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Performance and Emission Studies of a Diesel Engine Fueled with Wood Pyrolysis Oil-Biodiesel Emulsions

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ABSTRACT

Wood pyrolysis oil (WPO) is considered as an alternative fuel for compression ignition engines. But, due to its poor combustion characteristics, it requires significant modification in the fuel to solve problems like miscibility, presence of water content etc, when it is used as an alternative fuel in compression ignition engines. In this study, an attempt is made to use wood pyrolysis oil-bio diesel emulsions in a diesel engine. Three emulsions of WPO and Jatropha methyl ester (JME) were obtained with the help of a surfactant, and used as fuels in a single cylinder, four stroke, air cooled, direct injection diesel engine. The emulsions were designated as WPO5, WPO10 and WPO15 where the numeric value indicates the percentage of the WPO in the emulsion. The performance and emission characteristics of the engine were obtained, analysed, and compared with those of diesel fuel and presented in this paper. The emulsions made with WPO15 show an improved performance and lower emissions than WPO5 and WPO10. Compared to diesel at full load, 11.3% higher brake thermal efficiency was achieved with WPO15. HC emissions were found to be lower by about 50% for WPO15 than for diesel fuel at full load. It is observed that about 3% lower NO emissions were obtained with WPO15 at full load in comparison with diesel. The smoke opacity of WPO5 is lower by 22.7% at full load than that of diesel.

INTRODUCTION

The issues of energy availability and its security have caused serious concerns around the world, and prompted researchers to look for better alternatives to reduce the dependency on petroleum products. Bio fuels produced from lignocellulosic materials and vegetable oils are critical factors in reducing the dependency on fossil fuels. Biodiesel is considered as one of the best well-suited fuels for diesel engines. It is an oxygenated fuel made from vegetable oils and animal fats by the conversion of the triglycerides to esters (primarily methyl esters) via various esterification processes [1]. Bio-diesel is composed of alkyl esters of fatty acids. These esters have a relatively low flash point, a high heating value, as well as density and viscosity comparable to those of raw vegetable oils. Many studies show that unburned hydrocarbons (HC), carbon monoxide (CO) and sulfur levels are significantly less in the exhaust gas, while using biodiesel as fuel. However, a noticeable increase in the oxides of the nitrogen (NOx) levels is reported with biodiesel [2,3,4,5]. Biodiesel blends reduce the levels of global warming gases such as CO_2. Its additional advantages include outstanding lubricity, excellent biodegradability, superior combustion efficiency and low toxicity, among other fuels [6].

Although bio-diesel is considered as a potential alternative fuel, it has some demerits like poor cold flow properties and lower oxidation stability than petroleum fuels [7, 8]. Saturated compounds are responsible for the unfavorable cold flow properties observed in bio-diesel, and the unsaturated esters are mainly responsible for the reduced oxidation stability [8]. After long storage periods, gums and other oxidation products are likely to form more unsaturated compounds in bio-diesel. The oxidation rate of unsaturated fatty esters depends on the number and position of double bonds [8]. Treatment with oxidation inhibitors containing hindered phenols is the most common approach to increase the oxidative stability of bio-diesel. Bio-oil obtained from the pyrolysis of biomass sources contains many hindered phenols [9] known to be good anti-oxidants [10]. Bio-oil also contains nano-particles of oligomeric materials, which could serve as nucleation centers modifying the crystallization behavior of some bio-diesel fractions. It was reported that the pH value of the bio diesel is reduced when it is blended with pyrolysis oil [11].

Bio-oils produced from the pyrolysis of biomass sources are also considered to be alternative fuels for diesel engines. Bio-oil is obtained from the condensation of biomass derived pyrolytic vapors, which are produced from the thermal degradation of biomass substances (cellulose, hemicellulose, and lignin) [12]. Bio-oils can be used for power generation [13]; however their high acidity, low thermal stability, low calorific value, high viscosity, and poor lubrication characteristics limit their use as transportation fuel. Therefore, instead of using the bio-oils as transportation fuel, they can be used as additives or extenders for transportation fuels in diesel vehicles. Compression ignition engines fueled with diesel are mainly preferred in transportation. WPO cannot be blended with diesel fuel, because of its poor miscibility. It doesn't disperse in diesel fuel because of its different surface tension and hydroscopic nature [14]. Several methods of using WPO in diesel engines have been discussed by various researchers [15,16,17,18]. Out of these, the emulsification method described by Michio Ikura avoids the problem of the miscibility of WPO with diesel fuel. Surfactants can be used to make emulsions with two different density liquids by reducing their surface tension. It was reported that the biodiesel emulsions made with water reduces the NOx emissions considerably [19,20,21].

