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Effect of Cooling Cleaning System on the Performance and Emission Characteristics of Producer Gas Operated Dual-Fuel CI Engine

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Abstract

The performance and emission characteristics of liquid fuel-producer gas operated dual fuel engine depend on the quality of PG as tar content and temperature. In the present work cooling cleaning system has been used with the gasifier-engine system to reduce the tar content and cool the producer gas before inducting into the combustion chamber of the CI engine. The experiments were conducted on 5.2 kW, DI, 4 stroke, CI engine operated at 1500 rpm. It has been observed, improved performance and reduced emission levels for the CI engine dual-fuel operation with the use of cooling cleaning system. Experimental results showed that the temperature of the PG after the cooling cleaning system was reduced to 31^0C-34^0C which is a requirement for the CI engine operation 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 smoke 7%-8.5% compared to the wet filter provided with the gasifier-engine system.

Keywords: Cooling cleaning; downdraft gasifier; agricultural residues; producer gas.

NOMENCLATURE

CI	Compression Ignition
HOME	Honge Oil Methyl Ester
PG	Producer Gas
RGS	Redgram Stalk
DI	Direct Injection
CR	Compression Ratio
BTE	Brake Thermal Efficiency
EGT	Exhaust Gas Temperature
NOx	Oxides of Nitrogen
HC	Hydro Carbon
CO	Carbon Monoxide
bTDC	before Top Dead Centre
HSU	Hartridge Smoke Unit
CV	Calorific value

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 for 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 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. Some energy conversion techniques developed have the capacity to replace conventional energy sources with renewable energy sources used in the hybrid power generation mode for future needs. The biomass is available abundantly in India in the form of agricultural residues for energy, about 500-540 million tonnes per year 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 by which solid biomass is converted into combustible gaseous fuel through a series of thermochemical reactions in the so-called gasifier reactor. 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 is attracting more attention as a source of renewable energy, one of the major problems that have not yet been addressed is the reduction of tar in the gas of biomass gasification [9]. Tar consists of a wide range of light-weight hydrocarbons that can block the gas generator, turbine and engine [12-14]. In particular, the downdraft gasifier adapted to the application of the engine has the highest tar content in the producing gas. The PG tar content depends on the operating parameters of the gasifier, the type of raw material, gasifying agent and the type of gasifier [5]. Gas cleaning and waste management in a gas engine system is one of the challenges in adopting this technology for small-scale power generation. It has been reported that the design and volume of the cooling cleaning system is an important aspect of the design of the gasification-engine system [15]. The acceptable limit of tar content in the PG for IC applications ranges from 10 mg / Nm^3 to 100 mg / Nm^3 [12-16]. Tar produced in the producer gas can be removed by chemical means, such as catalytic and thermal cracking [10, 17, 18], with higher operating costs [13, 21], or by physical methods, such as wet scrubbers and water sprays these have problems with the removal of tar solvents [21-22]. In addition to the removal of the tar-based solvent, the use of a wet cleaning system has among the disadvantages a decrease in the heating value of the PG and the energy conversion efficiency. Therefore, the development of low-cost tar removal technology, the least disposal problems and high efficiency are essential conditions for the future conversion of energy by gasification [10, 20]. Biomass-based dry filters can be an economical and environmentally friendly option, and the use of corn cobs, wood chips 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 using a dry biomass filter [19-21]. A cleaning system with an indirect cooling system that eliminates wastewater treatment processes and filters that can be reused as a raw material for gasifier is a promising alternative to conventional cleaning technologies [24].The literature reviewed, 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 reduction of the tar content in the PG from downdraft gasifier and improving the quality of the product gas by adopting wet and dry filters.

