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EFFECT OF ADDITIVE ON THE PERFORMANCE, EMISSION AND COMBUSTION CHARACTERISTICS OF A DIESEL ENGINE RUN BY DIESEL-PAPAYA METHYL ESTER BLENDS

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ABSTRACT

In this investigation, the effect of Di-tert butyl peroxide (DTBP) as additive on the performance, exhaust emissions and combustion characteristics of a single cylinder direct injection compression ignition engine fuelled with papaya seed oil methyl ester (PSME) has been studied. Base data was generated on a 5.2 kW single-cylinder diesel engine with standard diesel fuel. PSME-diesel blends ranging from 25% to 100% of PSME with diesel fuel by volume were prepared and tested in the diesel engine without and with the addition of DTBP. Improved performance reduced NOx emissions with slight increase in smoke density and HC emissions were observed for PSME blends with additive than those for PSME blends without additive. Earlier heat release and increase in cylinder pressure were also observed for blends with additive.

Key words: Papaya seed oil, Biodiesel blend, Additive, Diesel engine, Performance and emission analysis.

INTRODUCTION

Due to the increasing concern about the fuel shortage and environmental protection several researches has been made on improving fuel economy and decreasing exhaust emission. Limited resources of petroleum oil forced the researchers to develop the use of alternative fuel without much modification in the existing engine. Vegetable oils are the better alternate for diesel fuel since it is having long chain hydrocarbon structure, but the properties like high density, high viscosity, lower calorific value and more molecular weight

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lower their thermal efficiency. However, these problems can be rectified by transesterification, dilution and cracking[1]. Biodiesel produced by a chemical reaction called transesterification where vegetable oil react with methanol in the presence of a catalyst to produce ester (biodiesel) and glycerine as a by-product is an alternative for diesel fuel. A significant advantage of biodiesel over diesel is that it contains molecular oxygen, and almost similar cetane number[2-4]. Knothe et al.[5] reported that density, cetane number, hydrocarbon chain length and oxygen content of the biodiesel influence the emissions of a diesel engine driven by biodiesel. Trapel and Mayer[6] proved that the performance and efficiency of the engine increases significantly with the increase in biodiesel content with reduction in CO and HC emissions with a penalty of increase in NOx emissions in the exhaust gas and they suggested that, the higher NOx emissions can be reduced by water injection. Rajan and Kumar[7] have investigated the performance of a diesel engine and observed increase in brake thermal efficiency and decrease in CO and smoke emissions with an increase in NOx emission at full load using biodiesel compared to diesel fuel. Hegde and Rao[8] observed higher brake thermal efficiency and lower BSFC for a diesel engine fuelled with Calophyllum Inophyllum (punnai) biodiesel and additives. Lahane and Subramanian[9] observed that diesel engine driven by B20 blend biodiesel increase the performance parameters and lower the emissions. Saravanan et al.[10] reported that Mahua oil methyl ester gives lower emissions as compared with neat diesel in a DI diesel engine. Gattamaneni et al.[11] investigated the performance of diesel engine with rice bran oil methyl ester and reported that significant improvement in CO, HC and soot emissions with slight increase of NOx were observed along with ignition delay and peak heat release rate and the increase is high with increase in biodiesel content compared to diesel. Balusamy and Marappan[12] reported the methyl ester of Thevetia peruviana seed oil results in lower emission of CO, HC and higher NOx as compared to that of diesel. Qi et al.[13] reported that the peak pressure rise and maximum heat release rate are lower for biodiesel during premixed combustion. Godiganur et al.[14] reported that 20% addition of Mahua oil methyl ester with 80% diesel gives better performance and lower emissions in a heavy duty diesel engine.