Nowadays, biodiesel can be used alone or mixed in any ratio with petroleum diesel fuel. The most common blend is a mix of 20% biodiesel with 80% petroleum diesel (B20) [22]. However, some biodiesels can be used as they are. In this case, WPO can be used to get an emulsion, so that it can improve the oxidation stability and also replace a certain percentage of biodiesel. In this present investigation, bio-oil obtained from the pyrolysis of woody biomass is used to make emulsion with jatropha methyl ester (biodiesel). Three different emulsions were made by taking WPO in 5%, 10% and 15% on a volume basis, with remaining percentages of JME. Surfactant Span-80 (sorbitane monooleate) is used to prepare the emulsions of WPO and JME. The performance and emission characteristics of the single cylinder, air cooled, DI diesel engine, developing a power output of 4.4kW at 1500rpm was studied with the WPO-JME emulsions, and compared with the results of diesel, JME, and presented in this paper.

EXPERIMENTAL ANALYSIS

PRODUCTION OF WOOD PYROLYSIS OIL

The Bio-oil used in this investigation was obtained from pine wood feed stock, available in the packing container boxes. The feed stock was cut into small pieces and fed in to the stainless steel pyrolysis reactor. It was a slow pyrolysis process with a heating rate of 10° per minute. The optimum yield of the pyrolysis oil was obtained at the temperature ranges between 450 °C and 500 °C. The optimum yield obtained was around 60%. The pyrolysis oil obtained was characterized to find the physical properties and elemental composition. The GC-MS chromatogram of the WPO is shown in Figure 1. The GC-MS analysis of pyrolysis oil shows that the pyrolysis oil contents like Oleic acid, 1, 3-Dimethoxy-2-hydroxybenzene, Methoxyphenol are large in proportion. Most of the components identified are the phenols with ketones and aldehydes groups attached, and nearly all the functional groups showed the extensive existence of the oxygen. On the other hand, the analysis proved that the abundant aldehydes and ketones make the pyrolysis oil hydrophilic and hydrated in nature, which makes the separation of water from pyrolysis oil difficult [14]. These phenols present in the WPO will improve the oxidation stability of the biodiesel fuels.

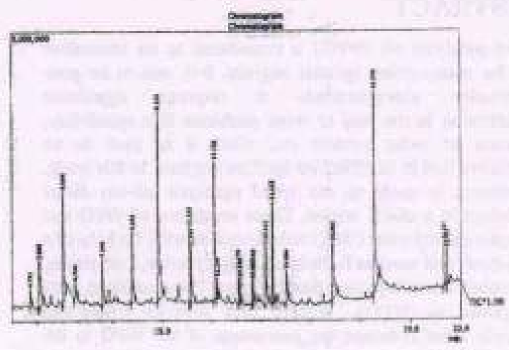


Figure 1. Gas chromatogram of wood pyrolysis oil sample

PREPARATION OF BIODIESEL EMULSIONS WITH WPO

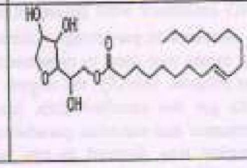
The Methyl ester of Jatropha (JME), commonly known as biodiesel from jatropha, was produced by the transesterification process. In the transesterification process, jatropha oil was reacted with an alcohol in the presence of a strong acid or base, producing a mixture of fatty acid alkyl esters and glycerol. About 3-4 grams of catalyst (NaOH) were dissolved in 100 ml of methanol to prepare alkoxide, which is required to activate the alcohol. Around 15-20 minutes vigorous stirring was done in a closed container until the alkali was dissolved completely. The alcohol catalyst mixture was then transferred to the reactor containing moisture free jatropha oil. Continuous stirring of the resulting mixture at a temperature between 60-65 °C was carried out for one hour; then the resulting mixture was taken out and poured into the separating funnel, and the glycerol was separated from the mixture to get the methyl ester of jatropha oil. Water washing was done later, in order to remove the moisture and impurities from the biodiesel. The properties of WPO compared with diesel and JME are given in Table 1.