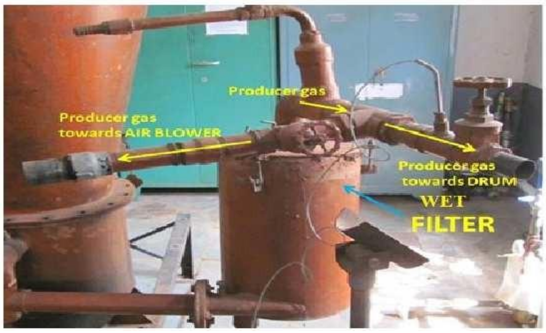
2. COOLING AND CLEANING SYSTEM USED

In the present work, a wet filter and two dry filter combinations were used to filter impurities and substantially lower the temperature of the PG. The wet filter is made of mild steel and has an internal wire mesh wrapped with a nonwoven fabric filter to remove tar and other particles as well as water supply during operation. The dry filters are made of 10 mm thick stainless steel and wrapped with a nonwoven fabric filter mounted inside the filter to prevent high deposits of tar and dust. The cooling cleaning of the PG discharged from the gasifier was carried out only by means of a wet filter, and then combinations of the wet filter and the dry filters were used, as shown in Fig. 1. The PG was then passed into a silica chamber to remove the moisture content of the gas. The two-stage filtration ensures that the purified gas is used in internal combustion engines. When passing through the dry filter condenses water vapor and removes tar from the gas stream. The dry filter 1 was designed with a volume of 60% and the dry filter 2 at 100% compared to the stroke volume of the internal combustion engine, which provides a larger contact surface for the gas.

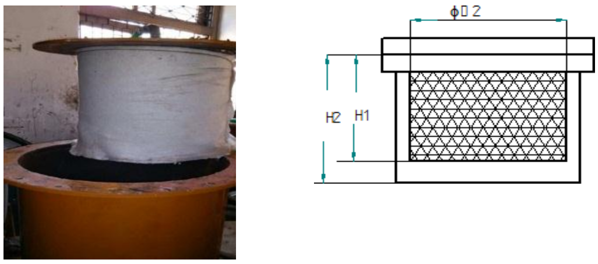
The wet and dry filters of the cooling cleaning system are shown in Figures 1 (a), (b) and (c), their dimensions shown in Table 1. The output of the wet filter is connected to the bottom of the first dry filter and the top of the first dry filter gas outlet is connected to the bottom of the second dry filter. The gas leaving the top of the second dry filter is connected to the engine by a venturi-meter to measure the amount of gas supplied during operation.

Table.1 Dimensions of dry filters

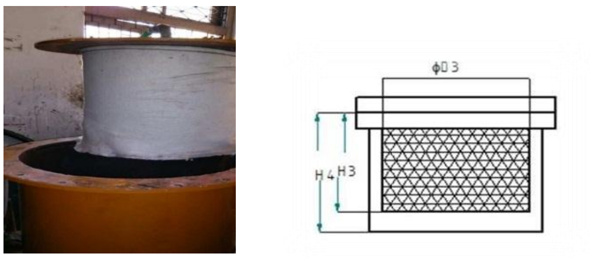
Type	Dimensions
Dry filter-1	D_2=1250mm,H_1=470mm, H_2=490 mm
Dry filter-2	D_3=1500mm,H_3=470mm, H_2=490mm



(a)



(b)



(c)

Figure 1. (a)Wet filter b) Dry filter 1(c) Dry filter 2

3. CHARACTERISTICS OF THE 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 diesel, biodiesel derived from Honge oil (HOME) were used as fuels for the dual-fuel engine operation and their properties are given in Table 2.

