Characterisation of Diethyl ether Blended Waste Plastic Oil used as a Fuel in Variable Compression Ratio Engine – An Experimental Study

Budda Govinda Rao*, Yellapragada Datta Bharadwaz and Pittala Sai Radha Krishna
Department of Mechanical Engineering, Gayatri Vidya Parishad College of Engineering (A), Visakhapatnam, INDIA
*govind_budda@rediffmail.com

Abstract
This study is aimed at investigating the effect of compression ratio on the performance and emission characteristics of a single cylinder four stroke variable compression ratio engine fuelled with diethyl ether blended waste plastic oil. Various proportions of diethyl ether blended waste plastic oil P95DEE5 (95% waste plastic oil and 5%diethyl-ether), P90DEE10 (90% waste plastic oil and 10% diethyl ether) and 100% plastic oil (P100) are used for conducting the performance tests.

From the experimental investigation, it is found that Brake thermal efficiency is higher for P90 DEE10 blend with compression ratio 18 at brake power 2.85 kW. Brake specific fuel consumption is lower for P90 DEE10 blend with compression ratio 18 at brake power 2.85 kW.CO emissions are lower for P90 DEE10 blend with compression ratio 18 at brake power 2.85 kW. HC emissions are higher for the P90 DEE10 blend when compared to all the test fuels used. NOx emissions are lowered for P90 DEE10 blend when compared to all test fuels with compression ratio 18 at brake power 2.85 kW.

Keywords: Variable Compression Ratio (VCR), Waste Plastic Oil (WPO), Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC), Emissions.

Introduction

The number of automobiles running on petroleum products has grown to a large extent in this modern world for transportation. The petroleum products are derived from the fossil oil which is a non-renewable source of energy. Using the petroleum products as a source of energy for automobiles increasing its consumption and depleting the fossil fuels and reduces to zero level in the future. So, many experimental studies are going on to run the engine with alternate fuels like biodiesel, vegetable oil, rice bran oil, soya bean oil, water emulsions etc. and to have the same efficiency or higher. The present study deals with waste plastic oil blended with diethyl ethers an alternative fuel for the diesel engines.

Devraj et al[1] studied the Performance, Emission and Combustion characteristics of waste plastic pyrolysis oil blended with diethyl ether (DEE) in two different proportions with 5% and 10% used as a fuel in single cylinder water-cooled diesel engine. It was observed that Brake power for DEE is less than that of waste plastic oil but brake thermal efficiency (BTE) for 10% DEE at full load is higher. There is a reduction in emissions of both CO and NOx but there is a slight increase in hydrocarbon emissions.

Kaimal and Vijayabalan[2] Carried out the experimental investigation using plastic oil blended with DEE in three different proportions 5%, 10% and 15% as a fuel in high-speed single cylinder direct injection diesel engine. Experiments revealed that plastic oil DEE blends have lowered brake specific energy consumption (BSEC) and there is improvement in brake thermal efficiency (BTE). Overall, 15% blended plastic oil with DEE gives better performance and lower CO emissions with a reduction in smoke by 25% and NOx by 29%.

Hariharan et al[3] carried out the experimental investigation on single cylinder four-stroke direct injection diesel engine using Tyre pyrolysis oil (TPO) as main fuel and DEE as an additive by admitting it with intake air at flow rates 65g/h, 130g/h and 170g/h. Experimental results show that TPO-DEE at130g/h shows better performance with high peak pressure than diesel fuel (DF) at full load but ignition delay is longer by 2.8^{o} crank angle than DF thereby reducing the thermal efficiency by 2.5%. NOx emissions are reduced but there is a slight increase in smoke, HC, carbon emissions than DF.

Bridjesh et al[4] carried out the experimental investigation on a single cylinder constant speed four stroke diesel engine using 2-Methoxy ethyl acetate (MEA) and DEE as additives with waste plastic oil-diesel blends. The fuels tested consists of 50% diesel with (a) 50% waste plastic oil, (b) 40% waste plastic oil and 10% MEA(c) 40% waste plastic oil and 10% DEE. The author concluded that BTE has increased for all the test fuels used and it is more for the fuel with MEA as an additive. The emissions of hydrocarbon, carbon monoxide and smoke were decreased for the MEA and DEE additives. BSFC has increased for additively added test fuels.

Sezer[5] studied the thermodynamic, performance and emission characteristics of a diesel engine using dimethyl ether (DME) and diethyl ether (DEE) as test fuels. These test fuels showed lower pressure and temperature in cylinder than diesel due to this there is an increase in the specific fuel consumption for the same injection rate. Test fuels showed declination in brake power by 32.1% and 19.4% respectively for DME and DEE respectively and increase in brake specific fuel consumption by 47.1% and 24.7% for DME and DEE respectively.

