An Overview of Ignition Delay and Combustion of Biodiesel Fuelled in CI Engine

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Abstract – Biodiesel fuel has capability to avoid the shortage of transportation fuel energy sources. A diesel engine combustion and emission characteristics are mainly dependant on the ignition delay (ID). This review represents the parameters affecting the ignition of the different biodiesel fuel. The analysis comparative study between various biodiesel and diesel is described. The comparative results show that the combustion of biodiesel in engine is slightly different from the engine running with petroleum diesel. The survey results show that combustion characteristics of biofuels are slightly different from an engine operating with different biodiesels. Many researchers reported that biodiesel has early start of combustion and shorter ignition delay as compared to diesel. Higher cetane number (CN), lower compressibility and fatty acid composition of biodiesel have been observed as the main parameters for early start of combustion and shorter ignition delay. In addition, it is also revealed that the heat release rate (HRR) of biodiesel is less than pure diesel due to the less lower heating value, less volatility, higher viscosity and shorter ignition delay.
Index Terms - *Biodiesel, VCR engine, ignition delay, Combustion, Emission.*

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I. Introduction

Various parameters affect the efficient combustion such as, evaporation and atomization of the fuel, Mixing with surrounding gas, Auto ignition, Oxidation, Turbulence and fuel combustion, Interaction with cylinder wall fuel, Heat transfer between fuel and surrounding gas, Combustion gas and Heat transfer between the cylinder wall and the like can be mentioned . Mixing of uniform air fuel is greatly affected by the shape of the combustion chamber and fuel injection characteristics. The higher the injection pressure, the faster the combustion speed and the higher the combustion chamber gas temperature. This is because the evaporation rate of the sprayed fuel becomes faster and the penetration into the combustion chamber decreases [1-3]. The experiment index map determines the shape and size of the cylinder pressure diagram. It is also useful for the purpose of determining heat release. Because the properties of both pure mixed biodiesel and mixed biodiesel are different from the physical and chemical properties of diesel fuel, it has a major impact on engine performance and emissions. Detailed studies on the characteristics of biodiesel and the impact on combustion and fuel injection systems are needed if this fuel is used in a diesel engine without any change in engine geometry [4, 5].

Application of biodiesel has several advantages, but in order to overcome its limitations, it is necessary to improve some of its inherent properties. Biodiesel is more viscous than petroleum diesel [6-8]. Studies have shown that increasing blend ratio and increasing viscosity may degrade the atomization quality of the injected fuel. The result is increased in mean droplet diameter and disintegration time [9-11] of the sprayed fuel. The injected fuel quantity, injection timing, and spray pattern can be affected by higher viscosity and specific gravity of the biodiesel. In order to achieve a reduction in brake specific fuel consumption (BSFC) and emissions while maintaining other engine performance parameters at an acceptable level, it is necessary to know the combustion and HRR characteristics of the biodiesel. Differences in physical properties between diesel fuel and biodiesel fuel affect combustion characteristics and heat release characteristics [12-15]. Many studies have been conducted on ID and combustion behavior of biodiesel-fueled diesel engines. As a result of the research, biodiesel fuel was confirmed to be early start of combustion (SOC), ID shortening and decrease in HRR. The differences in various parameters of these studies, fuel injection timing, injection pressure, engine load, compression ratio etc. differ. Biodiesel has a lower calorific value, thereby causing a specific power loss [16, 17]. The test was carried out under steady-state conditions of a four-cylinder turbocharged DI diesel engine at full load and 1400 rpm engine speed. As a result, pure biodiesel (B100) showed a BSFC 13.8% higher compared to diesel. This is mainly because the heating value of biodiesel is lower than that of diesel. Therefore, biodiesel contains about 12% less calorific value than diesel [14]. Several technologies such as applying a turbocharger to diesel engines, viscosity reducing additives, preheating, exhaust gas recirculation, doping, oxidation technology, and low heat exclusion concepts are used for large biodiesel scale application. Many studies have reported that the combustion behavior of biodiesel and diesel are not identical. However, although biodiesel has many advantages over diesel fuel, there are needs to improve some properties, including viscosity, volatility and compressibility of biodiesel that affect ID and combustion behavior. This review outlines the previous work on ignition delay, combustion and emissions characteristics using biodiesel. The data presented from authentic sources in this document will lead the researcher to select the appropriate route in the future.

