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Effect of DEE Oxygenate on Diesel in Algal Biodiesel-Diesel Blends on the Combustion Phenomenon of DI Compression Ignition Engines

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ABSTRACT:

Biodiesel derived from Stoechospermum marginatum is analysed in a CI engine to understand its feasibility to be used as fuel. In this study, Soxhlet extraction method was applied to extract the bio oil from the brown sea weed (S. Marginatum) with n-hexane as solvent. Considering the low FFA content through titration, base single stage transesterification process with methanol and NaOH at molar ratio of 8:1 is used and it yielded 84.5% of bio diesel. The test fuel is prepared with processed algae bio diesel and Di-Ethyl Ether in different blend ratios namely D80AB20, D70AB20DEE10 and D60AB20DEE20. The variation in combustion aspects are evaluated with constant concentration of algal bio diesel at 20% with variation in diesel and oxygenate concentrations. Consequential variation is observed in the combustion behaviour of CI engine on fuelling with test fuels. Comparable in-cylinder pressure is observed in bio-diesel blends and oxygenated blends. D70AB20DEEE10 exhibits superior heat release rate and pressure rise at all loads. The peak in-cylinder pressure and variation in ignition delay are also analysed in this study.

KEYWORDS:

Compression ignition engines; Stoechospermum marginatum; Algae biodiesel; Oxygenate; Combustion

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1. Introduction

The energy crises of fossil fuels reduction, growing anxiety of the explosive petroleum crude value and environmental hazards have trigged importance in the search of different fuel for internal combustion engines. Diesel fuel is mostly used in commercial, transportation, industrial sectors and agriculture for the generation of mechanical energy and electricity. Diesel engine emissions like CO, HC, NO_x and smoke contaminates the living environment and makes it unsuitable for human life. There are several categories of alternative fuels existing for IC engines but, bio-diesel is the significant alternative to the diesel engines. Biodiesel is extensively considered in recent years for CI engines. It is a renewable substitute and environmental friendly as a green energy source. To attain the crucial goal of sustainability, the energy that has no minimal negative environmental, economic and society impacts are to be used [1-2]. The main benefits of bio-diesel over petroleum fuels are superior lubricity, renewable resources, biodegradable, higher cetane number and flash point, less harmfulness blends with diesel, use in existing engine without further alterations and CO, HC, particulate matters are reduced.

Bio-diesel from animal fat is potential to be eco-friendly on comparison with bio-diesel of all alternative fuels. The usages of first and second generation bio fuels are popular. The edible feedstock like sunflower oil, palm oil, coconut oil and peanut oil are termed as first generation bio fuels. The non-edible oil such as jatropha raw oil, mahua raw oil and pongamia raw oil are termed as second generation bio fuels and it is used as alternative fuel for diesel engine. There are many biodiesel sources available for CI engines out of which macro algae are deliberated to be future generation bio fuel. Through their metabolism, algae produce abundant lipid content. In this present scenario oil cost increases every day and the economic possibility of using algae bio-diesel as an alternative fuel source is promising [3-5]. Macro algae are photosynthetic organism with the capability to convert carbon-di-oxide and sun light into energy and can reproduce numerous times in a day.

Macro algae are categorized under seaweeds based on their colour pigmentation as phaeophyceae (brown algae), rodophyceae (red algae) and chlorophyceae (green algae) [6]. Many researchers experimentally studied the combustion characteristics of biodiesel and oxygenate blends with diesel. Shelke et al [7] experimentally studied the combustion characteristics of a cotton seed biodiesel fuelled diesel engine. Transesterification process was carried out on vegetable oil using methanol and KOH as catalyst. The physio-chemical properties of the bio-diesel were marginally dissimilar from diesel. The combustion characteristics such as start and end of combustion, combustion duration ignition delay, premixed, diffusion and after burning combustion phases were inspected and compared with neat diesel. It was observed that extreme rate of pressure rise and ignition delay diminished for bio-diesel compared to neat diesel. Ignition delay decreased from 11°CA with base diesel to 6.5°CA with B20 bio-diesel. Kumar et al [8] analyzed the impact on combustion, performance and emission of biodiesel by using additives in direct injection diesel engine.

Allwayzy et al [9] experimentally studied the combustion of microalgae oil and ethanol blended with diesel fuel. The blend of algae oil, ethanol and commercial diesel (MOE20%) has been established to be consistent and constant without surfactant. The engine test outcome with MOE20% specified a very similar engine performance of brake power, torque, in-cylinder pressure, and brake specific fuel consumption to that of PD. The performance, combustion and injection characteristics of DI diesel engine have been studied experimentally with canola oil methyl ester and waste palm oil methyl ester by Ozsezen et al [10]. The consequence indicated that BP is reduced by 4-5% while BSFC increased by 9-10%. On other hand, methyl ester caused reduction in unburned hydrocarbon by 17-26%, CO by 59-67%, CO_2 by 5-8% and smoke capacity by 56-63%. Valipour [11] investigated on effect of additives on performance, combustion and emission characteristics of engine fuelled with bio-diesel diesel. By the end outcome, the effects of additives diminish the CO, HC, CO_2, particulate matter but faintly increase in NO_x. The addition of suitable capacity additives to diesel and bio-diesel which boost the engine combustion and performance.