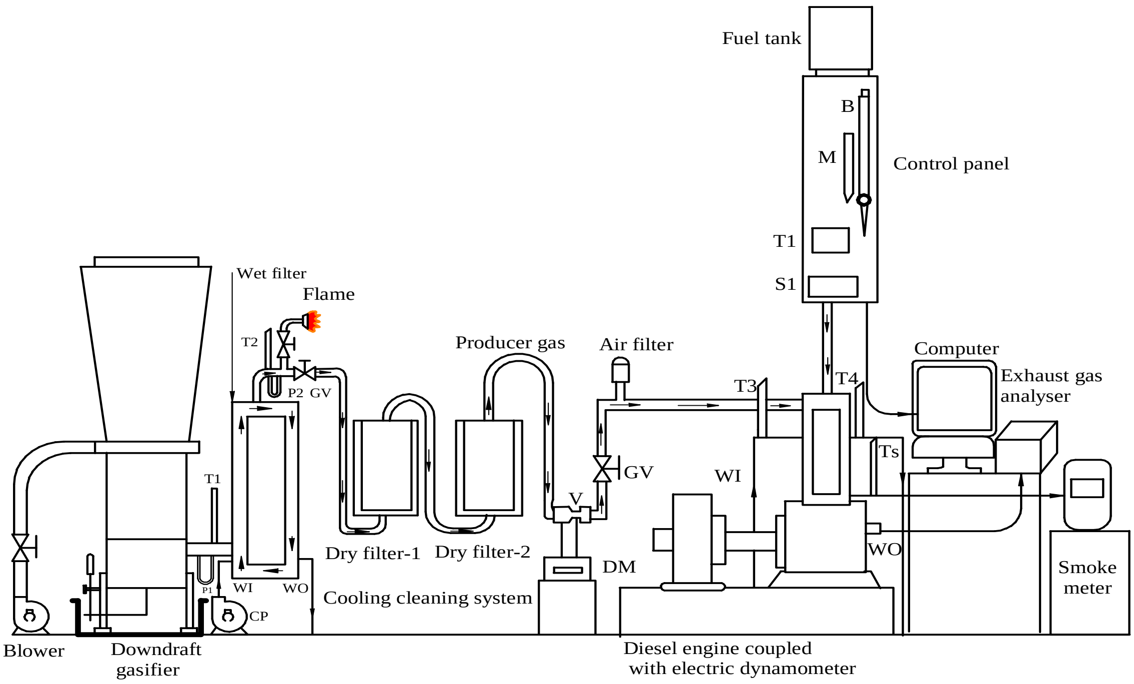
Table 2. Properties of diesel, HOME and redgram stalk [25, 26]

Sl No.	Properties	Diesel	HOME	Biomass composition	Redgram stalk (biomass)
1	Viscosity @ 40 ^{0}C(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

The experiments were conducted on a four-stroke diesel engine, single cylinder and VCR test bed. Figures 2 (a) and (b) illustrate the schematic experimental setup. An eddy current dynamometer was used to load the engine. The downdraft gasifier was properly connected to the engine via the cooling cleaning system. The PG was generated in the downdraft gasifier and is supplied to the engine after cooling and cleaning.

(a)



(b)

Figure 2. (a) Photographic view (b) Experimental setup

The flow rate of producer gas was measured using a calibrated venturi-meter provided with the digital manometer. The cylinder pressure was measured using the piezoelectric transducer. The quantities of injected fuels diesel and HOME were measured on a volumetric basis. For fixed brake power, more quantity of HOME is injected compared to diesel because of lower CV and viscosity higher.

A Hartridge smoke meter and 5-gas analyzer were used to measure exhaust emissions during operation. The flow rate of gas and speed of engine were kept constant during the experiments. Current experimental work on the operation of dual-fuel engine complied with injection times of 27^0bTDC and injection pressures of 240 for HOME and 205 bar for diesel.

4.1 Measurement of pressure

The pressure drop is measured regularly through the gasifier, the gas cooling cleaning system and the airflow through the orifice. The pressure in the gasifier is closer to atmospheric pressure and will be usually measured per water column. The pressure drop and the differential pressure can be measured using a U-tube manometer (range 0-100 mm) filled with colored liquid. To be practical and portable, they are made from a transparent glass tube and connected by flexible hoses.

4.2 Measurement of gas flow

The producer gas leaving the cooling cleaning system was measured using a venturi-meter with a digital manometer. The supplied venturi-meter provides the pressure signals with the least pressure drop due to downstream of the diverging section of the venturi-meter, it retains the amount of gas by converting the speed into pressure. The venturi-meter has been designed to minimize the impact of tar and other particles.

4.3 Measurement of temperature

Thermocouples (such as the Chromel-Alumel K type) were used to measure temperatures at different points. Low temperatures are conveniently measured with ordinary thermometers and high temperatures by thermocouples. Thermocouples are also used with automatic measurement recording. The Chromel-Alumel thermocouple can be used to record continuous high temperature and provide an almost linear electrical signal. Sheathed thermocouples are used in current experimental work with PG applications since thermocouple alloys will react with various gaseous compositions.

