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Effect of Emulsified Palm Oil Biodiesel-Diesel Blends to the Combustion Characteristics of Compression Ignition Engine

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Abstract. The increasing energy consumption and the high rate exhaustion of fossilized fuels encourage researchers to find new alternative for the future generation. One of the possible solution to dampen the rate is by biodiesel-water emulsion. In the present study, emulsified biodiesel with 5% (B20W5), 10% (B20W10), 20% (B20W20) and 30% (B20W30) of water in volume were prepared with diesel-biodiesel blend (B20) to be used as fuel in an unmodified compression ignition direct injection engine. All tests were operated at engine speed of 2500 rpm and two different loads namely 20% and 40%. The in-cylinder pressure traces obtained from the series of experiments were used to investigate the trends of rate of heat release (RoHR), rate of pressure rise (RoPR) and mass fraction burned (MFB). The results show that the peak in-cylinder pressure was reduced by 5.9% and the maximum of RoHR is decreased by 8.8%. Furthermore the peak value of RoPR also decrease by 6.4%. All the results were achieved by using B20W5. Therefore, the emulsion of diesel-biodiesel blend is suitable as an alternative technique to improve combustion characteristics while lessen the dependency on fossil fuels.

1. Introduction

Rapid exhaustion of fossil fuels and the sensitivity towards global climate change have led many researchers to explore new alternative for the energy. In addition to that, due to the commencement of industrial revolution in the beginning of 19^{th} century, the consumption of global energy has been increasing day-by day. Figure 1 shows the global primary energy consumption by source 1800-2017, measured in terawatt-hour (TWh) per year [1]. At this rate, the scientists had predicted that the petroleum-based fuels will soon be exhausted in 2052 [2]. It is first discovered by Rudolf Diesel in year 1897 that an engine could be ignite without a spark [3, 4]. In the past decades, biodiesel has been taken into consideration as a leading source to replace partially the fossil fuels role. Extensive researches have been conducted to ensure that the biodiesel is suitable to be operated in unmodified direct injection compression ignition engine. It is to be noted that some of the study yielded favorable results towards the biofuels as compared to neat diesel [5]. There are several types of biodiesel showed promising results such as palm oil, cottonseed oil, rapeseed oil, jatropha oil, soybean oil, sunflower oil and canola oil. Table 1 shows that different countries will produce different types of biodiesel depending on the availability of the feedstocks in their region [5, 6]. In term of area, the highest yielding oilseed biofuel crops is oil palm [7, 8]. Numerous studies have been done to inspect the effect of the palm oil methyl ester (POME) blend with neat diesel towards the engine performance and combustion characteristics. Senthur Prabu et al [9] analyse the effect of additives on combustion characteristics of preheated palm oil biodiesel-diesel blends in direct injection diesel engine and found out that under regular operating conditions the in-cylinder pressure of blended fuels has similar trend to that of neat diesel fuel.

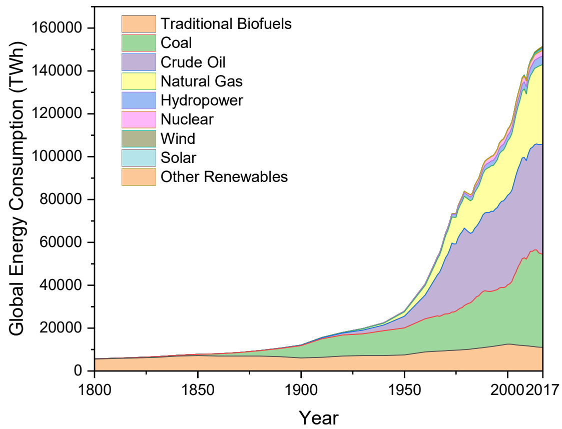


Figure 1. Global primary energy consumption by source 1800-2017

Concentration of water, concentration of surfactant, emulsification technique, stirrer speed, process duration are the factors that affect the stability of the emulsion fuels. Nour and Yunus [10] investigated the effect of surfactant concentration to the viscosity of the emulsion. They found that the viscosity increase when the concentration of the surfactant increased. In the similar study [11], a homogenizer is used to mixing the emulsion in the different speeds (3000-8000 rpm). It is concluded that the stability increased when the speed was increased from 3000 rpm to 5000 rpm. The further increased will only waste of energy as it showed no significant different. The previous study by Noro et al. [12] to investigate the effect of tween group surfactants reported that the rate of separation largely contributed by the type of surfactants used.