II. FUNCTIONING OF DIESEL ENGINE

A. Combustion

The operating principle of diesel engine is compression ignition. The pressure, fuel and air fuel mixture is automated. This mixture should mix with the rapidly swirling hot air in the combustion chamber. Generally, high compression ratios in the order of 12–24 are used in diesel engines to ensure high temperature and pressure, and thus auto ignition of the fuel–air mixture. The combustion process of compression ignition engine is divided in three parts as shown in Fig. 1 [18]

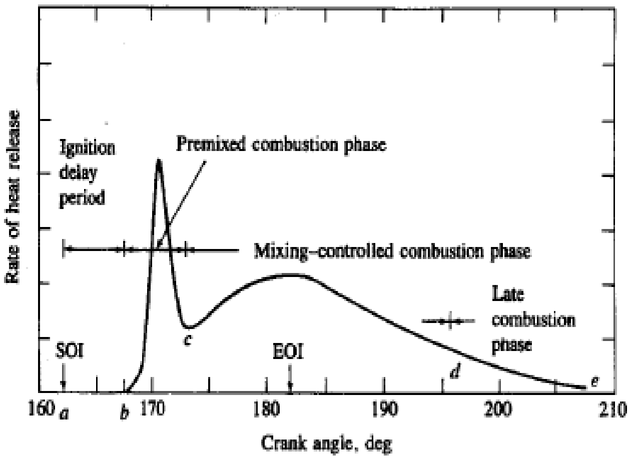

Fig. 1 Combustion process of compression ignition engine

B. Ignition Delay

Combustion process of compression ignition engine is shown in fig. 1. Ignition delay is shown by curve a-b which is considered to be a very important parameter of combustion [8]. If this period is also called the preparatory phase during which some fuel has already been admitted into the combustion chamber is, the HRR-crank angle curve separates from the motoring curve is as SOC. Delay period in the diesel engine exerts a very great influence on both engine performance and design. The delay period has been found to be different when diesel and biodiesel are used individually.

III. IGNITION OF BIODIESEL

The start of combustion and injection timing both affect on ignition delay. The change in fuel properties influences more on ID. Due to the more viscosity and lower compressibility of the biodiesel there is an advanced start of injection [19-21]. The start of fuel injection is usually taken as the time when the injector needle lifts off its seat, and the SOC can be defined by the change in slope of the heat- release rate that occurs at ignition. The start of fuel injection is an important feature as it affects the combustion characteristics, exhaust gas temperature and exhaust emissions of the engine. Ignition delay is governed by the cetane number. Effect of different biodiesels on ID and injection timing in comparison to diesel is presented in Table 1. The lower compressibility and density of the biodiesel cause the shorter ID or earlier injection timing that results in, advanced combustion as well. Usually, the early injection leads to higher combustion temperatures, although the premixed combustion period is reduced due to the shorter ignition delay [22].

TABLE I

EFFECT OF DIFFERENT BIODIESELS ON ID AND SOC COMPARED TO DIESEL

Sr. No.	Biodiesel type	CN relative to Diesel	Effect on ID and SOC
1	Soybean oil methyl ester	Higher	Shorter ignition delay and earlier start of combustion[5]
2	Soybean oil methyl ester	Slightly higher	Shorter ignition delay[14]
3	Rapeseed oil methyl ester	Higher	Earlier start of combustion[23]
4	Waste cooking oil methyl ester	Higher	Shorter ignition delay which decreases with the increment of % UCME in the blend[26]

Senatore et al. [23] revealed that the earlier start of fuel injection using the rapeseed oil methyl ester as compared to diesel. Experimental study conducted by Canakci and Van Gerpen [24] in John Deere 4276T model diesel engine using soybean oil methyl ester (SOME) and yellow grease methyl ester (YGME). Results implied that the SOC for SOME and YGME are3.41 and 4.21 earlier than that of diesel fuel. In addition, the shorter ID of 0.751 and 0.631 for SOME and YGME were found as compared to diesel. The early SOC and shorter ID is attributed the fact of higher cetane number of SOME of 51.5 and YGME of 62.5 as compared to diesel of 42.6. Likewise, Monyem [25] obtained the shorter ID of 0.61 using SOME as compared to diesel fuel. The effect of engine load on ID for four-stroke constant speed direct injection (DI) diesel engine using used cooking oil methyl ester (UCME) is presented by Rao et al. [26]. According to the results, the ID of the UCME is significantly lesser than that of the diesel and reduces as the proportion of UCME in the mixture increases: at the maximum load of 4.4 kW, an ID of 151 crank angle (CA) is obtained for diesel 14.11 CA shows 20% UCME, 13.81 CA 40% UCME, 131 CA 60% UCME, 12.71 CA 80% UCME, 12.61 CA 100% UCME. It was found that when entering the combustion, smaller macro cyclic oleic acid fatty acid methyl esters increased ID loss with increasing loading. This may be due to higher combustion temperatures and exhaust gas dilution at higher loads.