5. RESULTS AND DISCUSSION

This section presents the results of the investigation of the operation of the diesel/HOME-PG dual-fuel engine with the cooling cleaning system for effective two-phase tar removal. During the first phase, the performance and emission characteristics are obtained in the HOME/diesel-PG dual-fuel mode with a wet filter. In addition, in the second phase, the effects of the combination of wet filter and dry filters on the performance and emission characteristics are obtained on the dual-fuel diesel/HOME-PG operation.

5.1 Operating parameters

5.1.1 Pressure drop in gasifier, wet filter and dry filters

The pressure inside the gasifier is closer to atmospheric pressure (with the exception of high-pressure gasifiers) and will usually be measured in mm of the column of water. Figure 3 presents the evolution of the gas pressure at the outlet of the gasifier and in the course of the filters over time. The small deviation in the recorded gas pressure corresponds to the gasifier output due to the change in gas composition over time. Fig. 3 shows that the dry filter does not affect much for the pressure at the outlet of the gasifier since it only acts after cooling cleaning system. The pressure drop at the exit of the gasifier with cooling cleaning system ranged from 13 to 18 mm of water column for a load range of 0 to 80%. These values are small and it can thus be observed that the PG derived from the raw material of the biomass of redgram stalk do not pose a lot of pressure drop problems to the dry filters. The particles stick together during the collision, this which facilitates agglomeration for highest contact between the gas to be cleaned and the wash water. The wet filter condenses the tar particles from the PG while eliminating them.

The results show that the tar concentrations of less than 50-60 mg/Nm^3 can be achieved by using dry filters with a wet filter. It also resulted that the use of dry filters with a wet filter resulted in a lesser pressure drop. As a result, the use of a dry filter did not initially influence the pressure drop and then indicated that water losses of 13 to 18 mm were satisfactory, regardless of the load. This is low, so it may be revealed that the operation of the suction gasifier on PG derived from the redgram stalk does not pose such pressure drop problems. The nonwoven textile fabric in the dry filters allows the gas to pass through different porous media collecting particles ranging in size from 0.5 to 100 µm. Due to the small size of the opening, the pressure difference across the filter increases slightly. However, after 20 minutes of operation, the pressure drop slightly tends to increase because of clogging of the filter pores. During experimentation, the deposition on the fabric material of the filter gradually increases in thickness, resulting in an increase in pressure. The cooling cleaning system affected the gathering of captured materials, thus requiring automatic or routine cleaning or replacement.

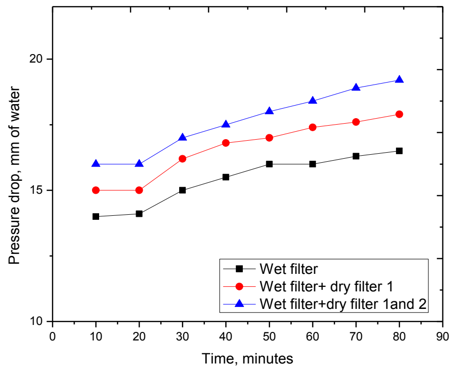


Figure 3. Variation of pressure drop with time

5.1.2 The temperature of the gas with wet filter and dry filter combinations

Figure 4 shows the change in gas temperature as a function of time for wet filter and dry filters. It was observed that a larger temperature drop occurred through the wet filter and that the change in temperature remained almost constant throughout the operating period. The temperature of the PG increases little by crossing dry filters. This is due to the fact that the amount of oxygen supply increases with an increase in the air/fuel ratio and thus causes an increase in the level of oxidation of the volatile substances. In turn, these volatile substances convert more chemical energy into sensible heat, which results in a higher temperature. For the combination of dry filters, the temperature drop is lower than the operation with a wet filter only. The temperature of the PG increases during a longer operating period because the tar particles trapped in the filter element and the filter element are heated and transfer the part of the heat to PG as a result, decreasing the temperature drop across the filter combinations.