Table 1. Properties of wood pyrolysis oil compared with diesel and jatropha methyl ester

Properties	ASTM method	Diesel	WPO	JME
Specific gravity at 15 °C	D 4052	0.83	1.15	0.88
Net calorific value[MJ/kg]	D 4809	43.8	20.58	39.1
Flash point[°C]	D 93	50	98	118
Fire point[°C]	D 93	56	108	126
Pour point[°C]	D 97	-6	2	-1
Carbon residue[%]	D 4530	0.1	12.85	-
Kinematic viscosity at 40 °C[cSt]	D 445	2.58	52.3	4.6
Cetane number	D 613	50	-	51
Moisture content (wt %)	-	0.025	15-30	-
Carbon (%)		86.5	49.1	77.1
Hydrogen (%)		13.2	6.2	11.81
Nitrogen (%)		Nil	3.0	0.119
Sulphur (%)		0.3	0.05	0.001
Oxygen by difference (%)		Nil	41.65	10.97

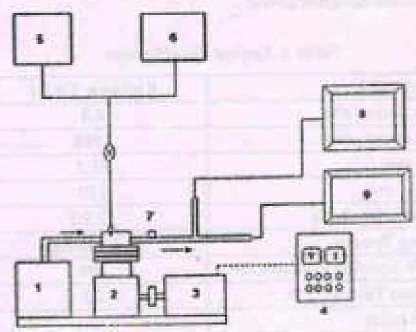
Direct water-oil emulsions show less viscosity than an oil-water emulsion. This property is very important for heavy fuel oil handling. In this investigation, a lipophilic surfactant Span 80 (sorbitan monooleate) with hydrophilic-lipophilic balance (HLB) = 4.3 was used to make a water-in-oil emulsion, which will reduce the interfacial tension as well as to improve the adherence between the phases of the WPO and the JME. The specifications of the surfactant Span-80 are given in Table 2. Three WPO fuel emulsions were prepared from WPO 5%, 10% and 15% and JME 95%, 90% and 85% respectively, with the addition of surfactant Span-80 2% by volume. The resultant mixture was shaken vigorously for about 30 minutes. Then, the emulsion produced was observed visually for about eight hours, and it was found that the emulsions WPO5, WPO10 and WPO15 were found to be stable. There was no phase separation during the observation period. Since the emulsions made with 2% addition of the surfactant are stable, experiments were not tried above 2% surfactant addition.

Table 2. Chemical structure and specifications of surfactant

Type	HLB	Specific gravity	Chemical structure
Span-80	4.3	0.98	

EXPERIMENTAL SETUP

The schematic of the experimental setup was given in Figure 2 and the specification of the test engine was given in Table 3.



1. Air box	2. Diesel engine	3. Alternator
4.Resistive load	5. Diesel fuel tank	6. Alternative fuel tank
7. Thermocouple	8. Gas analyser	9. Smoke meter

Figure 2. Schematic diagram of experimental setup

Experiments were conducted in a single cylinder, four stroke, air cooled, direct injection diesel engine coupled to an alternator. The load act on the alternator was varied with a resistive load bank. The exhaust gas temperature was measured with the help of a K-type thermocouple fitted in the exhaust pipe. Fuel consumption was measured with the help of a solenoid controlled automatic burette. An air box was used to damp out the pulsations produced by the engine, for ensuring a steady flow of air through the intake manifold. Air consumption was measured by an air flow sensor fitted in the air box. A speed sensor was connected near the flywheel of the engine to measure the speed. Engine exhaust emissions were measured with an AVL 444 exhaust gas analyser that measures unburnt hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO_2) and nitric oxide (NO) emissions. HC and NO emissions were measured in ppm and CO and CO_2 were measured in percentage volume. An AVL 437 C diesel smoke meter was used to measure the smoke opacity of the engine exhaust. Initially, the engine was operated with diesel fuel to get the baseline data, and then with JME. The performance and emission parameters were evaluated. Then, the engine was allowed to run with the three emulsions WPO5, WPO10 and WPO15. The results were compared with those of diesel and JME operations. The engine was allowed to run with diesel fuel in between the WPO emulsions, to eliminate the cumulative effects. Finally, the engine was allowed to run with diesel fuel to flush out the WPO emulsions in the fuel line. The engine was able to produce the designed power.

