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Performance and Emission Characteristics of Producer Gas Operated Dual Fuel Diesel Engine with Cooling Cleaning System

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Abstract

The performance and emission characteristics of liquid fuel-producer gas operated dual-fuel engine depend on the quality of producer gas (PG) as tar content and temperature. In the present work cooling cleaning system has been adopted for the gasifier-engine system to reduce the tar content and cool the PG before inducting into the combustion chamber of the diesel engine. The experiments were conducted on 5.2 kW, DI, 4 stroke, diesel engine operated at 1500 rpm. It has been observed, improved performance and reduced emission levels for the dual-fuel operation of engine with the use of cooling cleaning system. Experimental results showed that the brake thermal efficiency increased by 2-12% for the diesel/HOME-PG dual-fuel engine operation and tar content of PG was reduced from 320mg/Nm^3 to about 55mg/Nm^3 entering to the engine. Also, the emission levels were reduced, such as hydrocarbon 11.1%-19% and carbon monoxide 10.5%-20% compared to the wet filter provided with the gasifier-engine system. However, NOx emission levels were increased by 8% because of higher temperature due to combustion of improved quality of PG. The temperature of the PG after the cooling cleaning system was reduced to 31^{0}C-34^{0}C which is requirement for the diesel engine operation.

Keywords: Cooling cleaning system; downdraft gasifier; redgram stalk; producer gas

1. Introduction

The rural lives of Indians are depending on the agriculture for food and energy. India has about 6 lakh villages and 3rd largest energy consuming country in the world. To supply the needed energy to rural areas is becoming very difficult because of increasing consumption and transmission, maintenance related problems. This can be addressed suitably to some extent by producing energy from renewable energy sources like solar, wind, biodiesels and

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biomass-derived fuels [1-3]. The biofuels are available in sufficient quantity in the rural area for agricultural and domestic applications, in the form of biomass and agricultural residues. Also, biomass may be generated in the form of forest residues, agro-industrial wastes and energy plantation in the available wasteland.

As conventional processes of biomass utilization for energy are primeval and inefficient. The some developed energy conversion techniques have the capability of substituting conventional energy sources with the renewable energy sources used in the hybrid mode of energy generation for future requirements. The biomass is available abundantly about 500-540 million tonnes per year in India in the form of agricultural residues for energy according to Government of India estimation [4].

Biomass can be used for energy applications by direct combustion or converting biomass into solid, liquid and gaseous fuels which are convenient to use. There are various different technologies has been developed and used for biomass energy conversions such as combustion, pyrolysis, gasification and fermentation, some are commercialized and some are developing for commercialization. Biomass gasification one of the convenient and flexible technologies for heat or electricity application and for choosing biomass feedstocks from different origin such as forest wastes, agricultural residues, municipal solid wastes, agro-industrial wastes and energy plants [5, 6]. The biomass gasification is the most promising energy conversion technology [7]. Biomass gasification is the process in which solid biomass is converted to combustible gaseous fuel through the series of thermochemical reactions, in the reactor called gasifier. The product gas is the producer gas (syngas) comprises of hydrogen (H_2), carbon monoxide (CO), and methane (CH_4) with traces of other gases [7, 8]. The applications of PG include electricity generation using IC engines and gas turbines, and heating applications [9]. Biomass gasification has higher energy conversion efficiency (about 60% higher) and applications next to electricity [10-11]. Although biomass has higher attention as a renewable energy source, one of the major problems still not addressed is the reducing the tar present in the producer gas [9]. Tar consists of a wide range of low weight hydrocarbons that can cause blockage in the gasifier, turbine and engine [12-14]. Particularly the downdraft gasifier which is suitable for the engine application has the higher tar content in the producer gas. The tar content of PG depends on the operating parameters of the gasifier, feedstock type, gasifying agent and gasifier type [5]. Gas cleaning and waste handling in a gasifier-engine system is one of the challenges for the adoption of this technology for small-scale power generation. It has been reported that the design and volume content of the cooling cleaning system is an important aspect of the gasifier-engine system design [15]. The acceptable limit of the tar content in the PG for IC engine application is ranging from $10mg/Nm^3$ to $100mg/Nm^3$ [12-16]. The tar present in the producer gas can be removed by chemical methods, such as catalytic and thermal cracking [10, 17-18] which have higher operating expenses [13, 21] or by physical methods, such as wet scrubbers and water spray, which have issue with the disposing of tar solvents [21-22]. Besides disposal of tar solvent, disadvantages of using a wet cleaning system include a decrease in heating value of the PG and the energy conversion efficiency. Therefore, development of tar removal technology with low cost, least disposal issues, and high efficiency are requirements for future of energy conversion through gasification [10, 20]. Biomass-based dry filters may be an economical and environmentally friendly option and using corn cobs, wood shavings, and dry coconut coir, charcoal and sawdust has been explored [21-23]. To further improve the tar removal process, studies have used the direct cooling system, including wet scrubbers and water spray towers, before use of a dry biomass filter [19-21]. A cleaning system equipped with an indirect cooling system that eliminates waste effluent treatment process and filter mediums which can be reused as gasifier feedstock is a promising alternative to conventional cleaning technologies [24]. The literature review, presented the problems associated with the presence of tar in the producer gas and the different tar removal processes, but the combined wet and dry cooling cleaning systems were not used effectively. The present work is concerned with the reducing of the tar content in the producer gas from downdraft gasifier and improving the quality of the product gas by adopting wet and dry filters.

