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Combustion of biodiesel in CI engine

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Abstract
Biodiesel is one of the promising renewable, alternative and environmentally friendly biofuels that can be used in diesel engine with little or no modification in the engine. In the present article an overview of combustion characteristics of CI engine running with biodiesel is described. The tests on engine running with different fuels (biodiesel and diesel) have resulted in almost overlapping P-V diagrams. The power output values for both the diesel and biodiesel fuels are almost the same. The engine running with biodiesel has produced slightly higher incylinder pressure and peak heat release rate than the engine running with normal diesel at all operating conditions. Furthermore, the brake specific fuel consumption values for the engine running with biodiesel are higher than the engine running with normal diesel. These studies showed that biodiesel is good gas oil substitute but an increase in the nitrogenous oxides emissions was observed at all operating conditions. The rates of pressure rise and heat release are higher for biodiesels as compared to neat diesel. Many researchers observed shorter ignition delay in combustion for most of the renewable fuels.

Keywords: Biodiesel, Combustion, Ignition Delay, Heat release rate.

1. Introduction

A large number of studies have shown that biodiesel is one of the promising renewable, alternative and environmentally friendly biofuels that can be used in diesel engine with little or no modification in the engine The stringent emission laws, the depletion of fossil fuels and relation of fuels with politics have forced the world to find alternatives to fossil fuels. Numerous vegetable oil esters (biodiesel) have been investigated for use in internal combustion engines and have been shown to have higher potential to reduce CO2 emission The interest in renewable energy sources for energy production is not new. Many studies have been conducted to qualify various oil and their blends from plants and vegetables as alternative renewable energy sources. This renewable source of fuel may also help in reducing the net production of CO2 from combustion sources and our dependence on fossil fuels. Often the vegetable oils investigated for their suitability as biodiesel are those which occur abundantly in the country of testing [1-3]. As oil and gas reserves gradually dwindle and global warming due to CO2 emissions become more obvious the world is going to need to consider alternative fuels, especially where road transport is concerned. Much research has been done to investigate the use of vegetable oils as a road transport fuel. Vegetable oils can be used in diesel engines either in its neat form, called straight vegetable oil and need many engine modifications, or in forms produced as a result of chemical reactions such as transesterification. There are a number of different recipes for producing shorter chain length chemical structures and these products are called bio-diesel [4, 5].

The maximum combustion pressure generally increases at both low speeds and high speeds and it has a minimum value for all blending ratios compared to diesel. The pressures and pressure rise rates for pure biodiesel is almost similar to those of gas oil. Biodiesel, however, exhibits slightly lower pressure rise rate than gas oil, which appears to be advantageous with the new fuel. The biodiesel seems to have slightly delayed combustion (location of maximum pressure and pressure rise rate are shifted later). The maximum pressure rise rate in the pre-chamber is reduced as the load increased for all the biodiesel fuels examined. At low loads the pure biodiesel fuel exhibits slightly higher rate of pressure rise than pure gasoil and their blends. Advancing the injection timing generally increases the maximum pressure and maximum pressure rise rate. (dP/dq) max. Reduced with higher compression ratio for pure biodiesel fuel. The biodiesel fuel produced close torque and power as gasoil at all engine

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speeds examined. The biodiesel fuel was found to be good replacement of gas oil fuel from the point of view of torque and power produced combustion noise or engine roughness and vibration, as well as the cyclic variability and smoothness of engine operation [6-8].

The NOx emission is increased with increasing the concentration of biodiesel. The NOx emission of biodiesel and diesel are compared by various researchers indicating more emissions for biodiesel. The peak cylinder pressure and rate of pressure rise for biodiesel blends are slightly higher than those with the diesel fuel. HRRs are higher for biodiesel blends compared to diesel fuel. The combustion duration is higher for biodiesel blends at full load compared with diesel fuel. Renewable diesel fuels have shorter ignition delays when compared with diesel. Most of the renewable diesel fuels are also observed to have lower peak in-cylinder pressure and heat release rates. The biodiesel addition to the diesel fuel consistently caused early SOC timing with combination of early SOI timing and shorter ID. Meanwhile, HRR max values in the premixed combustion phase generally decreased with the decrease of fuel injection during shorter ID periods. Combustion duration generally increased with biodiesel additions for the all engine loads. Pmax did not change remarkably with the biodiesel addition for the all engine loads, while its locations were slightly moved away from TDC except at full load. However, dPmax values decreased at medium and high loads. Variation on the IMEP values depends on SOC timing and combustion phasing. A slightly increment on BSFC and some reduction on BTE were observed with the addition of the biodiesel for the all engine loads. NOx emissions increased while smoke emissions decreased with the biodiesel additions for the all engine loads [9-12].

