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Research Paper

BIODIESEL PRODUCTION FROM WASTE PORK LARD AND AN EXPERIMENTAL INVESTIGATION OF ITS USE AS AN ALTERNATE FUEL IN A DI DIESEL ENGINE

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Biodiesel is an alternative diesel fuel that can be produced from different kinds of vegetable oils and animal fats. It is an oxygenated, non-toxic, sulphur-free, biodegradable, and renewable fuel and can be used in diesel engines without significant modification. However, the performance, emissions and combustion characteristics will be different if it is used in different types of engine. In this study, the biodiesel produced from waste pork lard by transesterification process and Waste Pork Lard Methyl Ester (WPLME) blends of 25%, 50%, 75% and 100% in volume are compared with diesel fuel. WPLME has properties that differ from diesel fuel. A minor increase in Specific Fuel Consumption (SFC) and slight decrease in Brake Thermal Efficiency (BTE) for its blends were observed. The significant reduction of Hydro Carbon (HC) and smoke emission was found for WPLME and its blends at high engine loads. Carbon monoxide (CO) revealed no evident variation for all tested blend. Nitrogen Oxides (NOx) were slightly higher for WPLME and its blends. The significant improvement in reduction of NOx and a minor increase in CO_2 and O_2 were identified with the use of Selective Catalytic Reduction (SCR). WPLME and its blends exhibit combustion stages similar to diesel fuel. The use of transesterified WPLME can be partially substituted for the diesel fuel at most operating conditions in terms of the performance parameters and emissions without any engine modification.

Keywords: Waste pork lard methyl ester, selective catalytic reduction, Carbon monoxides

INTRODUCTION

Biodiesel has received much attention in the past decade due to its ability. It is one of the source to replace fossil fuels, which are likely to run out within a century. Especially, the environmental issues concerned with the

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exhaust gas emission by the usage of fossil fuels also encourage the use of biodiesel, which has proved to be ecofriendly for more than fossil fuels (Ekrem, 2010). Bio-fuels made from agricultural products (oxygenated by nature) reduce the India's and most of the countries dependence on oil imports, support local agricultural industries and enhance farming incomes and moreover offer benefits in terms of usually reduced emissions. Among those, vegetable oils, animal fats, their derived bio-diesels (methyl or ethyl esters) and bio-alcohols are considered as very promising fuels. Experimental work on the use of bio-ethanol in diesel engines have been reported (Ecklund *et al.*, 1984; Hansen *et al.*, 2005; and Rakopoulos *et al.*, 2008). Bio-fuel production is a rapidly growing industry in many parts of the world. Bio-ethanol is the primary alternative at present to gasoline for spark-ignition engines and animal fats, their derived bio-diesels and bio-ethanol mixed with diesel fuel for compression ignition (diesel) engines. However, other bio-fuels such as biobutanol (Miers *et al.*, 2008), biomass-derived hydrocarbon fuels and hydrogen are being researched at present, being regarded as next generation bio-fuels (Hansen *et al.*, 2009).

The main disadvantages of animal fats, as diesel fuels are due to increased viscosity, i.e., 10-20 times greater than the normal diesel fuel. Although short-term tests using neat animal fats and vegetable oils showed promising results. To solve the problem of the high viscosity of neat animal fats and vegetable oils, the following usual methods are adopted: blending in small ratios with diesel fuel, micro-emulsification with methanol or ethanol, cracking, and conversion into bio-diesels mainly through the transesterification process (Graboski and McCormick, 1998; and Demirbas, 2003). The advantages of bio-diesels as diesel fuel are minimal sulfur and aromatic content, and higher flash point, lubricity, cetane number, biodegradability and non-toxicity. On the other hand, their disadvantages include the higher viscosity and pour point, and the lower calorific value and volatility. Furthermore, their oxidation stability is lower, they are hygroscopic, and as solvents may cause corrosion in various engine components. For the above reasons, it is generally accepted that blends of diesel fuel up to 20% bio-diesels, animal fats and vegetable oils can be used in existing diesel engines without modifications. Experimental works on the use of animal fats, vegetable oils or bio-diesels in blends with diesel fuel for diesel engines have been reported for example in the references (Rakopoulos *et al.*, 2006; and Bueno *et al.*, 2009).

In the present study, Waste Pork Lard Methyl Ester (WPLME) is considered as a potential alternative fuel for an unmodified diesel engine because it has high oil content (around 80%) for biodiesel production. It is commonly available in and around new Jersey and Philadelphia. Pork is the culinary name for meat of domestic pig. The main aim of this study is to investigate the engine performance, emission and combustion characteristics of a diesel engine fueled with Waste pork lard methyl ester and its diesel blends compared to those of standard diesel. It is hoped that the new data presented here will help in developing new predictive methods or procedures for this actual problem.

THE BIODIESEL PRODUCTION AND CHARACTERIZATION

Biodiesel Production Procedure

The biodiesel fuel used in this study was produced from the transesterification of Waste pork lard with methanol (CH_3OH) catalyzed by potassium hydroxide (KOH). A titration was performed to determine the amount of KOH needed to neutralize the free fatty acids in Waste pork lard. The amount of KOH needed as catalyst for every litre of Waste pork lard was determined as 12 g. For transesterification, 210 ml CH_3OH plus the required amount of KOH were added for every litre of Waste pork lard and the reactions were carried out at 65 °C. The water wash process was performed by using a sprinkler which slowly sprinkled water into the WPLME container until there was an equal amount of water and WPLME in the container. The water WPLME mixture was then agitated gently for 75 min, allowing the water to settle out of the WPLME. After the mixture had settled, the water was drained out.