Table 1. Production/origin country for different types of feedstocks.

Country	Production quantity in 2017 (billion litres)	Feedstocks
U.S	6.0	Soybean, Corn, Jojoba
Brazil	4.3	Soybean, Animal fat
Germany	3.5s	Rapeseed
Argentina	3.3	Soybean, Corn, Sugarcane
Indonesia	2.5	Palm oil
France	2.3	Rapeseed, Sunflower
Thailand	1.4	Palm oil
Spain	1.3	Olive, Sunflower
China	1.0	Rapeseed, Cottonseed
Poland	1.0	Rapeseed
Colombia	0.6	Sugarcane, Palm oil
Canada	0.5	Rapeseed
Malaysia	0.4	Palm oil
India	0.3	Rapeseed, Cottonseed

Introduction of water to the biodiesel blend will decrease the heat of combustion, improve thermal efficiency and reduce the exhaust emissions [13, 14]. Generally, diesel engine release toxic emissions such as nitrogen oxides (NOx), carbon dioxides (CO_2) and carbon monoxides (CO) [15]. The major strategy to reduce the NOx emissions is by reducing the in-cylinder temperature during the combustion period [16]. Perumal and Ilangkumaran [17] compared the combustion characteristics between pongamia biodiesel and emulsified pongamia biodiesel with water. They concluded that the net heat release for emulsified pongamia biodiesel with water is decreased due to the low heat content. Similar studies by Yusof and Abdullah [18] reported that the decrease in the lower heating value results in an increase in the BSFC. Maawa et al [19] reported that the reduction of 12.75% of brake specific fuel consumption (BSFC) by using emulsified diesel-biodiesel blend.

Generally, emulsion fuels are thermodynamically unsteady systems, consists of two incomplete immiscible phases. Emulsion fuels are slowly separated into two immiscible liquids over a time. To overcome this problem, the presence of surface-active agents (or) surfactants is important to lower the surface tension between oil and water molecules [20]. The most common processes of an emulsion fuel destabilization are droplet-droplet coalescence, flocculation and creaming [21]. Surfactants are amphiphilic molecules that contain a polar head group and a non-polar tail group that is amalgamated to weaken the surface tension of water and the interfacial tension of the oil-water interface. In water-diesel emulsion, the polar group attracted in the direction of the water and the nonpolar group attracted in the direction of the diesel. Proposed by Griffin in 1949, the hydrophilic-lipophilic balance (HLB) is a semiempirical methods used to describe the relationship between the water-soluble and oil-soluble parts of a surfactant [22]. The HLB value ranges from 0 to 20. In the low range of 3.5 to 6.0, surfactants has a tendency to make stable for use in water-in-oil (W/O) emulsions. Surfactants with high HLB values in the 8 to 18 range are most commonly used in oil-in-water (O/W) emulsions [23].

The goal of this study is to investigate the effect of water content in the form of emulsion with blended POME biodiesel-diesel to the combustion characteristics. The combustion characteristics were measured throughout the experiment and the results were compared to neat diesel.

2. Materials

The materials and experimental procedure used in this series of experiment like emulsified fuels preparation, the emulsion stability techniques, and the experimental engine setup will be presented in this section.

Table 2: Proportion of contents for emulsion fuel

Type of Fuel	**Percentage of Diesel (%)**	**Percentage of Biodiesel (%)**			
D	100	0			
B20	80	20			
	Percentage of Biodiesel B20 (%)		**Percentage of Water (%)**	**Percentage of surfactant Tween 80 (%)**	**Percentage of surfactant Span 80 (%)**

B20W5	95	5	1	1
B20W10	90	10	1	1
B20W20	80	20	1	1
B20W30	70	30	1	1

The following materials were used for the experimental analysis; pure diesel, POME biodiesel, distilled water, and Tween 80 Span 80 and for the surfactants. Table 2 shows the proportion of contents to prepare six types of fuel that will be used in this series of experiments.