Ibrahim[6] used DEE as an additive to study the performance of C.I engine operated with the diesel-biodiesel blend. The DEE is added in two proportions of 5% and 10% and results are analysed. It is observed that the DEE added in 5% showed better results when compared with diesel-biodiesel blend with 10% DEE. With 5% DEE brake specific fuel consumption decreased and thermal efficiency increased whereas for 10% DEE thermal efficiency decreased.

Mohebbi et al[7] studied the combustion characteristics of a reactivity controlled compression ignition (RCCI) engine using ethanol and DEE mixture blended with diesel used as a test fuel in the engine. The experiment is conducted using DEE with 20% and 40% by volume mixed with ethanol were injected into the intake port. Higher ignition delay is observed at 40% DEE. The addition of DEE has improved the IMEP. DEE enhanced the oxidation of HC which intern reduced the HC emissions but particulate emissions are higher.

Paul et al[8] have studied the performance and emission characteristics of a single cylinder four-stroke diesel engine using two blends of diesel-DEE and four blends of diesel-DEE-ethanol blends as test fuels. This study shows that brake thermal efficiency of the engine increased with 5% DEE addition but decreased with 10% concentration, increase in DEE additive increases BSEC and decreases the particulate matter, NOx emissions, CO emissions and HC emissions. Among diesel-DEE-ethanol blends, the blend with 10% DEE and 10% ethanol shows better performance in all the aspects.

Srihari et al[9] have studied the performance and emission characteristics of single cylinder premixed charged compression ignition (PCCI) engine fuelled with 20% cottonseed oil blended diesel with 5%, 10%, 15% of DEE as an additive. Experiments concluded that addition of DEE improves fuel properties such as density, cetane number, auto ignition temperature. Test fuel with 15% DEE shows higher cylinder pressure and shows a significant reduction in NOx, HC, CO and smoke. BSFC and BTE for 15% DEE are found to be higher than other test fuels.

Ibrahim[10] has studied the performance, combustion characteristics of a single cylinder diesel engine fuelled with different ratios of DEE and diesel (with a maximum DEE proportion of 15% by volume) experimentally and compared with diesel fuel. It is observed that with 15% DEE the brake thermal efficiency is increased and there is also increase in the specific fuel consumption, maximum cylinder pressure, maximum heat release rate compared to diesel engine at all engine load conditions.

Ananthakumar et al[11] carried out an experimental investigation on variable compression engine fuelled with diesel, waste plastic oil blend along with DEE additive to analyse its performance, combustion and emission characteristics. The waste plastic oil is mixed with diesel in three proportions with 2.5%, 7.5% and 12.5% by volume that contains DEE at a volume of 2.5% each. Adding DEE increases BTE of all test fuels compared to diesel and pure plastic oil but SFC is higher compared to diesel. emissions of CO_2 are decreased, unburned HC, smoke emissions of test fuels are closer to diesel. However, emissions of CO, NOx, are high for the WPO and its blends.

From the literature review, it is evident that waste plastic oil can be used as a fuel in diesel engine, using only waste plastic oil as a fuel decreases the efficiency and increases emissions. Using waste plastic oil with DEE improves brake thermal efficiency and reduction in emissions of CO, NOx and slight increase in unburnt hydrocarbons. So, in order to reduce the emissions and to improve the efficiency of the waste plastic oil it is blended with diethyl ether along with waste plastic oil.

Material and Methods

Blends and fuels used: In the present work, waste plastic oil is mixed with diethyl ether in two proportions (i.e., 5% and 10%) to form blends. Blends used in this experimental work are as follows, P95DEE5 (95% plastic oil + 5% diethyl ether) P90DEE10 (90 % plastic oil + 10% diethyl ether) above mixtures are prepared based on percentage by volume basis. Along with these blends waste plastic oil and diesel are used.

Experimental Setup and Procedure: The experimental setup consists of a single cylinder four-stroke diesel engine. It has a special tilting cylinder block arrangement; which is useful for altering the compression ratio without changing the combustion chamber geometry. Hence, it is regarded as a variable compression ratio (VCR) engine. VCR engine is connected to an eddy current type dynamometer for loading purpose. The experimental setup is equipped with online DAQ for measuring various performance parameters of the engine. Experimentation is carried out with test fuels such as WPO, P90DEE10, P95DEE5 and Diesel.

All the fuels are tested for their performance and emission characteristics by varying loads and compression ratios in the range of 2 to10 kg and 16 to18 respectively. A Labview based IC Engine software is used to record the performance parameters such as brake-power, brake specific fuel consumption, brake thermal efficiency, exhaust gas temperature, etc.,. Five gas analyzer is used to measure the emissions from various test fuels used in the experiment.

Result and Discussion

Brake Thermal Efficiency: The below figures 2(a), 2(b) and 2(c) shows the variation of brake thermal efficiency of the fuels Diesel, WPO, P95 DEE5 and P90 DEE10 tested with VCR engine. The variation in brake power for compression ratio from 16 to 18.