Biodiesel Properties

A series of tests were performed to characterize the compositions and properties of the produced WPLME. The fuel properties of WPLME and its blends with diesel fuel are shown in Table 1, properties and fatty acids present in pork lard are shown in Table 2 and also, phosphorous 246 mg (35%), ash content 3.78 ± 0.5, acid value C12:0.1, water content 57.87 g, oxidation stability. It is shown that the viscosity of WPLME is evidently higher than that of diesel fuel. The density of the WPLME is approximately 5.47% higher than that of diesel fuel. The lower heating value is approximately 9.08% lower than that of diesel fuel. Therefore, it is necessary to increase the fuel amount to be injected into the combustion

Table 1: Properties of Biodiesel in Comparison with Commercial Diesel and Best Blends

Properties	Commercial Diesel	WPLME 50	WPLME 100
Density @ 15 °C in gm/cc	0.8344	0.8568	0.8801
Specific Gravity @ 15°/15°C	0.8360	0.8585	0.8832
Kinematic Viscosity @ 40 °C (mm²/s)	3.07	4.12	6.83
Flash Point (°C)	60	108	150
Fire Point (°C)	69	118	161
Cloud Point (°C)	15	21	27
Calorific Value (kJ/kg)	44125	46782	45789
Cetane Number	47	52	54

Source: Laboratory Evaluation at Etalab-Chennai

Table 2: Properties and Composition of Fatty Acids Present in Pork Lard

Properties	Pork Lard
Acid Value (mg KOH/g)	0.71
Iodine Value (g I2/100 g)	67
Water content	0.03
Myristic 14:0 *	1.5
Palmitic 16:0	23.7
Palmitoleic 16:1	2.2
Stearic 18:0	12.9
Oleic 18:1	41.4
Linoleic 18:2	15.0
Linolenic 18:3	1.0
Arachidic 20:0	0.2
Gadoleic 20:1	0.9
Erucic 22:1	<0.5

Source: Laboratory Evaluation at Etalab-Chennai chamber to produce the same amount of power. Fuels with flash point 174-178 °C > 120 °C are regarded as safe. Thus, WPLME is an extremely safe fuel to handle compared to diesel fuel. Even 25% WPLME blend has a flash point much above that of diesel fuel; making WPLME a preferable choice as far as safety is concerned. The analysis results of cold filter clogging temperature, a criterion used for low temperature performance of the fuels, suggest that the performance of WPLME is as good as diesel fuel in cold surroundings. With the increase of biodiesel percentage in blends, pour point or cold filter plugging point of blends increases (Qi *et al.*, 2009).

EXPERIMENTAL

Equipment and Method

The engine Kirloskar TV1 was used; their specifications are shown in Table 3. The engine bench is shown in Figure 1. An eddy-current dynamometer was connected with the engine and used to measure the engine power. An exhaust gas analyzer (AVL Di-gas analyser) was employed to measure NOx, HC, CO, O_2 and CO_2 emission on line. To ensure the accuracy of the measured values, the gas analyzer was calibrated before each measurement using reference gases. The AVL smoke meter is used to measure the smoke density. The smoke meter was also allowed to adjust its zero point before each measurement. The AVL combustion analyser is used to measure the combustion characteristics of the engine. The accuracies of the measurements and the uncertainties in the calculated results are shown in Table 4.

Engine Test Procedure

The experiments were carried out by using neat diesel as the base line fuel (denoted as D), 25% WPLME + 75% diesel (denoted as

Figure 1: The Layout of the Engine Test Bench

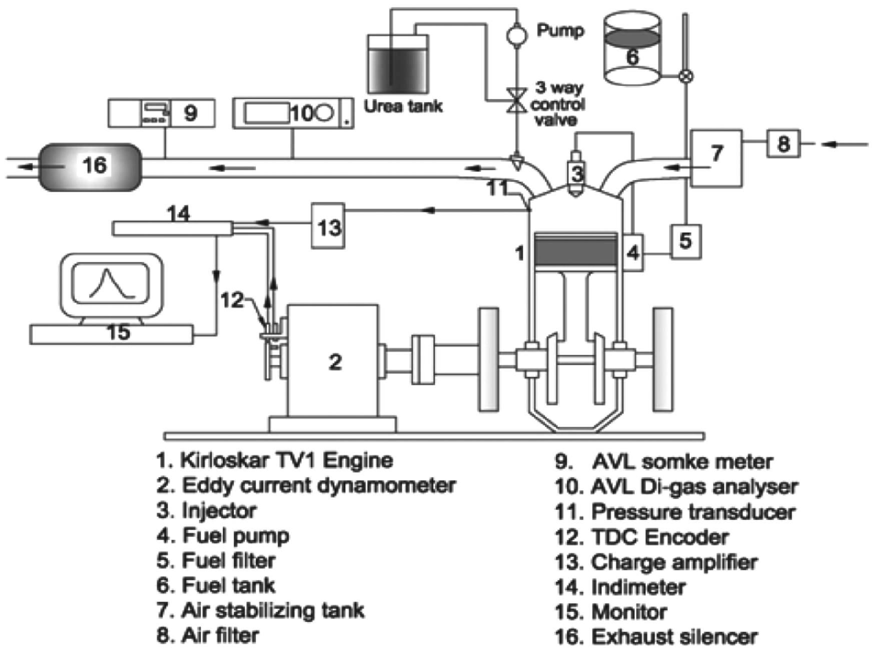


Table 3: Specification of the Test Engine

Type	Vertical, Water Cooled, Four Stroke
Number of Cylinder	One
Bore	87.5 mm
Stroke	110 mm
Compression Ratio	17.5:1
Maximum Power	5.2 kW
Speed	1500 rev/min
Dynamometer	Eddy Current
Injection Timing	23° Before TDC
Injection Pressure	220 kgf/cm^2

