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Performance Improvement of A Diesel Engine Fuelled By Cashewnut Shell Oil on Blending with Oxygenates - *An Experimental Study*

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Abstract

The high viscosity of cashew nut shell oil (CNSO) creates difficulties in combustion and heat release in the engine. To enhance the combustion of CNSO in diesel engines, oxygenates like diethyl ether (DEE) and dimethyl carbonate (DMC) are blended in small proportions by volume with neat CNSO. These blends are tested in a single cylinder, four stroke, 1500 rpm, 5.2 KW, direct injection diesel engine fitted with eddy current dynamometer. The performance, emission and combustion characteristics are studied at various loads on the engine at a constant speed of 1500 rpm and compared with neat CNSO and diesel fuel operations. On analyzing the results it is found that both 10%by volume of DEE, 10% volume of DMC with neat CNSO improve the performance of the engine. Among these two blends of oxygenates, DEE blend is better than DMC blend. The brake thermal efficiency of DEE 10 blend is 27.15% compared to DMC 10 blend's efficiency of 25.38 %. Neat CNSO operation has 23.1% of brake thermal efficiency. The ignition delay for DEE 10 blend reduces by 2 degree, DMC 10 blend reduces by 1 degree when compared to neat CNSO operation which has 12 degre of ignition delay. The NO emissions of DEE 10 blend is 1008 ppm and 985 ppm for DMC 10blend, while neat CNSO emits 953 ppm.. The smoke emission of CNSO is 4.27 BSU, whereas it is 4.12 BSU and 4.17 BSU respectively for DEE10 blend and DMC10 blend. Pure diesel operation has 30.14% of brake thermal efficiency, 7 degree of ignition delay, 1118 ppm of NO emission and 3.64 BSU of smoke emission.

Keywords: Cashew nut shell oil, Diethyl Ether, Dimethyl carbonate, Alternate fuels, Diesel engine

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1. Introduction

The fast depletion of fossil fuels and its related economic factors had created the need for new sources of energy for combustion engines. India is blessed with vast cultivable land and the vegetation is good in many regions. There are many vegetable oils identified by the researchers which can be used as an engine fuel.

In the last two decades, extensive research was carried out in using various vegetable oils such as Jatropa oil, Karanja oil, rubber seed oil, cotton seed oil, coconut oil etc in diesel engines using different techniques such as preheating, Transesterification, blending with orange oil, blending with methanol, blending with diethyl ether, and hydrogen supplementation. Edwin[1] et al. studied the performance of rubber seed oil in a diesel engine with port injection of diethyl ether. At peak power output the percentage of brake thermal efficiency was boosted by 7.5% with 200g/hr of injection. Senthil[2] et al. investigated the improvement in the performance of jatropha oil with methanol blending as engine fuel. They reported that jatropha oil's performance was improved at full load from 27.3% brake thermal efficiency to 28.5% with a reduction in smoke emission of 0.4 BSU, by blending 30% of methanol with jatropha oil. Similarly, the brake thermal efficiency increased to 28.3% with a corresponding reduction in smoke emission of 0.2 BSU was reported with 30% blend of orange oil with jatropha in the same study.

Huseyin[3] in his study on the effect of blending diesel fuel with cotton seed oil and sunflower oil in a 10 HP, variable speed diesel engine reported, that cotton seed oil 15% blend with diesel developed 6.5 kW power at 2500 rpm on par with pure diesel operation. Leenus[4] et al. studied the performance improvement of cotton seed oil, and reported an improvement of 2.4 % in the brake thermal efficiency and a drop of 0.4 BSU of smoke emissions when 15% by volume of orange oil was blended with cotton seed oil in a 1500 rpm, 5.2 kW engine at its full load. Rakopoulos[5] et al. experimented with blends of diesel and cottonseed oil in a Mercedes-Benz, OM 366 LA model, 800–2600 rpm, six-cylinder engine. They reported that the brake thermal efficiency of 20% blend of cotton seed oil with diesel was equal to that of pure diesel operation, that is s 38.5% brake thermal efficiency at 60 % load at 1200 rpm as well as 1550 rpm.