Papaya oil produced from papaya seed is non edible, yellowish, and sticky have the potential to be used as alternative feedstock for biodiesel production. Wong and Othman[15] investigated the potential of papaya and rambutan seed oils for biodiesel production and reported that properties of biodiesel produced using immobilized lipase such as density; acid value, iodine value and cetane number were found to meet the European Standard of Biodiesel. Malacrida et al.[16] investigated the physicochemical characteristics like fatty acid, to copherol, and carotenoid composition of papaya seed oil and reported that the physicochemical properties of the papaya seed oil are in agreement with those of conventional seed oils. They also reported that Papaya seed oil has very good oxidative stability without added synthetic antioxidants and hence, the potential of the papaya seeds for oil production will be good. Prabharan et al.[17] investigated the performance, combustion and emission characteristics of DI diesel engine driven by Papaya Methyl Ester and reported that bio-diesel operating with standard injection timing shows increase in brake thermal efficiency when compared to that of diesel fuel at the expense of higher NOx. Literature review reveals that blending of 20% biodiesel with petroleum diesel will cause a significant reduction in particulate emissions but, with an increase in NOx emissions by 1 to 3 percent. Sundar Raj and Sendilvelan[18] investigated performance and emission parameters of a diesel engine by adding 3-Pentanone ($C_5H_{10}O$) and Methyl anon ($C_7H_{12}O$) with diesel fuel as oxygenated fuel additives and found that addition of oxygenated hydrocarbons in suitable ratio increased the brake thermal efficiency and reduced the soot with respect to the availability of oxygen content in the fuel and EGR (exhaust gas recirculation) reduces NOx emissions of the oxygenated fuels over 55% without any adverse effect on fuel economy and efficiency. McCormick et al.[19] examined a number of approaches for NOx reduction from biodiesel and reported that the cetane enhancers DTBP and EHN are effective at reducing NOx from biodiesel. Vedharaj et al.[20] reported that kapok biodiesel with 1,4-Dioxane as additive improved the brake thermal efficiency with reduced emissions for B25 blends.

The objective of the present study is to analyze the effect of DTBP added with the PSME biodiesel as an additive on the performance, emission and combustion characteristics of a diesel engine with various blends and to compare the results with neat diesel.

EXPERIMENTAL

Materials and methods

Fuel preparation

Papaya seed oil having high viscosity is transeterified with methanol in the presence of catalyst potassium hydroxide (KOH) to chemically break the molecule and to form methyl ester-biodiesel (PSME). The PSME prepared is then filtered to separate it from glycerol. The properties and compositions of neat fuel and PSME blends without and with additive DTBP were determined as per the methods approved by Bureau of Indian Standards and the values of B100 and optimum blend B25 are compared with neat diesel fuel in Table 1.

Table 1: Properties of PSME in comparison with diesel

Properties	Diesel	B100	B100 with additive	B25	B25 with Additive
Specific gravity @ 15°C	0.829	0.8811	0.8890	0.846	0.835
Kinematic viscosity @ 40°C in cSt	2.57	4.52	4.48	3.95	3.88
Flash point	53°C	159°C	91°C	132°C	82°C
Fire point	59°C	171°C	103°C	119°C	92°C
Calorific value in kJ/kg	44645	42460	42790	42115	42197
Cetane number	51	53	52	52	52

Parameter tested and experimental procedure

A Kirloskar (TV-1) made single cylinder diesel engine developing a power output of 5.2 kW at 1500 rpm with a water cooled eddy current dynamometer for loading was used. The engine was set to operate at a constant speed of 1500 rpm with a standard injection pressure of 216 bar at variable loading conditions. The specification of the engine is given in Table 2. The fuel flow rate was measured using a burette and a stop watch on volume basis. To measure the exhaust gas temperature K-type thermocouple with digital display were employed. A standard AVL437C smoke meter was used to measure the smoke density. HC, CO, CO_2, O_2, and NOx emissions were measured on dry basis using a non-dispersive infrared (NDIR-AVL-444 digas) analyzer. NOx and HC emissions were measured in ppm and CO, CO_2, and O_2 emissions were measured in terms of vol. %. The error analysis of the analyzer is given in Table 3. AVL combustion analyzer 619 with Indi meter hardware and indwin software (version 2.2) is used to measure the combustion parameters like in cylinder pressure, heat release rate (HRR) etc. The schematic experimental set-up is shown in Fig. 1.