Nomenclature

BTE	Brake Thermal Efficiency
bTDC	before Top Dead Centre

CV	Calorific Value
CO	Carbon Monoxide
DI	Direct Injection
EGT	Exhaust Gas Temperature
HC	Hydro Carbon
HSU	Hartridge Smoke Unit
HOME	Honge Oil Methyl Ester
NOx	Oxides of Nitrogen
PG	Producer Gas
RGS	Redgram Stalk

2. Cooling cleaning system used

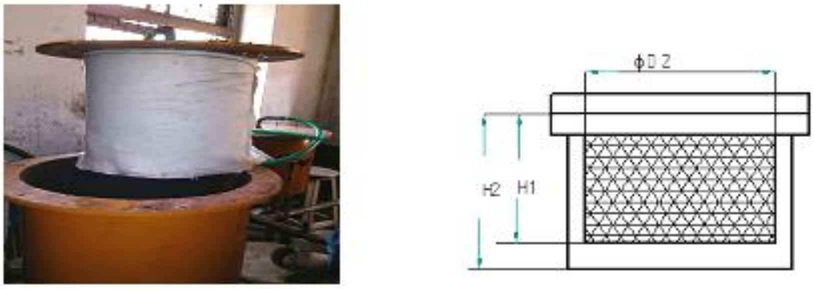
In the present work, one wet filter and two dry filters combinations were used which filters the impurities and lowers the temperature of PG substantially. The wet filter is made up of mild steel and has internal metallic mesh wrap around by non-woven textile fabric filter for removal of tar and other particles along with water supply during operation. Dry filters have the 10 mm thick stainless steel and wrapped with non-woven textile fabric filter mounted inside the filter to prevent high tar and dust. First cooling and cleaning of PG coming out of the gasifier was carried out by wet filter only and later combinations of the wet filter and two dry filters were used as shown in Figure 1. The cooled PG is then passed through a silica chamber to remove the moisture content of the gas. The use of two-stage filtering ensures the cleaned gas to the extent to use in the IC engines. In the dry filter, water vapour or tar condenses from the gas stream. The dry filter 1 was designed with a volume of 60% and dry filter 2 of 100% compared to IC engine swept volume which provides a more contact area for the gas.

Wet filter and dry filters of cooling cleaning system are shown in Fig. 1 (a), (b) and (c), their dimensions are given in the Table1. The outlet from the wet filter is connected to the bottom of the 1st dry filter and from the top of 1st dry filter gas outlet is connected to the bottom of the 2nd dry filter. The outlet gas from the top of the 2nd dry filter is connected to the engine through venturimeter to measure the quantity of gas supply during operation.