On average, it was found that the temperature of the gas exiting the gasifier was 140°C to 150°C and that, if the temperature was above 150°C, it indicated partial combustion of the gas. This usually happens when the airflow in the gasifier is greater than the required value. The redgram stalk biomass has an acceptable temperature range due to the presence of acceptable volatiles. However, the presence of ash in the redgram stalk creates some operational problems. The results showed that the use of dry filters lowered the gas temperature from 31°C to 34°C due to longer residence time in the dry filter. This trend is facilitated by the use of gas directly in the engine, which is between 30^{0}C and 40^{0}C.

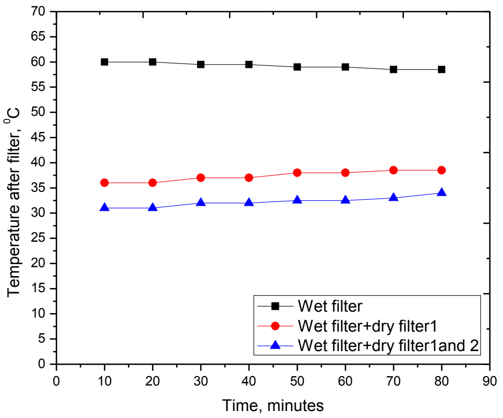


Figure 4. Variation of the temperature with time

5.1.3 Gas flow rate with filter combinations

Figure 5 shows the flow of PG through the combination of wet filter and dry filters and it is noted that the use of dry filters reduces the gas flow than the wet filter alone and thus guarantees acceptable standards. The flow rate of the PG is not greatly affected by the wet filter, but dry filter combinations with wet filter reduce flow over time as the tar and dust particles trapped in the filter element block the flow. Some gas requires periodic cleaning and replacement of the filter elements.

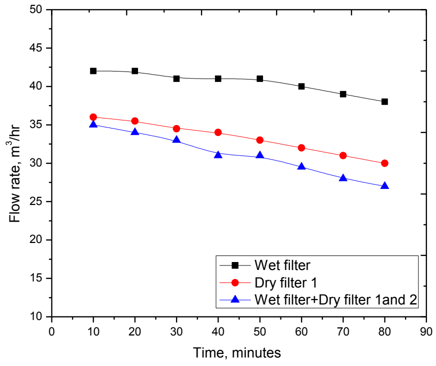


Figure 5. Variation of the gas flow rate with time

5.2 Performance parameters

Variations in exhaust gas temperature (EGT) with brake power for different filter combinations are shown in Fig. 6. The HOME-PG dual-fuel operation with wet filter results in an increase in EGT than the wet filter with both dry filters. The EGT depends on the superiority of the PG, the quantity of PG introduced to the combustion chamber and the combustion of the PG in the engine. The higher EGT was resulted with a wet filter due to partial burning of high viscosity HOME and slow-burning PG. This might be attributed to the combustion of combined fuels in the diffusion combustion phase rather than the premixed combustion phase [1]. For the same fuel mixture of the HOME-PG operation, the use of the wet filter with both dry filters showed the reduction in an EGT compared to the operation with a wet filter only and might be attributed to that less thermal energy was used the higher combustion due to the tar present. Further, the decrease in flame speed during the rapid combustion phase results in slow combustion of fuels, which also explains the trends. The EGT value of the HOME-PG operation with wet filter, wet filter and dry filter 1, and wet filter with both dry filters was 460^{0}C, 450^{0}C and 412^{0}C compared to 402^{0}C for diesel-PG operation with wet filter and both dry filters for 80% load.

