2011 2nd International Conference on Environmental Science and Technology
IPCBEE vol.6 (2011) © (2011) IACSIT Press, Singapore

Performance and Emission Studies in a Diesel Engine Using Bio Oil-Diesel Blends

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***Abstract*-Bio oil from pyrolysis is considered as an alternate fuel for diesel engine. In recent years some pilot plants of pyrolysis process for the production of bio oil from biomass have been established in many countries. The main problems associated with the use of pyrolysis oil in diesel engines have to be removed in order to use the bio oil in a wide range of commercial applications. An attempt was made to use modified bio oil blended with diesel fuel in a single cylinder, four stroke, air cooled, DI diesel engine. The performance and exhaust emissions such as unburned hydrocarbons [UBHC], carbon monoxide [CO], carbon-di-oxide [CO_2] and nitric oxide [NO] were measured from the diesel engine at different power outputs. The performance and exhaust emissions were studied from the engine with three different WPO based fuels such as WPO diesel emulsion, and two WPO diesel emulsions with addition of 2% and 4% Diethylether. The results were compared with the diesel fuel data, analysed and it is presented in this paper.It is observed from the results that 1.94%, 3.02% and 2.94% increase in the brake thermal efficiency was achieved with WPO10, WPO10 with 2%DEE and WPO10 with 4%DEE. The NO and HC emissions were lower with only WPO diesel emulsion.For the other emulsions the HC and NO emissions were higher than diesel fuel operation.**

Keywords- Wood pyrolysis oil, diesel engine, performance, emission, emulsification, surfactant, Diethyl ether

I. INTRODUCTION

Diesel engine power plants are preferred where power has to be generated in small quantity or used as standby sets which are required for commercial use. In many countries the demand of fuel for diesel engines increases owing to much usage in agriculture, transportation and power generation. But, on account of high fuel consumption of diesel fuel the need for replacement of diesel fuel has become essential. Many alternative fuels for diesel engines such as vegetable oil esters, tyre pyrolysis oil, orange oil etc were introduced in the last two decades. Utilization of biomass as alternative fuel for compression ignition engine has a great scope especially in developing and undeveloped countries. The bio mass can be converted into useful energy by adopting different techniques such as dry combustion, anaerobic digestion, bio photolysis, pyrolysis, liquefaction, gasification, hydrolysis and solvent extraction[1].Out of these techniques, pyrolysis has advantages like simple method, low pressure operation, negligible waste product and high conversion efficiency in the order of 83%. It is the thermal decomposition process of waste substances in the absence of oxygen or little presence of oxygen. Pyrolysis of biomass yields solid, liquid and gaseous products like char, pyrolytic oil and pyrogas [2].

Pyrolysis oil derived from biomass has become attractive but it is still under development. Flash pyrolysis oil was used as fuel in a small diesel power plant [3]. The pyrolysis oil obtained from hard wood was tested for its physio-chemical properties. The pyrolysis oil was used in Petter AVB test engine that had a capacity of 4.8kW at 2000 rpm. Different

fuels such as diesel, ethanol and pyrolysis oil were used as fuel with certain proportion of ignition improver added by volume to pyrolysis oil and ethanol. For ethanol, 3% and 5%of ignition improver was added whereas for pyrolysis oil 3%, 5% and 9% of ignition improver was added. From the engine tests, it was observed that the injector nozzle coked very fast and the bore for the cylinder pressure transducer was clogged. By fueling ignition improved ethanol as an intermediate fuel, the problem of miscibility of pyrolysis oil with diesel fuel was rectified. The best emission results except for the smoke number were obtained with 5% ignition improver addition.

An experimental study was conducted to determine the feasibility of using flash pyrolysis oil of wood in diesel power plants [4]. The study includes the spray analysis, engine tests, thermogravimetric analysis (TGA), single-drop reactor tests and corrosion tests. It was reported that the flash pyrolysis oil needs to be modified or to be mixed with another substance to make the self ignition possible. The engine was found to have difficulties such as build up of carbonaceous injection system fault and engine seizing. Char generation was noticed in a TGA apparatus and in the single droplet atmospheric reactor. Fast erosion of steel components in the diesel engines was also noticed when it was fueled with wood pyrolysis oil. The high oxygen content of WPO reduces the heating value drastically and also the stoichiometric air/fuel ratio. This requires more fuel consumption than diesel fuel to obtain the same power.