Another study was conducted by Ozsezen and Canakci [27] using waste palm oil methyl ester (WPOME) and canola oil methyl ester (COME). This study reports the early bio-diesel SOC compared to diesel. The average SOC timing of WPOME and COME occurred at 9.351 CA before top dead centre and 8.551 CA BTDC(Before top dead center), respectively, but the SOC timing for diesel was 8.151 CA BTDC. Therefore, the use of WPOME and COME has CA initial value of 1.21 CA and CA of 0.41 CA compared with diesel, respectively. N wafor et al. [28] reported that biodiesel with a slightly lower CN could exhibit slower delay times and slower combustion rates, thus resulting in delayed combustion, higher emissions and lubricating oil temperature. A comparative study on the combustion characteristics of diesel and biodiesel from soybean oil was conducted by Canakci et al. [14].

In order to investigate the influence of engine load on ID, Sahoo and Das [29] conducted experiment on a single cylinder diesel engine using Jatropha, karanja, polanga diesel and biodiesel was performed. The result proved that the ID of biodiesel and its blend is shorter than the ID of diesel. The ignition timing is delayed in proportion to the increase of biodiesel in the mixture. The brake thermal efficiency (BTE) of the blend increases from medium to full load conditions, which can be attributed to the increase in the oxygen content of the mixture, while the combustion period is shortened for all biodiesel, blends [30]. The chemical reaction during injection of biodiesel at high temperature resulted in the decomposition of high molecular weight esters. These complex chemical reactions resulted in the formation of low molecular weight gases. Rapid gasification of this light oil within the fringe of the spray widens the jet, thus volatile combustion compounds are ignited early and the delay period is shortened. Biodiesel with a higher molecular weight from jatropha, karanja and polanga oil is likely to respond as well. Rodriguez et al. [31] conducted an experiment using biodiesel derived from palm and rapeseed and biodiesel derived from diesel, and found that biodiesel has shorter ID than diesel. This observation closely resembles the results of other researchers. The shorter ID of biodiesel is also due to the presence of rich oxygen content in biodiesel [32, 33].

IV. Combustion of Biodiesel

In this section, we reviewed the combustion characteristics of biodiesel fuel used in diesel engines, the pressure rise rate, and the combustion characteristics of HRR with a brief explanation. The maximum HRR is 71.459 J/1. CA is recorded with diesel 61 BTDC and the maximum HRR is 51.481 J/1. A study conducted by Ozsezen et al. recorded for UCME at 81 BTDC [26]. Experimental investigation carried out with water cooled DI, naturally aspirated, 4 stroke 6 cylinder 6.0 L Ford Cargo diesel engine using COME and WPOME. The survey results show that the maximum HRR of 0.41 kJ/1 CA is obtained with Diesel 5.61 BTDC, the maximum HRR of 0.73 kJ/1 CA is found at 4.5 BTDC in the COMOME, and the maximum HRR 0.34 kJ/1 CA is obtained with WPOME 5.81 BTDC In this regard, similar results are obtained from Ozsezen et al. [29] Using biodiesel for WPOME and COME. Peak cylinder gas pressures of WPDC and COME were measured at 8.34 MPa and 8.33 MPa, respectively, at 6.751 CA (ATDC) after top dead center, but the peak cylinder gas pressure of diesel at 71 CA ATDC was 7.89 MPa It was. Biodiesel's maximum cylinder gas pressure was higher than that of petroleum diesel due to the earlier timing of bio-diesel's BSFC, CN, boiling point, oxygen content and start of injection (SOI).

Recent studies were conducted by Gumus [8] of Lombard in 6 LD 400 single cylinder diesel engines using hazel nut core oil methyl ester with various conditions. The combustion characteristics of single cylinder, 4.4 kW DI compression ignition engine and electro dynamometer Used cooking oil methyl ester (UCME) and its blend were fueled and compared with baseline diesel fuel [26]. Combustion performance was measured using AVL indicator software connected to the engine. These experimental results showed that the maximum pressure was about 2.2 to 4.4% higher than in the case of diesel fuel. The maximum HRR due to UCME combustion is observed as 51.481 J / 1. During CA at 81 BTDC, HRR diesel is recorded as 71.459 J / 1. CA at 61 BTDC [26].