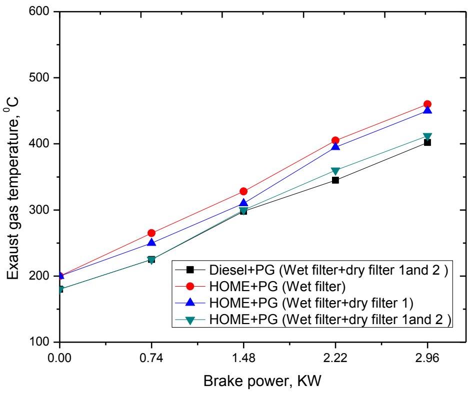


Figure 6. Variation of the EGT with brake power

5.3 Emission characteristics

Figure 7 shows the variation of opacity of smoke with brake power for different filter combinations. The lower smoke levels resulted from the dual-fuel diesel-PG operation compared to the HOME-PG operation for all other filter combinations used. For the same fuel combinations, lower smoke levels were found with wet filter and both dry filters compared to dual-fuel operation with other filter combinations. The smoke opacity of the HOME-PG operation with wet filter, wet filter with dry filter 1 and wet filter with both dry filters was 38HSU, 35HSU and 35.5HSU, compared to 32HSU for diesel-PG operation with a wet filter and both dry filters at 80% load. This might be attributed to the heavier molecular weight of the tar in the PG, resulting in incomplete fuel combustion and soot oxidation. The lower air-fuel ratio for the HOME-PG combination and the higher viscosity of HOME are also reasons for the trends.

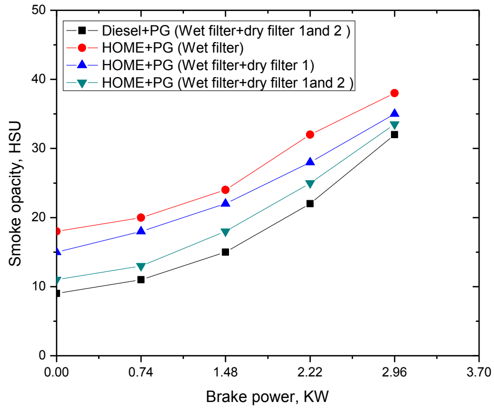


Figure7. Variation of the smoke opacity with brake power

Figure 8 shows the variation of fuel substitution for bi-fuel operation with brake power for different combinations of filters used. Maximum fuel substitution is of paramount importance for the operation of the engine in dual fuel mode. It depends on the properties of the injected fuel, such as the cetane number, the viscosity, the CV and the basic design of the engine. The fuel substitution values were higher for dual-fuel operation with a combination of wet filter and both dry filters, compared to single wet filter operation, because the combination filters arrangement improves both quality and quantity of the PG. In addition, dual-fuel operation with filter combinations improves the ear loop and reduces fuel consumption. This means that less liquid fuel is consumed, allowing more PG induction for the same power production.

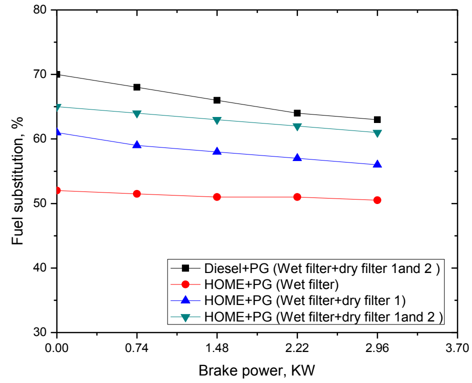


Figure 8. Variation of the fuel substitution with brake power

The percentage of fuel substitution in the operation of the HOME-PG dual-fuel engine with wet filter, wet filter and dry filter 1, and wet filter with both dry filters was 51%, 56% and 61% compared to 63% for diesel-PG operation with wet filter and both dry filters at 80% load.

6. CONCLUSION

The important results of the effect of cooling cleaning system on engine performance and the emission characteristics of the dual-fuel engine with diesel/HOME producer gas derived from redgram stalk as an inducted fuel are highlighted and the following conclusions were drawn from the study.

- ➢ The cooling cleaning system used resulted in a better quality PG with lower temperature and lower tar for all fuel combinations and engine parameters selected.
- ➢ Smoke opacity was reduced by 8.5% and 7% for HOME-PG operation with wet filter and dry filter 1, and wet filter with both dry filters compared to operation with wet filter only.
- ➢ The fuel substitution of approximately 63% for diesel-PG operation with wet filter and both dry filters, compared to 61% for HOME-PG operation for the same filter combinations.
- ➢ The diesel and the HOME can be used as a fuel injected into an engine operating in dual fuel mode with PG as an induced fuel, also not requires any major modification of the engine.

Overall, it can be seen that dual fuel diesel/HOME-PG operation with the arrangement of the combined filters has resulted in improved performance and smooth engine operation with reduced emissions.

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