The emulsification of palm oil biodiesel-diesel mixed was prepared by adding the required amount of water together with 1% in volume of each surfactant. The blend then was stirred using IKA RW20 digital overhead stirrer at a speed of 800 rpm for 15 minutes. The emulsified biodiesel is then tested for physical and chemical properties. Meiji IM7100 Binocular Inverted metallurgical microscope is used to observe the microstructure of the emulsified biodiesel.

The physiochemical property test of the fuel were conducted using standard equipment. The density was tested using Portable Density/Specific Gravity Meter following ASTM D1298. The accuracy of the apparatus is ±0.001 g/cm^3. The kinematic viscosity test was conducted following ASTM D445 standard using CANNON-Fenske Routine Viscometer. The measuring range of the apparatus is 1.6-8.0 mm^2/s. The Oxygen Bomb Calorimeter was used to measure the calorific value using ASTM D4809. The accuracy of the equipment without calibration is ± 0.100 °C. The test was run thrice and the mean value was calculated.

3. Methodology

The engine tests were carried out on a four stroke, multi cylinder Mitsubishi 4D68 compression ignition engine. The water-cooled, naturally aspirated and direct-injected engine was attached to 150 kW eddy current dynamometer. The technical specification of the engine is given in Table 3. One of the cylinder was connected to Kistler 6041A pressure sensor to obtain the pressure inside the cylinder. Gas analyzer Kane 900 was installed in the exhaust to collect emissions data. The schematic diagram of the experimental arrangement is given in Figure 2.

Table 3: Test engine specifications.

Engine model	Mitsubishi 4D68
Configuration	In line 4
Type	Direct injection with glow plug
Rated brake power, (kW)	64.9 @ 4500 rpm
Maximum Torque, (Nm)	177 @ 2500 rpm
Bore, (mm)	42.7
Stroke, (mm)	93
Engine displacement, (cc)	1998
Compression ratio	22.4:1
Combustion chamber	Swirl chamber
Cooling method	Water cooled

Initially the engine is fuelled with neat diesel in order to acquire the baseline operating characteristics. The engine was operated with no load condition for about five minutes before it is increased gradually at 20%, 40% and 60%. The data was obtained data acquisition device DEWE-800. After that, the series of experiment were repeated with five types of fuel namely B20, B20W5, B20W10, B20W20 and B20W30.

4. Results and Discussion

4.1 Physical Characteristic

Figure 3 shows the photographs of emulsified biodiesel with different percentage of water. The round dots are the droplet of water while the rest is dispersed mixed diesel-biodiesel for mixed diesel-biodiesel is more viscous than water [24]. As can be seen, the introduction of water in the biodiesel can form micro-emulsion in water-in-oil (W/O) structure. Figure 3(a) is emulsified biodiesel with 5% of water, Figure 3(b) is emulsified biodiesel with 10% of water, Figure 3(c) is emulsified biodiesel with 20% of water and Figure 3(d) is emulsified biodiesel with 30% of water. In the Fig.1 (a), the water droplet disperse more even and tight, followed by Figure 3(b), Figure 3(c) and Figure 3(d). We can conclude that the more volume of water in W/O, the bigger the dispersed droplets.

4.2 Fuel Properties

It is important to characterize the fuel properties that effect the combustion characteristic before it is tested on the engine. The tested properties in this study are density, kinematic viscosity and calorific value. The tests were repeated three times and the average of the three results were used. Table 4 shows the ASTM standard, the apparatus used and the results of the measurement properties of the fuel.