India is the largest producer and processor of cashews (*Anacardium occidentale*) in the world. In India, cashew cultivation covers a total area of about 0.77 million hectares of land, with an annual production of over 0.5 million metric tonnes of raw cashew nuts. The world production of cashew nut kernel was 907,000 metric tonnes in 1998. The cashew nut shell liquid is reported to be 15–20% by weight of the unseparated nut in Africa and 25–30% by weight in India. Considering that the shell weight is about 50% of the weight of the nut-in-shell, the potential of cashew nut shell oil is about 450,000 metric tonnes per year. The natural cashew nut shell oil contains 80.9% of anacardic acid and 10-15% cardol and small amount of polymeric substances as reported by Rajesh[6] et al. They studied the extraction of cashew nut shell oil, using super critical carbon dioxide. They reported that the extraction pressure had a strong influence on the quantity of cashew nut shell oil extracted. At 200 bar and 333K, the extract had 86% of cardol and it reduced to 63% for 300 bar, and 333K. The IUPAC name of anacardic acid which forms 80% of

cashew nut shell oil, is 2-hydroxy-6-[(8*Z*,11*Z*)-pentadeca-8,11,14-trienyl]benzoic acid. The chemical formula is $C_{22}H_{30}O_3$ and the molar mass is 342.4718 g/mol.
Azam[7] et al. empirically calculated the iodine value and a saponification number of this plant family which amounts to 92.6 and 204 respectively. Cardonal is obtained from CNSO by pyrolysis. Velmurugan and Loganathan[8] studied the performance of cashew nut shell oil and diesel blends. They reported that the performance of the B20 blend was closer to that of diesel operation with a brake thermal efficiency of 30%, whereas pure diesel operation had 33%. The neat CNSO was reported to have a brake thermal efficiency of 27%. Mallikappa[9] et al. studied the performance and emission characteristics of a 10 HP twin cylinder diesel engine. A brake thermal efficiency of 25% and 500 ppm of NO_x emission were reported at peak load for 20% blend of cardanol biodiesel with diesel. They reported that this blend can be used in compression ignition engines without any modifications. Kasiraman[10] et al. studied the improvements in the combustion, performance and emission characteristics of a diesel engine with neat cashew nut shell oil and camphor oil blend. They reported an improvement in brake thermal efficiency of 6% compared to neat CNSO operation when 20% blend of camphor oil and CNSO was used. The same blend had emissions of 137 ppm of HC and 0.32% CO under peak load conditions compared to neat CNSO emissions of 143 ppm of HC and 0.38 % of CO. Kasiraman[11] et al. in their study on blending diethyl ether of 30% by volume with CNSO reported a percentage increase in brake thermal efficiency of 28% when compared to that of neat CNSO operation, an increase in NO emission of up to 1050 ppm at full load operation of the engine, whereas neat CNSO operation emits 983 ppm of NO. Kasiraman[12] et al. reported a brake thermal efficiency increase of 4.14% over neat CNSO operation when 30% by volume of ethanol is blended with CNSO, and 2.07% for 30% methanol blend as well. The heat release rate was improved by 7.11 J/deg CA and 4.77 J/deg CA respectively for the above blends, when compared to neat CNSO operation. On their study of the effect of orange peel oil addition to CNSO, Kasiraman[13] et al. reported that the smoke emission of the orange peel oil blend by 30% by volume reduced to 4.07 BSU from 4.22 BSU obtained for neat CNSO operation. Similarly the brake thermal efficiency improved to 28.9% by the same blend from 23.1% of neat CNSO.
Earlier studies on cashew nut shell oil had mainly concentrated on transesterification of cashew nut shell oil. The present work was taken up to investigate the improvement of cashew nut shell oil performance in a diesel engine, using a simple technique of the direct blending of cotton seed oil, which has better fuel properties such as a higher cetane number higher calorific value and lower viscosity.
DEE is a highly volatile and inflammable, colorless liquid. It has a flash point of -40^0 C and an auto ignition temperature of 170^0 C. Its molecular formula is $(C_2H_2)_2O$. DMC is a highly volatile and inflammable liquid. It has a flash point of 90^0 C. Its molecular formula is $C_3H_6O_3$. Being highly volatile, these oxygenates are expected to improve the combustion of CNSO.

The blends of DEE and DMC with CNSO were prepared in proportions on volume basis. 90% CNSO and 10% DEE blend (DEE 10), 90% CNSO and 10% DMC blend (DMC 10). Their properties were found out experimentally.

In the present work, the engine tests were conducted in a single cylinder four stroke constant speed diesel engine of 1500 rpm with variable load to study the performance, emission and combustion characteristics of neat CNSO, DEE 10, DMC 10 and diesel fuel to identify the best blend for the improved performance.

2. Test Fuels

Before and after the oil was blended, fuel properties were examined in accordance with the standards of the Bureau of Indian Standards (BIS). The Table 1 presents the fuel properties of all the test fuels.