Table 1
Properties of Blends

Properties	P95DEE5	P90DEE10	P100	Diesel
Calorific value (KJ/kg)	44506.1	42622	45187.2	44798.1
Moisture (%)	0.019	0.022	0.21	-
Sulphur (%)	0.48	0.49	0.12	-
Flash point (^{0}C)	66	62	28.15	-
Pour point (^{0}C)	6	4	24	-
Total sediments (%)	0.008	0.08	0.087	-
Viscosity (cSt)	1.09	1.04	2.64	1.9
Density(kg/m^3)	774	795	801.3	832

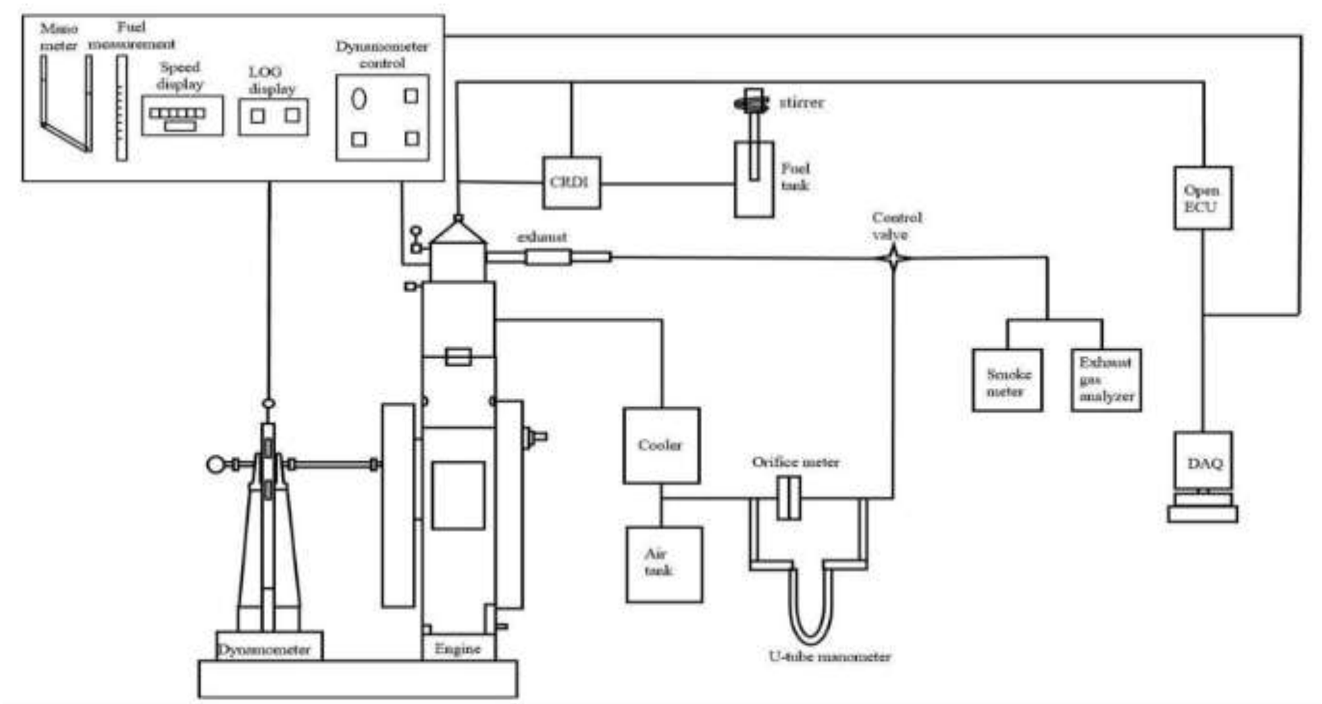

Fig. 1: Schematic layout of the engine setup.

Table 2
Specifications of engine

Engine model	Kirloskar
Type	4-stroke, naturally aspirated and water cooled
Number of cylinders	1
Bore	87.5 mm
Stroke	110 mm
Cylinder volume	661 cc
Range of compression ratio	12:1 to 18:1
Injection timing	25 degrees BTDC
Injection pressure	200 bar
Maximum power	5.2 kW at 1500 rpm
Injection nozzle	3 hole