Experiments were performed on a single cylinder engine with blends of wood pyrolysis oil with different percentages of oxygenated compounds and micro emulsions of WPO in diesel fuel [5]. Two different fuels like Diethylene glycol dimethyl ether (Diglyme) WPO blends at different percentages and two different emulsions with 30% of WPO in No.2 diesel fuel. Diglyme is added with the pyrolysis to improve the self ignition characteristics. Lower NO emissions were found with increasing the percentage of WPO. Hydro carbon emissions were also found to be lower than diesel upto 30% WPO and beyond that it increased. Carbon monoxide emissions were found to be more due to the poor self ignition characteristics of the WPO. It was noticed that residuals were occasionally found to stick on nozzle stem and sac volume with no trace of corrosion in the injection system. Pyrolysis oil contains many reactive components that can form higher molecular weight species. Also the higher viscosity and poor volatility of wood pyrolysis oil is unfavorable for fueling it in diesel engines. The hydroscopic nature of the pyrolysis oil also weakens the stability of pyrolysis oil when it is blended with diesel fuel[6]. Hence, it is necessary to modify the wood pyrolysis oil so that it can be used as an alternative fuel in diesel engines.

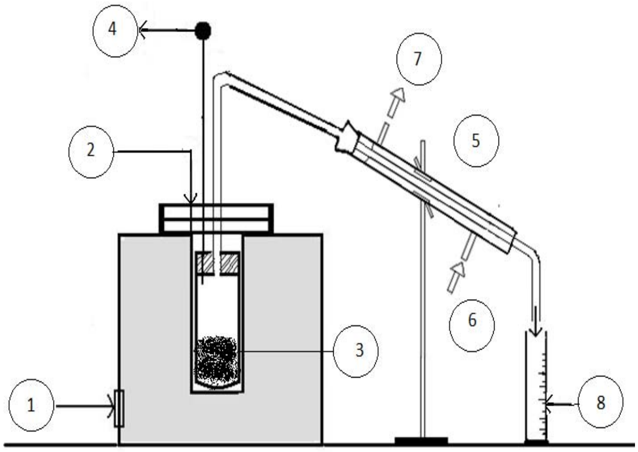
Emulsion is one of the techniques used while a fuel has to be mixed with another fuel of hydroscopic nature. An emulsifier is required to mix a certain proportion of alcohol with pyrolysis oil and a little ignition improver[7]. The emulsifier generally extends the water tolerance of alcohol/pyrolysis oil fuel blends. An emulsion was prepared for pyrolysis oil with diesel fuel using a surfactant ranging from 0.8 to 1.5% by volume. The stable emulsion was prepared using two surfactants namely hypermer and CANMET. The price of the earlier one was higher for 30% emulsion than the later one. Further, the fuel properties such as heating value cetane number, viscosity and corrosivity were determined. The heating value and cetane number of pyrolysis oil were too low compared to that of diesel fuel.It was observed that the viscosity was found to reduce when the emulsion was prepared with a maximum of 20% pyrolysis oil. Increasing the emulsifier content results in higher viscosity, but it offers stability to the emulsion. Emulsifier upto 4% by volume can be used with additives like n-octanol, to reduce the viscosity of the emulsion. It was also mentioned that the feed stock and pyrolysis process must be precisely defined in order to allow the exact identification of the most appropriate emulsification technique.

Alahmer et al [8] have studied the performance of a variable speed diesel engine operating with diesel water emulsion. It was observed that a surfactant can be used to stabilize water in diesel mixture which cannot be maintained by natural mixing of diesel with water because of their different densities and forces of surface tension. Surfactants reduce the surface tension forces so that they permit two different densities of liquid to form a stable emulsion. Polysorbate 20[$C_{58}H_{114}O_{26}$]commercially known as Tween-20 is used as a surfactant whose stability and non toxicity makes it preferable for use as detergent and emulsifier in a number of domestic, scientific and pharmalogical applications. It is a poly oxyethylene derivative of sorbitan monalurate, and is distinguished by the length of the poly oxythene from the other members of the tween range. Emulsion prepared with an addition of Tween 20 surfactant 2% by volume with six different percentages of water as fuels were tested in a diesel engine. It was observed from the results that the 5% by volume of water diesel emulsion gave an optimum brake power and brake thermal efficiency compared with the other water diesel emulsions.In the present study, the surfactant Tween 20 was used to prepare an emulsion of WPO and diesel. The emulsion of WPO and diesel was used as fuel in a single cylinder, air cooled, direct injection diesel engine with addition of different percentages of ignition improver. The performance and emission parameters of the engine was analysed, compared with diesel operation and presented in this paper.

