Investigation of Various Parameters of Dual Fuel Engine Using Biomass Waste – Producer Gas as an Induced Fuel

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Abstract:
Due to various shortcomings of the transmission of electricity in rural areas, the concept of rural electrification is gaining popularity these days. Many small-scale biomass-based gasifier-engine systems are installed in the villages in order to provide an uninterrupted and cheap supply of electricity for various kinds of everyday requirements. In the present work, an optimized downdraft biomass gasifier is used to produce the producer gas from three different biomass materials viz. Sugarca ne bagasse, cotton stalks and wood chips. These biomass materials are used in two different combinations viz. 1:1 ratio of sugarcane bagasse & wood chips; 1:1 ratio of cotton stalks and wood chips. The composition of gas produced from both the samples shows that the cotton stalks and wood chips generate a gas with higher calorific value as compared to the one produced using sugarcane bagasse and wood chips. These gases are used to run a dual fuel CI engine. The comparative investigation of various parameters, i.e. performance, emission and noise characteristics of a modified dual fuel engine is done, by running the engine on pilot fuel mode as well as on dual fuel mode using two different samples of producer gas. The maximum diesel replacement of ~54% is observed with a ~5% loss in brake thermal efficiency in the case when cotton stalks and wood chips are used as raw materials. The NOx emissions were reduced by ~70% with a slight increase of ~3 dB in the noise levels of the engine.

Keywords: Performance characteristics; Emission characteristics; Noise characteristics; Dual fuel engine; Biomass gasification; Economic analysis

1. Introduction:
Due to tremendous increase in the industrialization, the diesel are getting depleted at a high rate. Due to this, the concentrations of environmental pollutants as well as the GHGs (Green House Gases) in the atmosphere are continuously increasing, which have their own deadly effects [1]. The world, at a whole is now interested in shifting on some other energy resources. In that case, biomass has proved to be a promising resource, as it is easily available and quite cheap as compared to the diesel. There are many processes, by which biomass can be converted into some more compatible products [2–6].

Due to the high carbon conversion efficiency and low operational costs, biomass gasification appears to be an attractive technique [7]. This technique finds its application in fixed or mobile IC engines, furnaces, for drying of food and other eatables such as cereals, tea, coffee in the drying units, metallurgical industries, gas turbines etc. [6,8]. Since these days, rural electrification has been the prevalent issue, so a lot of work is done and is ongoing on the use of gasification derived producer gas in fixed IC engines to supply a significant amount of electric energy at the community or village level.
Figure 1 Explains the present status of the biomass power potential of major states of India along with the installed power potential. It is clear from Figure 1 that ~21% of biomass energy potential is actually converted into useful energy. So, these biomass gasification systems are an attractive alternative for the diesel.

![Figure 1 Bioenergy potential and installed electric potential of some of major states of India](image)

In most of the present work, it has been reported that a maximum possible efficiency in the gasification process ranges from 80–95%, with a tar content as low as 1 mg/Nm³ [10]. It has been reported that the use of producer gas in the DFCI (Dual Fuel Compression Ignition) engine has replaced the use of diesel by a significant amount and even 80% of diesel replacement has been observed [11]. Though very less literature has been reported on the emission characteristics of the DFCI engine on diesel and dual fuel modes, yet in the so far reported work it has been observed that on dual fuel mode, there is a significant reduction in the NOx emission by 50–75% whereas the CO and HC emissions are found to be increasing in almost all the cases. [12,13]. Like the emission characteristics, there is also some variation in the noise characteristics of the DFCI engine when operated on the dual fuel mode. In this area also ample literature has not been reported. However, in some of the reported cases, it is found that on an average, there is an increase of ~2–4 dB in the noise of the DFCI engine, when operated in dual fuel mode [14]. Keeping in mind the limitations of the previously reported work, the following objectives were made:

- Preparation of producer gas from sugarcane bagasse and carpentry waste; cotton stalk and carpentry waste.
- Use of both the samples of the producer gas in a modified dual fuel CI engine.
- Performance investigation of the engine on both the modes (pilot fuel mode and dual fuel mode).
- Emission investigation of the engine on both the modes.
- Noise investigation of the engine on both the modes.

### 2. Materials and methods

To carry out the experimental investigation, various steps are followed, which are explained as follows:

#### 2.1 Fuel collection:

Three types of biomass materials viz. sugarcane bagasse (SB), cotton stalks (CS) and carpentry waste (CW) are collected from local fields. The biomass materials are air dried to reduce the equilibrium moisture content less than 10% by mass. The dried biomass materials are then chopped to small particles with maximum edge length less than 25 mm to prevent the choking of the gasifier’s throat. The size of the all the three biomass materials are given in Table 1.
Table 1 Size and moisture specifications (air dried basis) of raw materials

| Raw material          | Before processing | After processing |
|-----------------------|-------------------|------------------|
| Sugarcane bagasse     | Fibers of 2 m length (maximum) | 0.1 mm to 0.99 mm (~10%) | 1 mm to 25 mm (~90%) |
| Cotton stalk          | Stalks of 1.5 m to 2 m length | <25 mm |
| Carpentry waste       | 5 mm to 20 mm     | 5 mm to 20 mm    |

The three biomass materials are blended with each other to make two different samples viz. S1 and S2. The composition of S1 and S2 is presented in Table 2.