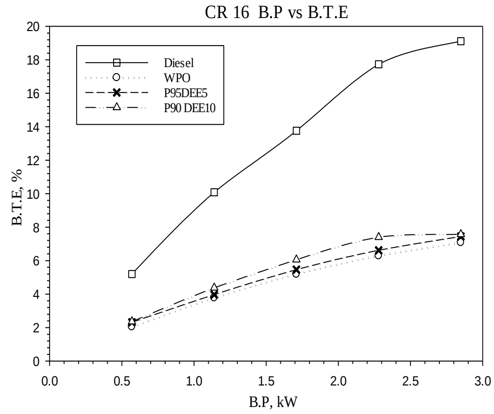

Fig. 2(a): Variation of BTE with B.P for CR 16 for DEE blends

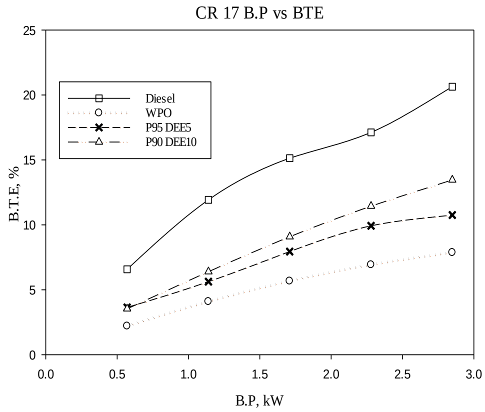

Fig. 2(b): Variation of BTE with B.P for CR 17 for DEE blends

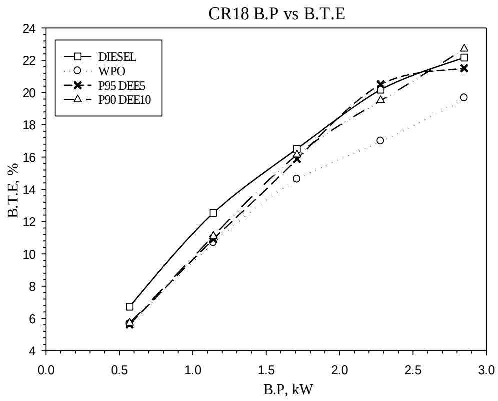

Fig. 2(c): Variation of BTE with B.P for CR 18 for DEE blends

The higher brake thermal efficiencies of the diesel, waste plastic oil, P95 DEE5 and P90 DEE10 are 22.17%, 19.67%, 21.50% and 22.70% respectively are observed at compression ratio 18 and with brake power 2.85 kW. The efficiencies of the blends are increased by 16%, 117%,188% and 200% for diesel, waste plastic oil, P95 DEE5 and P90 DEE10 respectively for compression ratio 18 compared to compression ratio 16 at brake power 2.85 kW. The brake thermal efficiency of waste plastic oil is increased with the percentage of diethyl ether in it. The brake thermal efficiency of waste plastic oil is increased by 15% and 9% on addition of 10% and 5% DEE respectively with compression ratio 18 and at brake power 2.85 kW. Moreover, brake thermal efficiency of P90DEE10 at compression ratio 18 is slightly more than diesel compared to compression ratio 16 at brake power 2.85 kW. The BTE increases with DEE percentage because DEE improves the cetane number of the fuel and provides excess oxygen into the cylinder for better combustion and better thermal efficiency.

Brake Specific Fuel Consumption (BSFC):