II. MATERIALS AND EXPERIMENTAL METHOD

A. *Production of wood pyrolysis oil*

For the present investigation, pyrolysis oil from waste wood was obtained by vacuum pyrolysis process. The schematic diagram of the pyrolysis process for deriving wood pyrolysis oil is given in Fig. 1. Thick wood obtained from package boxes were taken as raw materials, cut into small chips, washed and dried. These chips were fed into an externally heated reactor unit. The feed material was heated up in the reactor in the absence of oxygen or little presence of oxygen. The reactor used in the pyrolysis process is cylindrical in shape with inner diameter 200mm and outer diameter 250mm and a height of 250mm. The reactor is fully insulated by glass wool with thickness 50mm and refractory lining. The heat input to the electrical heater was 3kW. The temperature of the reactor was measured with the help of a temperature indicator provided in a temperature controller unit. The pyrolysis process for deriving wood pyrolysis oil was carried out at 500^{0}C. The products of pyrolysis in the form of vapour were sent to a water cooled condenser and the condensed liquid was collected in a container. The properties of wood pyrolysis oil is compared with diesel fuel and given in Table 1.



1. Furnace 2. Reactor 3. Feed material
4. Temperature controller 5. Condenser 6. Water inlet
7. Water outlet 8. Pyrolysis oil collector

Figure 1 Schematic diagram of pyrolysis setup

TABLE 1 COMPARISON OF FUEL PROPERTIES [3,9]

Properties	ASTM Standard	Diesel Fuel	WPO
Specific gravity at 15 °C	D 4052	0.83	1.2
Net calorific value[MJ/kg]	D 4809	43.8	18
Flash point[°C]	D 93	50	66
Pour point[°C]	D 97	30	-27
Kinematic viscosity at 40 °C[cst]	D 445	2.58	13
pH value	-	-	2.4
Moisture content (wt %)	-	0.025	15-30
Ash (wt%)	-	0.13	0.01

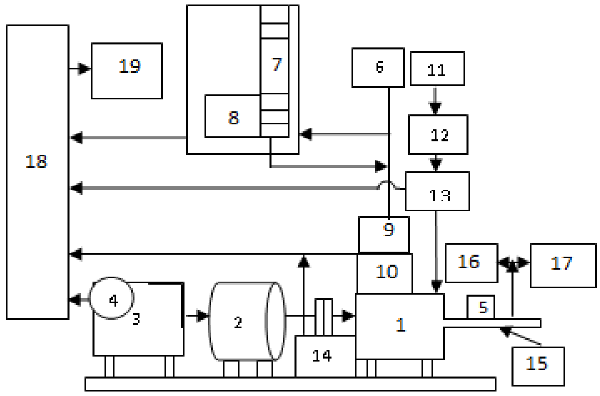
B. Emulsification of WPO

Generally pyrolysis oil can be used as an alternative fuel in compression ignition engines by adopting techniques such as blending, preheating, increasing injection pressure and improving ignition quality[7]. But, in case of wood pyrolysis oil, the pilot injection, addition of ignition improver and emulsification has been reported [3, 5, 7]. Blending of WPO with diesel fuel exhibited a draw back as wood pyrolysis oil is not miscible in diesel fuel and form stability. Therefore, different emulsions of wood pyrolysis oil with diesel using various surfactants have been carried out [10].Many surfactants such as Ampholak, Armotan, Carbopol, Hypermer, Tween 20, Span 20 have been reported to form stable emulsions [7,8,10]. In the present investigation Polysorbate 20 [Tween 20] having highest HLB number (16.7) was used to emulsify the wood pyrolysis oil with diesel fuel. Three percentages by volume of surfactant was used to emulsify 10% of WPO with 90% of diesel fuel.

Energy input for emulsifying two or more immiscible liquids can be given by shaking, stirring, homogenizing, or spray processes that are needed to initially form an emulsion [8, 10]. There are three different types of emulsions like water-in-oil emulsions, oil-in-water emulsions and bi-continuous emulsions.In this investigation, the water in oil emulsion was prepared by adding the surfactant to diesel and thereafter adding the bio-oil to the resulting mixture.

III. EXPERIMENTAL SETUP

Fig.2 shows the schematic diagram of the experimental setup. The engine [1] was coupled to an alternator [2] to provide the loading.