Table 3. Engine Specification

Make/Model	Kirloskar TAF 1
Brake power, kW	4.4
Rated speed, rpm	1500
Bore, mm	87.5
Stroke , mm	110
Compression Ratio	17.5:1
Cooling System	Air cooling
Nozzle Opening Pressure, bar	200
Injection Timing, °CA	23
No. of holes	3

UNCERTAINTY IN INSTRUMENTATION AND EXPERIMENTS

Uncertainty is a measure of the 'goodness' of a result. Without such a measure, it is impossible to judge the fitness of the value. Uncertainty or error analysis is necessary to establish the bounds on the accuracy of the estimated parameters. Evaluations of some unknown uncertainties from known physical quantities were obtained using the following general equation [23].

$$\frac{U_Y}{Y} = \left[\sum_{i=1}^{n}\left(\frac{1}{Y}\frac{\partial Y}{\partial xi}U_{xi}\right)^2\right]^{1/2}$$

In the equation cited, Y is the physical parameter that is dependent on the parameters, xi. The symbol U_Y denotes the uncertainty in Y. As a result, the maximum uncertainty of the experiment obtained was ± 3.13 %. Table 4 shows the instruments used in the present study and their uncertainties.

Table 4. Range, accuracy and uncertainty of the instruments

S.No	Instrument	Range	Accuracy	Uncertainty
1.	Load indicator	250-6000W	±10W	0.2
2	Temperature indicator	0-900	±1 °C	0.15
3	Burette	1-30cc	±0.2 cc	1.5
4	Speed sensor	0-10000 rpm	±10 rpm	±1
5	Exhaust gas analyser	NO:0-5000 ppm	±50 ppm	1
		HC : 0-20000 ppm	±10 ppm	0.5
		CO:0-10%	0.03%	1
6	Smoke meter	0-100%	±1 %	1

RESULTS AND DISCUSSION

PERFORMANCE PARAMETERS

Figure 3 shows the variation of the brake thermal efficiency with brake power for the different fuels. Thermal efficiency is the ratio between the power output and the energy introduced through fuel injection, the latter being the product of the injected fuel mass flow rate and the lower heating value (calorific value). The brake thermal efficiency of JME is found to be lower than that of diesel fuel, because of its lower calorific value and higher viscosity. WPO5, WPO10 and WPO15 show an increasing trend in the brake thermal efficiency compared to that of diesel as well as JME. This may be due to the micro explosion phenomenon, due to the volatility difference between two layers of the emulsion, which enhances the air fuel mixing, and hence, the improvement in the combustion efficiency.