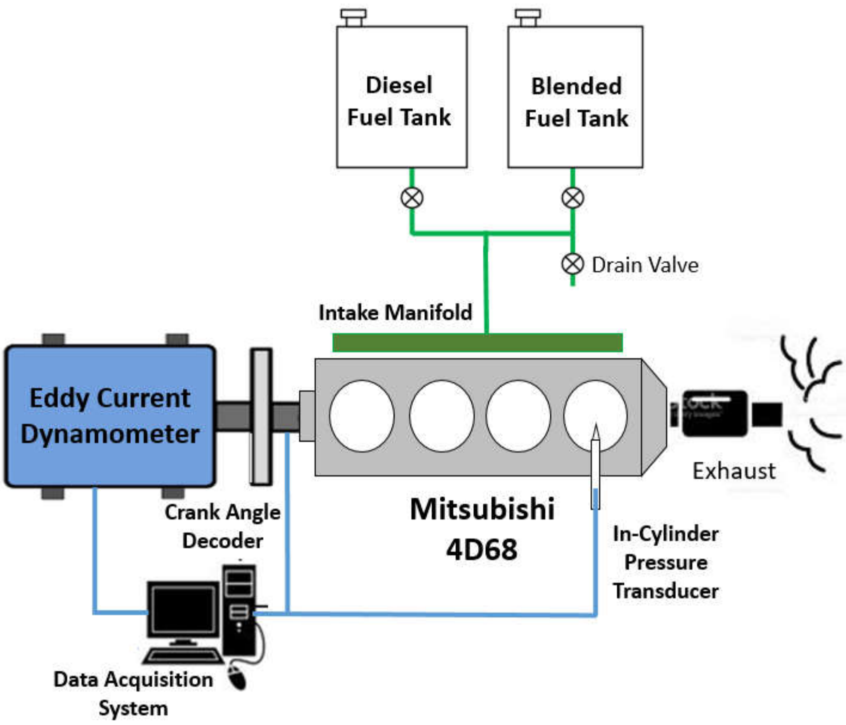


Figure 2. Schematic diagram of experimental arrangement.

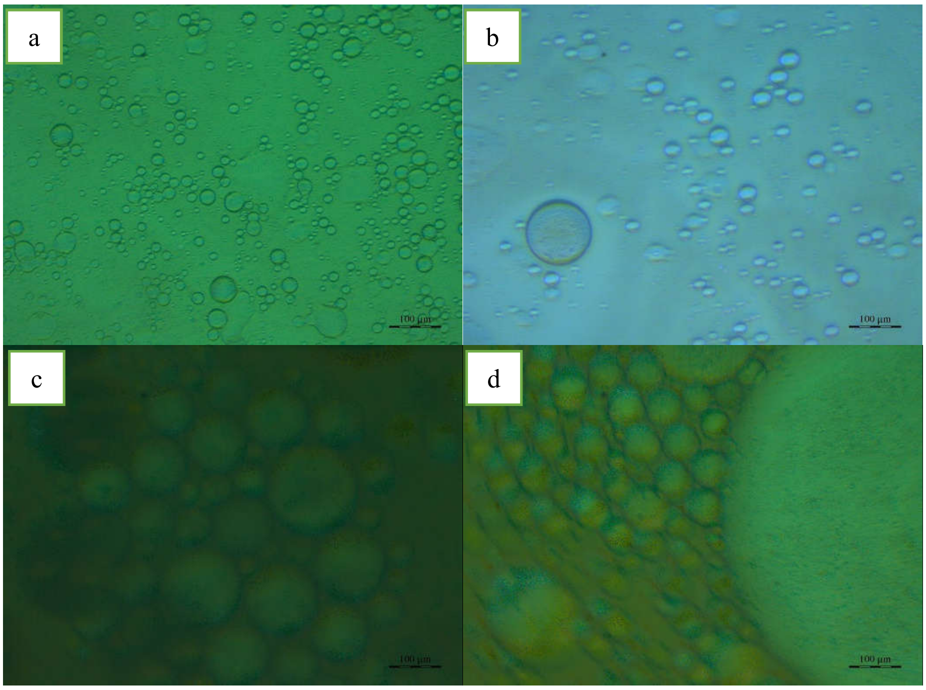


Figure 3. Photographs of emulsified biodiesel with different water content. (a) 5% of water, (b) 10% of water, (c) 20% of water, (d) 30% of water.

The density of the six blended fuels varies in the range of 820-890 kg/m^3. Obviously, when the 20% of POME biodiesel is added to the conventional biodiesel, the density of the blended fuel escalate. In addition to that, the density of the fuel is further increase when the percentage of water is increased. Similarly, the result agree with the previous study by Elsanusi et. al. [25]. The kinematic viscosity plays important role in the mixture formation, fuel spray and combustion process. From the table, it can be seen that the more the volume of the water, the more viscous of the fuel. The highest value of kinematic viscosity obtained by B20W30 which is 5.24 mm^2/s. The kinematic viscosity of the fuels lies in the range of 3.80-5.24 mm^2/s. Contrariwise, the calorific value is reduced when the water content is raise. Naik [26] concluded that the calorific value of the fuel decreases with increasing of its moisture content. The lowest calorific value is 31.03 MJ/kg acquired by B20W30.

