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Performance and Emission Characteristics of the Genset Fuelled with Dual Producer Gas–Diesel

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Abstract: A biomass downdraft gasifier coupled to a diesel electric generator can increase capacity of biomass utilization for electric power production with the biomass partially replacing diesel fuel. In the present paper, three biomass types were chosen as the feedstock for the gasifier–genset system to run in producer gas-diesel dual fuel mode: Jatropha seeds, Jatropha press cake, and 1:1 ratio of the seeds and the press cake (volumetric basis). Mass flow rate of the gas was maintained constant at 10kg/h. The engine rotational speed was kept constant at 3,000rpm, while the load was varied from 0.5 to 2 kWe. The press cake–derived gaseous fuel replaced diesel up to 52.7%. However, the poorer performances and emission characteristics were observed for dual fuel mode as compared with diesel only mode. This is related with fuel displacement of air, and the combustion characteristics of producer gas. Biomass type did not influence the engine performance, other than diesel consumption rate. For flue gas emissions, it was found that biomass fuel significantly increased CO emissions, but did not affect CO_2 significantly. A mixture of the Jatropha seed with the Jatropha press cake is not recommended as the feedstock for the gasifier system on account of different size of biomass particles which degrade the gasifier's operation. Also, it is suggested that a producer gas–fueled engine will be designed in the near future in order to improve efficiency and effectiveness of the engine performances.

Key Words: Producer gas, Diesel Dual fuel, Jatropha, Biomass

1. INTRODUCTION

The rapid growth of population recently has led to an increasing demand for energy and great amount of greenhouse gas emissions. Biomass gasification, a renewable technology, is a thermo–chemical process which is used to convert forestry, agricultural, and industrial wastes into gaseous fuel, namely producer gas, with neutral CO_2 emission. This technology, in addition, is more efficient than low temperature fermentation and digestion of lignocellulos feedstock (Janajreh and Shrah, 2013).

Biomass–derived producer gas with air as a gasifying agent is composed of H_2, CO, CO_2, CH_4, N_2, and small quantities of other hydrocarbons. The downdraft gasifier is a type of small scale gasification system. This gasifier is generally coupled to an electric generator for decentralized power generation, above all electricity generation in remote communities. The gas can be used to replace 100% gasoline and partial diesel fuel when used in internal combustion engines. Much research has focused on the performance and emissions characteristics of engines dual fuelled with producer gas–diesel using various biomass types. Uma et al. (2004) used wood; Ramdah et al. (2006) chose wood chips and coir-pitch as the biomass fuels; Sombatwong et al. (2013) used charcoal, Shrivastava et al. (2013) utilized a mixture of wood chips and mustard oil cakes; Hondoung et al. (2015) used longan tree-derived charcoal as the feedstock. Wood chips and charcoals are the most widely used as feedstocks. Jatropha seed and Jatropha press cake have yet to be used as the feedstock for downdraft gasifier-genset systems. The thrust of this present paper is to study the technical viability of Jatropha seed and Jatropha press cake as the feedstock for the gasifier-engine system.

2. METHODOLOGY

2.1 Biomass feedstock and producer gas

Three different types of biomass were utilized as feedstock of gasifier: Jatropha seed (PG1), Jatropha press cake (PG2) and a mixture of them (PG3) in a volumetric ratio of 1:1. The quality of producer gas is mainly influenced by specific design of gasifier, biomass properties, and operating parameters of gasification. Accordingly, the energy density of producer gas is 4–6MJ/m3 for Jatropha fired down draft gasifiers using air as the gasifying agent. The typical composition of producer gas is 20% H_2, 20% CO, 1% CH_4, the rest composed of inert gases–CO_2 and N_2 (Martinez et al., 2012). Diesel was used as the ignition source for all operating conditions as it is a compression ignition engine. The properties of producer gas and diesel are listed in Table 1.