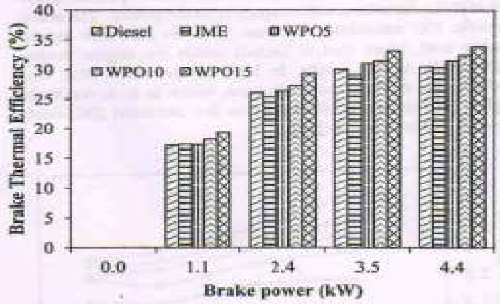


Figure 3. Variation of the brake thermal efficiency with brake power

The phenomenon of micro explosion is often observed during the combustion of fuel emulsions and multi-component fuel droplets, which are made up of two or more liquids with relatively large differences between their boiling temperatures. The micro explosion may occur when the superheat limit of the interior phase (which is far above the boiling point and is about 10% below the critical temperature for many substances) is lower than the saturation temperature of the surrounding phase. Intense disruption occurs due to the rapid evaporation of the droplet interior phase by spontaneous homogeneous nucleation, which results in a high pressure bubble inside the liquid phase [19]. The bubble grows violently causing the disruption of the liquid drop into small secondary drops, in a process known as secondary atomization or micro explosion. Water in oil emulsions has the micro explosion tendency. Here, the lower boiling point components present in WPO absorb the heat quickly, which leads to explosion of those lighter components through the surrounding oil layers called as micro explosion [20]. At full load, the brake thermal efficiency of the JME is marginally lower than that of diesel fuel, but the emulsions made with WPO5, WPO10 and WPO15 show increased thermal efficiencies in the order of 3.2%, 6.4% and 11.3% respectively. As the WPO content in the emulsion increases, the thermal efficiency is also found to increase.

Figure 4 shows the exhaust gas temperature variation with respect to brake power. Exhaust gas temperature is an indication of efficient combustion. Higher values of exhaust gas temperatures are indicative of inefficient combustion, with JME compared to diesel, due to the higher viscosity and poor mixture formation of the biodiesel fuel [24]. It is observed from the graphs that the JME shows the highest exhaust gas temperature among all the fuels tested, irrespective of the load. The heavier molecules of the biodiesel lead to continuous burning, even during the exhaust stroke which causes higher exhaust gas temperature [25]. For WPO5, WPO10 and WPO15, the exhaust gas temperatures are found to be lower than that of JME, but higher than that of diesel fuel at full load. Also, it is seen that the exhaust gas temperature of the emulsion decreases with an increase in the WPO content. The lower molecular weight components in the emulsion get vaporized during the combustion process, and absorb, the heat energy which decreases the local adiabatic flame temperature [26]. This may result in lower exhaust gas temperature compared to that of biodiesel.

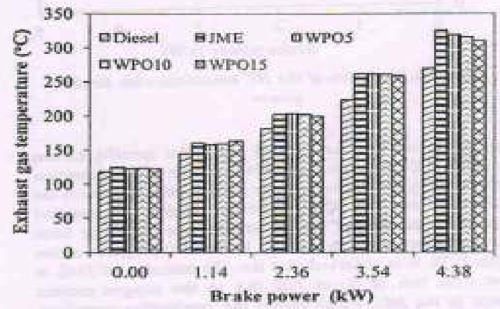


Figure 4. Variation of the exhaust gas temperature with brake power

EMISSION PARAMETERS

Figure 5 describes the variation of the brake specific hydrocarbon (HC) emissions with respect to brake power. The HC emissions of JME are found to be lower than that of diesel fuel since, the higher oxygen content of the JME leads to more complete burning than diesel fuel. For WPO5, WPO10 and WPO15, the HC emissions were found to be lower than that of JME.

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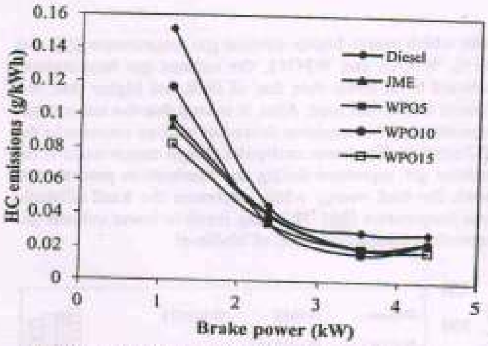

Figure 5. Variation of the HC emissions with Brake power

Figure 6 shows the variation of the brake specific carbon monoxide (CO) emissions with brake power. The combustion temperature in the engine cylinder significantly influences the oxidization rate of CO emission. Higher combustion temperature accelerates the oxidization rate of CO to form CO2, and thus results in less CO in the exhaust gases of the engine [27]. It is observed that the CO emission of JME is lower than that of diesel fuel due to the oxygen content present in the fuel, which makes the combustion complete. For all the WPO emulsions, the CO emissions are found to be higher than that of diesel fuel at all loads. Lower molecular weight substances in the emulsified fuels absorb the heat of vapourisation during combustion, which will reduce the combustion temperature and the oxygenating time for CO's conversion into CO_2 [28]. This may be the reason for higher CO emissions in the case of WPO emulsions.