Table 2: Specification of the engine

Engine type	Four stroke, Direct injection, Water cooled engine
No. of cylinder	one
Bore X Stroke	87.5 mm X 110 mm
Compression ratio	17.5:1
Rated speed	1500 rpm
Rated power	5.2 kW

Table 3: Error analysis

Parameters	O_2	NOx	HC	CO
% of error	1.05	0.94	1.03	0.09

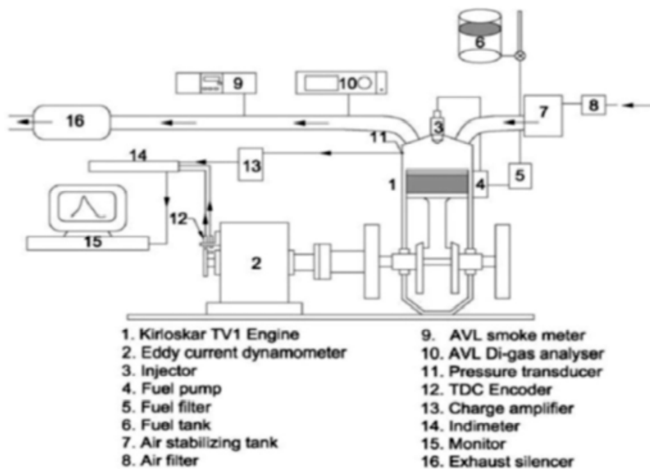

Fig. 1: Schematic diagram of experimental setup

Base data is generated with standard diesel fuel and 100% Bio diesel (B100), three fuel blends namely 75:25 (B25), 50:50 (B50) and 25:75 (B75) by volume of diesel and bio diesel were prepared and tested in the diesel engine without and with 2% addition of Di-tert butyl peroxide. The mixing protocol consisted of first blending the additive Di-tert butyl peroxide into the PSME and then blending this mixture into the diesel fuel. Readings were taken, when the engine was operated at a constant speed of 1500 rpm for all loads. The fuel flow rate and the emission characteristics like NOx and smoke were recorded and the engine performance was evaluated in terms of brake thermal efficiency, brake power, and brake specific fuel consumption. The cylinder pressure and heat release rate were recorded.

RESULTS AND DISCUSSION

The engine performance with fuels having different heat values and density can be compared with brake specific fuel consumption (BSFC). The experimental observation of BSFC for the neat diesel fuel and the various percentages of PSME without additive in its blends with diesel fuel with respect to brake power are shown in Fig. 2. It was observed from the figure that the BSFC decreased as the load increased for all the test fuels and also the BSFC was higher for PSME fuel than that of diesel fuel. High viscosity, surface tension and poor volatility of PSME results in poor atomization and increased BSFC to maintain the power output as demonstrated by Subramanian et al.[21] though PSME contain oxygen molecules in its structure, which can favor complete combustion. Among the blends without additive B25 shows minimum BSFC and hence it is taken as optimum and the other studies are based on the optimum blend. The BSFC with respect BP for the modified fuels (optimum blend, B100 and diesel along with DTBP additive) were noted and compared in Fig. 3. The BSFC of PSME fuel with DTBP additive is less than that of PSME fuel without additive as it decreases the viscosity of the blend and cause improvement in the fuel spray and atomization.