Table 4: The Accuracies of the Measurements and the Uncertainties in the Calculated Results

Parameters	Accuracy
Engine Load	± 0.2 kN
Engine Speed	± 1 rpm
Temperature	±1 °C
Smoke Meter	± 1 HSU
CO	± 0.05%
HC	± 10 ppm
NOx	± 50 ppm
BSFC	± 2%
BTE	± 2%
Pressure	± 1 bar
Crank Angle	± 1°

WPLME 25), 50% WPLME + 50% diesel (denoted as WPLME 50), 75% WPLME + 25% diesel (denoted as WPLME 75) and 100% neat WPLME (denoted as WPLME 100) at different engine loads from 0% to 100% in approximate steps of 25%. Before running the engine with a new fuel, it was allowed to run for sufficient time to consume the remaining fuel from the previous experiment. To evaluate the performance parameters, important operating parameters such as engine speed, power output, fuel consumption, exhaust emissions and cylinder pressure were measured. Vital engine performance parameters such as Specific Fuel Consumption (SFC), and Brake Thermal Efficiency (BTE) for biodiesel and its blends were calculated.

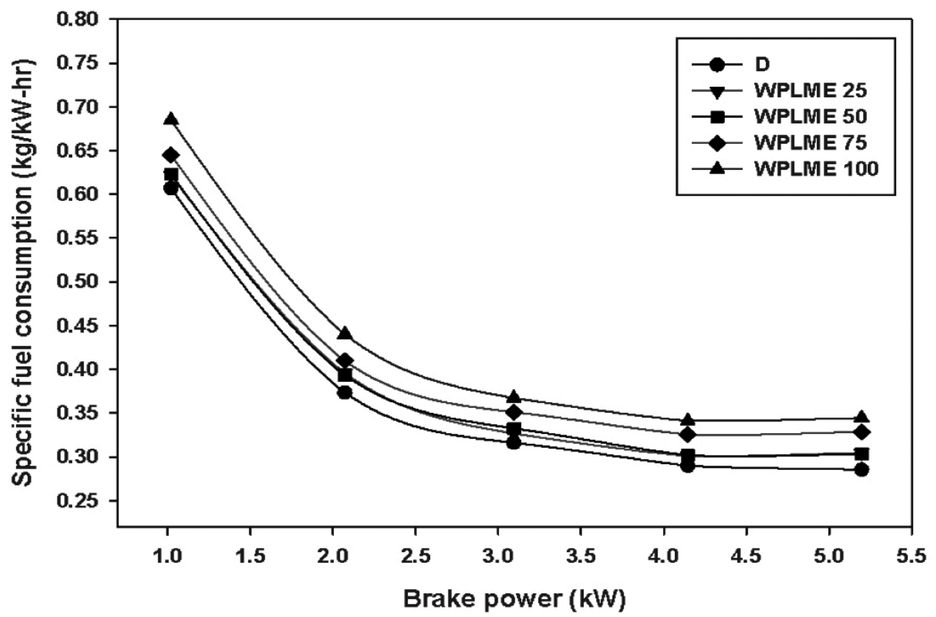
RESULT AND DISCUSSION

Performance and Emission Characteristics

The addition of WPLME as an oxygenated fuel was most effective in rich combustion at high engine loads. At low engine loads, the amount of fuel supplied to the engine was decreased, and the overall mixture was further leaned out. Therefore, the WPLME addition results in different effects on the performance and the emissions at different engine loads.

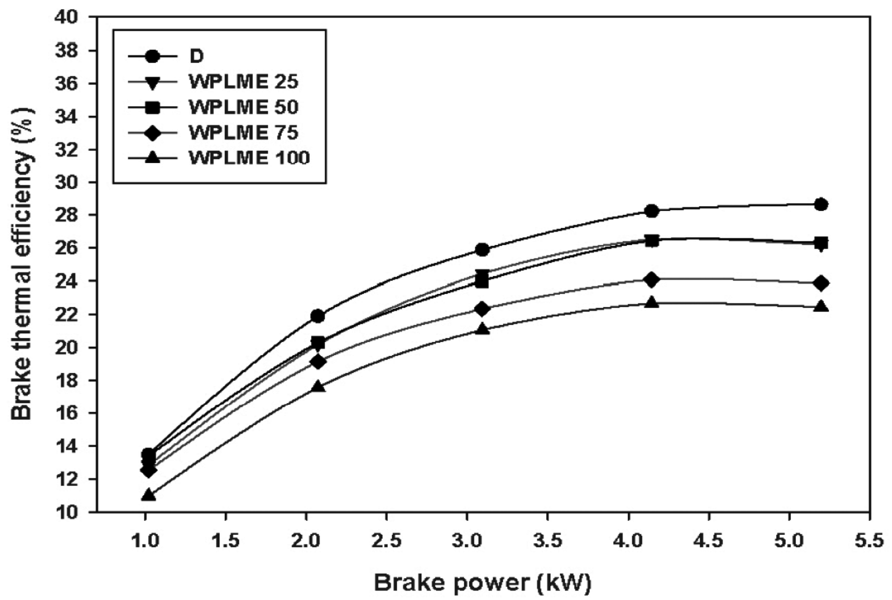
SFC is the ratio between mass flow of the tested fuel and effective power. Figure 2 shows the SFC variation of the WPLME and its blends with respect to brake power of the engine. In general, the SFC values of the biodiesel and its blends are slightly higher than those of diesel fuel under engine loads of all ranges. The lowest SFCs are 0.285, 0.304, 0.313, 0.328, and 0.344 kg/kW h for D, WPLME 25, WPLME 50, WPLME 75 and WPLME 100 respectively. The SFC of diesel engine depends on the relationship among volumetric fuel injection, fuel density, viscosity and lower heating value. More WPLME and its blends are needed to produce the same amount of energy due to its lower heating value in comparison with diesel fuel. As found by Ekrem (2010) the SFC was increased with the increasing proportion of biodiesel blends.