Table.1. Properties of Cashewnut shel oil , DEE blends & Diesel fuel

Property	Diesel	CNSO	DEE 10	DMC 10
Density @ 15^{0}C (gm/cc)	0.84	0.9581	0.9457	0.837
Kinematic Viscosity@ 40^{0}C in CST	4.59	55.3	28.99	31.16
Flash Point ^{0} C	50	234	22	48
Higher Calorific Value in MJ/kg	42.5	35.8	35.3	35
Cetane Number/CCI	45 – 55	33	46	34

3. Experimental Set Up

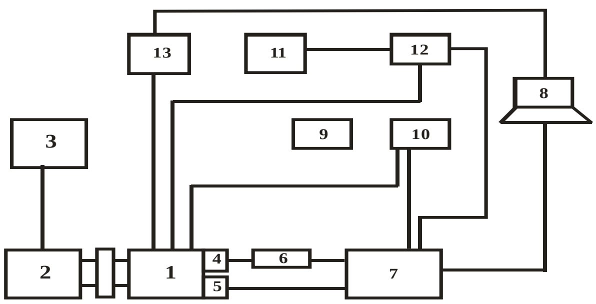

Figure 1. Experimental Set up

1. Engine ***2.***Eddy Current Dynamometer ***3.*** Dynamometer Controls ***4.***Pressure Pick Up.
5. TDC Sensor ***6.***Charge Amplifier ***7.*** High Speed Data Acquisition System ***8.*** Computer.
9. Air Supply Tank ***10.*** Air Measurement System ***11.*** Fuel Tank ***12.*** Fuel Measurement system. ***13.*** Exhaust Gas Analyser.

Figure 1 shows the experimental set up. A single cylinder four stroke direct injection water cooled diesel engine (KIRLOSKAR TV1 Model, 0.661 liters capacity, 5.2 kW@1500 rpm) with piezo and crank angle sensors was used for the experimental study. It was coupled with eddy current dynamometer (AG 20 model) with Load Cell 50 Kg Capacity (Maywood Instruments), magnetic pulse pickup and high speed data acquisition system. The engine was operated at constant speed of 1500 rpm. The air and diesel consumptions, loads and temperature measurements were obtained by interfacing with flow transmitters. For data processing, specialized software "ENGINE SOFT" was used. This software is interfaced with the engine with the help of suitable hardware. Hardware with various sensors and transducers provided the required input to the software. The emission from the engine was measured by AVL Five Gas Analyzer. At various loads on the engine, the CO, CO_2, Hydrocarbon and NO were measured. The smoke was measured by Bosch smoke meter.

4. Test Procedure

The engine was warmed up before starting the experiment after which the engine temperature was maintained constant by controlling the cooling water flow rate. Diesel, neat CNSO and one blend of CNSO with DEE and one blend of CNSO with DMC were used as test fuels in a DI diesel engine with variable load conditions at a constant speed engine of 1500 rpm. For each operating condition of engine load, the specific fuel consumption, engine power output, exhaust emissions, and crank angle-cylinder pressure were measured. The crank angle-cylinder pressure were averaged out for 100 combustion cycles and all experimental data were repeated at least thrice and averaged for improved test result accuracy and dependability. The heat release rate was estimated with the computer program developed indigenously.