Balaji et al [12] studied the combustion and emission characteristics of SI engine with gasoline blended with ethanol oxygenates compounds. The end result indicated that the increases the octane number and power output this may lead to increase the BTE. The CO, HC and NO_x exhaust emission decreases but the CO_2 concentration increases. The notable reduction in exhaust emission and improvement in combustion characteristic using ethanol as fuel additives to unleaded gasoline. Gopal et al [13] analyzed the effect of pongamia bio-diesel on combustion and emission of direct injection compression ignition engine. PME100 pongamia oil is primed and experienced on a diesel engine for dissimilar blends such as PME 20, 40, 60, and 80. Brake thermal efficiency, brake specific fuel consumption, carbon monoxide, hydrocarbon, smoke and nitrogen oxides are evaluated.

The effect exhibited that slightly lessens in performance and decline in CO, HC and smoke is observed. Imtenan et al [14] evaluated the effect of Di-Ethyl Ether (DEE) as oxygenated additives on palm bio-diesel diesel blend in the emission and combustion features on an average diesel engine. P20 DEE blends were valued in combustion and emission. DEE ($C_2H_5O_2$) is a highly flammable compound also called as ethoxyethane. DEE reduces the smoke and CO emissions on 35.5 and 25% respectively. HC emission was higher for DEE blends. NO_x is reduced for P10 D10 and average of 20% than P20. Combustion parameters like rate of heat release and in-cylinder pressure profile of the improved blends were also dissimilar the biodiesel blends. Jayaparabakar et al [15] estimated the combustion features of a CI engine fuelled with macro and micro algae biodiesel blends. CI engine influences injection timing and engine loading to be very significant aspects for combustion.

Cylinder pressure and heat release rate for the algae biodiesel blends is improved when advancing the ignition timing at prior combustion stages. Micro algae methyl ester shows enhanced combustion than macro algae methyl ester. How et al [16] experimentally studied the effect of bio ethanol as oxygen additives to biodiesel blends on engine combustion, performance and emission characteristics of a CRDI diesel engine. Blends of coconut biodiesel with diesel and ethanol were compared with base diesel. For biodiesel and ethanol biodiesel blends brake thermal efficiency and brake specific fuel consumption is higher. CO, NO_x and smoke were lower for ethanol biodiesel blends compared to base diesel. B20E5 shows slightly lower in peak pressure and peak heat release rate. Few other researchers [20-23] have carried out similar studies and obtained comparable results. Enhancement of the CI engine fuelled with any alternative fuel and evaluation of its combustion parameters is important.

The primary objective of this experimental study is to evaluate the feasibility of extracting oil from Stoechospermum marginatum species. Soxhlet extraction method is adopted to extract the algal oil. Transesterification technique is done to obtain fatty acid methyl ester. Further, the investigations are carried out to study the combustion characteristics of macro algae S. Marginatum bio-diesel. Also the effect of addition of DEE to diesel-algal bio-diesel is compared with base diesel. The blended preparations used in this study are D80AB20 (diesel 80% + bio-diesel 20%), D70AB20DEE10 (diesel 70% + bio-diesel 20% + DEE 10%) and D60AB20DEE20 (diesel 60% + bio-diesel 20% + DEE 20%).

2. Materials and methods

In this study, Stoechospermum marginatum, marine macro algae is collected from inter tidal zone of Tamil Nadu. The collected biomasses are washed and allowed to dry. The dried algal biomass is pulverized using electric power motor grinder. Soxhlet lipid extraction method is used to isolate the bio oil with n-hexane as extraction solvent. Continuous heating at 44° to 55°C extract the lipid content. The lipid is separated and heated for removing the n-hexane solvent. The crude algal oil is subjected to trans-esterification process to reduce the viscosity of algal oil. The reaction of algal oil, methanol (alcohol) and NaOH (catalyst) is done at molar ratio of 8:1 and 65°C reaction temperatures. After the reaction, the methyl ester is kept in a separation funnel for two days. Then, the lower layer of glycerol is drained out and the methyl ester is splashed with double distilled water. The transesterified algal biodiesel is then characterized by GC-MS, FTIR and NMR spectral studies. The physical and chemical characteristics of the fuel and fuel blends are defined by its fuel properties. To design the engine combustion chamber, fuel storage and fuel system fuel properties is necessary. The physio-chemical properties of diesel, bio-diesel and the bio-diesel blends (D80AB20, D70AB20DEE10 and D60AB20DEE20) are determined through ASTM D6751 and ASTM D975 methods are shown in Table 1.