2. Combustion in a CI Engine

The essential features of the CI engine combustion process can be summarized as follows: Fuel is injected by the fuel ignition system into the engine cylinder toward the end of compression the stroke, just before the desired start of combustion. The liquid fuel usually injected at high velocity as one or more jets through small orifices or nozzles in the injector tip, atomizes into small drops and penetrates into the combustion chamber. The fuel vaporizes and mixes with the high-temperature high- pressure cylinder air. As the air temperature and pressure are above the fuel's ignition point, spontaneous ignition of portions of the already mixed fuel and air occurs after a delay period of a few crank angle degrees. The cylinder pressure increases as combustion of the fuel-air mixture occurs. The consequent compression of the unburned portion of the charge shortens the delay before ignition for the fuel and air which has mixed to within comestible limits, which then burn rapidly. It also reduces the evaporation time of the remaining liquid fuel. Injection continues until the desired amount of fuel has entered the cylinder. Atomization, vaporization, fuel-air mixing and combustion continue until essentially all the fuel has passed through each process. In addition, mixing of the air remaining in the cylinder with burning and already burned gases continue s throughout the combustion and expansion processes. The combustion process is depends on the characteristics of the fuel, design of engine combustion chamber and fuel injection system and engine operating conditions. It is an unsteady, heterogeneous, three-dimensional combustion process. Higher compression ratio is used to improve fuel conversion efficiency.

Injection timing is used to control combustion timing. The delay period between the start of injection and start of combustion must be kept short and reproducible. A short delay is needed to hold the maximum cylinder gas pressure below the maximum engine pressure capacity. The spontaneous ignition characteristics of the fuel-air mixture must be held within limit. This is done by requiring that diesel fuel have cetane number that is a measure of ease of ignition of fuel [13-15].

3. Combustion Characteristics

A. Variation of pressure with crank angle

Figure1 shows that the in-cylinder pressure within the combustion chamber of the CI engine running with biodiesel and normal diesel in a CI engine. It shows that the peak cylinder pressure of the engine running with biodiesel is slightly higher than the engine running with diesel. The main cause for higher peak incylinder pressure in the CI engine running with biodiesel is because of the advanced combustion process initiated by easy flow-ability of bio-diesel due to the physical properties of biodiesel. In addition, due to the presence of oxygen molecule in biodiesel, the hydrocarbons achieve complete combustion resulting in higher incylinder pressure. In a compression ignition (CI) engine, the cylinder pressure depends upon the fuel-burning rate during the premixed burning phase. As the blend quantity increases the amount of fuel taking part in the uncontrolled combustion stage of the mixture increases, which results in a higher pressure raise [1, 3-5].

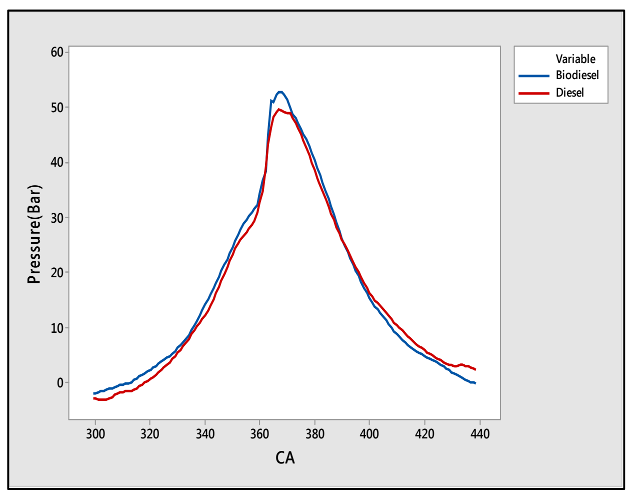

Fig 1: Variation of pressure with crank angle

B. Peak pressure and Variation of pressure with cylinder volume

Figure 2 depicts that P-V diagram of compression ignition engine, which was examined at different engine speed and at various engine load conditions. It shows that the power, which is produced by the engine cylinder and calculated from the P-V diagram does not show any significant change for biodiesel and pure diesel at different engine loads. This indicates that the biodiesel's lower heating value effect is compensated by the combustion related effects. At TDC the pressure is more in case of biodiesel compared to diesel [3-5].