Figure 2: Variation of SFC with Brake Power for Various WPLME Blends



Brake Thermal Efficiency (BTE) 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. BTE calculated for WPLME and its blends with diesel fuel are shown in Figure 3. The brake thermal efficiency values for WPLME and its blends are slightly lower than that of diesel fuel. The maximum BTE of diesel fuel is 30 % and those of WPLME

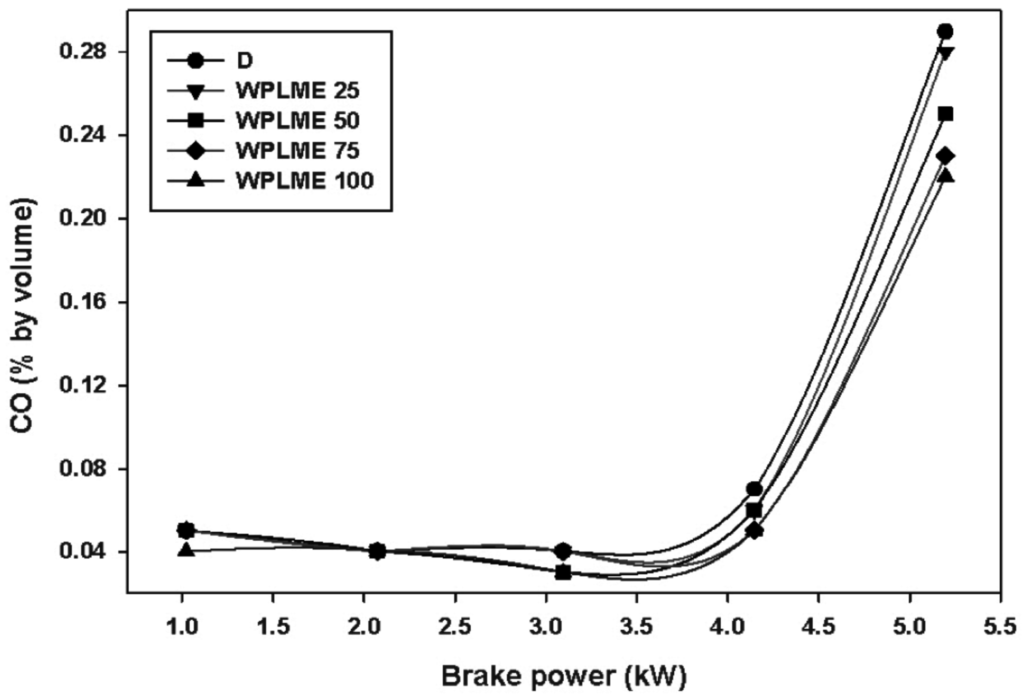
Figure 3: Variation of Brake Thermal Efficiency with Brake Power for Various WPLME Blends



and its blends are less than 30%. The main reason is that WPLME has a higher viscosity, high density and lower heating value than the diesel fuel. The higher viscosity leads to decreased atomization and fuel vaporization, and hence the BTE of biodiesel is lower than that of diesel fuel (Last *et al.*, 1995; and Nabi *et al.*, 2006).

Figure 4 shows the variations of CO emissions with respect to brake power of the engine. The air–fuel mixing process is affected by the difficulty in atomization of WPLME due to its higher viscosity. Also, the resulting locally rich mixtures of WPLME cause more CO to be produced during combustion. However, WPLME, which contains more number of oxygen atoms, leads to more complete combustion. At low and middle engine loads, the WPLME has only a slight effect on the CO emissions due to the dominant premixed lean combustion with excess air. The differences between the CO emissions of WPLME and its blends with diesel fuel are fairly small. At high engine loads, the CO emissions of WPLME and its blends are evidently lower than those of diesel fuel. The CO emission of diesel fuel is 0.11% but those of WPLME and its blends are less than that 0.08% at high engine load. This may be due to the more oxygen content of WPLME compared with diesel fuel. In addition, it is because WPLME has C/H ratio less than that for diesel fuel (Lapuerta *et al.*, 2008). However, the amount of decrease in CO emissions does not depend on the WPLME percentage in the blends. Last *et al.* (1995) also reported that a decrease in CO emissions can be observed when using biodiesel and its blends with diesel fuel but the trend in reduction is not linear (Zheng *et al.*, 2008).

Figure 4: Variation of Carbon Monoxide with Brake Power for Various WPLME Blends



The variation of HC emission for WPLME blend fuels under various engine loads are shown in Figure 5. At a lower load, the blends containing higher percentages of diesel have higher HC emission. It may be due to the lower viscosity of blends with higher percentages of diesel and a larger diesel dispersion region in the combustion chamber. However, at full load, diesel had the highest HC emission. There was a reduction of 16% HC emission for the WPLME 100 blend. As known, the formation of unburned hydrocarbons originates from various sources in the engine cylinder, and their theoretical study is still at its infancy (Tree and Svensson, 2007).

