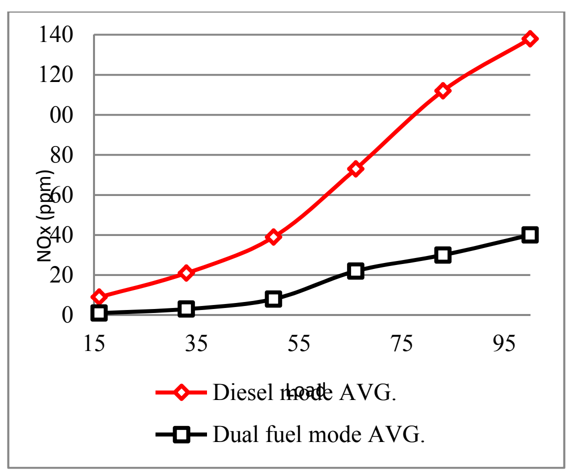

Fig. 8 NOx emission with respect to load.

HC emissions

On pilot fuel mode, the engine shows relatively lower HC emissions as compared to the dual fuel mode. The hydrocarbon emissions follow an increasing trend in both the modes and almost same slope is observed in both the cases. The engine used for the experimental analysis had a constant volumetric efficiency, i.e. it could inhale a specific quantity of gaseous fluid at all the times. The gaseous fluid can be the only air (pilot fuel mode) or mixture of air and producer gas (dual fuel mode).

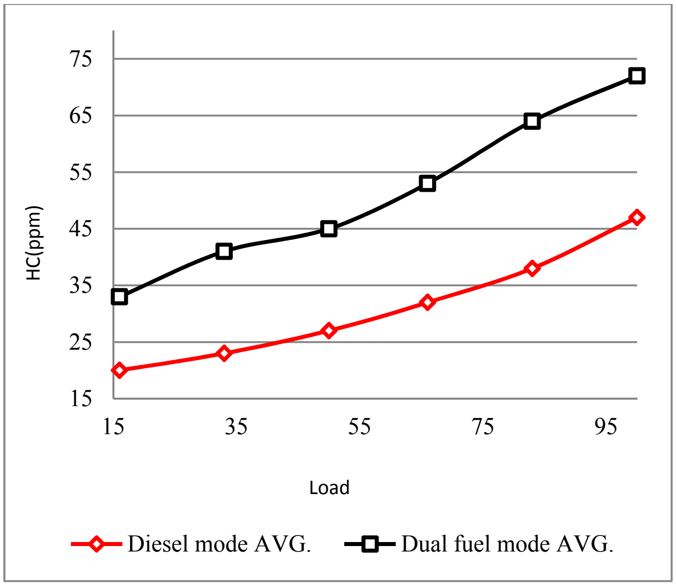

Fig. 9: HC emissions with respect to load variations

On dual fuel mode, an air deficient atmosphere is created in the combustion chamber or it can be said that the engine is now supplied with rich fuel mixture. This causes an incomplete combustion of the fuel due lack of air/oxygen in the combustion chamber. So, some part of the fuel comes out uncombusted or partially combusted.

5. CONCLUSION

From the physical observations, it is concluded that the engine shows a smooth and sustained working. From the analysed results, the following is concluded:

- Dual fuelling with the gasification derived producer gas is a good concept of generating valuable energy from a waste.
- Valuable conventional fuel can be significantly replaced using gasifier-dual fuel engine system.
- At present the engine showed an increased concentration of HC but, a slight modification in the injection system can make the system better in terms of emission characteristics
- Dual fuel operation results in a decrease of 51% fuel consumption, 71% NOx emissions as well as the exhaust gas temperature.
- The gasifier-dual fuel engine system will be a popular energy generation system in the coming years.

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