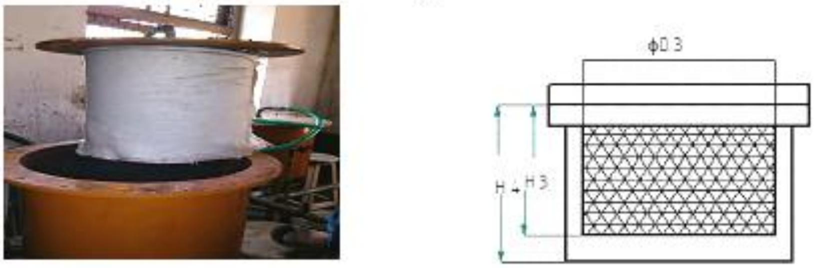
Table1. Dimensions of dry filters

Type	Dimensions
Dry filter-1	ΦD2=1250mm,H1=470mm, H2=490mm
Dry filter-2	ΦD3=1500mm, H3=470mm, H2=490mm

(a)



(b)



(c)

Fig. 1. (a) Wet filter; b) Dry filter 1; (c) Dry filter 2.

3. Characteristics of fuels used

In the present study selected biomass, agricultural residue, redgram stalk was dried and briquetted to use in the gasifier. The redgram stalk is available abundantly in the region and has suitable properties for gasification. The redgram stalk for downdraft gasifier and biodiesel derived from Honge oil (HOME) were used for the engine applications and their properties are given in Table 2.

Table 2. Properties of diesel, HOME and redgram stalk [25, 26]

Sl No.	Properties	Diesel	HOME	Biomass composition	Redgram stalk (biomass)
1	Viscosity @ 40^0C(cst)	4.59 (Low)	5.6	Moisture content % w/w	4.20
2	Flash point ^{0} C	56	163	Volatile matter % w/w	82.84
3	CV MJ/ kg	45	36	Fixed carbon % w/w	8.94
4	Specific gravity	0.830	0.870	Ash content % w/w	4.02
5	Density kg/m^3	830	890	Nitrogen % w/w	3.79
6	Type of oil	Diesel	Non-edible	Calorific value MJ/kg	16.8
7	--------	--------	------	Bulk density kg/m^3	501.5

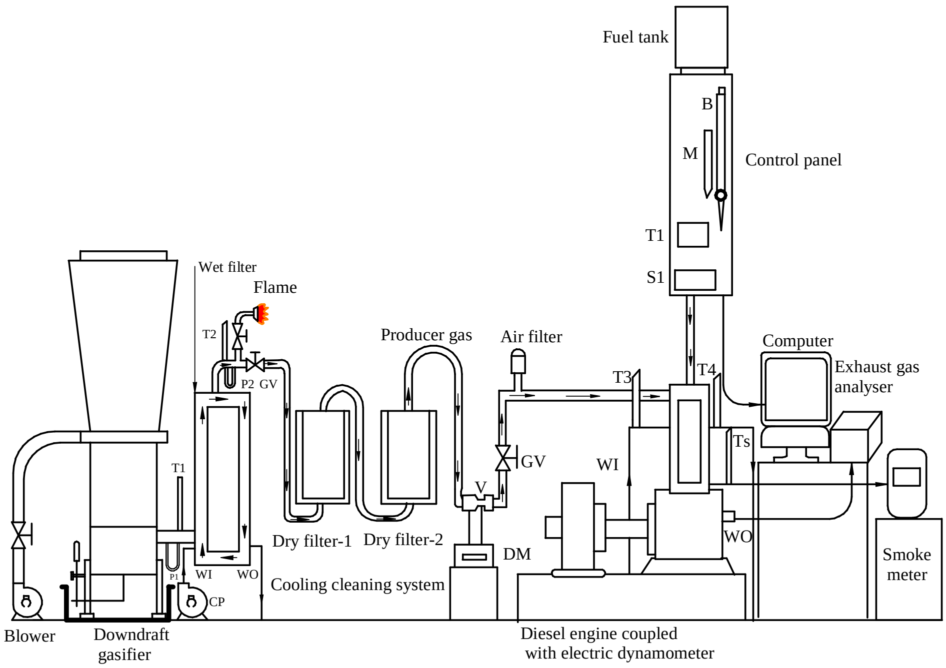
4. Experimental setup

Experiments were conducted on 4 stroke, single cylinder and VCR diesel engine test rig Fig. 2 (a) and (b) shows the schematic experimental setup. Eddy current dynamometer was used for loading the engine. The downdraft gasifier was suitably connected to the engine through with the cooling cleaning system. The PG was generated in the downdraft gasifier and is supplied to the engine after cooling and cleaning.