Table 1. Properties of producer gas and diesel fuel (Shrivastava et al., 2013)

Properties	Producer gas	Diesel
Formula	–	$C_{12}H_{26}$
Density (kg/m^3) at 1atm and 20 °C	1.287	840
Auto ignition temperature (K)	–	527
Air fuel ratio at stoichiometric	1.12	14.5
Flammability limits (volume %)	–	0.6–5.5
Lower calorific value (MJ/kg)	5	42.5

2.2 Experimental setup

The experimental apparatus is illustrated in Fig. 1. The system is comprised of a closed top stratified downdraft gasifier, a cooling/cleaning unit, and a diesel genset. The gasifier is used to convert the biomasses into fuel gas using a thermo–chemical process. Air as a gasifying medium was introduced into the gasifier by a blower. Producer gas emerging from the gasifier was hot and laden with fly ash, solid particles, tar compound, and water vapor. The cooling and cleaning system was used to cool down, dehumidify and clean the gas. This system is composed of a cyclone filter, a shell-tube heat exchanger, and a dried-bed filter. The cyclone filter removes large-sized particles from the gas stream based on the concept of centripetal acceleration. The heat exchanger was designed to cool the gas to

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ambient temperature level in order to condense tar and water vapor into liquid drops. The dried–bed filter was made of charcoal layered under the fabric material. This filter absorbed the remaining light tar element and captured the small-sized solid particles. The gas was relatively clean prior to admission to the engine. Five 0.5 kWe heaters were connected in parallel to load the electric generator.

2.3 Experimental Procedure

The biomasses were dried under sunlight for six hours before being gasified to insure that moisture content in biomasses was low. Small amount of burning charcoal was placed at the bottom of the gasifier to initiate combustion. After 10 minutes producer gas began to flow, but only became stable enough for generator operation after about

Fig. 1. Experimental apparatus of the gasifier–genset system

30min. The gas flow rate was kept constant at 10kg/h using an orifice and U–tube manometer to measure, while the diesel consumption rate was determined using a glass burette and a stop watch. The rotational speed was maintained constant at 3,000rpm. The electric load was varied between 0.5kWe and 2kWe. A Delta L–1600 exhaust gas analyzer was used to measure flue gases CO and CO_2. The experiment was repeated three times for each setting, and the experimental data were consequently the average values.

2.4 Performance characteristics

In the present study, diesel consumption rate, producer gas flow rate and specific energy consumption, and electricity–thermal efficiency were the measured performance parameters. The specific fuel consumption (SFC) is defined as the ratio of total fuel (diesel plus producer gas) consumption rate divided by the genset load (see Eq. 1). The calculation of specific energy consumption (SEC) is shown in Eq. 2. It is equal to total thermal energy of fuel divided by electric power output. The electricity thermal efficiency, as demonstrated in Eq. 3, is inversely proportional to the specific thermal efficiency.

$$SFC = \frac{\dot{m}_{diesel} + \dot{m}_{PG}}{\text{Electric Power}} \quad \text{(Eq.1)}$$

$$SEC = \frac{(\dot{m} \times LHV)_{diesel} + (\dot{m} \times LHV)_{PG}}{\text{Electric Power}} \quad \text{(Eq.2)}$$

$$\text{Efficiency} = \frac{1}{SEC} \quad \text{(Eq.3)}$$

Where:

- SFC : Specific fuel consumption (kg/kWeh)
- SEC : Specific energy consumption (MJ/KWeh)
- $\dot{m}_{diesel}$: Mass flow rate of diesel (kg/h)
- $\dot{m}_{PG}$: Mass flow rate of producer gas (kg/h)
- LHV : Lower heating value (MJ/kg)

3. RESULTS AND DISCUSSION

3.1 Engine performance

3.1.1 Diesel consumption rate (kg/h)

Diesel flow rate of various fuel modes over the entire load range is shown in Fig. 2. The diesel consumption rate increases with increasing electric power output, regardless of fuel mode. A decreased diesel consumption rate is observed for dual fuel mode as compared with the diesel only mode. The type of biomass was not significant when the genset was operated at part load regime; however the biomass type had a considerable effect of on the diesel consumption rate at high load operation. For all engine loads, the lowest diesel consumption rate was achieved with Jatropha press cake as the feedstock. The highest diesel flow rate for the dual fuel mode occurred with the mixture of Jatropha seed and Jatropha press cake as the feedstock. This is likely related to great disparity in size of biomass particles which affects the producer gas quality. At 1.5kWe load, producer gas converted from the Jatropha press cake could replace diesel up to 52.7%, the maximum value recorded.