Table 2 Mass fraction distribution of the biomass materials

| Sample | Sugarcane bagasse (%) | Cotton stalks (%) | Carpentry waste (%) |
|--------|------------------------|-------------------|---------------------|
| S1     | 50                     | 0                 | 50                  |
| S2     | 0                      | 50                | 50                  |

These samples are used one at a time for the production of producer gas.

2.2 The gasifier setup

For the preparation of the producer gas, a downdraft biomass gasifier system with a throat is used, which is further coupled to a gas cleaning system to remove the tar and other contaminants.

Both the samples S1 and S2 are fed into the biomass gasifier one at a time. The gasifier has well defined and distinct zones, namely drying zone, pyrolysis zone, combustion zone and the gasification zone. The schematic diagram of the biomass gasifier is represented in Figure 2. The various numbered parts of the gasifier are: 1: Hopper and Zone 1 – Drying & pyrolysis, 2: Air inlet, 3: Zone 2 – Combustion, 4: Zone 3 – Reduction, 5: Drain tub for ash removal, 6: Water inlet for the scrubber, 7: Scrubber for cooling and cleaning of gas, 8: Drain box, 9: Secondary filter for tar, particulate and moisture removal, 10: Safety filter for ultra cleaning of gas, 11: Bypass valve, 12: Flare control valve, 13: Flare burner for testing gas quality, 14: DFCI engine test setup, 15: Eddy current dynamometer.

Figure 2 Schematic diagram of the experimental setup. [15].

2.3 The dual fuel engine setup
A newly purchased “Kirloskar” make single cylinder, four stroke compression ignition engine is used for the present experiment. As the engine was initially designed to operate on only diesel, a modification in the form of gas carburetor is done in order to make it a dual fuel engine. The carburetor had two inlets and an outlet. One of the inlet is connected to the clean gas supply from the gas cleaning system and the other is connected to the ambient air supply via an air filter. The mixing of the gas and the air takes place inside the carburetor. The gas carburetor is a simple T-Joint piping socket which has two inlets and an outlet. The diameters of the inlets and the outlet are 2 inches each. As the induction effect of the engine, the air gas mixture is induced into the combustion chamber and it ignites with the spray of the diesel at high pressure.

The engine is initially run on the pilot fuel mode by keeping the compression ratio constant at 18. On dual fuel mode, the engine is supplied with a constant gas supply of 5.03 Nm$^3$/hr, controlled manually using a ball valve and measured by means of orificemeter. The engine is run using the following fuels:
- Diesel alone
- Diesel and the producer gas prepared from sample S1.
- Diesel and the producer gas prepared from sample S2.

2.4 Performance, emission and noise measurement:
The performance characteristics of the dual fuel engine are analysed using ICenginesoft™ software provided by Apex Innovations Pvt. Ltd., India. which provides the data related to different performance parameters of the engine. The emission characteristics of the engine are analysed using a probe type model, ACE-8000 of Maxicem Portable Gas Analyser. The noise levels of the engine are measured using SC310 model of CESVA Sound Level Meter and Spectral Analyser.

3. Results

3.1 Proximate analysis

These biomass materials were also tested for their proximate analysis using ASTM D7582-15 standard.

| Component          | Sugarcane bagasse | Cotton stalk | Carpentry waste |
|--------------------|-------------------|--------------|-----------------|
| Volatile matter (%)| 76.58             | 64.72        | 72.05           |
| Moisture (%)       | 8.48              | 7.75         | 9.2             |
| Fixed carbon (%)   | 12.02             | 23.42        | 17.71           |
| Ash (%)            | 2.92              | 4.11         | 1.04            |
| Calorific value (kJ/kg) | 18342.65   | 18489.78     | 18773.60        |

3.2 Performance characteristics

![Figure 3 Variation of brake power with variation of load](image-url)
3.2.1 Brake thermal efficiency

The Figure 3 shows that there is an almost a linear increase in the brake thermal efficiency with an increase in percentage of load. Due to the low C.V. of the gas, there is a slight reduction in the brake thermal efficiency of the engine in dual fuel mode for both S1 and S2. At medium values of load, there is the least reduction in the brake thermal efficiency. In case of dual fuel mode, the maximum thermal efficiency of the engine is observed to be 23.34% for sample. The maximum thermal efficiency of the engine is observed to be 24.9% at the dual fuel mode in case of sample S2 whereas at the pilot fuel mode, the maximum brake thermal efficiency of the engine is found to be 29.4%.