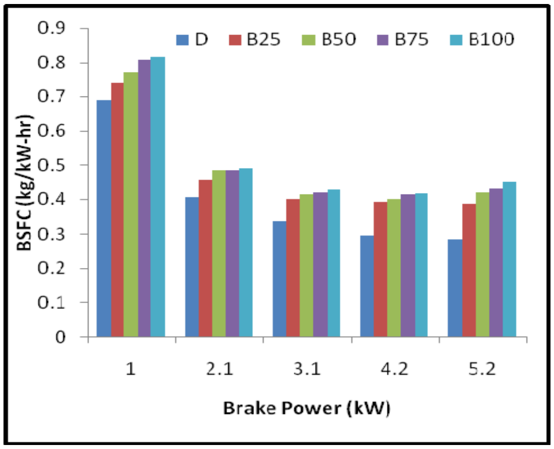

Fig. 2: BSFC for PSME blends with BP

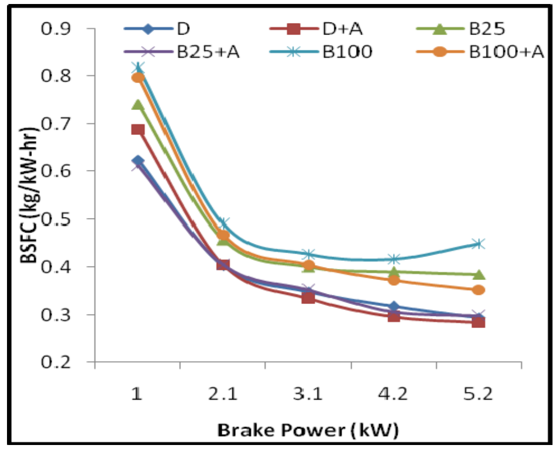

Fig. 3: Comparison of BSFC for modified blends

The PSME blends with DTBP resulted in higher BTE compared with PSME blend without additive and it may be due to larger surface area to volume ratio of the additive as demonstrated by Kelso et al.[22] From Fig. 4, it is evident that at full load condition, the BTE of B25 with additive is increased by 3% compared with B25 fuel blend. DTBP present in the fuel favors to improve atomization and better mixing of air-fuel mixture as it acts as a catalyst and oxygen buffer for the combustion enhancement[23]. This can also be attributed due to variation in viscosity of the fuel.

Fig. 5 shows the comparison of exhaust smoke density with brake power for the neat diesel fuel, B100 and B25 blend without and with the addition of DTBP. The presence of oxygen in the PSME assists the combustion and reduces the engine smoke for blends without additive than the diesel fuel and the reduction is high for higher blends. 11% decrease in smoke density than neat diesel fuel was observed for B100 without additive at high load, whereas the reduction is 5.8% for B25 without additive. Post flame oxidation during air fuel interaction in the fuel rich regions may be the other reason for this reduction.

On the other hand increase in the smoke density of the exhaust gases using DTBP additives is observed when compared to PSME blends without additives. The increase is 20% and 61%, respectively for B25 and B100 fuels respectively. The reason for the increase in smoke emission with using additive may be due to the reduction of oxidative free radical formation[24].