5. Results and Discussion

5.1. Performance characteristics

5.1.1. Brake thermal efficiency

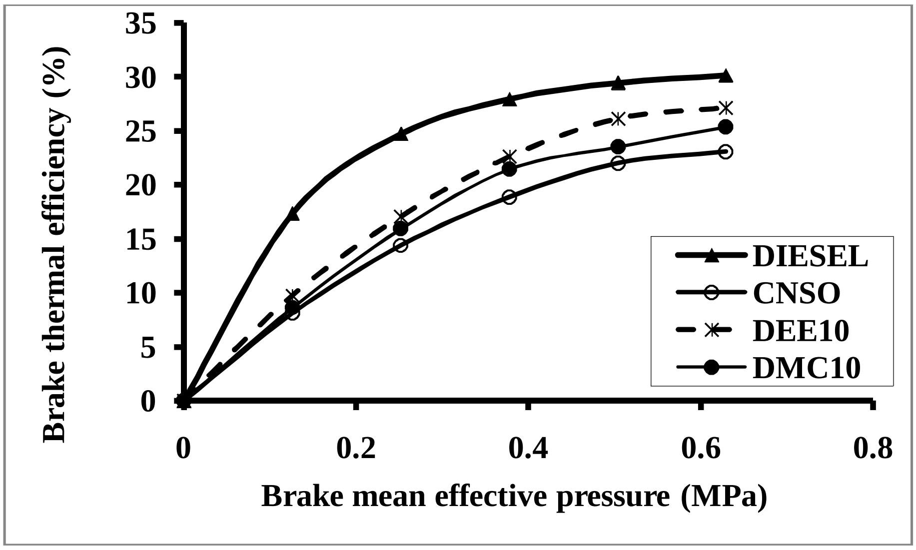

Figure 2. Variation of brake thermal efficiency with load

Figure 2 shows the variation of brake thermal efficiency with load. As the viscosity of the CNSO-DEE blend is less, atomization, vaporization and mixing of the injected fuel improves resulting in improved combustion. Hence the brake thermal efficiency of DEE 10 blend improved to 27.15%, DMC 10 blend improved to 25.38%.

5.2 Emission characteristics

5.2.1. NO Emission

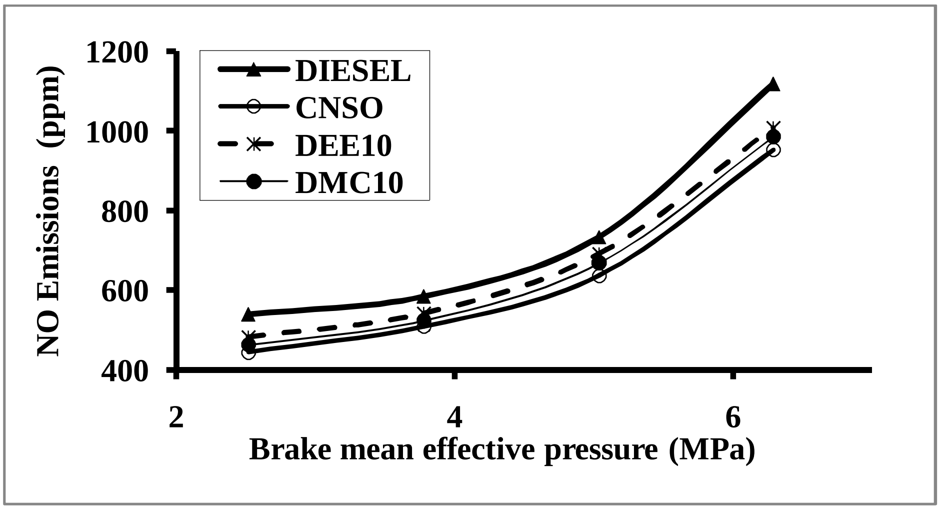

Figure 3. Variation of NO Emissions with load

Figure 3 shows the variation of NO emissions with load. The lower heat release rate and combustion temperature are the reasons for less NO emissions of CNSO. As the combustion improves the NO emissions also increases with DEE blends. At full load the NO emissions are 1118, 1008 and 985 ppm respectively for diesel, DEE 10 blend, DMC10 blend respectively. Neat CNSO emits 953 ppm of NO.

5.2.2. CO emission

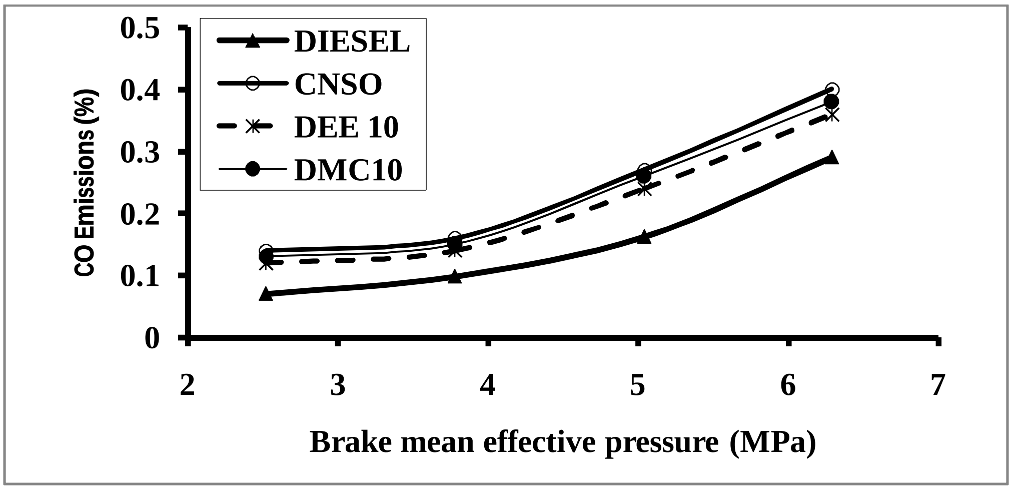

Figure 4. Variation of CO Emissions with load

The incomplete combustion of CNSO and its blends leads to higher percentage of CO emissions. As the presence of DEE, DMC in the blend enhances combustion, the percentage CO decreases. Figure 4 shows the variation of CO emissions with load. At full load the CO emissions are 0.29. 0.36 and 0.38 percentages for diesel, DEE 10 blend,DMC10 blend and 0.4 % for CNSO respectively.