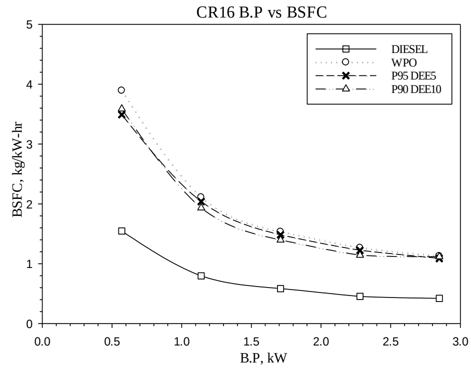

Fig. 3(a): Variation of BSFC with B.P for CR 16 for DEE blends

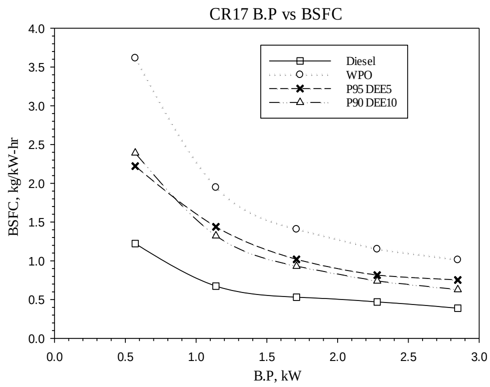

Fig. 3(b): Variation of BSFC with B.P for CR 17 for DEE blends

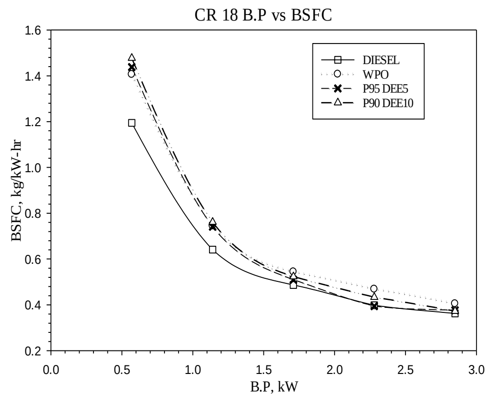

Fig. 3(c): Variation of BSFC with B.P for CR 18 for DEE blends

The above figures 3(a), 3(b) and 3(c) shows the variation of brake specific fuel consumption of the fuels Diesel, WPO, P95 DEE5, P90 DEE10 tested with VCR engine with variation in brake power for compression ratio from 16 to 18. The brake specific fuel consumption at compression ratio 18 with brake power 2.85kW for diesel, waste plastic oil, P95 DEE5 and P90 DEE10 are 0.36, 0.40, 0.38 and 0.37 kg/kW-hr respectively. Moreover, it is observed that P90 DEE10 has lower brake specific consumption and almost equal to diesel.

The brake specific fuel consumption for Diesel, WPO, P95 DEE5 and P90 DEE10 are decreased by 13.8%, 64%, 65.38% and 66.66% respectively from CR16 to CR18 at 2.85kW brake power. For P95 DEE5 the BSFC is reduced by 7.135% and for P90 DEE10 the brake specific fuel consumption is reduced by 8.148% when compared to P100 with compression ratio 18 at brake power 2.85 kW. The higher amount of diethyl ether content reduces brake specific fuel consumption. This is because of the extra oxygen content in diethyl ether, high latent heat of diethyl ether leads to higher heat in cylinder that helps for complete combustion of fuel.

Carbon monoxide (CO) emissions: The following figures 4(a), 4(b) and 4(c) shows the variation of CO emissions for Diesel, WPO, P95 DEE5 and P90 DEE10 along with brake power for compression ratio from 16 to 18. The CO emissions first decreases and then increases with increase in the brake power. The percentage of CO emissions at CR 18 and with brake power 1.71kW for diesel, waste plastic oil, P95 DEE5 and P90 DEE10 are lower and they are observed as 0.04%, 0.23%, 0.18% and 0.12% respectively. This is because at higher brake power higher loads are observed where decreases amount of entering air increases and CO emissions but further increase in brake power increases load reduces the rate of combustion.

The CO emissions are greatly reduced with the increase in the compression ratio for all the test fuels used for the study. For Diesel, WPO, P95 DEE5 and P90DEE10 the CO emissions are reduced by 82%, 97%, 97.65% and 96.41% respectively from CR 16 to CR18 at brake power 2.85kW. The percentage of CO emissions at compression ratio 18 with brake power 2.85kW for diesel, waste plastic oil, P95 DEE5 and P90 DEE10 are 0.085%, 0.25%, 0.19% and 0.16%. This is due to the fact that with increase in the compression ratio reduces the ignition delay which leads to higher temperatures and higher heat release in cylinder which leads to oxidation of CO to CO_2. Hence CO emissions are reduced.

The CO emissions are very much higher for the waste plastic oil but when it is mixed with diethyl ether, the CO emissions are reduced by 23% for P95 DEE5 and by 34% for P90 DEE10 compared to plastic oil at compression ratio 18 with brake power 2.85kW. The percentage of CO emissions decreases as the content of diethyl ether increases in the fuel blend this is due to the supply of excess oxygen through diethyl ether and this excess oxygen from diethyl ether increase combustion and reduces CO by oxidation.

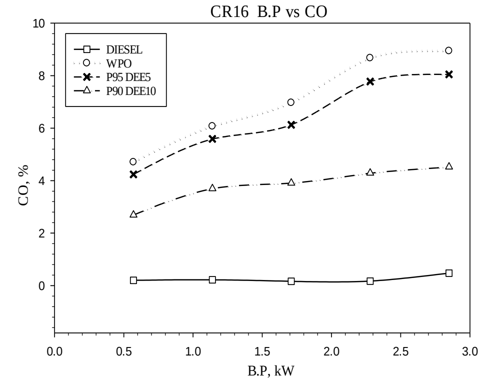

Fig. 4(a): Variation of CO emissions with B.P for CR 16 for DEE blends.

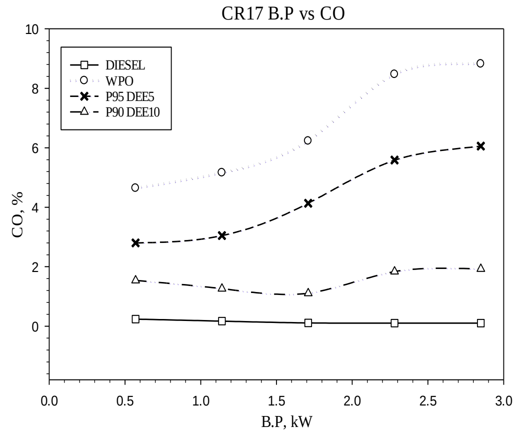

Fig. 4(b): Variation of CO emissions with B.P for CR 17 for DEE blends.