Table 1: Properties of test fuel

Properties	Neat diesel	Algae bio-diesel	D80AB20	D70AB20DEE10	D60AB20DEE20
Density, 15°C, kg/m^3	850	890	869	862	852
Kinematic viscosity, 40°C, Mm^2/s	2.6	4.84	3.89	3.26	3.10
Calorific value, kJ/kg	44800	42052	3923	37362	35260
Cetane number	46	63	59	57	52
Flash point, °C	64	128	124	79	70
Fire point, °C	70	136	130	110	98

The density of algal biodiesel is 890 kg/m^3 which is higher than the base diesel at 15°C. The use of DEE in fuel blends which reduce the densities of D80AB20, D70AB20DEE10, and D60AB20DEE20 compared with algal biodiesel but it is higher than the base diesel and within the ASTM D 6751 and ASTM D 975 limits. Kinematic viscosity which affects the atomization and flow features is one of the main physio-chemical properties of the bio-diesel and diesel fuel. The kinematic viscosity of D80AB20, D70AB20DEE10 and D60AB20DEE20 are determined as 3.89, 3.26, and 3.10 mm^2/s at 40°C which is lesser on comparison with algal biodiesel (4.84 mm^2/s) and within the ASTM D 6751 and ASTM D 975 range. The quantity of heat energy produced when burning a unit quantity of hydrocarbon fuel is termed as calorific value. The calorific value of algal biodiesel and the biodiesel blends (D80AB20, D70AB20DEE10, D60AB20DEE20) is found to be 42052, 39230, 37362, 35260 kJ/kg and it is slightly lower compared with base diesel (44800 kJ/kg).

Cetane number of algal biodiesel and other biodiesel blends are 63, 59, 57, and 52 which is higher than diesel. Algal bio-diesel and bio-diesel blends have flash and fire point much higher than the diesel fuel specifying that algal bio-diesel and bio-diesel blends proved to be safe than neat diesel. Fuel blending is done by using ultrasonication of algal bio-diesel, diesel and DEE as oxygenated additives. The most usual blending ratio is termed as D80AB20 (80% of conventional diesel and 20% of S. Marginatum algal methyl ester). In this experimental study 20% of algal bio-diesel is added to 70% and 60% of diesel and further it is added with 10% and 20% of DEE oxygenates which is denoted as D70AB20DEE10 and D60AB20DEE20 respectively.

3. Experimental setup

The study of combustion characteristic is carried out in a single cylinder, four stroke direct injection compression ignition engine of 3.5 kW running at 1500rpm and 17.5:1 compression ratio. The engine nominal specifications are given in the Table 2. The water cooled eddy current dynamometer is used for loading the engine. For obtaining the pressure-crank angle reading, NI USB-6210, 16-bit, 250kS/ data acquisition system is used. Static injection timing and engine speed are kept constant during the course of this investigation. The schematic arrangement of test engine is shown in Fig. 1. The in-cylinder combustion pressure is measured by a pressure sensor fixed on the cylinder head which is visible to the combustion chamber with respect to crank angle. For computing crank angle, a crank angle encoder is fixed on the crank shaft. The experiment is primarily started with the fuel and later as the engine reached the warm up state, it is changed to bio-diesel and DEE blends. For analysing the combustion parameters, the pressure-crank angle illustration were documented and managed by the data acquisition system. Total fuel consumption is measured by a fuel level indicator. The intake air flow rate is measured by an orifice mounted on the air box in the suction coupled with U-tube manometer. Thermocouples of range 0-1200°C are fitted to measure the exhaust gas temperature.

Table 2: Single cylinder Kirloskar Diesel test engine specifications

Parameter	Value
Rated power	3.5kW @ 1500rpm
Compression ratio	17.5:1
Bore & stroke	87.5x110mm
Rated speed	1500rpm
Dynamometer type	Eddy current water cooled
Swept volume	661.45cc
Dynamometer Arm length	185mm

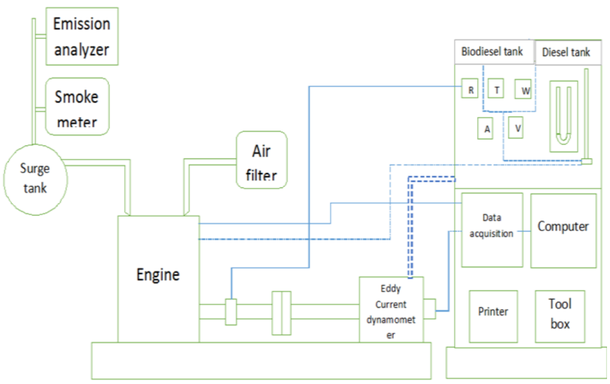

Fig. 1: Schematic experimental setup

4. Results and discussions

4.1. Combustion characteristics

In a CI engine, combustion characteristics are a complicated phenomenon. The combustion parameters are discussed with the parameters namely, rate of heat release, intensity, ignition delay period, combustion duration and cylinder gas pressure. Cylinder pressure statistical deviation obtained from the engine is used to calculate these parameters. “Engine soft” engine performance analysis software is used.