5.2.3. Hydrocarbon emission

The variation of HC emission with load is shown in Figure 8. The improvement in combustion due to oxygenates in the blend reduces the unburned hydrocarbon content in the exhaust. The oxygenates are highly volatile which results in better evaporation and combustion. At full load the HC emissions are 130, 140 and 146 ppm for diesel, DEE 10 blend, DMC 10 blend respectively. Neat CNSO emits 150 ppm of unburned HC.

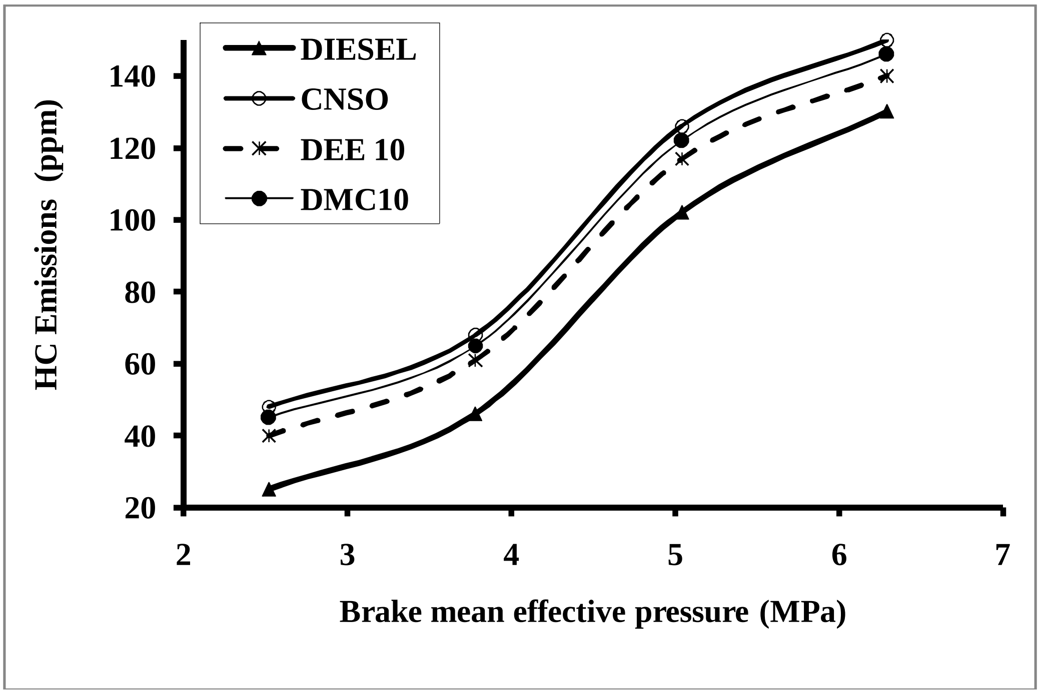

Figure 5. Variation of HC emission with load

5.2.4. Smoke emission

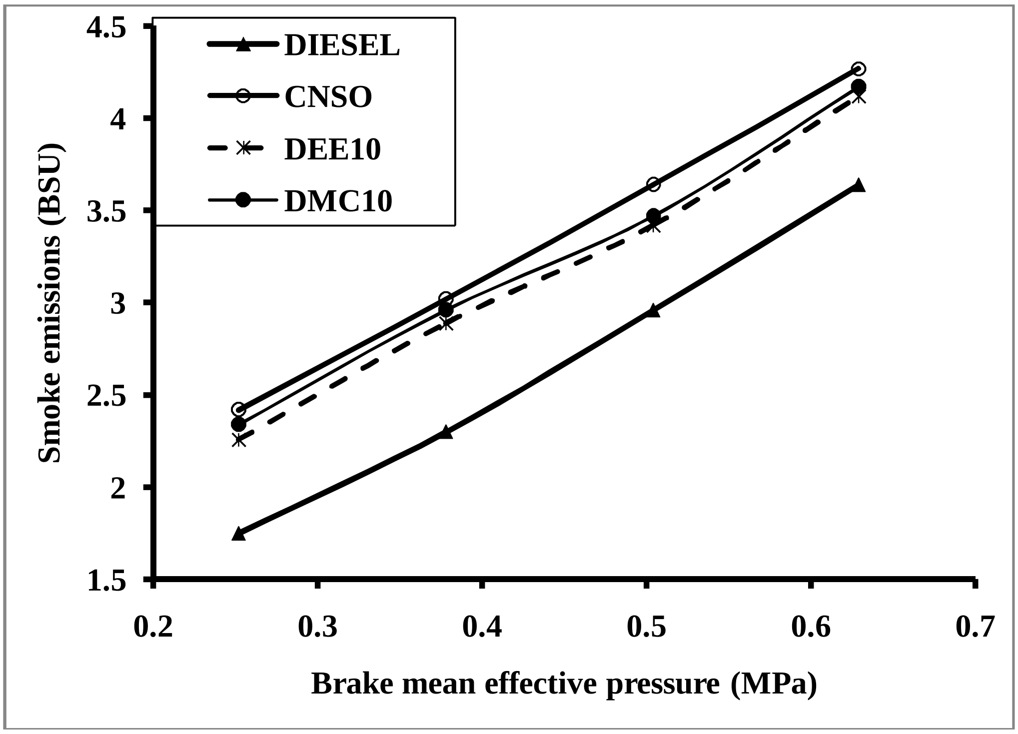

Figure 6. Variation of smoke emissions with load

As the viscosity is reduced due to blending with DEE, the blend is easily atomised and vaporised resulting in better combustion. This phenomena reduces the dark smoke emissions for the blends when comared to neat CNSO. At full load the smoke emissions are 3.64, 4.12 and 4.27 BSU for diesel, DEE 10 blend and CNSO respectively. DMC 10 blend emits 4.17 BSU of smoke. The smoke emissions of above fuels are shown in Figure 6.

5.3. Combustion Characteristics

5.3.1. Heat Release Rate

The heat release rates for DEE 10 blend, DMC 10 blend, CNSO and diesel fuel for peak load are shown in Figure 7. The rapid combustion and mixing controlled phases are clearly distinguished in the diagramfor these test fuels. The presence of oxygenates accelerates the heat release process. Low self ignition temperature of oxygenates provides easy ignition for initiating the combustion of CNSO quickly. It is observed that the peak heat release rates are 73.14, 70.73, 62.67 and 79.65 J/deg CA for DEE 10 blend, DMC 10 blend, CNSO and diesel fuel respectively.