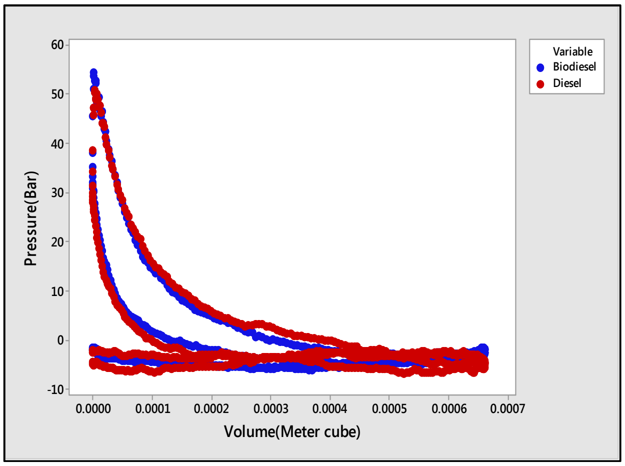

Fig 2: Variation of pressure with cylinder volume

C. Rate of increase of pressure

Figure3 shows the variation in the rate of pressure rise (ROPR) for the biodiesel and diesel tested fuels with engine load. ROPR is indicative of noisy operation of an engine. When the injection timing is retarded, the rate of pressure rise is marginally higher than that of the standard injection timing. The rate of pressure rise depends on the amount of heat released in the initial stages of combustion and the fuel quality. It can be noted that the rate of pressure rise is higher for biodiesel than diesel. This is due to higher ignition delay that results in the accumulation of fuel and sudden combustion which will produce higher peak release rate and pressure rise.

The biodiesels mostly have their peak dp/dh just before TDC with a tendency to move towards the TDC as load increases. It is also noted that the cylinder pressure variation rate increases with increasing engine load. The large change in pressure variation as load increases might be a result of the high temperature and pressure environment which would allow for faster combustion upon fuel injection. This mainly depends on the fuel chemical and physical properties, which affect the mixing and ignition process. Higher in-cylinder pressure increasing rate generally leads to more combustion noise [5-9].

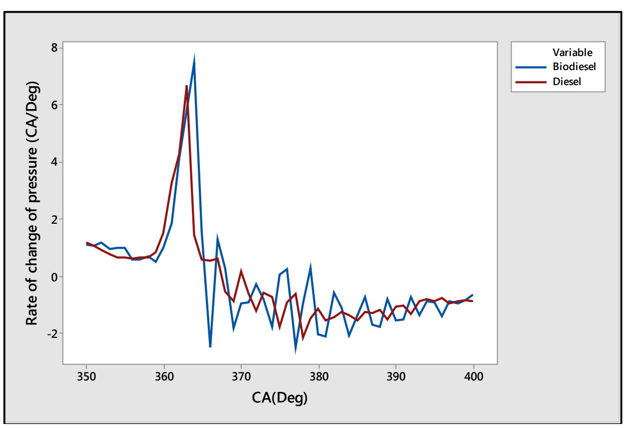

Fig 3: Rate of increase of pressure with crank angle

D. Heat Release Rate

The heat release rate (HRR) is an important parameter to analysis the combustion phenomena in the engine cylinder. The important combustion phenomena parameters such as combustion duration and intensity can be easily estimated from the heat release rate diagram.

The HRR diagram also provides key input parameters in the modelling of the NOx emission. The heat release rate is modelled by applying the first law of thermodynamics.

The simplified model is shown in equation (1).

$$\frac{dQ}{d\theta} = \frac{1}{\gamma - 1}\left(\gamma p \frac{dV}{d\theta} + V \frac{dP}{d\theta}\right) \quad (1)$$

Where dQ/dθ is rate of heat release (kJ/deg), P is the incylinder gas pressure, V is in-cylinder pressure, and γ is the ratio of specific heats in the equation (1), the cylinder content is assumed to be homogeneous mixture of air and combustion products. It is further assumed that a uniform temperature and pressure exist at any moment during the combustion process. To determine the HRR of the internal combustion engine by equation (1), the engine geometry specification that has been used and the cylinder pressure that were recorded during the tests were used.

Figure 4 shows heat release rate indicating that the ignition delay for biodiesel and their blends was shorter than that for diesel. It can also be seen that the maximum heat release rate of biodiesel and their blends is lower than that of diesel. This is because, as a consequence of the shorter ignition delay, the premix combustion phase for biodiesel and their blends is less intense. On the other hand, while running with diesel, increased accumulation of fuel during the relatively longer delay period resulted in higher rate of heat release. Because of the shorter delay, maximum heat release rate occurs earlier for biodiesel and their blends in comparison with neat diesel. However, the heat release during the late combustion phase for biodiesel is marginally lower than that of diesel. This is because the constituents with higher oxygen content are adequate to ensure complete combustion of the fuel that is left over during the main combustion phase and continue to burn in the late combustion phase.