4.2. In-cylinder pressure

In-cylinder pressure evaluation is the most significant for understanding the combustion phenomena. The variation of cylinder pressure (bar) against crank angle (degrees) of diesel, D80AB20, D70AB20DEE10, D60AB20DEE20 fuels at no, part and full load conditions are presented in Figs. 2, 3 and 4 respectively. The cylinder pressure is specified by the capability of any fuel to mix with air and burn constantly. Under different operating conditions, diesel with bio-diesel and DEE blends follows the related course of the standard diesel fuel as cylinder pressure is observed. It is also to be noted that as the load increases, peak cylinder pressure increases of all fuels. At no load condition, peak pressure of diesel and D80AB20 are determined as 45.57 bar and 46.57 bar at 8° ATDC as shown in Fig. 2. Peak pressure and small delay for D80AB20 is faintly higher compared with diesel due to its higher cetane number. Maximum in-cylinder pressure is reduced and delayed for DEE blends. D70AB20DEE10 and D60AB20DEE20 exhibited peak cylinder pressure of 46.26 bar and 44.62 bar respectively at 8° ATDC. Combustion pressure reduced despite higher cetane number of DEE. It is to be noted that peak cylinder pressure of DEE decreased with increase in addition of DEE, which lowered the in-cylinder pressure of DEE blends.

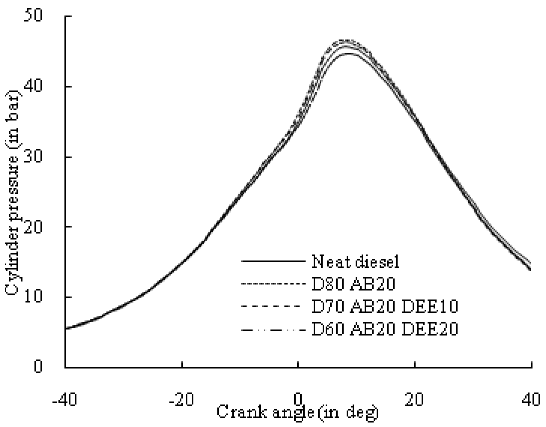

Fig. 2: Variations in in-cylinder pressure at no load

The maximum cylinder pressure for diesel, D80AB20, D70AB20DEE10 and D60AB20DEE20 are 57.53 bar, 57.59 bar, 57.93 bar and 57 bar at 8° ATDC at part load condition is shown in Fig. 3. The peak pressure of D80AB20 is marginally higher than the base diesel due to continuous increase in cetane number, oxygen content and advance in start of combustion. The reduction of peak pressure for DEE blends is due to vaporization of DEE. The peak pressure at part load is more or less similar for all fuels. The peak pressure for biodiesel and DEE blends occurs within 1° to 10° ATDC which is as reliable to diesel. Increasing the load increases the peak pressure and reduces the delay period.

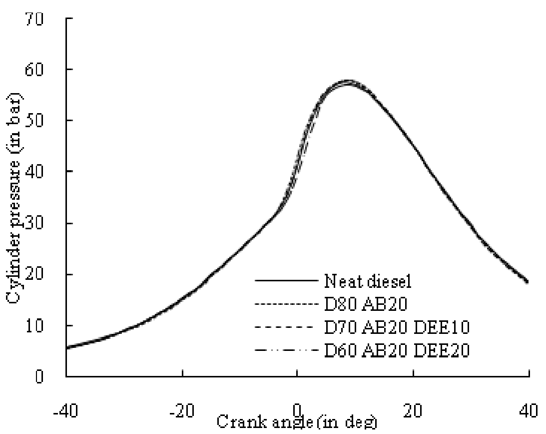

Fig. 3: Variations in in-cylinder pressure at part load

The maximum in cylinder pressure for D80AB20 is 67.39 bar at 9° ATDC. Diesel produced 66.24 bar at 10° ATDC at full load condition as shown in Fig. 4. High peak pressure of D80AB20 blend is due to enhanced oxygen content which raises fuel air combination rate as well as boiling point compared with diesel. Peak pressure is slashed and quite delayed for DEE blends. D70AB20DEE10 and D60AB20DEE20 shows peak cylinder pressure of 65.63 bar and 66.42 bar at 10° and 9° ATDC respectively. Combustion pressure is precipitated by higher cetane number and may be due to vaporization of DEE at low load operations, the cylinder pressure arises nearer to TDC for diesel and biodiesel blends. This is due to ignition delay period lengthening which increases the advancing of combustion time by up to 10-12° ATDC [17-18].