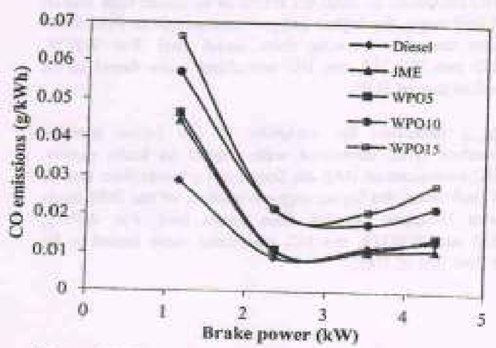

Figure 6. Variation of the CO emissions with Brake power

Figure 7 depicts the variation of the brake specific nitric oxide (NO) emissions with respect to brake power. The brake specific NO emissions decrease with the increase in the engine load. More fuel is burned inside the engine during high loads, which results in high temperature. This will facilitate the oxidization of nitrogen, which in turn, results in higher NO emissions according to the extended Zeldovich thermal NO mechanism [29].

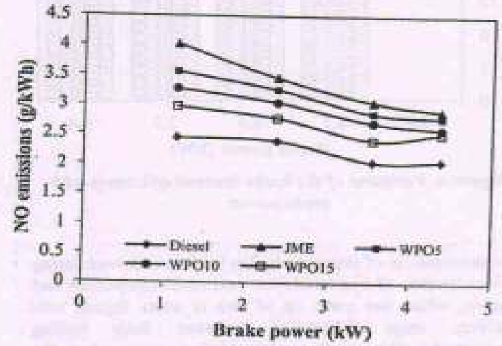

Figure 7. Variation of the NO emissions with Brake power

In the case of JME, the burning continues in the exhaust, due to the heavier molecules present in it, which in turn, increase the exhaust gas temperature [25]. This will lead to higher NO emissions. It is observed that about 11.3%, 5.4% and 1.5 % increase in the NO emissions is obtained with JME, WPO5 and WPO10 respectively, at full load compared to that of diesel. There is a significant decrease in the NO emissions by 3% when fueled with WPO15. When compared with JME, the NO emissions are found to be lower by about 6.6%, 11.1% and 16.3% for WPO5, WPO10 and WPO15 respectively, at full load.

Figure 8 describes the variation of the smoke opacity with respect to brake power. The smoke opacity of JME is 16.6% higher than that of diesel due to its heavier molecules of hydrocarbons [25].

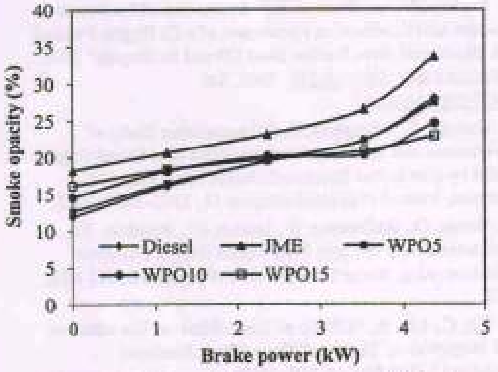

Figure 8. Variation of the smoke opacity with Brake power

The percentage decrease in the smoke opacity of 2.1%, 13.8% and 22.7% was obtained for WPO5, WPO10 and WPO15 respectively, at full load when compared with diesel. This may be due to the effects of enhancement in the spray volume, considerable amount of air entrainment in the emulsion spray, and the micro-explosion effect during the combustion process [30].

CONCLUSION

The performance and emission characteristics of diesel, JME and three biodiesel emulsions were investigated in a single cylinder, four stroke, air-cooled, direct injection diesel engine. From the experimental results the following conclusions are drawn.

1. At full load, the emulsions made with WPO5, WPO10 and WPO15 show increased thermal efficiencies in the order of 3.2%, 6.4% and 11.3% respectively, compared to that of diesel fuel.

2. The JME shows the highest exhaust gas temperature among all the fuels tested, irrespective of the load. For emulsified biodiesel fuels, exhaust gas temperatures are found to be lower than that of JME at full load.