It can be seen that the CI engine running with biodiesel has a higher peak in the heat release rate diagram than the diesel. This phenomenon can be explained on the basis of the presence of the oxygen molecule in biodiesel fuel that results in the air-mixed fuel in the cylinder to burn completely and increase the heat release rate. The cumulative heat release for the diesel and biodiesel is shown in and it can be seen that the biodiesel has higher cumulative heat release. Rapid heat release is in the combustion phase due to more fuel is accumulated in the combustion [7, 8-11].

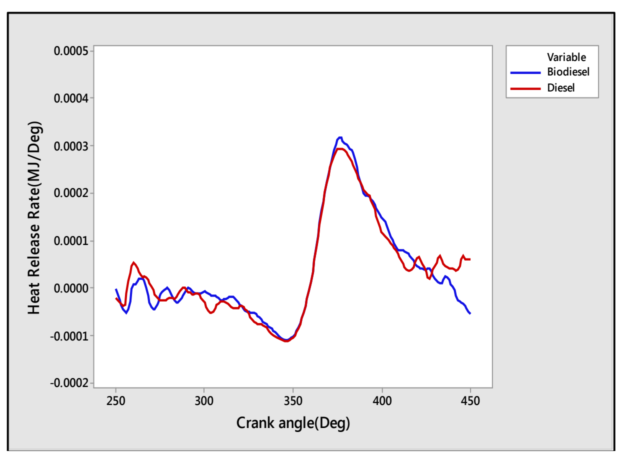

Fig 4: Rate of heat release with crank angle

E. Cumulative Heat Release Rate
The cumulative heat release is an important parameter to characterize the efficiency of the combustion process. The cumulative heat release (Qac) in combustion cylinder is found by equation (2).

$$Qac = \int dQ = \int \frac{\gamma}{\gamma-1}(PdV + VdP) \quad (2)$$

The variation in cumulative heat release (CHR) with crank angle is presented in Figure 5. The figure shows that there is a tendency of late heat release in the earlier stage of combustion for biodiesel compared to diesel. But the CHR value of diesel fuel quickly exceeds the CHR for biodiesel at a later stage of combustion. The main reason for the decrease in the CHR is lower heating value (LHV) of biodiesel as compared to diesel fuel. CHR increased with the rise in the engine load due to the increase in the quantity of fuel injected into the cylinder [8-12]

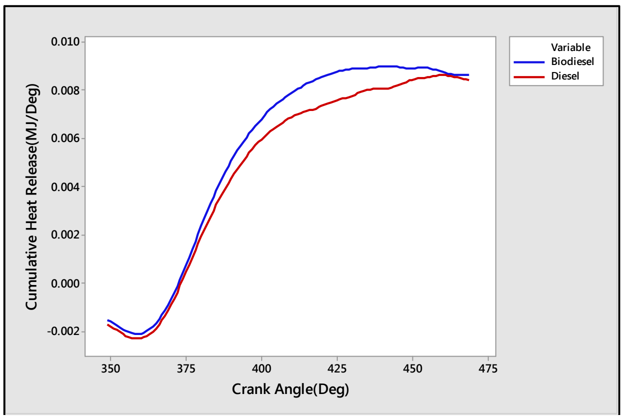

Fig 5: Cumulative heat release with crank angle

F. Ignition Delay(ID) and Combustion Duration(CD)
The increase in fuel viscosity, particularly for petroleum-derived fuels, results in poor atomization, slower mixing, increased penetration and reduced cone angle. These results in longer ignition delay. But biodiesel is not derived from crude petroleum the opposite trend is seen in the case of biodiesel and their blends. The delays are consistently shorter for biodiesel than diesel with the difference increasing with load. Biodiesel usually includes a small percentage of diglycerides having higher boiling points than diesel. However, the chemical reactions during the injection of biodiesel at high temperature resulted in the break-down of the high-molecular weight esters. These complex chemical reactions led to the formation of gases of low-molecular weight. Rapid gasification of this lighter oil in the fringe of the spray spreads out the jet, and thus volatile combustion compounds ignited earlier and reduced the delay period. Ignition delay is the most important parameter in the combustion analysis. Ignition delay is influenced by a group of parameters such as engine speed, intake air temperature and pressure, fuel type, air-fuel ratio, fuel quantity, quality fuel atomization. The type of fuel plays the important role for ignition. It has been noted that the ignition delay decreases with biodiesel, it is mainly due to maximum cylinder pressure higher temperature and higher cetane number [10, 11].