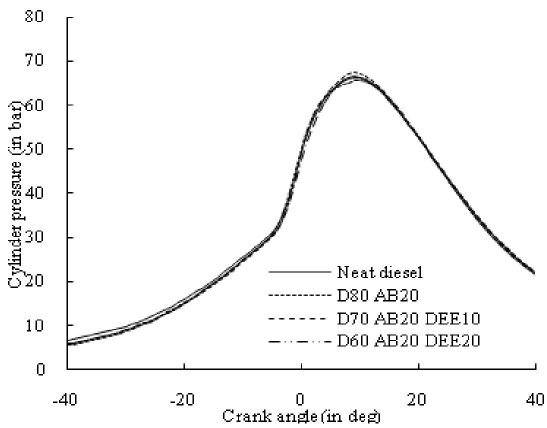

Fig. 4: Variations in in-cylinder pressure at full load

5. Rate of heat release

In a compression ignition engine, the amount of heat released in the premixed combustion is influenced by the rate of air fuel mixing, heat value of the fuel and ignition delay. Based on the first law of thermodynamics, the combustion phase is split into diffusion and premixed phase. The calculation of heat release as per Krieger and Bormann heat release (Q_n) analysis Eqn. is given as,

$$Q_n = \frac{\lambda}{\lambda - 1} P \frac{dV}{d\theta} + \frac{1}{\lambda - 1} V \frac{dp}{d\theta}$$

Where, θ is the crank angle, P is the cylinder gas reassure (Pa), V is cylinder volume (m^3) and λ is the ratio of specific heat (taken as 1.25 for diesel). The deviation of rate of heat release versus the crank angle of neat diesel, D80AB20, D70AB20DEE10 and D60AB20DEE20 for no, part and full load conditions are shown in Figs. 5, 6 and 7 respectively. The maximum rate of heat release for diesel and D80AB20 are 19.29 and 19.08 kJ/CAD at 1° ATDC for no load condition as shown in Fig. 5. The maximum heat release rate for D80AB20 fuel blend is lower than the diesel fuel. As diesel has higher calorific value, during the delay period accumulation of additional diesel releases enormous amount of heat. The lowering of D80AB20 is due to small ignition delay and due to its greater viscosity than the diesel fuel. The heat release rate for DEE blends D70AB20DEE10 and D60AB20DEE20 are 19.57 and 18.27 kJ/CAD at 1° ATDC. The heat release rate for D70AB20DEE10 is higher than diesel and other bio-diesel blends because of its vaporization and higher cetane number of DEE which causes injection in low gas temperature due to high latent heat of evaporation. The maximum rate of heat release of D60AB20DEE20 decreased with increase in DEE concentration.

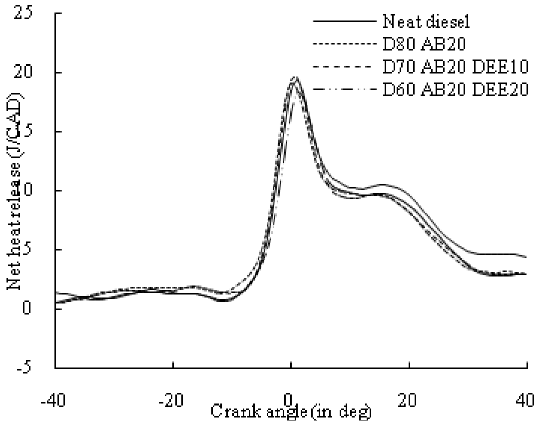

Fig. 5: Variations in rate of heat release at no load

At part load condition, the maximum heat release rate for neat diesel, D80AB20, D70AB20DEE10 and D60AB20DEE20 are 36.1, 36.46, 36.6 and 36.14 kJ/CAD at -2°, -2°, -2° and -1° crank angle BTDC as shown in Fig. 6. In this instance, maximum heat release rate for diesel is lower than D80AB20 blend which depicts more delay period and higher cetane number of D80AB20 causes higher rate of heat release. The source for maximum rate of heat release for D70AB20DEE10 blend is due to the high cetane number of DEE, higher volatility and its capacity to mix with air. The decrease of D60AB20DEE20 by addition of DEE leads to elevated latent heat of evaporation causing the injection of fuel in low gas temperature.

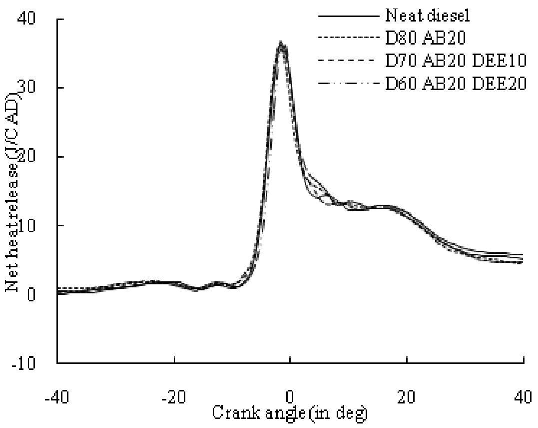

Fig. 6: Variations in rate of heat release at part load

The maximum heat release rate at full load condition for diesel, D80AB20, D70AB20DEE10 and D60AB20DEE20 are 46.22, 45.47, 48.95 and 45.38 kJ/CAD at -3°, -4°, -3° and -3° crank angle BTDC as displayed in Fig. 7. Maximum rate of heat release for diesel is higher than D80AB20 blend may be due to higher calorific value and accumulation of more diesel releases maximum heat by the ignition delay. D70AB20DEE10 has higher peak heat release rate than diesel and other bio-diesel blends [19].