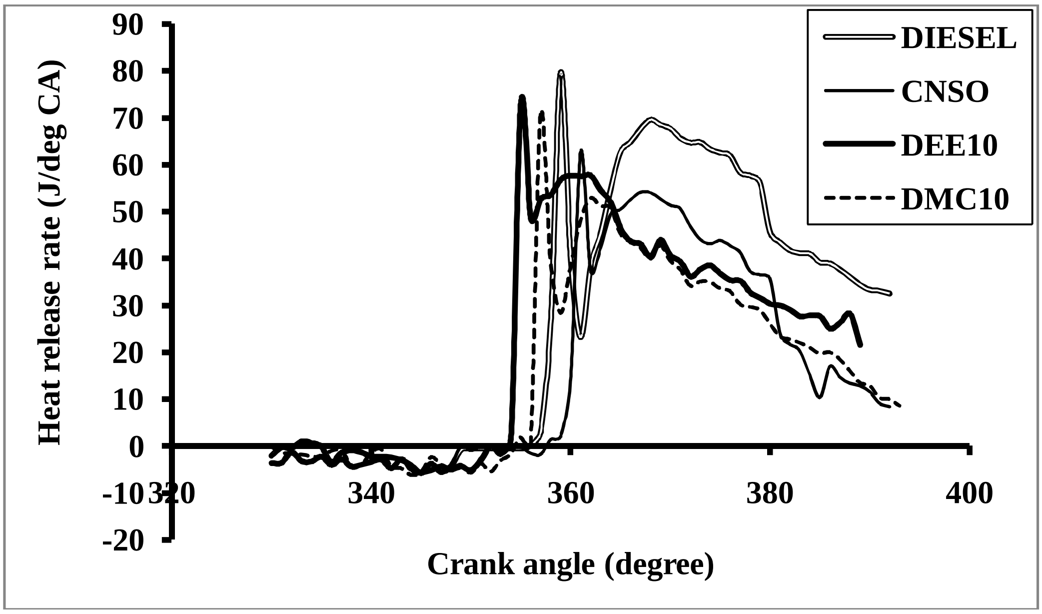

Figure 7. Heat Release rate diagram

5.3.2. Ignition delay

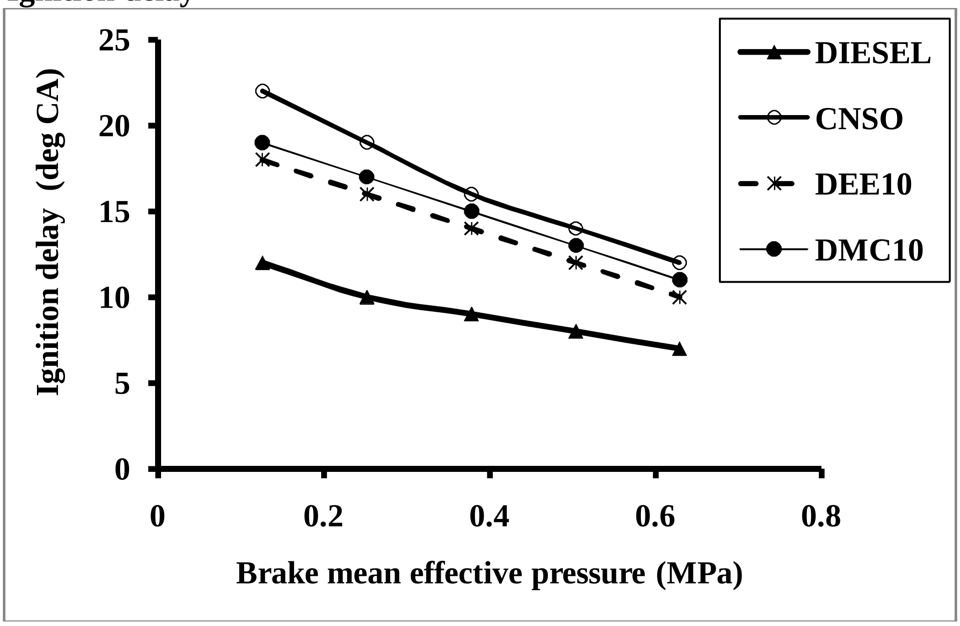

Figure 8. Variation of Ignition delay with load

The variation of ignition delay is shown in Figure 8. The ignition delay is calculated as the time required to release 5% of heat energy. As the oxygenates are highly volatile, it helps in reducing the time taken for initiating the combustion of CNSO. The ignition delay for diesel, DEE 10 blend, DMC 10 blend and CNSO are 7, 10, 11 and 12 degree of crank trave respectively.

5.3.4 Maximum rate of pressure rise