The flow rate of producer gas was measured using a calibrated venturimeter provided with the digital manometer. The cylinder pressure was measured using the piezoelectric transducer. The quantities of both injected fuels diesel and HOME have been measured on the volumetric basis. For the fixed brake power, more amount of HOME is injected compared to diesel as its calorific value is lower and also it has higher viscosity. The specifications of the engine and downdraft gasifier are given in Table 3.

Hartridge smoke meter and five-gas analyzer were used to measure exhaust gas emissions during the operation. Throughout the experiments, the gas flow rate and the engine speed were kept constant. In the present experimental work for dual-fuel engine operation, an injection timing of 27^0bTDC and injection pressures of 205 and 240 bar for diesel and HOME were maintained respectively.

(a)



(b)

Fig. 2. (a) Photographic view; (b) Experimental setup.

Table 3. Specifications of the engine and downdraft gasifier

Sl. No.	Diesel engine		Downdraft gasifier	
	Parameters	Specifications	Parameters	Specifications
1	Type of engine	Single cylinder 4 stroke DI diesel engine	Supplier	Harith Avani Technologies Pvt Ltd. Bangalore
2	IOP	205 to 240 bar	Rated capacity and gas flow	62735 kJ/h and 15 Nm^3/h
3	Rated power	5.2 kW @1500 RPM	Average gas CV	19MJ/kg
4	Cylinder Diameter	87.5 mm	Rated biomass consumption	10 kg/hr
5	Stroke length	110 mm	Hopper storage Capacity	40 kg
6	Compression Ratio	17.5: 1	Conversion efficiency	70-80%

5. Results and discussion

This section presents the results of the investigation of diesel/HOME-PG dual-fuel engine operation with cooling and cleaning system was carried out for successful removal of tar in two phases. In the first phase, performance and emission characteristics are obtained on diesel-PG dual-fuel operation with wet filter only. Further, in the second phase, effects of the wet filter and dry filters combination on the performance and emission characteristics are obtained on the diesel/HOME-PG dual-fuel operation.

5.1. Operating parameters

5.1.1. The temperature of the gas with wet filter and dry filter combinations

Variation of gas temperature with respect to time for wet filter and dry filter combinations is shown in Fig. 4. It was observed that larger temperature drop takes place across the wet filter and temperature change remains almost constant over the entire period operation. The temperature of the PG increases little while passing through dry filters. This is because increased air-fuel ratio increases the amount of oxygen input and thus there is an increase in the degree of oxidation of volatiles. This volatiles in return convert more chemical energy into sensible heat energy and results in higher temperature. For the dry filters combination, the temperature drop is less compared to wet filter only operation. The temperature of the PG increases for a longer period of operation because of the tar particles trapped in the filtering element and filtering element get heated and transfers the part of the heat to PG. Thereby decreasing the temperature drop across the filter combinations.

On an average, the temperature of the gas leaving the gasifier was found to be 140^0C to 150^0C and if the temperature is more than 150^0C, is an indication of partial combustion of gas. This generally happens when the air flow rate through the gasifier higher than the required value. The redgram stalk has an acceptable temperature range due to acceptable volatile matter in it. However, ash presence in the redgram stalk leads to some operational problems. Results showed that use of dry filters lowers the gas temperature to 31^0C to 34^0C due more residence time in the dry filter. This trend is facilitated use gas directly into the engine which is 30^0C to 40^0C