1. Engine	2. Alternator	3. Control panel
4. Load switch	5. Thermocouple	6. Fuel tank
7. Burette	8. Fuel sensor	9. Fuel filter
10. Fuel pump	11. Air filter	12. Air box
13.Air flow sensor	14. Speed sensor	15. Exhaust pipe
16. Gas analyser	17. Smokemeter	18. Computer withdata acquisition system

Figure 2 Schematic diagram of the experimental setup

The fuel consumption was measured with the help of a burette [7] and a fuel sensor [8]. Air enters to an air filter [11] and then to air box [12]. Air intake was measured by air flow sensor [13] that was fitted in the air box. A speed sensor [14] was connected near the flywheel of engine to measure the speed. The exhaust pipe [15] had a provision to access the probes of an AVL 444 exhaust gas analyser [16] that measured unburnt hydrocarbon [HC], carbon monoxide [CO] and nitric oxide [NO] emissions. HC and NO emissions were measured in ppm and CO and CO_2were measured in percentage vol. An AVL 437 C diesel smoke meter [17] was used to measure the smoke density of the engine exhaust. Data collected like fuel consumption, speed, air flow and exhaust gas temperature for the corresponding loads were fed to the data acquisition system [18] and displayed in the monitor of the computer [19]. The specifications of the engine used are given in Table 2.

TABLE 2 ENGINE SPECIFICATIONS

Make/Model	Kirloskar TAF 1
Brake power, kW	4.4
Rated speed, rpm	1500
Bore [mm]	80
Stroke [mm]	110
Compression Ratio	17.5:1
Nozzle Opening Pressure [bar]	200
Injection Timing [^{o}CA]	23

The performance and exhaust emissions were studied from the engine running with three different WPO based fuels which are WPO diesel emulsion, and two WPO based fuels which are WPO diesel emulsions addition of 2% and 4% DEE. Diethyl ether [DEE] an ignition improver having high cetane number (>125) was added at 2% and 4% by volume basis with the emulsion of WPO and diesel. All tests were carried out by starting the engine with diesel fuel only. After running the engine with different emulsions, the engine was run with diesel fuel to flush out the emulsion present in the fuel line.

IV. RESULTS AND DISCUSSION

A. *Performance Parameters*

Performance parameters of the diesel engine such as brake thermal efficiency, brake specific energy consumption and exhaust gas temperature were determined for the tested fuels, compared with diesel fuel operation, analysed and presented in this section.

1) Brake Thermal Efficiency

Fig. 3 shows the variation of the brake thermal efficiency with brake power for different WPO and diesel emulsions. It is observed from the figure that the brake thermal efficiency of diesel fueled operation at full load is 28.64%.

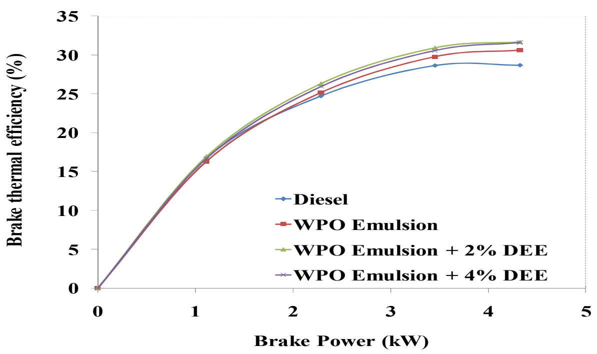


Figure 3Variation of brake thermal efficiency with brake power

In case of WPO-diesel emulsions the brake thermal efficiencies of three blends WPO10, WPO10 with 2% DEE and WPO10% with 4%DEE at full load are 30.58%, 31.66% and 31.58% respectively. The brake thermal efficiency is higher for the emulsions compared to that of diesel.The reason for higher thermal efficiency in case of WPO 10 may be due to lower viscosity of the WPO diesel emulsion that leads to better fuel atomization [12]. It is evident from the graph the increase in the addition of DEE increases the brake thermal efficiency of the remaining emulsions as it is an ignition improver.