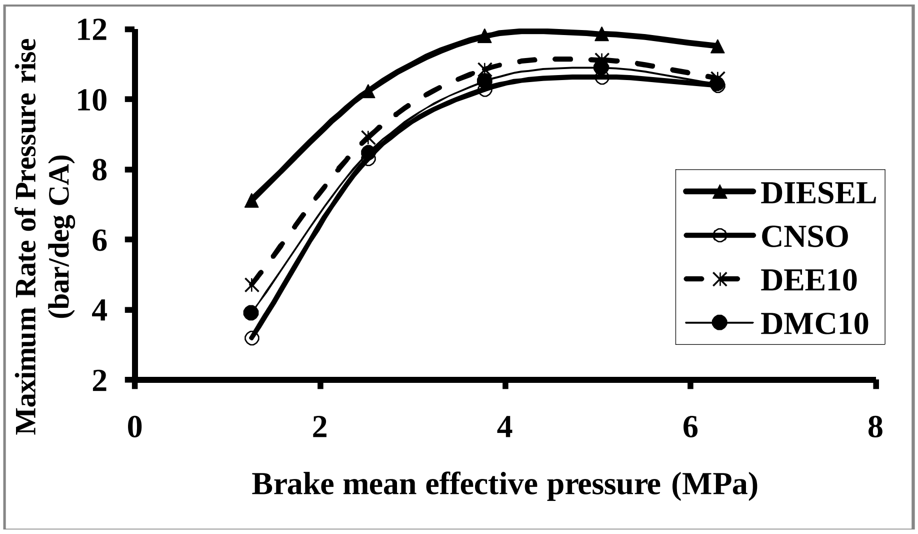

Figure 9. Variation of maximum rate of pressure rise with load

The maximum rate of pressure rise observed is plotted in Figure 9. Rate of combustion depends up on the vaporisation and mixing of fuel in the cylinder during the course of combustion. Rate of pressure rise is lower in the case of CNSO as a result of poor atomisation which results in improper combustion. On oxygenate blending with CNSO, combustion improves and hence rate of pressure rise increases. The maximum rate of pressure rise for diesel, DEE10 blend, DMC10 blend and neat CNSO are 11.52, 10.6, 10.45, 10.4 bar/ deg CA respectively.