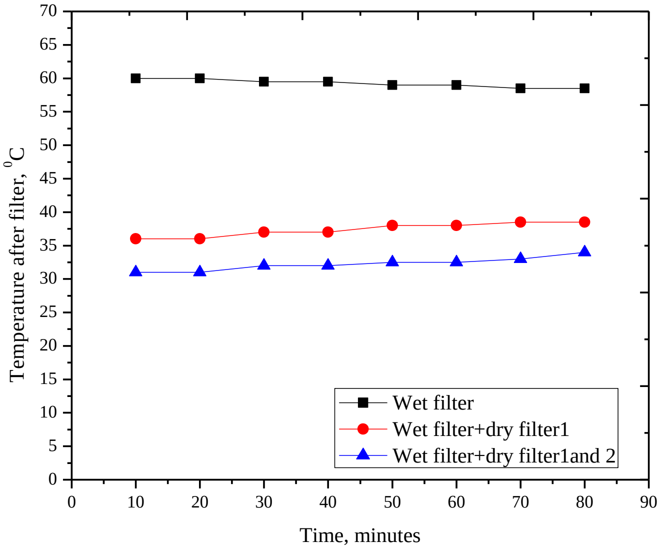


Fig. 3. Variation of the temperature with time.

5.2. Performance parameters

In this section, the effect of cooling cleaning system on the performance of CI engine operating on diesel/HOME-PG dual-fuel has been presented. During the experimental investigation, the engine was operated on dual-fuel mode with manufacturer setting (injection timing 23^{0}bTDC, injection pressure 205 bar, compression ratio 17.5) for diesel-PG operation and optimized engine setting (injection timing: 27^{0}bTDC, injection pressure 240 bar, compression ratio 17.5) for HOME-PG operation with wet filter and dry filter 1. Further, the effect of the use of dry filter 2 along with the wet filter and dry filter 1 was also investigated. The engine was operated with 6 hole nozzle each having 0.25 mm diameter at a constant speed of 1500rpm. Finally, the effect of cooling cleaning system on the performance of the dual-fuel engine was investigated and analyzed.

The variation of the brake thermal efficiency with brake power for different filter combinations is presented in Fig. 4. The BTE of the dual-fuel engine operated using HOME–PG with wet filter, wet filter with dry filter 1, and wet filter with dry filter 1 and 2 at 80% load were found to be 16%, 16.5% and 18% compared to 18.4% for diesel-PG operation using wet filter with dry filter 1 and 2 respectively. From the results, it has been observed that higher BTE for diesel-PG operation compared to HOME-PG operation for all filter combinations used. For HOME-PG dual-fuel operation the incomplete combustion due to the higher tar content, a lower air-fuel ratio with use of wet filter lowers the performance when compared to wet filter with dry filter 1 and 2 combinations.

Further increased ignition delay of HOME, the lower flame temperature and flame velocity of PG are also responsible for the trends. In addition, for the same fuel combination, dual-fuel operation with wet filter, and dry filter 1 and 2 resulted in improved BTE compared to wet filter only. This could be due to improved quality of PG, volumetric efficiency, and better mixing air-PG. It is clear that insufficient air for the combustion of the HOME-PG combination when wet filter alone used.

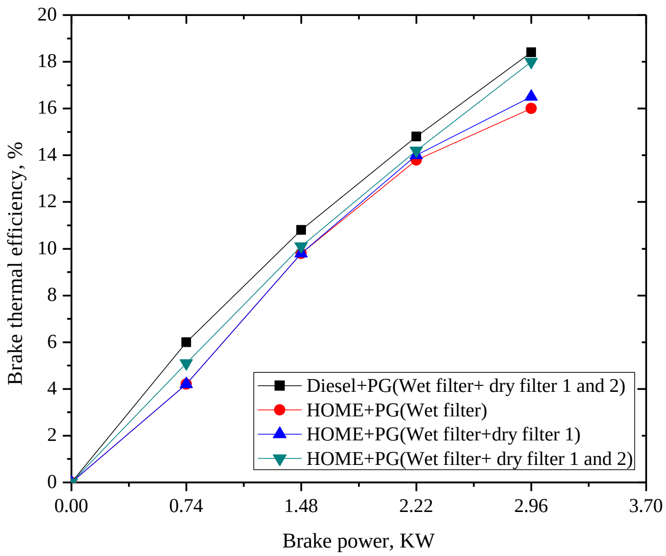


Fig. 4. Variation of the BTE with brake power.