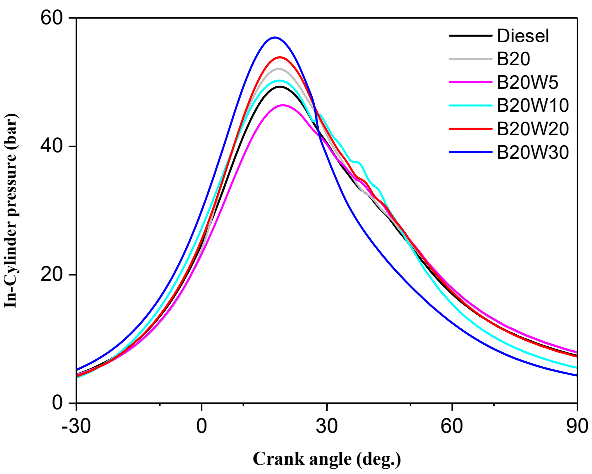
4.3 Engine Combustion

Figure 4 demonstrate the experimental in-cylinder pressure traces from 30° before top dead centre (BTDC) to 90° after top dead centre (ATDC) for all types of fuel while the engine speed is set at 2500 rpm and braking 20% and 40% load. The in-cylinder pressure are identical for all type of fuels during the compression and expansion strokes. In contrary, there is significant difference when the combustion stroke took place. Comparing the effect of biodiesel in the blend, the peak pressure increased 5.5% from 49.32 bar to 52.06 bar at 19° for 20% load ATDC when the neat diesel is blended with POME. This is the contribution of high oxygen content and cetane number of blended fuel [27, 28]. Sharon et. al. [29] found that the increasing percentage of biodiesel will give the increase in maximum cylinder pressure which is similar to present study. The addition of 5% of water in the blend give the reduction of the peak cylinder pressure to 5.9% compared to neat diesel and 10.9% compared to diesel-biodiesel blend at 20% engine load. The integrated natural flame luminosity decreases with the increase of water content and reduce the flame temperature hence, reduces the peak temperature of the combustion [30-32]. This leads to a lower peak pressure [33]. The further increase in water percentage of 10% (B20W10), 20% (B20W20) and 30% (B20W30) will only resulted in higher peak pressure. This is due to the increased self-ignition temperature triggered by the high water density [11]. When the load is doubled, the peak pressure of B20W30 almost reached 60 bar.

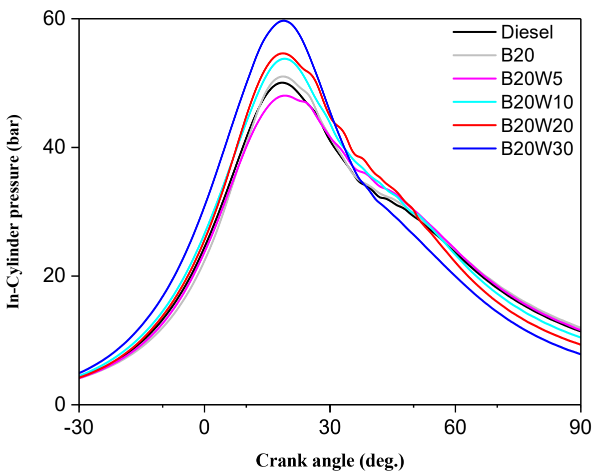
Table 4. Measured properties of blended fuels.

Property		**Density (kg/m³)**	**Kinematic viscosity @ 40°C (mm²/s)**	**Calorific value (MJ/kg)**
ASTM Standard		D1298	D445	D4809
Apparatus Used		Portable Density/Specific Gravity Meter	CANNON-Fenske Routine Viscometer	Oxygen Bomb Calorimeter
Fuel	D	820	3.80	42.50
	B20	854	3.91	42.05
	B20W5	860	4.02	41.66
	B20W10	871	4.38	38.67
	B20W20	877	4.72	35.94
	B20W30	890	5.24	31.03