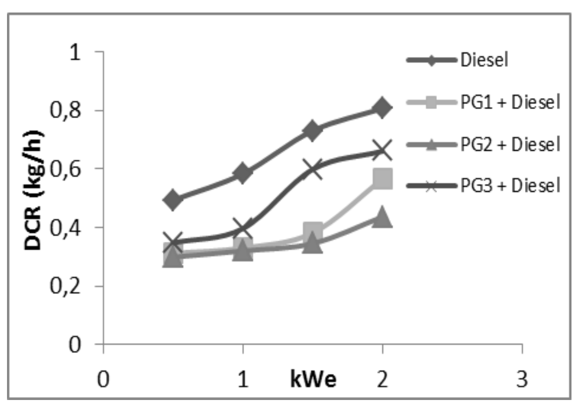

Fig. 2. Diesel consumption rate (kg/h)

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3.1.2 Fuel and specific energy consumption

Specific fuel consumption (SFC) is presented in Fig. 3. The SFC sharply increases for all producer gas–diesel dual fuel mode operations as compared with the diesel only mode, especially at part load. This is due too high mass flow rate of the low energy content producer gas. The SFC for dual fuel mode, however, fell considerably with increasing load owing to better combustion of fuel–air mixture at high load, and thus high temperatures.

The trend of specific energy consumption (SEC) follows that of the SFC, as seen in Fig. 4. The thermal energy used was extremely high for all dual fuel modes at low load. At high load, the specific thermal energy consumption of dual fuel modes was greater than that of diesel only mode by a factor of approximately two. For all fuel modes the SEC decreases with increasing engine load. The SEC was found to be higher for all dual fuel modes than for the diesel only mode. This is consistent with the results reported by Ramadhas et al. (2006) and Shrivastava et al. (2013). For dual fuel modes, the magnitude of the SEC for this study is much higher than that of the results published by Shrivastava et al. (2013) was due to higher amount of gas flow rates was used in the present study.

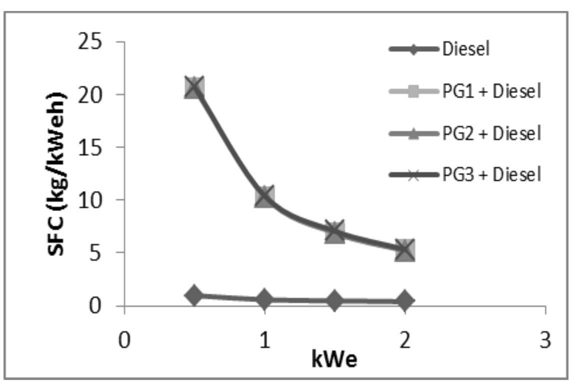

Fig. 3. Specific fuel consumption (kg/kWeh)

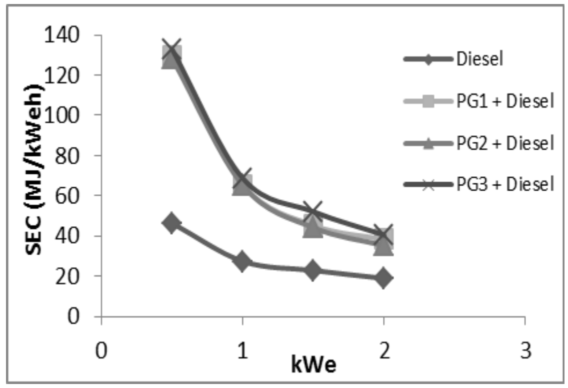

Fig. 4. Specific energy consumption (MJ/kWeh)

3.1.3 Electric –thermal efficiency (ETE)

Electric-thermal efficiency (ETE) was calculated using Eq.3. As seen in Fig. 5, the efficiency improves with increased load. However, the ETE for dual fuel modes was lower than that of diesel only by a factor of about 2 for all loads. The effect of biomass type on the ETE for dual fuel mode was not significant. At 2kWe load, the ETE decreased from 19% for straight diesel to roughly 9.5% for dual fuel modes. It is due to low flame speed of producer gas, decreasing their engine's thermal efficiency, as well as less complete combustion caused by the reduction of oxygen with producer gas flow.