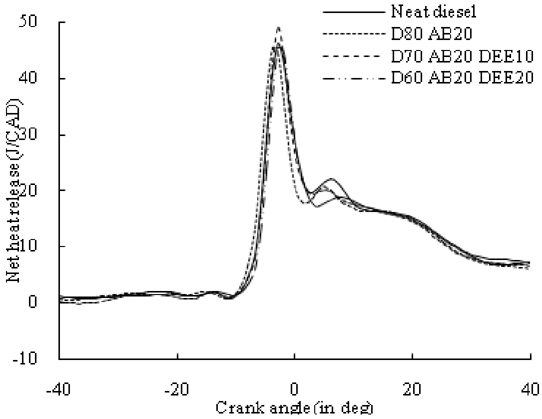

Fig. 7: Variations in rate of heat release at full load

6. Rate of pressure rise

The variation in maximum rate of pressure rise with crank angle for diesel, D80AB20, D70AB20DEE10 and D60AB20DEE20 are shown in Figs. 8, 9 and 10. The unexpected rise and fall of in cylinder pressure to crank angle is the rate of pressure rise (dP/dθ) which specify engine knocking. The rate of pressure rise which helps to realize the softness of the engine operation is the main derivative of the cylinder pressure. For diesel engine, the maximum rate of pressure rise is less than 10 bar/deg which is the limit range. The peak pressure rise advance firstly with load and it diminishes by the main influence of premixed phase at lower loads. At higher loads, the diffusion phase of combustion remains crucial. The peak pressure rise rate for diesel, D80AB20, D70AB20DEE10 and D60AB20DEE20 for zero loads are 1.94, 2.02, 2.09 and 1.99 bar/deg at 0°, -1°, 0° and 1° of crank angle respectively and it is shown in Fig. 8. The maximum rate of pressure rise is improved for all biodiesel blends compared with diesel fuel which may be mainly due to higher kinematic viscosity and lesser ignition delay. The maximum rate of pressure rise is for D70AB20DEE10 which is higher than diesel and other biodiesel blends depicting its superior latent heat of vaporization.

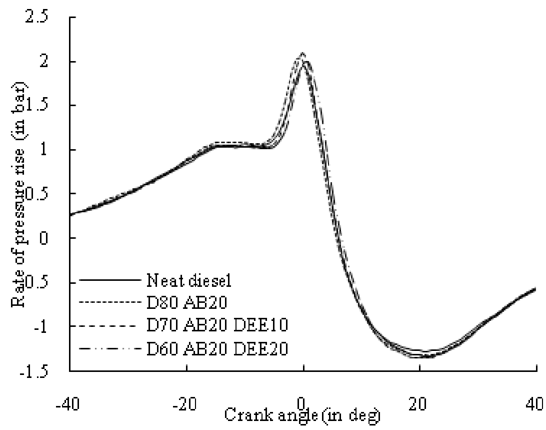

Fig. 8: Variations in pressure rise rate at no load

At part load condition, the maximum rate of pressure rise for neat diesel, D80AB20, D70AB20DEE10 and D60AB20DEE20 are determined as 4.01, 3.87, 4.17 and 4.1 at -2° of crank angle as shown in Fig. 9. The maximum rate of pressure rise is greater for diesel compared with D80AB20 biodiesel blend.

Also it can be noted that D70AB20DEE10 illustrate higher maximum rate of pressure rise than diesel and biodiesel blends by the influence of lengthened delay period and high latent heat of evaporation of DEE.

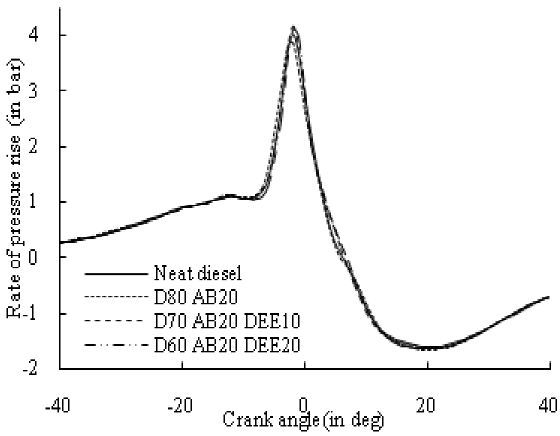

Fig. 9: Variations in pressure rise rate at part load

Fig. 10 shows 5.24, 4.98, 5.13 and 4.89 bar/deg as the maximum pressure rise rate for neat diesel, D80AB20, D70AB20DEE10 and D60AB20DEE20 at -3° crank angle at full load condition. The maximum pressure rise rate for D80AB20 bio-diesel blend is lower than the diesel fuel because of its lower calorific value and higher cetane. The DEE blend D70AB20DEE10 showed higher maximum rate of pressure rise compared with bio-diesel blends. This is due to high latent heat of evaporation and higher cetane number of DEE which increases the rate of pressure rise.