3.2.2 Fuel consumption

There is a significant decrease in the diesel consumption due to the use of producer gas in both cases viz. S1 and S2 as represented in Figure 4. In diesel mode, the fuel consumption shows a linear trend. In dual fuel mode, at lower loads, a lesser replacement of diesel is noted, as compared to the higher loads. There is an increase in the gaseous fuel consumption due to its relatively lower CV. A maximum of 48.5% and 54.76% of the diesel replacement is observed in case of the dual fuel mode S1 and S2 respectively.

![Figure 4 Diesel consumption with variation of load](image)

3.2.3 Brake specific energy consumption

Figure 5 shows the BSEC of the engine with respect to the load variations. A decreasing trend of BSEC is observed on both the modes of operation viz. diesel mode and dual fuel mode. The BSEC is observed to decrease sharply for lower load upto a value of 1.25 kW however a regular decreasing trend is followed at the higher loads. This is because, the increasing engine load, increases the brake power output of the engine,
with a lesser increase in the fuel consumption, so the SEC shows a decreasing trend with load increase. The BSEC at the dual fuel mode is higher in comparison to the diesel mode due to the low C.V. of the producer gas. Relatively higher values of the BSEC are observed in the dual fuel mode operation using sample S1.

3.3 Emission characteristics

3.3.1 Hydrocarbon emissions (HC):
As indicated by Figure 6, a significant increase in the HC emissions of the engine is observed when operated on dual fuel mode in both the cases of S1 and S2. This increase can be explained as, when engine is operated at dual fuel mode, the volumetric efficiency of the engine being constant, the volume of air inside the combustion chamber is reduced due to its replacement with producer gas, due to which there prevails a condition of insufficient oxygen. Also the producer gas has ~50% nitrogen content as a result the effective collisions of the fuel molecule with oxygen are greatly reduced so, some part of the fuel comes out unburnt. The other reason is the improper mixing of the fuel, which results into the poor combustion and hence more concentration of HCs are observed in the engine exhaust. Maximum concentration of HCs is observed to be 78 ppm in the case of dual mode operation using the sample S1. These results are in a good agreement with those published by Singh et al. 2018 [15].

![Figure 6 Hydrocarbon emissions with load variation](image)

3.3.2 Exhaust gas temperature

![Figure 7 Exhaust gas temperature with load variation](image)
As indicated by Figure 7, in all the cases the temperature of the exhaust gas shows an increase on increasing the load values. This is due to the fact that at higher loads more fuel is injected and it produces more heat and hence higher temperatures are observed. But, in case of the dual fuel mode S1, the maximum temperature of the exhaust gas is observed to be 145°C and the maximum exhaust gas temperature of 189°C was observed in case of dual fuel mode S2 due better combustion as compared to S1. In case of diesel mode the exhaust gas temperature is observed to be 209°C. The reason for this decrease in the exhaust temperature on the dual fuel mode is the incomplete combustion and low C.V. of the gas. Singh et al. 2018 [15] have also reported similar results.

3.3.3 Nitrogen oxide emission
It is presented in Figure 8 that with the increase in the load, the engine shows an increasing trend of NOx concentration. The reason for this trend is that at higher loads, more fuel is injected into the combustion chamber, on burning, it increases the temperature of the combustion chamber and at high temperature, the nitrogen (N₂) reacts with the oxygen and forms various types of oxides. But in the case of the dual fuel mode, a significant reduction in the NOx is noted. This is due to decrease in the temperature of the combustion because of incomplete combustion of the fuel. The maximum concentration of the NOx in the exhaust gas is observed to be 42 ppm and 63 ppm on dual fuel mode using sample S1 and S2 respectively. The results are quite related to those reported by Singh et al. 2018 [15].

![Figure 8 NOx emissions with load variation](image)

**Figure 8** NOx emissions with load variation

3.4 Noise characteristics:

![Figure 9 Noise variations with respect to load](image)

**Figure 9** Noise variations with respect to load
As shown in Figure 9, an increase in the engine noise levels is observed when operated at high load, but at load >3 kW the noise levels show a slight decrease in dual fuel mode and this decrease is noted at load >2.25 on diesel mode. On an average, there is an increase of ~3.4dB of noise levels when the engine is operated on the dual fuel mode in both the cases. It is observed that greater noise levels are produced in case of dual fuel mode operation using S1.

4. Conclusion

From the physical observations, it is concluded that the engine shows a smooth and sustained working with a slight increase in the noise. From the analysed results, the following conclusions are drawn:

- The producer gas is able to replace the diesel by 54% with 6% loss in the brake thermal efficiency.
- The dual fuel mode operation leads to increase in the HC emission by ~30 ppm.
- The engine shows reduced NOx emission on dual fuel mode.
- The noise levels of the engine are observed to increase by 3.4 dB on dual fuel mode.
- The cotton stalks are observed to be a slightly better fuel as compared to the sugarcane bagasse.

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