In the analysis, the characteristics of the investigated combustion parameters are determined as follows. The start of fuel injection (SOI) or in other words dynamic fuel injection was determined by using the needle-lift signals. SOI is a point of the needle-lift signal just rising from zero. Injection delay (IND) is defined as a time between the static fuel injection timing and dynamic fuel injection timing (SOI). The start of combustion (SOC) was determined from the second derivation of in-cylinder pressure in which crank angle point passes through zero before rising to the maximum value of slope. Ignition delay (ID) is the crank angle between the SOI and SOC. CA10, CA50 and CA90 are the crank angle locations of 10%, 50% and 90% accumulated HRR, respectively. Combustion duration (CD) was determined as the crank angle interval from CA10 and CA90 [8-14].

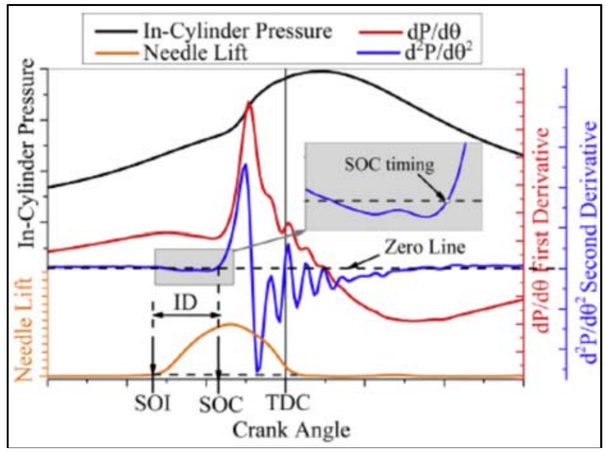

Fig 6: Determination of start of combustion

G. Mass Fraction Burnt
The variation of the mass fraction burnt for biodiesel and standard diesel with the crank angle at full load is given in Figure 7. At full load conditions the mass fraction burnt of biodiesels is slightly higher than that of standard diesel. Due to the oxygen content of the biodiesels the combustion is sustained in the diffusive combustion phase. At crank angle before 360°, the mass fraction burnt for the fuel biodiesel is higher than the standard diesel. But at crank angle after 360°the mass fraction burnt is slightly closer to each other. The efficient rate of combustion is shown by the highest rate of burning [11-15].

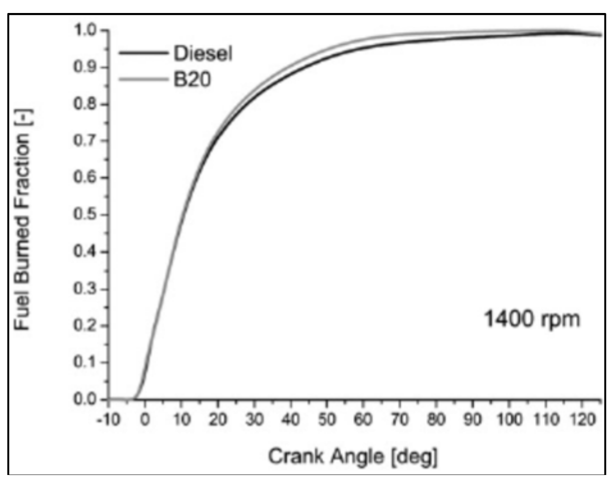

Fig 7: Fuel burned fraction with crank angle

4. Conclusions

The study of review on combustion of biodiesel in CI engine and its effect on ignition delay period, rate of pressure rise, heat release rate, cumulative heat release and fuel burned fraction at different load conditions and various blends leads to the following conclusion:

1. In-cylinder peak pressure for biodiesel is higher than that of for pure diesel.
2. The power produced by the engine cylinder and calculated from the P-V diagrams are almost same.
3. The net HRR of biodiesel fuel is lower than petroleum diesel due to lower heating value of the biodiesel.
4. In all cases the ignition delay for biodiesel was found to be shorter than pure diesel.
5. CD generally increased with biodiesel additions for the all engine loads
6. CO2 emissions for the all engine loads slightly increased with the biodiesel additions.
7. The biodiesel was found to be good replacement of gas oil fuel from the point of view of torque and power produced combustion noise or engine roughness and vibration, as well as the cyclic variability and smoothness of engine operation.

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