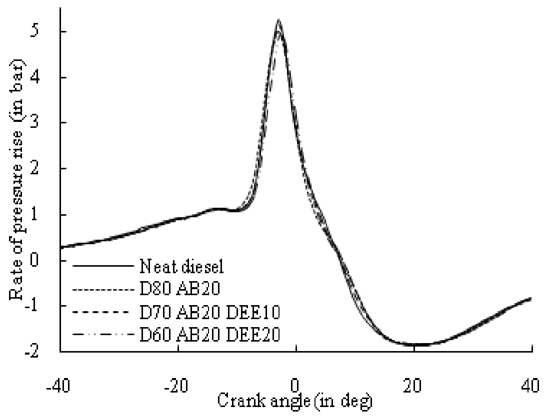

Fig. 10: Variations in pressure rise rate at full load

7. Cumulative heat release

Cumulative heat release is the quantity of energy consumed for given outputs. For all fuels, cumulative heat release rises in the subsequent part of the combustion. It extensively increases by increase in the engine loads. The variation of cumulative heat release for diesel, D80AB20, D70AB20DEE10 and D60AB20DEE20 at no, part full load conditions are shown in Figs. 11, 12 and 13 respectively. The maximum CHR for diesel, D80AB20, D70AB20DEE10 and D60AB20DEE20 are 0.68 bar (70° - 95° CA), 0.59 bar (49° - 84° CA), 0.58 bar (49° - 84° CA) and 0.56 bar (50° - 96° CA) for zero load condition as shown in Fig. 11. Whereas, 0.88 bar (73° - 103° CA), 0.84 bar (70° - 79° CA), 0.85 bar (70° - 77° CA) and 0.85 bar (67° - 85° CA) at part load condition is shown in Fig. 12.

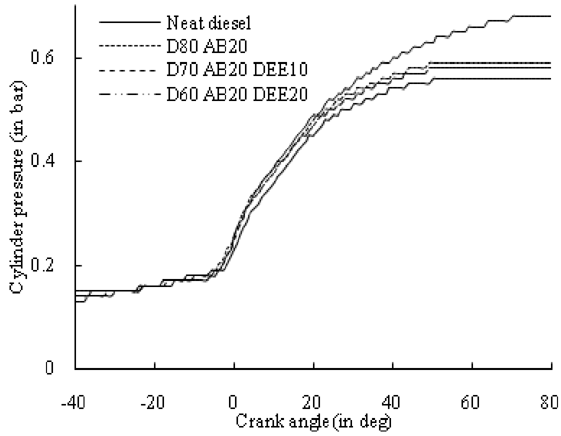

Fig. 11: Variations in cumulative heat release at no load

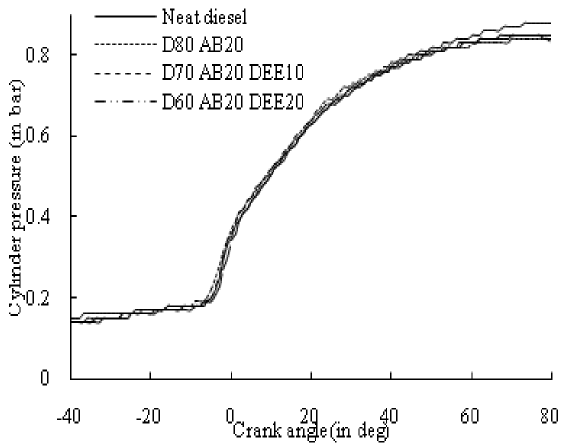

Fig. 12: Variations in cumulative heat release at part load

For full load condition, the maximum cumulative heat release is 1.1 bar (82° - 99° CA), 1.06 bar (71° - 82° CA), 1.08 bar (76° - 80° CA) and 1.06 bar (70° - 86° CA) for diesel, D80AB20, D70AB20DEE10 and D60AB20DEE20 as shown in Fig. 13. Cumulative heat release rate has increased for all fuel for increasing the engine loads. It is observed that base fuel diesel achieved maximum cumulative heat release rate at no, part and full load conditions. This depicts the higher calorific value of diesel which release extreme heat in combustion chamber due to ignition delay.