5.3. Emission characteristics

The environmental pollution concern, have the much importance to reduce the emission levels from IC engines and particularly diesel engines because emission levels are mainly due to the quality of the combustion that takes place inside the engine. The fuel composition of both injected and inducted fuel, and engine design and operating parameters are the main parameters affecting the combustion [2, 15]. The emissions were measured at a steady-state operation of the engine using calibrated instruments. The variations of exhaust emissions in the dual-fuel engine with wet filter and dry filters combinations presented in the following sections.

The variations of HC and CO emissions with brake power for different filters combinations are presented in Figures 5 and 6. The both HC and CO emission levels in the exhaust are an indication of incomplete combustion of the fuels used. For the same fuel combinations, dual-fuel operation with the wet filter alone resulted in higher HC and CO emission levels compared to other filters combinations. This is due to incomplete combustion attributable to improper cracking of tar. In addition, lower adiabatic flame temperature and lower CV of HOME along with slow-burning of PG are also reasons for the trends. Also, the availability of oxygen is insufficient for combustion due to replacement of air by PG and already the presence of CO in the PG leads to incomplete combustion of diesel-PG and HOME-PG combination.

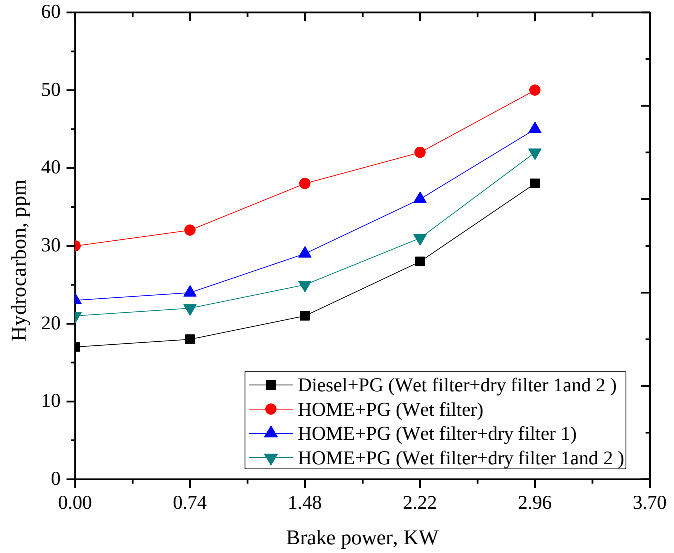


Fig. 5. Variation of the HC emissions with brake power.

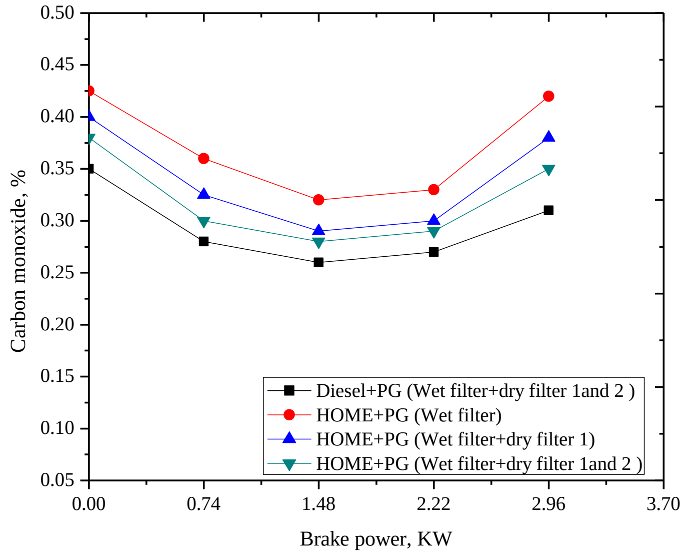


Fig. 6. Variation of CO emissions with brake power.