Figure 6 shows the variations of NOx emissions with respect to engine loads. There are mainly three factors, oxygen concentration, combustion temperature and cetane number affecting the NOx emission. NOx emission of WPLME and its blends are slightly higher than those of diesel fuel. The difference of NOx emission between diesel fuel and WPLME and its blends are not more than 75 ppm. The higher temperature of combustion and the presence of oxygen with WPLME cause higher NOx emission, especially at high engine loads. In the same way, Nabi *et al.* (2009) has reported NOx emission were found to increase due to the presence of extra oxygen in the molecules of WPLME blends. Approximately 2.5% increase in NOx emission was realized with 25% WPLME blends. It has also been reported by Zheng *et al.* (2008) that the WPLME with a cetane number similar to the diesel fuel produced higher NOx emission than the diesel fuel. However, the WPLME with a higher cetane number had comparable NOx emission with the diesel fuel. A higher cetane number would result in a shortened ignition delay period

Figure 5: Variation of Hydrocarbon with Brake Power for Various WPLME Blends

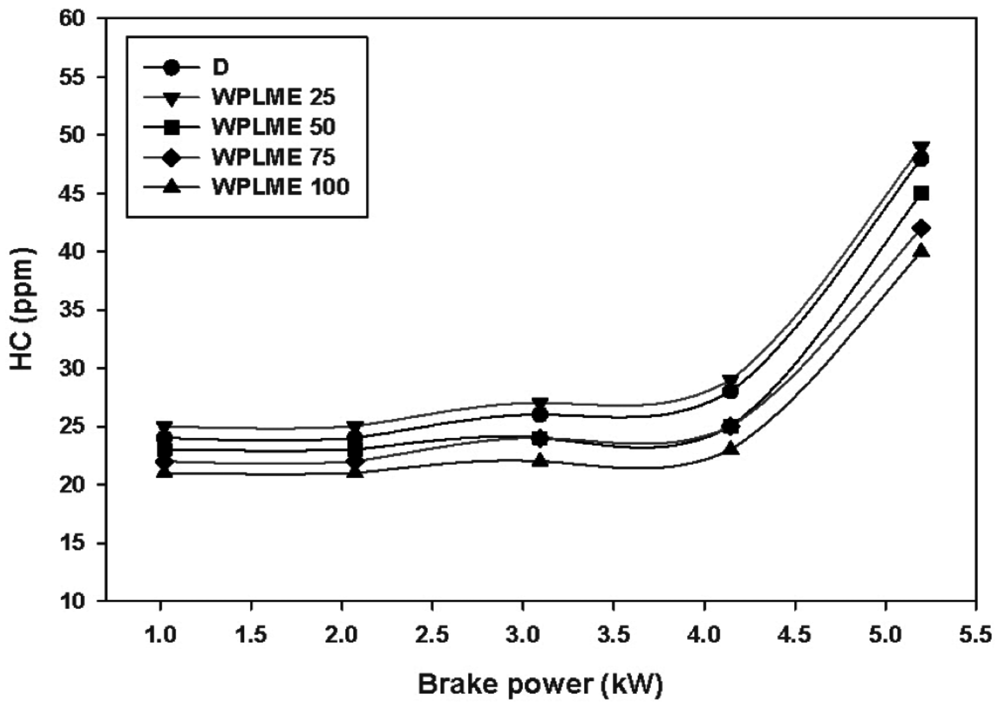
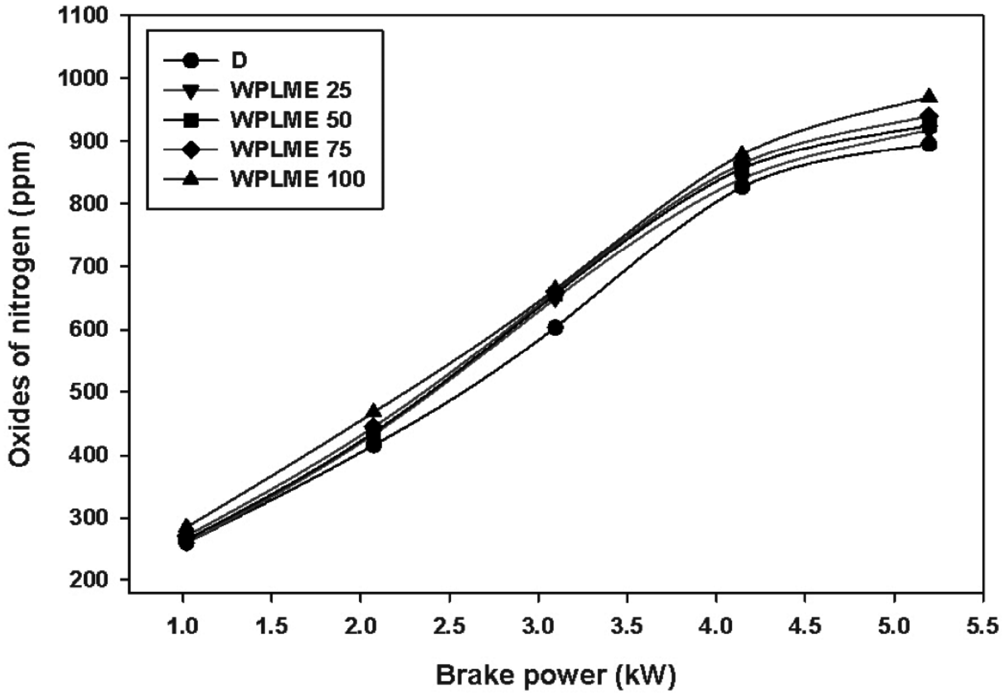


Figure 6: Variation of Oxides of Nitrogen with Brake Power for Various WPLME Blends



thereby allowing less time for the air/fuel mixing before the premixed burning phase. Consequently, a weaker mixture would be generated and burnt during the premixed burning phase resulting in relatively reduced NOx formation. Reduction of NOx with WPLME may be possible with the proper adjustment of injection timing and introducing Exhaust Gas Recirculation (EGR) or Selective Catalytic Reduction technology (SCR).