3. HC emissions were found to be lower by 14.28% for JME when compared with diesel at full load. For WPO5, WPO10 and WPO15 they are lower by 35.7%, 35.7% and 50% respectively, at full load compared to that of diesel.

4. The CO emissions of JME are lower than that of diesel fuel, and they are found to be higher in the case of all the WPO emulsions.

5. About 11.3%, 5.4% and 1.5 % increase in the NO emissions was obtained with JME, WPO5 and WPO10 respectively, at full load compared with diesel. There is a significant decrease in the NO emissions by 3% when fueled with WPO15. When compared with JME, the NO emissions were found to be lower by about 6.6%, 11.1% and 16.3% for WPO5, WPO10 and WPO15 respectively at full load.

6. The smoke opacity of the JME is 16.6% higher than that of diesel. The percentage decrease in the smoke opacity of 2.1%, 13.8% and 22.7% was obtained for WPO5, WPO10 and WPO15 respectively, at full load when compared with diesel.

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REFERENCES

1. Ramadhas, A. S., Muraleedharan, C., and Jayaraj, S., "Performance and Emission Evaluation of a Diesel Engine Fueled with Methyl Esters of Rubber Seed Oil", Renewable Energy 30, 1789-1800, 2005.

2. Sahoo, P. K., Das, L. M., Babu, M. K., Arora, P., Singh, V. P., Kumar, N. R., and Varyani, T. S., "Comparative Evaluation of Performance and Emission Characteristics of Jatropha, Karanja and Polanga based Biodiesel as Fuel in a Tractor Engine", Fuel 88, 1698-1707, 2009.

3. Demirbas, A., and Demirbas, M. F., "Importance of Algae oil as a Source of Biodiesel", Energy Conversion and Management 52, 163-170, 2011.

4. Lapuerta, M., Armas, O., "Effect of Biodiesel Fuels on Diesel Engine Emissions", Progress in Energy and Combustion Science 34,198-223, 2008.

5. Narayana, L., Gattamaneni, R., Subramani, S., "Combustion and Emission Characteristics of Diesel Engine Fuelled with Rice Bran Oil Methyl Ester and its Diesel Blends", Thermal science 12, 139-150, 2008.

6. Balat, M., and Balat, H., "Progress in Biodiesel Processing", Applied Energy 87, 1815-1835, 2010.

7. Knothe, G., "Dependence of Biodiesel Fuel Properties on the Structure of Fatty Acid Alkyl Esters", Fuel processing technology 86, 1059-1070, 2005.

8. Dunn, R.O., "Effect of Antioxidants on the Oxidative Stability of Methyl Soyate (biodiesel)", Fuel Process. Technol. 86, 1071-1085, 2005.

9. Garcia-perez, M., Adams, T. T., Goodrum, J. W., Das, K. C., and Geller, D. P., "Bioresource Technology DSC Studies to Evaluate the Impact of Bio-oil on Cold Flow Properties and Oxidation Stability of Bio-diesel", Bioresource Technology 101, 6219-6224, 2010.

10. Yung, C.L., Choo, Y.M., Cheng, S.F., Ma, A.N., Chuah, C.H., Yusof, B., "The Effect of Natural and Synthetic Antioxidants on the Oxidative Stability of Palm Diesel", Fuel 85, 867-870, 2006.

11. Garcia-Perez, M., Chaala, A. Pakdel, H., Kretschmer, D., Rodrigue, D., Roy, C., "Multiphase Structure of Bio-oils", Energy Fuels 20, 364-375, 2006.

12. Mohan, D., Pittman, C.U., Steele, P. H., Mohan, D., Pittman, C.U., and Steele, P. H., "Pyrolysis of Wood / Biomass for Bio-oil : A Critical Review Pyrolysis of Wood / Biomass for Bio-oil : A Critical Review", Energy and fuels 20, 848-889, 2006.

13. Garcia-Perez, M., Lappas, P., Hughes, P., Dell, L., Chaala, A., Kretschmer, D., Roy, C., "Evaporation and Combustion Characteristics of Bio-oils Obtained by Vacuum Pyrolysis of Wood Industry Residues", IFRF Electron. J. 2006.