2) Brake Specific Energy Consumption

When two different fuels are blended together the brake specific fuel consumption will not be more reliable because the calorific value and density of two fuels are different. In such a case brake specific energy consumption will be more appropriate. The variations of the brake specific energy consumption for the tested fuels are shown in Fig. 4.The BSEC of a blended fuel is the product of the BSFC and calorific value of the corresponding blend. The BSEC of diesel fuel varies from 21.61MJ/kWh at low load to 12.57 MJ/kWh at full load.It can also be observed from the figure that the BSEC values for WPO diesel emulsions are 11.72MJ/kWh, 11.36MJ/kWhand11.39MJ/kWh respectively. The energy consumption is higher in the case of emulsions because of this lower energy content.

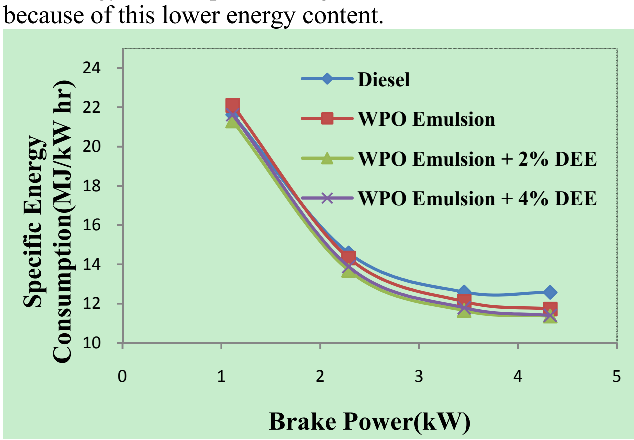


Figure 4Variation of basicspecific energy consumption with brake power

Therefore the energy required to produce the same power output at the corresponding load is more than that of diesel operation.

3) Effect on Exhaust Gas Temperature

Exhaust gas temperature measured from the engine is an indication for the conversion of heat into work. It is observed from the Fig. 5 that exhaust gas temperature varies from 118^{0}C to 269^{0}C at full load for diesel operation. It is evident from the figure that the exhaust gas temperatures of the different WPO diesel emulsions are higher than diesel fuel operation.

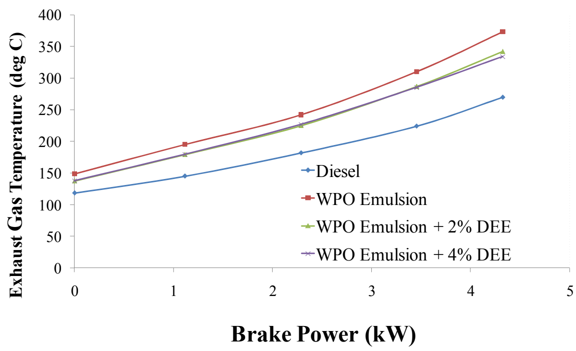


Figure 5Variation of exhaust gas temperature with brake power

This is due to heat release in the later part of the combustion process [13].

B. Exhaust emissions

1) NO emissions

Fig. 6 shows the formation of NO at various brake power for the different emulsions and diesel fuel. Nitric oxide constitutes more than 90% of the oxides of nitrogen in an engine exhaust[14].

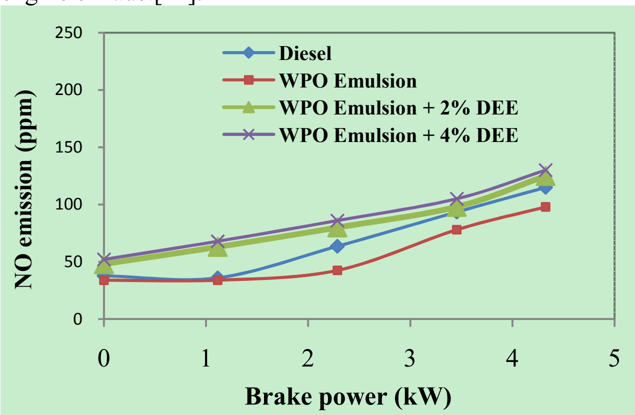


Figure 6Variation of NO emissions with brake power

Nitric oxide reacts with ozone in the atmosphere in the present of ultraviolet rays from sun and generates nitrogen-di-oxide. Further nitrogen tri-oxide is formed from nitrogen di-oxide. Among all these oxides, the principal pollutant is nitric oxide which is a necessary ingredient of our life cycle. The formation of oxides of nitrogen is due to thermal root leading to thermal NO, hydrocarbon fragment related root leading to prompt NO and fuel bound nitrogen that results fuel bound NO. The thermal root is the most important root since 90% of NO is formed due to that reason. Two principle factors that affect formation of NO are temperature and oxygen fraction [15]. It is observed that the NO emissions are lower for WPO diesel emulsion due to more water content in the wood pyrolysis oil which reduces the combustion temperature. Addition of DEE improved the combustion that results in higher NO emissions.