Figure 5 illustrate the variation of rate of heat release (RoHR) for different blend of emulsion at 20% and 40% engine loads from 30° BTDC to 90° ATDC. The heat release rate between fuels are differs depending on the contents of the fuels. It is notable that the rate of heat release for B20W5 is the lowest at the peak which is 516.6 J/deg. at 20% engine loads and 511.4 J/deg. at 40% engine loads. This is caused by the low heat content of the emulsified blend. The heat also will be carried out by the evaporating water molecules [17]. Previous study by Raheman and Kumari [34] also reported that the evaporation process and additional mass of water lowered the temperature. B20W30 recorded the highest RoHR which yields maximum rate of 618.6 J/deg. and 628.0 J/deg. at 20% and 40% engine loads, respectively. The reduction of 8.8% achieved by B20W5 for the peak of RoHR at 20% engine load compared to diesel fuel.

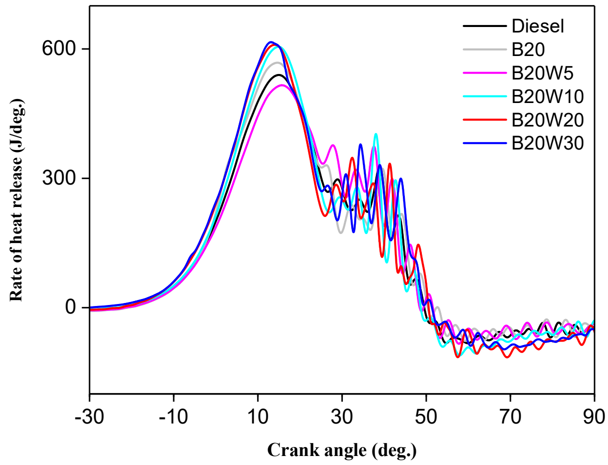


(a) In-cylinder pressure traces against crank angle at 20% engine load

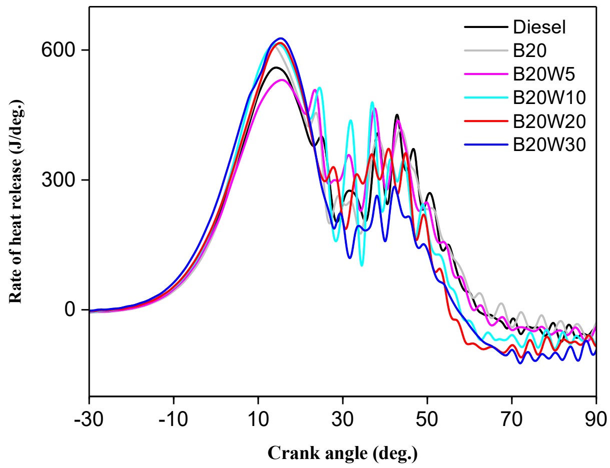


(b) In-cylinder pressure traces against crank angle at 40% engine load

Figure 4. Distribution of in-cylinder pressure at 20% and 40% engine loads.



(b) Rate of heat release against crank angle at 20% engine load



(a) Rate of heat release against crank angle at 40% engine load

Figure 5. Rate of heat release against crank angle for different blend of emulsion at 20% and 40% engine loads.

Rate of pressure rise (RoPR) is related directly to the engine operation which is the first derivative of cylinder pressure. Figure 6 explicit the RoPR against the crank angle for diesel, diesel-biodiesel blend and emulsion fuel with various percentage of water with 2500 rpm engine speed and 20% engine loads. It can be seen that the trend of RoPR for blend B20W10 is comparable to neat diesel. B20W5 has the lowest peak with 1.6 bar/deg. This is 6.4% of reduction compared to neat diesel. While B20 has the highest peak with 2.3 bar/deg. The difference in peak pressure rise is caused by oxygen content and cetane number of the blended fuels [27]. It can be concluded that adding POME biodiesel to the blend will increase the RoPR and the introduction of water will reduce the RoPR.