The HC emission levels of the dual-fuel engine HOME–PG operation with wet filter, and wet filter and dry filter 1, and wet filter with dry filter 1 and 2 were found to be 50ppm, 45ppm and 42ppm compared to 38ppm for diesel-PG operation with wet filter, and dry filter 1 and 2 at 80% load respectively. Similarly, CO emission levels of the dual-fuel engine HOME–PG operation with wet filter, and wet filter and dry filter 1, and wet filter with dry filter 1 and 2 were found to be 0.42%, 0.38% and 0.35% compared to 0.36% for diesel-PG operation with wet filter, and dry filter 1 and 2 at 80% load respectively.

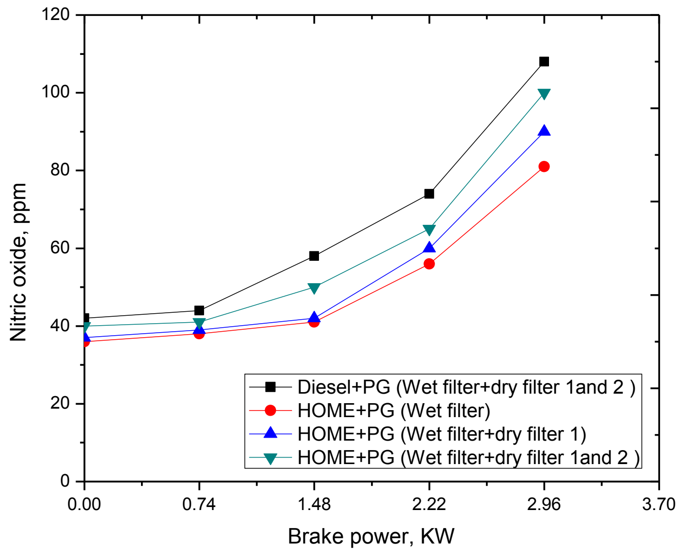


Fig. 7. Variation of the NOx emission level with brake power.

The variation of NOx emission levels with brake power for different filters combinations is presented in Fig. 7. It was observed that the HOME–PG dual-fuel operation with wet filter and dry filters combination resulted in higher NOx levels compared to dual-fuel operation with the other filters combinations over the entire load range. It might be ascribed to higher heat release during the premixed combustion phase because of better quality PG with lower tar content resulted in improved combustion. Because of this reason BTE also higher for diesel-PG and HOME-PG operation with both wet filter and dry filters combination used. However, for same fuel combination, the lower air-fuel ratio at entire load range and unavailability of oxygen for combustion lowers the NOx levels with dual-fuel operation with the wet filter alone. The NOx emission levels of the dual-fuel engine HOME-PG operation with wet filter, wet filter and dry filter 1, and wet filter with dry filter 1 and 2 were found to be 81ppm, 90ppm and 100ppm compared to 108ppm for diesel-PG operation with wet filter, and dry filter 1 and 2 at 80% load respectively.

Conclusions

- The cooling cleaning system used was resulted in better quality PG with lower temperature and low tar content for all fuel combinations and engine parameters selected.
- On an average, at optimum operating conditions and at the 80% load, the HOME-PG derived from redgram stalk biomass operation with wet filter, and dry filter 1 and 2 resulted in 12% increased BTE compared to the operation of HOME-PG operation with wet filter only. Further diesel-PG operation with wet filter, and dry filter 1 and 2 resulted in 2% higher BTE than the HOME-PG operation for same filters combination.
- Similarly, for the HOME-PG operation with wet filter, and dry filters 1 and 2 combinations have the 11.1% and 19 % lower HC emission levels and the 10.5% and 20 % lower CO emission levels compared to wet filter only operation at 80% load.
- For HOME-PG operation with wet filter and dry filters 1 and 2 has the 8% lower NOx emission levels than the diesel-PG operation for the same filter combination.
- The diesel and HOME can be used as an injected fuel in dual-fuel mode engine operation with PG as an

inducted fuel and this does not require any major engine modifications.

On the whole, it can be observed that the dual-fuel diesel/HOME-PG operation with the combined filters arrangement resulted in better performance and smooth engine operation with lower emissions.

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