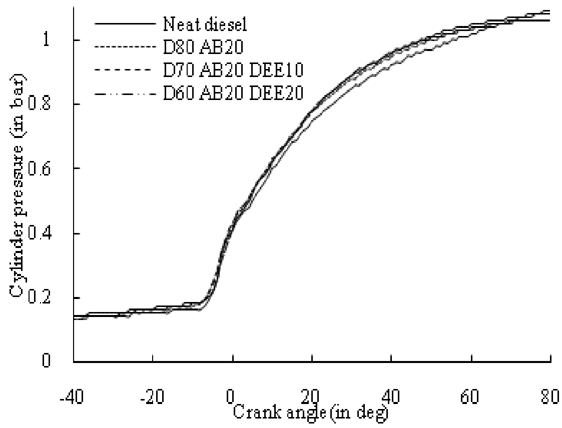

Fig. 13: Variations in cumulative heat release at full load

8. Ignition delay

The time duration between the start of injection and combustion in the cylinder is termed ignition delay. Ignition delay is a feature for combustion phenomena and ignition delay period start at the beginning of injection. Engine speed, compression ratio, fuels ignition quality (cetane number), cylinder gas pressure and quality and quantity of fuel atomization influences ignition delay. The ignition delay for diesel, D80AB20, D70AB20DEE10 and D60SB20DEE10 for various loading conditions respectively is shown in Fig. 14. The ignition delay for zero load is 7.45°, 7.12°, 6.98° and 6.01° whereas the same is 5.01°, 4.67°, 4.21° and 3.98° at part load condition. At full load, the ignition delay is determined as 3.89°, 3.12°, 2.73° and 2.41° for diesel, D80AB20, D70AB20DEE10 and D60SB20DEE10 respectively. Increase in load decreases the ignition delay period for all fuels. The ignition delay period for algal bio-diesel D80AB20 is shorter than diesel at no, part and full loads. The main reason for the lessening in ignition delay is higher cetane number of D80AB20 which leads to good atomization, better ignition quality, faster mixing and increased cone angle. On the other hand, the DEE blends showed very short ignition delay period than diesel and D80AB20 for increasing load conditions. This is due to higher latent heat of evaporation of DEE and higher cetane number which makes auto ignition easily and gives short ignition delay [20-21].

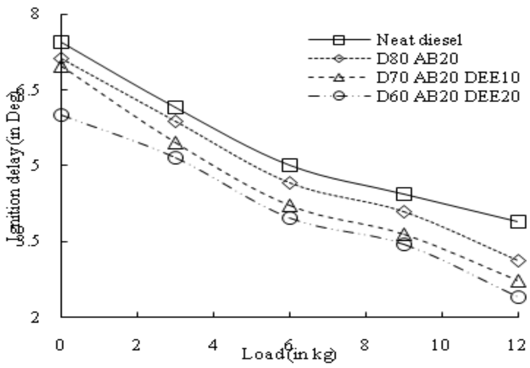

Fig. 14: Variations in ignition delay at all load

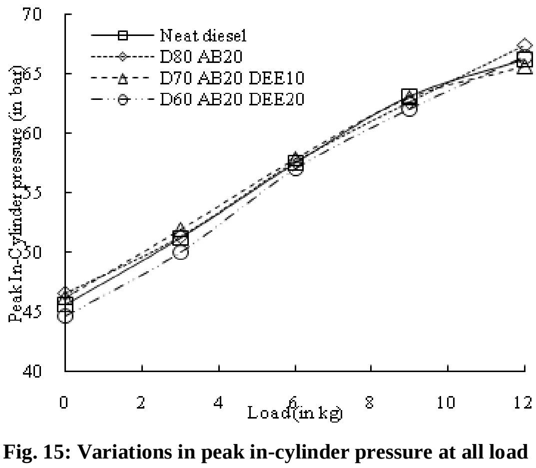

Fig. 15: Variations in peak in-cylinder pressure at all load

The variation of peak in-cylinder pressure at different load conditions for diesel, D80AB20, D70AB20DEE10 and D60AB20DEE20 are shown in Fig. 15. The peak in-cylinder pressure for D80AB20 is higher than base diesel and DEE blends. Increase in the concentration of DEE influenced a decrease in peak pressure. For D60AB20DEE20, the cylinder pressure is lower due to less heat release rate compared to diesel and bio-diesel blends.

9. Conclusion

The influence of DEE on the blends of algal bio-diesel-diesel in a CI engine with respect to its combustion phenomena is studied. The CI engine is able to operate smoothly with all blends of fuel throughout the entire loading conditions without any modification. The results are summarized below.

- D80AB20 exhibited higher in-cylinder pressure throughout all loads. Higher concentration of DEE20 showed better in-cylinder pressure at full load operations.
- Higher rate of heat release is due to enhanced diffusive combustion for D70AB20 DEE10 and it is followed by D80AB20 fuel blend.
- A significant increase in the rate of pressure rise is also observed when the engine is fuelled with D70AB20DEE10.
- A gradual decreasing trend of ignition delay was also seen in the test fuels. D70AB20DEE10 showed 2.73° CAD ignition delay at full load condition.
- Higher peak pressure was observed for D80AB20 as 67.39 bar at full load condition.
- The emission test results indicated that the algal bio-diesel blend is more suitable to be used as fuel in CI engine. Addition of oxygenate upto 10% enhanced the combustion performance significantly.

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