The variation of smoke emission at different loads for WPLME blends are shown in Figure 7. The significant reduction in smoke emission may be due to the oxygenated blends. Smoke is mainly produced in the diffusive combustion phase; the oxygenated fuel blends lead to an improvement in diffusive combustion for the WPLME 100 blend. Reduction in smoke emission of about 17% was recorded at full load for the WPLME 100 blend. Another reason of smoke reduction with biodiesel is the lower C/H ratio and absence of aromatic compounds as compared with diesel fuel. The carbon content in WPLME is lower than that of diesel fuel. More carbon in fuel, it is likely to produce more soot. Conversely, oxygen within a fuel decreases the tendency of a fuel to produce soot (Devan and Mahalakshmi, 2009).

Combustion Characteristics

Figure 8 shows the variation of cylinder pressure with crank angle for diesel, WPLME and its blends at 1500 rpm and at full load conditions. From this figure, it is clear that the peak cylinder pressure decreases with the increase of WPLME addition in the blends. However, the combustion process of the test fuels is similar, consisting of a phase of premixed combustion followed by a phase of

Figure 7: Variation of Smoke Density with Brake Power for Various WPLME Blends

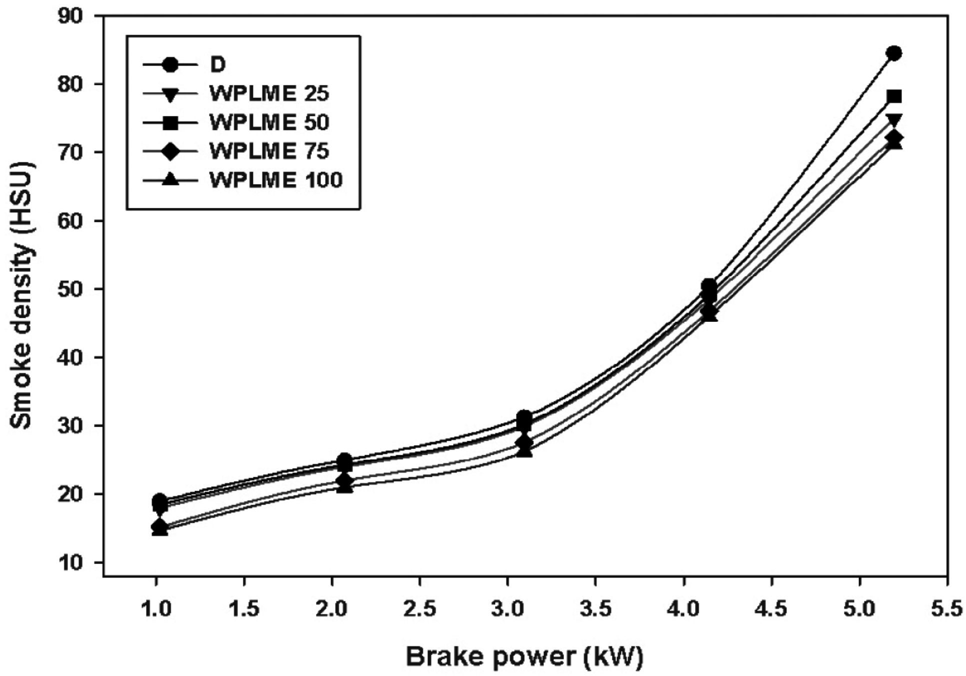
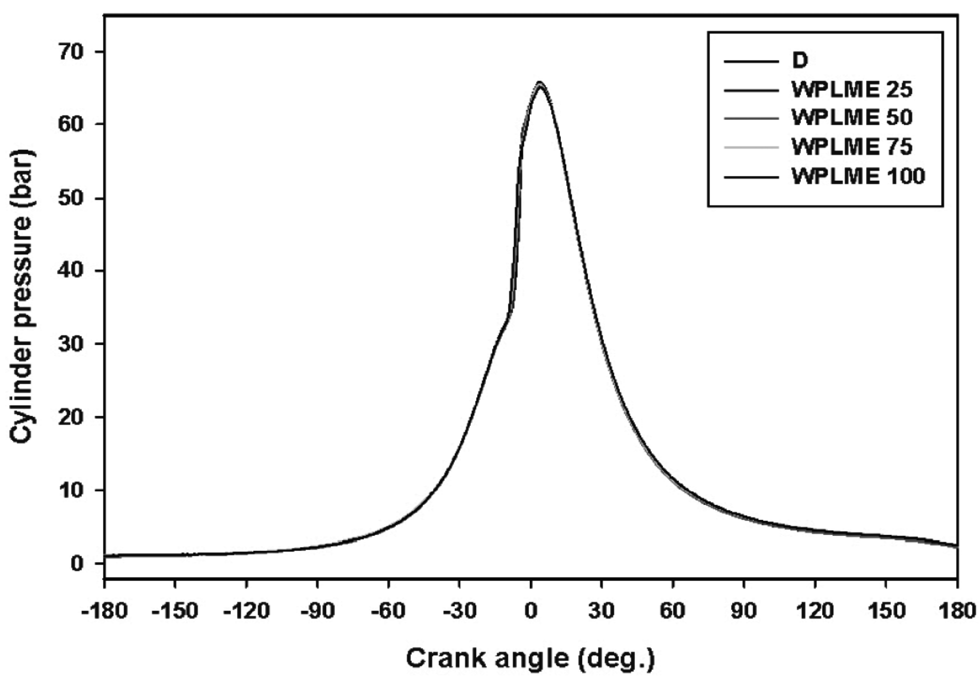