5.3.5. Combustion duration

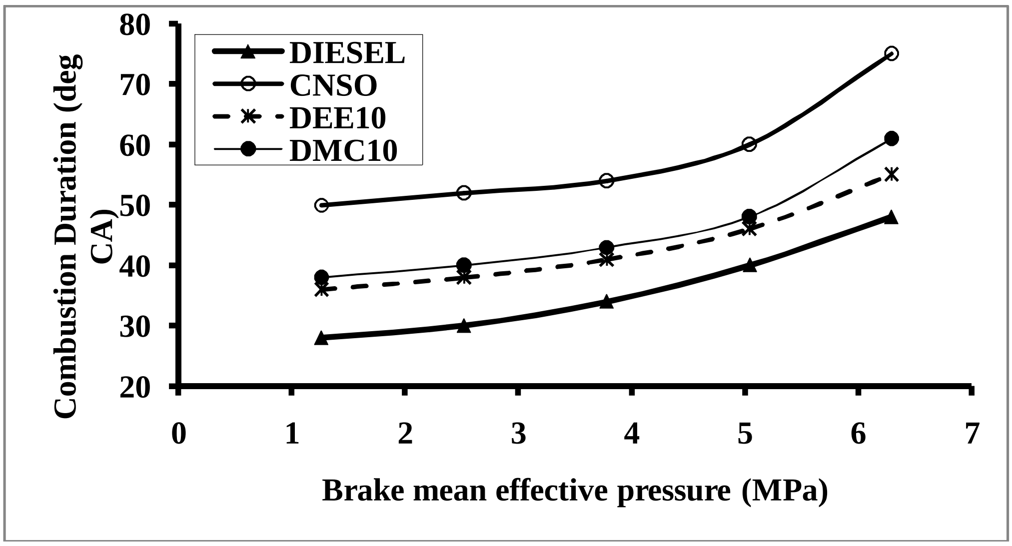

Figure 10. Variation of Combustion duration with load

Variation of combustion duration with load is shown in Figure 10. The oxygenates vaporise quickly than CNSO. Hence it accelerates the combustion of CNSO. This is due to superior properties of DEE such as lower viscosity and lower self ignition temperature also when compared to CNSO. At peak load, the combustion duration for diesel, DEE 30 blend, DMC 10 blend and CNSO are 48, 55, 61 and 75 crank angle degrees respectively.

Conclusions

The experimental tests were carried out in a single cylinder constant speed diesel engine with neat CNSO, DEE 10 , DMC 10 as test fuels. The results are compared with that of diesel fuel operation. The folowing conclusionss are drawn.

1. The blending of neat CNSO with DEE and DMC significantly improves the performance, emission and combustion characteristics of the engine.
2. The brake thermal efficiency and heat release rates of DEE and DMC blends are comparable with a minimum hike of 10% in magnitude. The brake thermal efficiency of DEE 10 blend is 27.15% compared to DMC 10 blend's efficiency of 25.38 %. Neat CNSO operation has 23.1% of brake thermal efficiency. Pure diesel developed peak power with 30.14% of brake thermal efficiency.
3. The NO emission of CNSO and its blends are lesser than diesel NO emissions. The NO emissions of DEE 10 blend is 1008 ppm and 985 ppm for DMC 10blend, while neat CNSO emits 953 ppm at peak load. Diesel fuel operates with a NO emission of 1118 ppm at same load.
4. The smoke emission of neat CNSO is higher than that of diesel fuel operation. The smoke emission of CNSO is 4.27 BSU, whereas it is 4.12 BSU and 4.17 BSU respectively for DEE10 blend and DMC10 blend. Diesel fuel has a smoke emission of 3.64 BSU at peak power output.
5. The maximum rate of pressure rise, ignition delay and combustion duration of the the oxygenate blends improve when compared to neat CNSO operation.
6. The ignition delay of DEE 10 blend is reduced by 2 degree when compared to neat CNSO. The DMC 10 blend reduce the ignition delay by 1 degree with respect to CNSO.

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