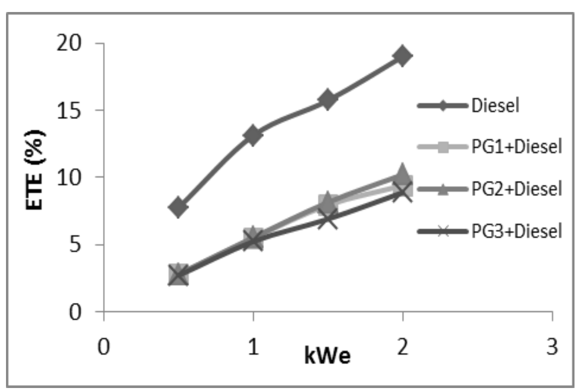

Fig. 5. Electric–thermal efficiency (%)

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3.2 Exhaust gas emission

3.2.1 CO emissions (%)

CO emissions are an indication of efficiency of fuel–air mixture combustion. The CO emissions of the various modes and loads are shown in Fig. 6. Dual fuel mode operation led to higher amounts of CO emissions gas owing to less complete combustion and presence of CO in producer gas. The increase in CO emission for dual fuel mode relative to diesel only mode have also been measured by Banapurmath et al. (2008); Shrivastava et al. (2013); and Sombatwong et al. (2013). With increasing engine load, CO emissions decreases slightly for all fuel modes, except press cake derived producer gas–diesel mode. The decrease in CO emissions indicates improved combustion with increasing load. The unusually high amounts of CO for Jatropha press cake (PG2) mode at low load was likely due to unstable gasifier operation on this fuel. It was speculated that the gas was poor, which led to less complete combustion. The CO content for all dual fuel modes at high load was fairly close: 0.7% for PG1+Diesel, 0.6% for PG2+Diesel, 0.45% for PG3+Diesel.

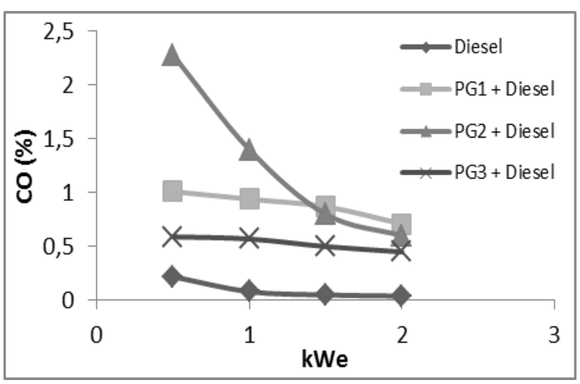

Fig. 6. CO emission (%)

3.2.2 CO_2 emission (%)

As shown in Fig. 7, CO_2 emission increased with increasing load and CO_2 emissions were higher for the dual-fuel modes. The high amount of CO_2 in the producer gas accounts for the presence of elevated levels of CO_2 in the exhaust gas. The typical volumetric percentage of CO_2 in the fuel gas is about 20%. The difference of CO_2 emission from the three dual fuel modes was marginal.

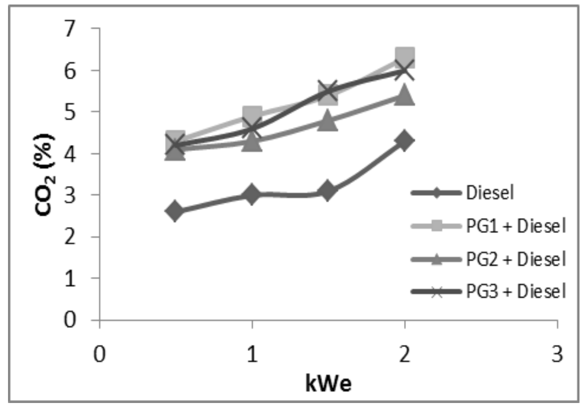

Fig. 7. CO_2 emission (%)

4. CONCLUSIONS

Biomass downdraft gasification technology can convert the Jatropha seeds, the press cake, and the seed–mixed press cake into gaseous fuel which can be used to drive a diesel electric generator successfully. The following conclusions are based on the study above:

- The producer gas derived from the press cake replaced up to 52.7% of the diesel.
- The effect of biomass type on specific fuel and energy consumption and electric-thermal efficiency was not significant.
- The electric–thermal efficiency was reduced by a factor of 2 in dual fuel modes, as the efficiency at 2kWeh decreased from 19% for straight diesel to roughly 9.5% for dual fuel mode.

- The influence of biomass feedstock on CO emission was very slight when the engine was operated at high load.
- CO and CO_2 emissions were always higher for dual fuel modes compared with diesel only, due to presence of these gases in producer gas.

Even though these three biomass types are viable feedstock for gasifier–genset system, the effect of varied gas flow rate on performance and emission characteristics of producer gas–dual fuel is left for further study. It is not recommended to use a mixture of the Jatropha seed with the Jatropha press cake as the feedstock for the gasifier system on account of the different size of biomass particle which negatively affects gasifier's operation.

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