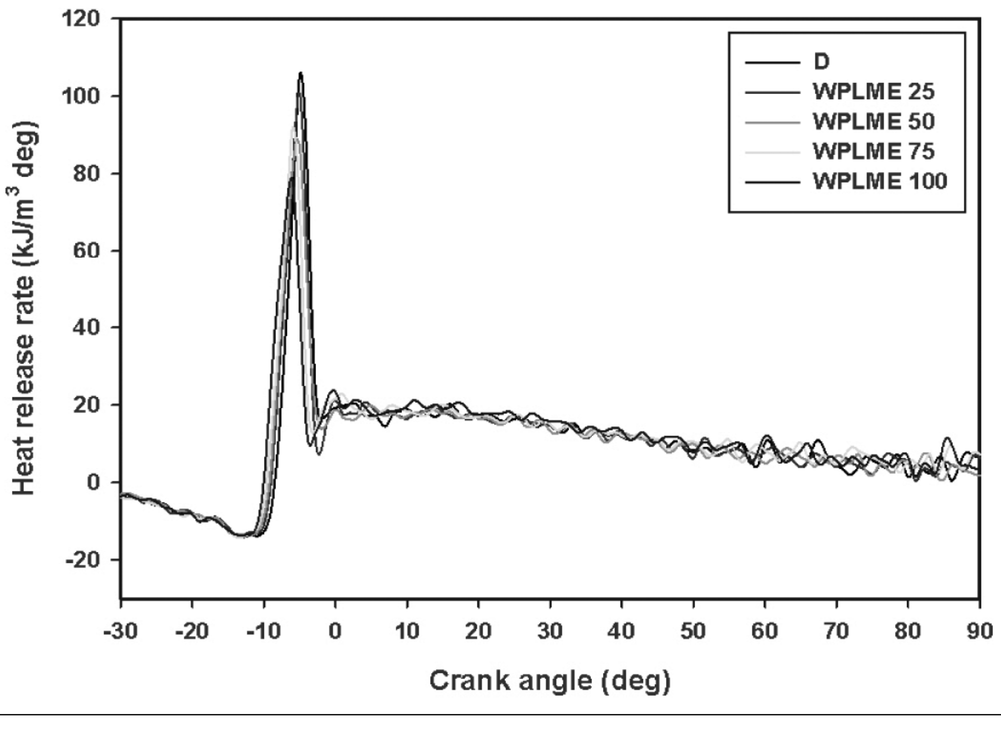
Figure 8: Variation of Cylinder Pressure with Crank Angle



diffusion combustion. Premixed combustion phase is controlled by the ignition delay period and spray envelope of the injected fuel (Ozsezen *et al.*, 2009; and Canakci *et al.*, 2009). Therefore, the viscosity and volatility of the fuel have a very important role to increase atomization rate and to improve air/fuel mixing formation. The cylinder peak pressure is lower because of the high viscosity and low volatility of WPLME and it blends than that of standard diesel. Peak pressures of 65.968, 65.682, 65.588, 65.250 and 65.205 bar were recorded for standard diesel, WPLME 25, WPLME 50, WPLME 75 and WPLME 100, respectively. Similar conclusions were drawn by other authors (Maria *et al.*, 1998; and Ozsezen *et al.*, 2009) and results were reported by Devan and Mahalakshmi (2009), who compared Poon oil biodiesel and diesel fuels at full-load in a single cylinder diesel engine. They reported cylinder pressures of 67.5, 63 and 60 bar for standard diesel, B20 and poon oil respectively and explained pressure reduction with the expected effects of poon oil viscosity on fuel spray and reduction of air entrainment and fuel/air mixing rates. However, the cylinder peak pressure of biodiesel fuels was lower than that of the pure biodiesel or was close to diesel fuel due to the improvement in the preparation of the air/fuel mixture as a result of the low fuel viscosity (Maria *et al.*, 1998; and Srivastava and Verma, 2007).

The heat release rate is used to identify the start of combustion, the fraction of fuel burned in the premixed mode and differences in combustion rates of fuels (Banapurmatha *et al.*, 2008). Analysis of cylinder pressure data to obtain the heat release rate for WPLME and its blends were conducted. Figure 9 shows the heat release rate indicating that the ignition delay for WPLME 100 and its blends was shorter than that of diesel. The maximum heat release rates of standard diesel, WPLME 25, WPLME 50, WPLME 75 and WPLME 100 are