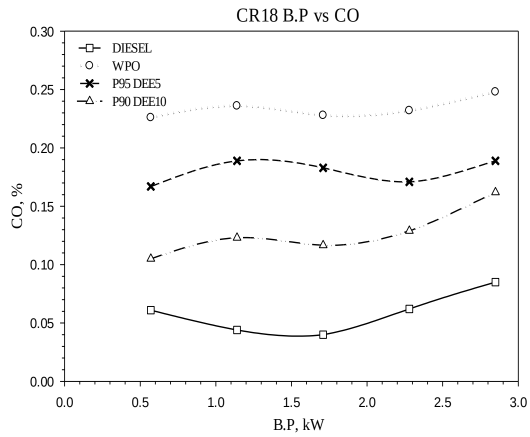

Fig. 4(c): Variation of CO emissions with B.P for CR 18 for DEE blends

Hydrocarbon emissions (HC): The following figures 5(a), 5(b) and 5(c) shows the variation of HC emissions for Diesel, WPO, P95 DEE5 and P90 DEE10 along with brake power for compression ratio from 16 to 18. The hydrocarbon emissions decrease as the brake power increases for P95 DEE5, P90 DEE10 but hydrocarbon emissions increase for the diesel, waste plastic oil as the brake power increases.

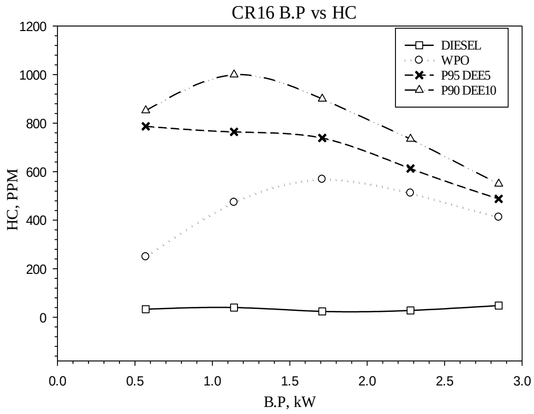

Fig. 5(a): Variation of HC emissions with B.P for CR 16 for DEE blends.

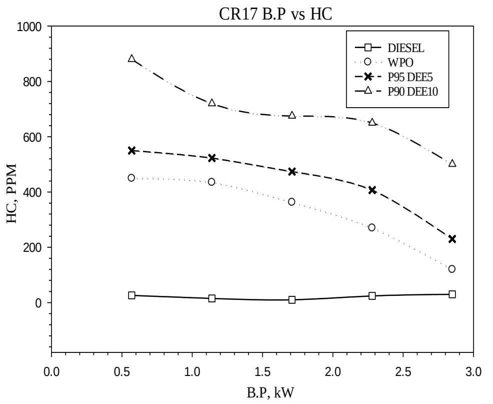

Fig. 5(b): Variation of HC emissions with B.P for CR 17 for DEE blends.

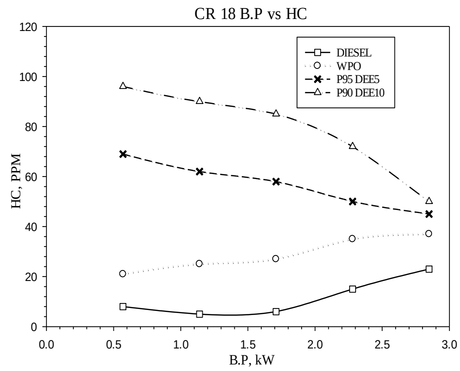

Fig. 5(c): Variation of HC emissions with B.P for CR 18 for DEE blends

This is due to the wall quenching and less amount of oxygen in cylinder for diesel, waste plastic oil at higher brake power. The HC emissions at compression ratio 18 and brake power 2.85kW are 23, 37, 45, 50 PPM for diesel, waste plastic oil, P95 DEE5 and P90 DEE10 respectively. The HC emissions for diethyl ether blends are higher compared to diesel and WPO due to the addition of more C-H bonds to the fuel blends through diethyl ether. As the Compression ratio increases, the declination of Hydrocarbon emissions is observed. The HC emissions are reduced by 52.08%, 91.04%, 90.77% and 90.90% for Diesel, WPO, P95 DEE5 and P90 DEE10 respectively for compression ratio 18 compared to compression ratio 16 at brake power 2.85 kW. This is because the higher temperatures produced during the higher compression ratios and lower ignition delay helps the fuel to burn completely. The HC emissions of waste plastic oil are increasing with the addition of diethyl ether to it.