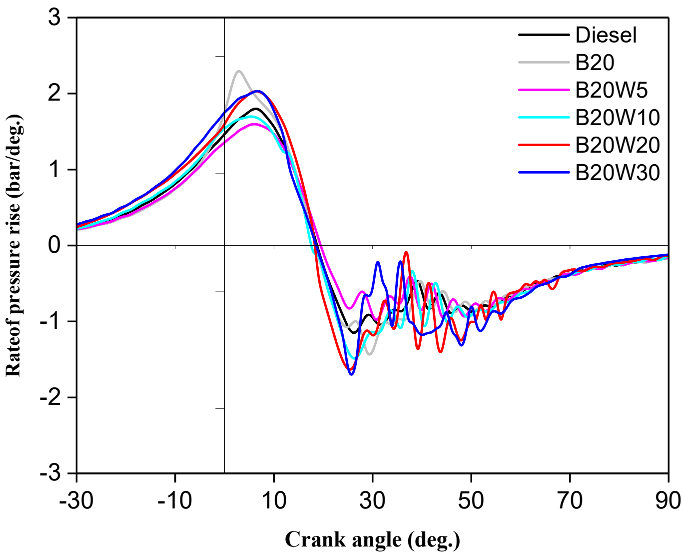


Figure. 6 Rate of pressure rise against crank angle for different blend of emulsion.

Mass fraction burned (MFB) reflect the amount of fuel burned inside the cylinder throughout the combustion process. The determination of MFB is highly depends on ignition delay duration and peak of the in-cylinder pressure. The curve of MFB of each tested fuels for at engine speed 2500 rpm and 40% engine load is shown in Figure 7. The MFB trends for diesel-biodiesel blends is comparable to conventional diesel. It is clearly obvious that the blend diesel-biodiesel at 20% and the introduction of water at 5% to the blend did not affect the combustion process in term of MFB. Conversely, the further addition of water at 10%, 20% and 30% in volume exhibit faster combustion compared to neat diesel. Another important indication for MFB is it shows how quickly the combustion takes place. From the graph, it can be seen that MFB for B20W30 reached unity faster compared to others. This results agreed with previous study by Baskar and Senthil Kumar [35].

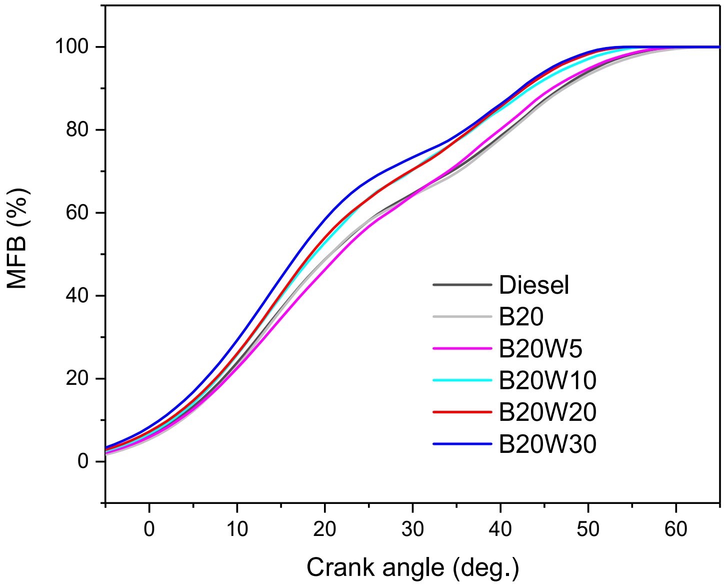


Figure 7. Mass fraction burned (MFB) against crank angle for different blend of emulsion.

5. Conclusions

Emulsified biodiesel containing 5%, 10%, 20% and 30% of water were prepared and tested for engine combustion characteristics in a four cylinder direct injection diesel engine. The results were compared with neat diesel as baseline fuel. From the analysis, several conclusions can be made which are follows;

1. Increased percentage of water in diesel-biodiesel blends will make the dispersed water droplets larger.
2. All four types of emulsion fuels showed more viscous than the diesel and diesel-biodiesel blend and it can be concluded that the more water content in the fuel, the higher the kinematic viscosity.
3. The results show that the peak in-cylinder pressure for B20W5 was reduced by 5.9% compared to neat diesel and 10.9% compared to B20.
4. The maximum value of RoHR at low load is decreased by 8.8%, achieved by B20W5 compared to neat diesel.
5. The emulsion fuel B20W5 was found to lower the peak value of RoPR. The maximum rate was reduced by 6.4% compared to diesel.
6. The addition of water content in the fuel resulted in faster combustion process compared to neat diesel.

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