2) CO emissions

CO emissions from WPO-diesel emulsions are compared with diesel fuel and shown in the Figure 7.The CO emission is an indication for incomplete combustion of fuel-air mixture that takes part in the combustion.Carbon monoxide emission from engine exhaust is lower in the compression ignition engines compared to spark ignition engines since the compression ignition are always operated with lean mixture [16].

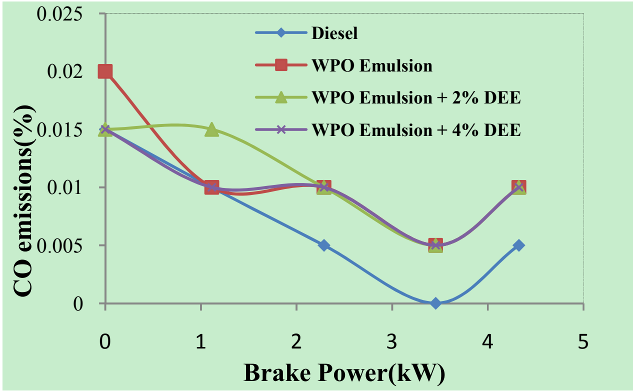


Figure 7 Variation of CO emissions with brake power

The CO emissions of WPO-diesel emulsions are slightly higher than diesel fuel due to poor atomization of the emulsion.

3) Unburned Hydrocarbon emissions

Diesel exhaust hydrocarbons are composed of fuel molecules, pyrolysis products of fuel compounds and partially oxidized hydrocarbons [17]. Unburnt hydrocarbon is the direct result of incomplete combustion of fuel in the combustion chamber [16]. It can be observed from the Figure 8 that unburnt hydrocarbon emissions are more in the case of WPO diesel emulsions due to more water content which leads to longer ignition delay and incomplete combustion.

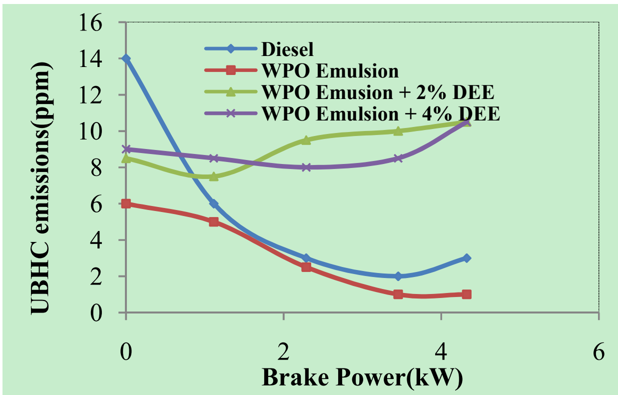


Figure 8 Variation of HC emissions with brake power

V. Conclusion

Pyrolysis process is a feasible method for bio-mass conversion into bio-oil. The bio-oil is a complex mixture of several organic compounds. Preliminary tests were conducted with an emulsion of WPO - diesel in a single cylinder diesel engine and the following results were obtained from the experimental study:

The brake thermal efficiency is higher for WPO-diesel emulsions compared to that of diesel oil due lower viscosity of the emulsion and addition of ignition improver.

The specific energy consumption is higher in the case emulsions; this is because of the lower energy content of emulsion. Availability of more oxygen content in the fuel reduces the heating value.

The exhaust gas temperatures of different WPO diesel emulsions are higher than diesel fuel operation. This is due to more oxygen availability in the pyrolysis oil and increased combustion duration.

The NO emissions are lower for WPO diesel blend due to more water content in the wood pyrolysis oil which reduces the combustion temperature and with DEE addition operation due to improved combustion rate the NO emissions are high.

The CO emissions of WPO-diesel emulsions are slightly higher than diesel fuel due to poor atomization of the emulsion.

The unburnt hydrocarbon emissions are more in the case of WPO diesel emulsions due to more water content and incomplete combustion.

ACKNOWLEDGEMENTS

The authors sincerely thank the Department of Science and Technology, Ministry of Science and Technology, New Delhi for their financial grant (No.SR/S3/MERC/061/2009, Dt.02.09.2009) to carryout this research work. The authors also thank the National Institute of Technology Rourkela for providing the necessary infrastructure to conduct the study.

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