The HC emissions are increased by 17.77% for P95 DEE5 and by 35.135% for P90 DEE10 when compared with waste plastic oil with compression ratio 18 at brake power 2.85 kW. This is due to the addition of diethyl ether increases the number of C-H bonds and high latent heat of diethyl ether also helps to increase HC emissions.

The following figures 6(a), 6(b) and 6(c) show the variation of exhaust gas temperature emissions for Diesel, WPO, P95 DEE5, and P90 DEE10 along with brake power for compression ratio 16 to18.

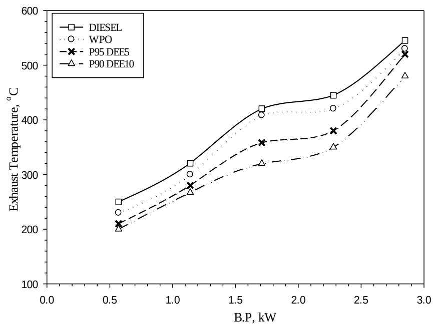

Fig. 6(a): Variation of Exhaust gas temperature with B.P for CR 16 for DEE blends

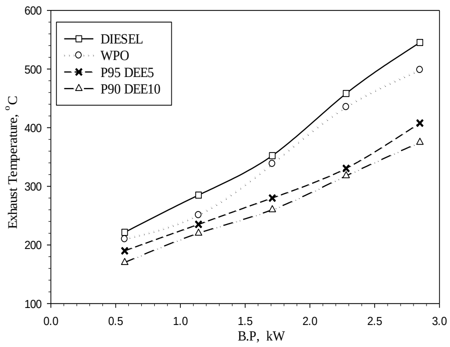

Fig. 6 (b): Variation of Exhaust gas temperature with B.P for CR 17 for DEE blends.

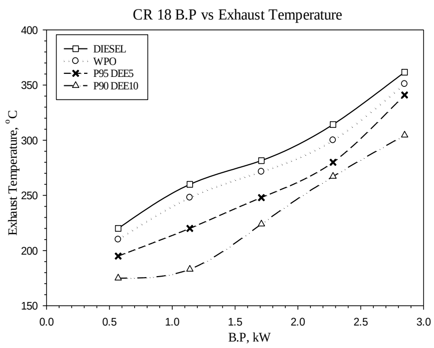

Fig. 6 (c): Variation of Exhaust gas temperature with B.P for CR 18 for DEE blends

Exhaust gas temperature is the measure of temperature exhaust gas at out let of the exhaust tail pipe. As the brake power increases the exhaust temperatures in the tail pipe also increases. High brake power and high speeds of the engine produces high exhaust gas temperatures. The exhaust gas temperatures at compression ratio 18 with brake power 2.85kW are 545^0C, 499^0C, 408^0C and 375^0C for Diesel, Waste plastic oil, P95 DEE5 and P90 DEE10 respectively.

At higher brake powers the amount of air throttling into the cylinder increases and complete combustion of the fuel takes place that results in high heat and high exhaust gas temperatures. The exhaust gas temperature is decreased by 33.675%, 33.77%, 34.42% and 36.53% for Diesel, WPO, P95 DEE5 and P90 DEE10 respectively for CR18 compared to CR16.This is due to the more heat energy developed at higher compression ratio is utilized effectively for developing brake power and less ignition lag are reasons for less exhaust gas temperatures. For the 100% waste plastic oil the exhaust gas temperature is less than the diesel but when it is mixed with diethyl ether the exhaust gas temperatures are further decreased.

The exhaust gas temperatures of waste plastic oil are reduced with the increase in the content of diethyl ether in it. The exhaust gas temperature is decreased by 2.85% and 13.21% for P95 DEE5 and P90 DEE10 respectively. When compared to diesel the exhaust gas temperatures of P90 DEE10 is decreased by 15.77% at CR 18 at brake power 2.85 kW. The exhaust gas temperature is decreasing because the latent heat of evaporation of diethyl ether is more than diesel which reduces exhaust gas temperature for DEE blends.

Nitrogen Oxide (NO_x) emissions: The following figures 7(a), 7(b) and 7(c) show the variation of nitrogen oxide emissions for Diesel, WPO, P95 DEE5 and P90 DEE10 along with brake power for compression ratio 16 to18. With the increase in the brake power, the nitrogen oxide emissions are increasing. The nitrogen oxide emissions for compression ratio18 with brake power 2.85 kW are 499, 480, 440 and 425 PPM for Diesel, waste plastic oil, P95 DEE5 and P90 DEE10 respectively.

The nitrogen oxides emissions are increasing due to the higher temperatures produced at higher brake powers increase the nitrogen oxide emissions. As the compression ratio increases NOx emissions are also increasing. NOx emissions are increased by 24.75%, 29.03%, 26.8% and 26.48% for Diesel, WPO, P95 DEE5 and P90 DEE10 respectively for compression ratio 18 compared to compression ratio 16 at brake power 2.85 kW.