14. Qi, Zhang., Jie, Chang., Tiejun, Wang., Ying, Xu., "Review of Biomass Pyrolysis Oil Properties and Upgrading Research", Energy Conversion and Management 48, 87-92, 2007.

15. Solantausta, Y., Nylund, N., Westerholm, M., Koljonen, T., Oasmaa, A., "Wood-Pyrolysis Oil as Fuel in a Diesel-Power Plant", Bioresource Technology 46,177-188, 1993.

16. Frigo, S., Gentili, R., Tognotti, L., Zanforlin, S. et al., "Feasibility of Using Wood Flash-Pyrolysis Oil in Diesel Engines," SAE Technical Paper 982529, 1998, doi: 10.4271/982529.

17. Bertoli, C., D'Alessio, J., Del Giacomo, N., Lazzaro, M. et al., "Running Light-Duty DI Diesel Engines with Wood Pyrolysis Oil," SAE Technical Paper 2000-01-2975, 2000, doi:10.4271/2000-01-2975.

18. Ikura, M., Stanciulescu, M., and Hogan, E., "Emulsification of Pyrolysis Derived Bio-oil in Diesel Fuel", Biomass and bioenergy 24, 221-232, 2003.

19. Shepherd, J. E., and Sturtevant, B., "Rapid Evaporation at the Superheat Limit", J. Fluid Mech. 121, 379-402, 1982.

20. Basha, J. S., and Anand, R. B., "Role of Nanoadditive Blended Biodiesel Emulsion Fuel on the Working Characteristics of a Diesel Engine", Journal of Renewable and Sustainable energy, 1-17, 2011.

21. Lif, A., and Holmberg, K., "Water-in-Diesel Emulsions and Related Systems", Advances in Colloid and Interface Science 126, 231-239, 2006.

22. Kannan, T., Marappan, R., "Thevetia Peruviana Biodiesel Emulsion used as a Fuel in a Single Cylinder Diesel Engine Reduces NOx and Smoke", Thermal Science.

23. Coleman, HW., Steele, WGJr.., "Experimentation and Uncertainty Analysis for Engineers", New York, John Wiley and Sons, 1989.

24. Pradeep, V. and Sharma, R., "Evaluation of Performance, Emission and Combustion Parameters of a CI Engine Fuelled with Bio-Diesel from Rubber Seed Oil and its Blends," SAE Technical Paper 2005-26-353, 2005, doi: 10.4271/2005-26-353.

25. Kannan, T., Marappan, R., "Comparative Study of Performance and Emission Characteristics of a Diesel Engine Fueled by Emulsified Biodiesel/Diethyl Ether Blended Biodiesel, Journal of applied sciences 11, 2961-2967, 2011.

26. Armas, O., Ballesteros, R., Martos, FJ., Agudelo, JR., "Characterization of Light Duty Diesel Engine Pollutant Emissions using Water Emulsified Fuel", Fuel 84,1011-018, 2005.

27. Lin, C., Lin, S., "Effects of Emulsification Variables on Fuel Properties of Two- and Three-Phase Biodiesel Emulsions," Fuel 86, 210-217, 2007.

28. Yusuf, N.N.A.N., Kamarudin, S.K., Yaakub, Z., "Overview on the Current Trends in Biodiesel Production", Energy Conversion and Management 52, 2741-2751, 2011.

29. Nishioka, M., Nakagawa, S., Ishijawa, Y., Takeno, T., "NO Emission Characteristics of Methane-Air Double Flame", Combust Flame 98, 127-38, 1994.

30. Subramanian, K. and Ramesh, A., "Use of Diethyl Ether Along with Water-Diesel Emulsion in a Di Diesel Engine," SAE Technical Paper 2002-01-2720, 2002, doi: 10.4271/2002-01-2720.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

WPO
Wood Pyrolysis Oil

JME
Jatropha Methyl Ester

HC
Hydrocarbons

CO
Carbon monoxide

CO_2
Carbon-di-oxide

NO
Nitric Oxide

GC-MS
Gas Chromatography Mass Spectroscopy

NaOH
Sodium Hydroxide

HLB
Hydophilic Lipophilic Balance

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