Figure 9: Variation of Heat Release with Crank Angle



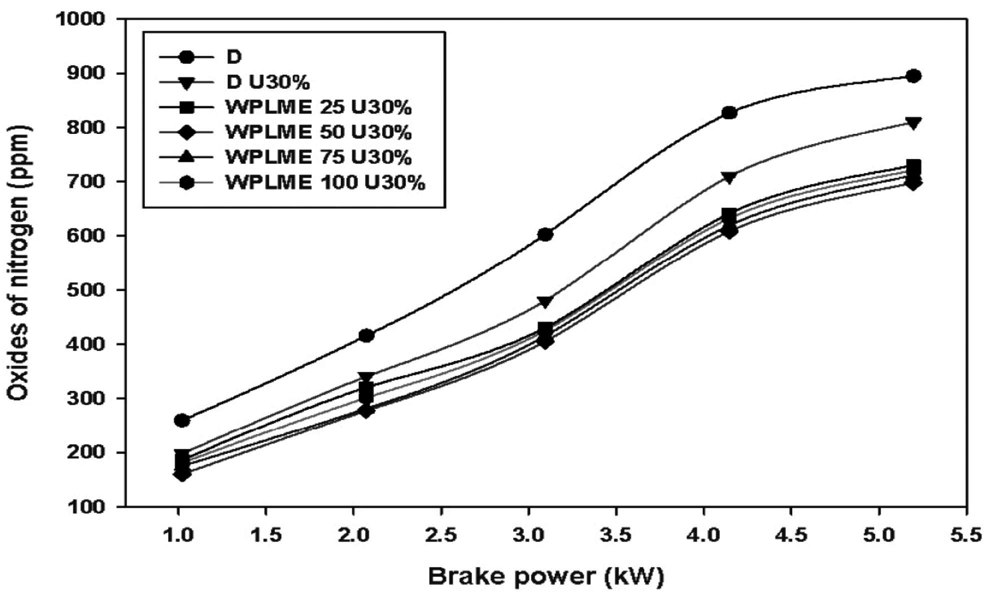
105.733, 100.761, 86.780, 91.914 and 78.322 respectively. This is because, as a consequence of the shorter ignition delay, the premixed combustion phase for WPLME and its blends are less intense. On the other side increased accumulation of fuel during the relatively longer delay period resulted in higher rate of heat release while running with diesel. Because of the shorter delay, peak heat release rate occurs earlier for WPLME and its blends in comparison with diesel. For WPLME 25, WPLME 50, WPLME 75 blends, the heat release peak was higher than that of WPLME 100 due to reduced viscosity and better spray formation. The less intense premixed combustion phase was due to the shorter ignition delay of WPLME compared with that of diesel. This was probably the result of the chemical reactions during the injection of WPLME at high temperature. Similar conclusions were drawn by Ozsezen *et al.* (2009) and explained that the crude sunflower-oil exhibited, in average, 2.080 longer ignition delay due to its lower cetane number when compared with diesel fuel.

Use of SCR Technology

NOx emissions of WPLME and its blends are slightly higher than those of diesel fuel. The higher temperature of combustion and the presence of oxygen with WPLME cause higher NOx emissions, especially at high engine loads. However, the WPLME with a higher cetane number has NOx emission compared with the diesel fuel. To reduce the NOx emission, urea is sprayed in the exhaust pipe (SCR). Selective catalytic reduction means converting Nitrogen Oxide (NO) into nitrogen (N_2).The various percentages of urea were sprayed in the engine exhaust to find the optimum percentage. It is found that 30% urea with 70% water gives the maximum reduction of NOx emission. Based on the trials, experimental work was carried out with WPLME and its blends.

Figure 10 shows the variation of NOx with brake power with effect of urea. The significant

Figure 10: Variation of Oxides of Nitrogen with Brake Power Effect of Urea 30%



reduction in NOx emission was identified by the use of SCR technology. SCR technology is to permit Nitrogen oxide wherein reactions to take place in an oxidizing atmosphere. It is called "selective" because it reduces levels of NOx using ammonia as a reductant within a catalyst system. The reducing agent reacts with NOx to convert the pollutants into Nitrogen, Water and tiny amounts of Carbon dioxide. The NOx reduction reaction takes place as the gases pass through the catalyst chamber. Urea is injected and mixed with the gases. The chemical equation for a stoichiometric reaction is:

$$4NO + 2(NH_2)_2CO + O_2 \rightarrow 4N_2 + 4H_2O + 2CO_2$$

The ideal reaction has an optimum temperature range between 630 K and 720 K. But it can operate from 500 K to 720 K with longer residence times (Rakopoulos *et al.*, 2008; and Prabhakar *et al.*). The minimum effective temperature depends on the various fuels, gas constituents and catalyst geometry.

CONCLUSION

The performance, emissions and combustion characteristics of a direct injection compression ignition engine fueled with WPLME and its blends have been analysed and compared with those of the diesel fuel. The WPLME is produced from waste pork lard by transesterification. The test properties of WPLME demonstrate that almost all the important properties of WPLME are in close agreement with those of diesel engines. Diesel engine can perform satisfactorily on WPLME and its blends with diesel fuel without any engine modifications.

The SFC increases with increase in percentage of WPLME in the blends due to the lower heating value of WPLME. The BTE of WPLME and its blends are slightly lower than that of diesel at high engine loads and remain almost same at lower engine loads.

The higher oxygen content in the WPLME results in better combustion and increases the combustion chamber temperature, which leads to higher NOx emissions, especially at high engine loads. The significant improvement in reduction of NOx and a minor increase in CO were identified by the use of Selective Catalytic Reduction (SCR).

CO emissions with WPLME and its blends have little difference from diesel fuel. It is also observed that there is a significant reduction in HC (up to 16%) and smoke emissions (up to 17%) at high engine loads.

The combustion starts earlier for WPLME and its blends than diesel. The peak cylinder pressure of WPLME and its blends are higher than that of diesel fuel and almost identical at high engine loads. The peak pressure rise rate and peak heat release rate of WPLME are higher than those of diesel fuel at low engine loads, but inversely at high engine loads.

The study suggests that excess oxygen contents of WPLME play a key role in engine performance and WPLME is proved to be a potential fuel for complete or partial replacement of diesel fuel.

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APPENDIX

Definitions/Abbreviations	
SFC	Specific Fuel Consumption
BTE	Brake Thermal Efficiency
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DI	Direct Injection
HC	Hydrocarbons
WPLME	Waste Pork Lard Methyl Ester
NOx	Nitrogen Oxides
WPLME 25	25% WPLME + 75% Diesel
WPLME 50	50% WPLME + 50% Diesel
WPLME 75	75% WPLME + 25% Diesel
WPLME 100	100% WPLME
SCR	Selective Catalytic Reduction