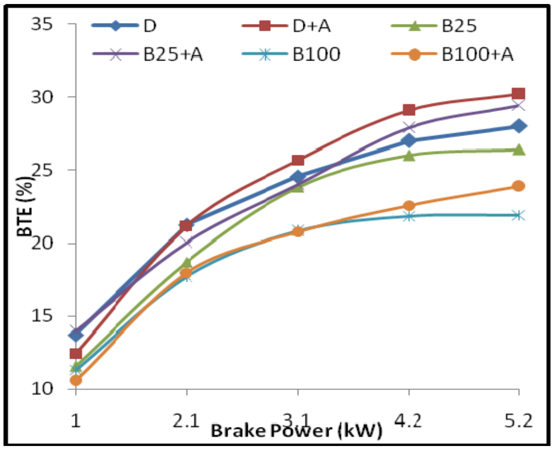

Fig. 4: Variations of BTE with BP

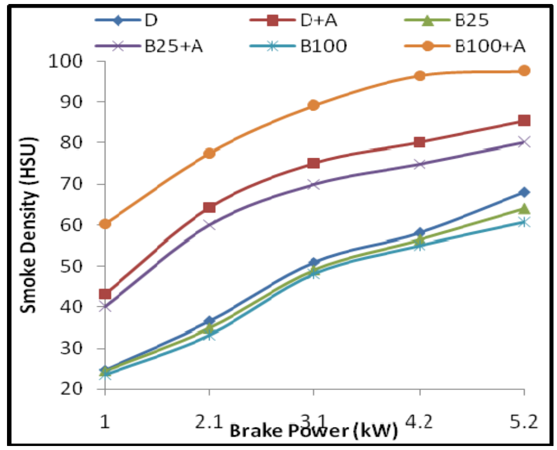

Fig. 5. Variations of smoke density with BP

The NOx emission for neat diesel fuel and other test fuels at different loading conditions were observed and the same is presented in Fig. 6. The formation mechanism of NOx is mainly related to the temperature and the availability of oxygen in the combustion chamber. When B100 is used as fuel, the heavier molecules and the presence of oxygen in the molecular structure enhance lengthy burning and favor more NOx formation than diesel fuel. However, reduction in NOx emission for the PSME diesel blends were observed and the reduction is higher for higher percentage of diesel as the diesel fuel is less denser than PSME with oxygen deficiency and low peak cycle temperature. The increase in NOx emission for B100 and B25 without additive than neat diesel fuel at maximum load was observed as 10.7% and 5.8%, respectively. The addition of DTBP reduces the NOx emissions at all loads for all test fuels. 27% and 35.5% were the reduction in NOx emission for B25 and B100 with additive than the respective ones without additive. The possible prevention of the contribution of free radicals, which are available in the additive (free radical quenching agents) in NO forming reactions during the combustion with the flame region is the reason for this reduction as illustrated by Erol and Gunnur[25].

Engine loading conditions, fuel properties and fuel spray characteristics are the three main parameters, which affect the HC emission for a diesel engine and hence increase in HC emissions were observed for higher loads than partial loads[26]. Fig. 7 shows the addition of diesel fuel with PSME reduces the HC. B25 shows a maximum of 9% reduction in HC emission at high load compared with B100. The HC emission also depends on the over mixing of fuel and air beyond flammability limits, excessive spray penetration, bulk quenching of combustion reactions and poorly atomized fuel from nozzle sac volume and nozzle holes after the end of injection. Addition of DTBP increases the HC emission of all blends compared with those without additive. 11.8% and 3% increase in HC at high load are the effects of DTBP addition with B25 and B100 fuels. The increase in HC emission with addition of DTBP may be attributed to the reduction of oxidative free radical formation[24].

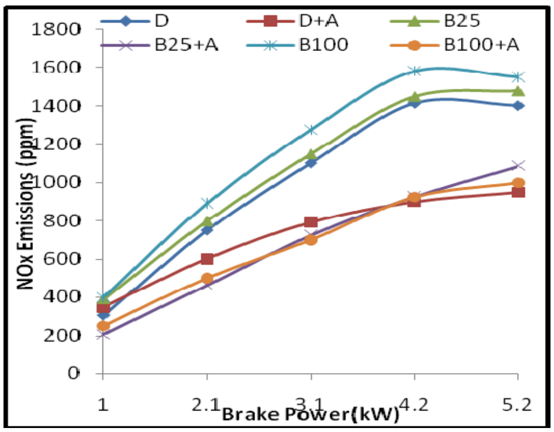

Fig. 6: Variation of NOx emission with BP

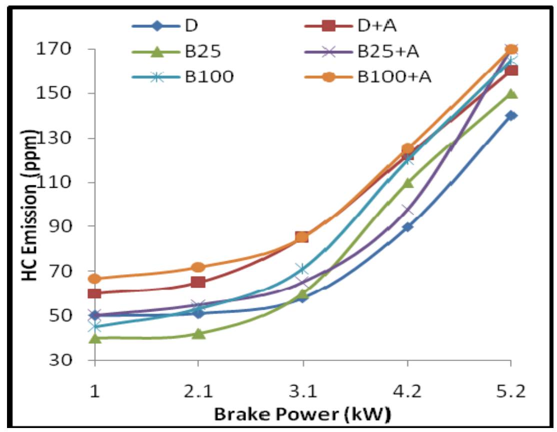

Fig. 7: Variation of HC emission with BP

Fig. 8 shows the traces of maximum cylinder pressure (Pmax) recorded for 100 operating cycles. The average maximum pressure for PSME blends is higher than that for neat diesel fuel and the increase is higher for higher proportions of PSME. B100 recorded an average value of 68.01 bar against 64.2 bar and 60 bar for B25 and neat diesel fuel, respectively. Addition of DTBP causes further increase in cylinder pressure. B25 and B100 blends with DTBP records 65.03 bar and 69.8 of average maximum pressure for 100 cycles of operation at high load. It could be attributed to the increased ignition delay that shortened the diffusion combustion which quickens the initiation of combustion[27].

Fig. 9 shows the cylinder pressure variation with respect to crank angle at full load condition for neat diesel fuel, B25 and B100 without and with the addition of DTBP. It can be seen that the blends ignite earlier and finish the combustion earlier than that of diesel. Increase in ignition delay causes higher combustion duration and hence gathering of fuel is higher in the premixed combustion phase that causes faster combustion and higher peak pressure. Compared to PSME blends PSME with additive could cause higher peak pressure due to the oxygen buffer character to the additive which promoted the complete combustion[28].