Lower ignition delay and a high heat release rate favors the higher temperatures at higher compression ratios. This high temperature favors the oxidation the nitrogen in air to nitrogen oxides. As the percentage of diethyl ether increases in waste plastic oil the amount of nitrogen oxide emissions is decreased by 8.33% for 5% DEE and by 11.458% for 10% DEE addition when compared to waste plastic oil with compression ratio 18 at brake power 2.85kW. The nitrogen oxide emissions for compression ratio 18 with brake power 2.85 kW are 499, 480, 440 and 425 PPM for Diesel, waste plastic oil, P95 DEE5 and P90 DEE10 respectively. For P90 DEE10 the Nitrogen oxide formations are slightly lesser than diesel this is due to the high latent heat of vaporization of DEE when compared to other fuels.

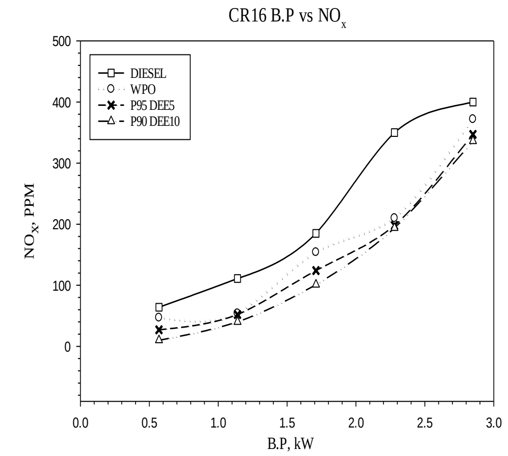

Fig. 7(a): Variation of NO_x emissions with B.P for CR 16 for DEE blends

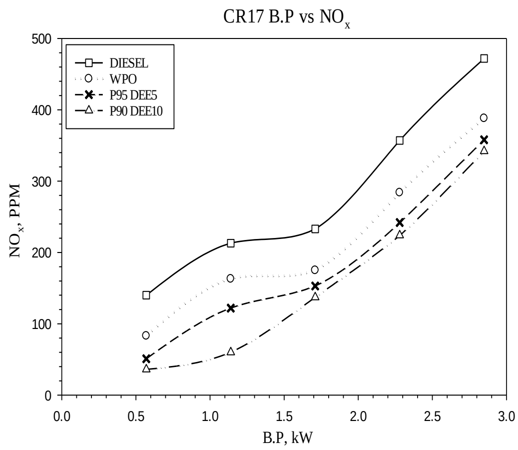

Fig. 7(b): Variation of NO_x emissions with B.P for CR 17 for DEE blends.

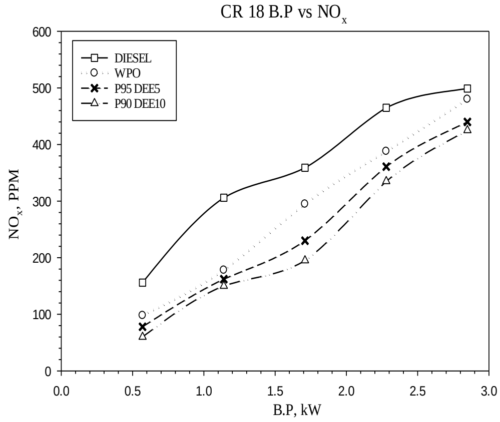

Fig. 7(c): Variation of NO_x emissions with B.P for CR 18 for DEE blends

Conclusion

Based on the experimental results, the following major conclusions have been drawn:

- Brake thermal efficiency is higher for P90 DEE10 blend with compression ratio 18 at brake power 2.85kW. It is 15% higher than the plastic oil (P100) and almost equal to the efficiency of diesel.
- Brake specific fuel consumption of P90 DEE10 blend is lowered by 66.66% for compression ratio 18 compared to compression ratio 16 at 2.85 brake power.
- Brake specific fuel consumption is lower for P90 DEE10 blend with compression ratio 18 at brake power 2.85kW. It is 8% lower than the plastic oil (P100) and almost equal to the diesel.
- CO emissions of P90 DEE10 blend are reduced by 96.4% for CR18 compared to CR16 at brake power 2.85 kW.
- CO emissions are lower for P90 DEE10 blend with compression ratio 18 at brake power 2.85kW it is lowered by 34% compared to the plastic oil (P100) but when compared to diesel P90 DEE10 has 90% higher CO emissions.
- NOx emissions of P90 DEE10 blend are reduced by 26.5% for CR18 compared to CR16 at brake power 2.85 kW.
- NOx emissions are lowered for P90 DEE10 blend when compared to all test fuels with compression ratio 18 at brake power 2.85 kw it is lowered by 11.458% and 15% compared to plastic oil (P100) and diesel respectively.

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