The lower HRR of UCME than diesel is due to the short ID and the long combustion period. By using biodiesel derived from rice oil, total heat release was reduced. The lower the calorific value of biodiesel, the higher the specific fuel consumption of 5.9% compared to petroleum diesel fuel. Also, by increasing the biodiesel concentration in the mixture, the total release during premixed combustion is ID [34]. Sahoo and Das [29] published different studies with various loads using diesel and biodiesel of polanga, jatropha, karanja. As a result, at peak loading, Polanga · biodiesel (PB 100) showed a peak pressure 8.5% higher than pure diesel, Jatropha biodiesel (JB 100) 7.6%, Karanja · biodiesel (KB 100) 6.9% there were. It was observed while the engine was operating in half load and no load condition. The maximum HRR of all biodiesel and its blends was lower than that of diesel. This is because the biodiesel and their blends have short IDs and the premixed combustion stage is slower. Meanwhile, while driving in diesel, an increase in accumulation of fuel during a relatively long delay period resulted in a higher heat release rate. Cylinder pressure and net HRR of the engine were analyzed by Solaxetar. Different blends of ROME and diesel were used at

4.5 bar engine operating conditions to show mean effective pressure (IMEP) and 6.1 bar IMEP [35]. According to their analysis, it has been found that as RME percentage in the fuel mixture increases, the ID tends to decrease and the fraction of fuel burned in the premixed phase increases. Under the operating conditions of 4.5 bar IMEP, the combustion periods of B 0 (diesel), B 20, B 50 and B 100 (pure biodiesel) are 301 CA, 301 CA, 281 CA and 281 CA, respectively, combustion under the operating condition of 6.1 bar IMEP For all fuels, the duration was 341 CA.

A similar CN combination of increased injection pressure and RME compared to diesel increased the amount of fuel undergoing premixed combustion at an earlier stage as indicated by the net HRR trend . Studies using hazelnut nuclear oil methyl esters and blends [8] suggested that the peak cylinder gas pressure (PCGP) increases with increasing biodiesel mixing ratio with an engine load (EL) of 10 Nm . PCG was occurred between 6.61 MPa and 7.05 MPa with 10 Nm EL and PCGP was obtained between 7.54 MPa and 7.96 MPa for 20 Nm. Using COME and WPOME, in a study compared to petroleum diesel, it is reported that combustion started due to ID and advanced injection.

Biodiesel (WPOME and COME) both took a long time to premix burn. The shorter ID and advanced injection will affect the start of combustion, duration, peak cylinder pressure. A survey of HRR of biodiesel from diesel and waste oil revealed that the total HRR during combustion is lower for B50 fuel compared to petroleum diesel. For B50 and diesel, the maximum HRR was 1.27 kJ / cycle and 1.6 kJ / cycle, respectively. The low HRR of biodiesel is due to the low calorific value of waste oil biodiesel [36].

V. Effect of Biodiesel Characteristic on Combustion Performance

Biodiesel has a lower specific energy than diesel. Since biodiesel has a calorific value about 9% lower than that of diesel, BSFC increases with increasing biodiesel ratio in the blends [21, 37-38]. Biodiesel blends are usually formed by mixing with ordinary diesel at different mixing ratios. From some studies it has been observed that blending of the mixture is important for combustion properties and release characteristics. Investigation by Lee et al. [9] was to observe the combustion and emissions characteristics of biodiesel common rail diesel engines at various mixing ratios. The results suggested that droplet size increases as biodiesel mixing ratio increases due to higher viscosity and surface tension. However, although the emission factor decreased with increasing biodiesel mixing ratio, NOx slightly increased due to shorter ID.

Physical properties such as kinematic viscosity, cetane number and surface tension of biodiesel are different from petroleum diesel. Both kinetic viscosity and surface tension are related to combustion and spray behavior. These two properties of biodiesel increase with increasing proportion of mixture in fuel. Since biodiesel has a higher cetane number, it leads to a high degree of ignition, resulting in higher NOx formation [9]. Sahoo and Das [39] carried out non-edible Jatropha, Karangaja, Polanga biodiesel in different blends in a single cylinder, 4-stroke diesel engine, and as a result, it was suggested that pollaga's biodiesel has the highest cylinder pressure jatropha it can be used under full load condition by karanja. It was also noticed that high cylinder pressure was observed according to blend concentration [39]. Qi et al. [40] conducted experiments to investigate combustion and emissions performance using bio-diesel and ethanol biodiesel microemulsion, report that microemulsion retards SOC and improves combustion characteristics compared to biodiesel. However, microemulsions increase HC, CO emissions and certain fuel consumption. Studies have been conducted using different proportions of diesel fuel, such as 5 vol.%, 10 vol.%, 15 vol.% of bio-diesel mixed with ethanol, resulting in a maximum pressure and heat release compared to diesel with a blend ratio it is clear that it increases with. The blend slightly increased the thermal efficiency, but there was no significant difference from the 10% and 15% blends compared to diesel. Biodiesel mixed with ethanol reduces NOx emissions and reduces the opacity of smoke of 35-85% [41].