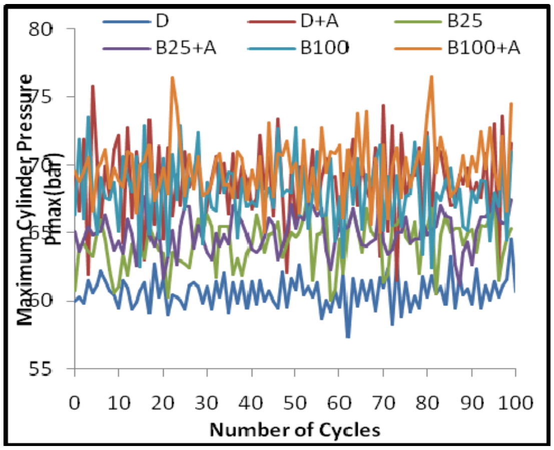

Fig. 8: Traces of Pmax for 100 cycles

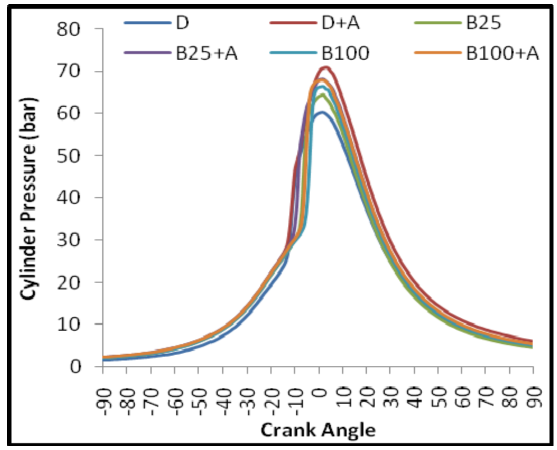

Fig. 9: Cylinder pressure variation with respect to crank angle at full load

Figs. 10 show the heat release rate (HRR) of neat diesel fuel, B25 and B100 without and with the addition of DTBP with respect to crank angle at full load condition. Accumulation of fuel during the ignition delay period resulted in higher values of HRR.

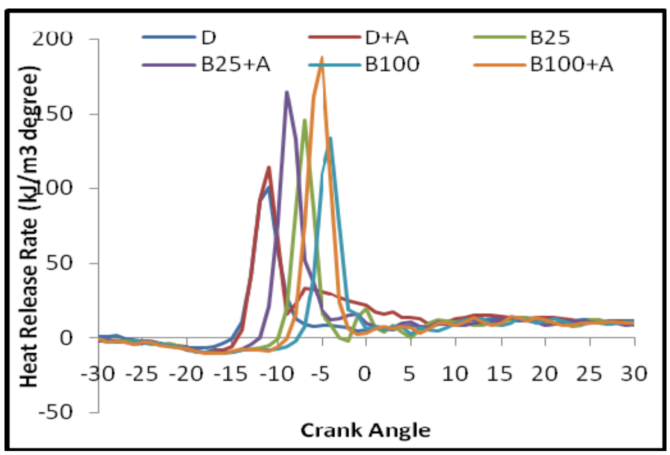

Fig. 10: HRR variation with respect to crank angle at full load

The HRR for B25 and B100 with additive are increased by 13.7% and 39% compared with those of B25 and B100 without additives. The addition of DTBP to PSME increased the HRR of the fuel, which agreed well with the findings of Vairamuthu et al. and Dinesh et al.[27,29]. This may be due to the activation energy of DTBP that promoted the oxidation by supplying oxygen.

CONCLUSION

From the investigation it is evident that, the properties of PSME-Diesel blend gets significant improvement regarding the combustion and emission characteristics by the addition of DTBP. The effect of advanced combustion of PSME was reduced by DTBP and thereby the brake thermal efficiency increased. In particular, it reduces the NOx emission compared to PSME blends and smoke density compared to neat diesel. Therefore, addition of DTBP is a good technique to improve the combustion qualities and emission characteristics of PSME for the application of higher blends in diesel engine.

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