Similar results were obtained by Lu et al. [42]. A comparative study in which bio gas biodiesel fuel was used as a dual fuel and combustion and emissions performance was investigated using biodiesel fuel of soybean oil methyl ester as a single fuel. It has been found that the rate of increase of biogas in dual fuel reduces combustion pressure and HRR. Compared with single fuel, dual fuel increased ID and burn time, but the indicated mean effective pressure decreased slightly [43]. Meanwhile, Yoon and Lee [44] states that fuel costs slightly increase peak cylinder pressure, heat release rate, IMEP compared to diesel and biodiesel. The properties of different types of biodiesel are strongly related to their fatty acid composition. Since the structure of the aliphatic compound in the fuel may affect many properties such as cetane number, viscosity, density, calorific value and low temperature characteristics, the fuel characteristics are dependent on fuel droplet size and size distribution, spray Characteristics, fuel evaporation, flame propagation and seed temperature [45, 46].

In general, the cetane number, the heat of combustion, the melting point, and the viscosity of the pure fat compound increases with increasing chain length and decreases as the unsaturation of the FAME molecule increases. In addition, as the degree of unsaturation increases, the calorific value, melting point, cetane number, viscosity and oxidation stability decrease but density, bulk modulus, fuel lubricity and iodine number increase. It is also recognized that the molecular structure of biodiesel greatly affects combustion and its associated emissions [47-48].

VI. Effect of Biodiesel on Engine Emissions

Biodiesel is an oxygenated fuel, the combustion of the engine is improved by the presence of molecular oxygen, so NOx emissions also increase. That injection timing, premixed combustion, fuel chemistry can also cause higher NOx [49]. Dorado et al. [50] Tested with 3 cylinder 4-stroke diesel diesel engine using olive oil methyl ester and diesel, and found stable combustion efficiency for both fuels [50]. Emissions were significantly reduced by 58.9%, 32%, and 8.9% in CO, NOx and CO 2, respectively, compared with diesel. In addition, even when using olive oil methyl ester, a slight decrease in BSFC was observed. Biodiesel contains 11% oxygen content, which burns the fuel completely during combustion, resulting in lower HC emissions [51].

A study used by Canakci [14] to observe the behaviour of exhaust gas and BSFC in a turbocharger DI diesel engine with atmospheric biodiesel fuel and petroleum diesel fuel with an engine speed of 1400 rpm. The results showed that biodiesel provides higher BSFC and NOx emissions. Control of the NOx emission amount mainly requires lowering of the in-cylinder temperature. Therefore, these higher NOx emissions can be controlled by using the EGR system [35, 52-53]. Zheng et al. [37] adopted the EGR system to investigate low temperature combustion in single cylinder DI diesel engines with various biodiesel and diesel. Biodiesel fuel was soybean, canola, yellow grease; diesel was ultra low sulphur type. Furthermore, simultaneous reduction of NOx and soot is reported when ID is 50% or more and EGR is 0%. In addition, 55% and 65% respectively with engine operating conditions of BMEP of 4.4 bar and BMEP of 3.1 bar. The recycled exhaust gas reduces the oxygen concentration in the combustion chamber and increases the specific heat of the intake charge, resulting in a decrease in the flame temperature. Reduction of oxygen and flame temperature reduces NOx production. However, some penalties were imposed even if EGR was applied [52]. Soot is a major means of radiation heat loss from in-cylinder flame and biodiesel produces less soot because it is oxygenated fuel. Therefore, combustion heat loss is lower for biodiesel flames that produce higher flame temperature and more NOx [15, 54].

VII. Conclusions

Biodiesel has higher viscosity, higher cetane number and lower compression ratio than diesel fuel. These fuel characteristics affect engine performance, combustion and emission characteristics. The main conclusions of this article are as follows:

1) Biodiesel has a shorter ignition delay which is prolonged with increasing biodiesel content in the fuel.

2) The main reason why the ignition delay of biodiesel is shorter is that the compressibility is low, the viscosity is high and the cetane number is high.

3) The peak cylinder pressure and net HRR of biodiesel fuel is lower than that of petroleum diesel due to low calorific value of biodiesel.

4) Biodiesel fuel reduces emissions such as CO, HC and PM, but ignition delay is shorter than petroleum diesel, injection progresses and NOx emissions increase.

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