Investigation of Mixture formation and Flame Development in Emulsified Biodiesel Burner Combustion

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Abstract

The alternative fuel play as a key element for renewable and prevention energy scenario. Thus, biodiesel fuel (BDF) has a potential for external combustion especially in burner combustion. However, biodiesel combustion still have problem of emitting NOx, CO and Particulate Matter (PM) into the atmosphere. For that reason, biodiesel-water emulsion is the simpler and cheapest way to reduce the emission of combustion. Therefore, the emulsification concept from biodiesel and water were studied with focusing in controlling of combustion process in order to minimize the harmful emission. The main purpose of this research is to investigate the effects of emulsified biodiesel on mixture formation, burning process and flame development in burner system. The studied parameters include equivalent ratio, water content in biodiesel-water emulsification and spray characteristics such as spray penetration length, spray angle and spray area. Blending of biodiesel ratio was varied from 5vol%(B5)-15vol%(B15). Water content under emulsified biodiesel was varied up to 15 percent, and equivalence ratio from 0.6 to 2.0. The spray image of different diesel-water ratio and equivalence ratio can be investigated using optical visualization technique and image processing technique. The real spray images with the time changes was analyzed and compared with based diesel fuel. The results show that the mixture formation exhibit influences to the ignition process and flame development. Higher of water contents thus predominantly influences to the chemical process during fuel-air mixing and associated with the variant in flame development and burning process.

Keywords
Water emulsion, Emulsified Biodiesel, Ignition Process, Mixture Formation, Flame Development, Optical visualization

Introduction

The growth of the economy and world population have driven the use of energy and natural resources. Biodiesel as one of the natural resources is being consumed heavily in the world demand. It can be used in many applications such as fuel in automotive and burner system. The main issue is BDF has high toxic emission such as Nitrogen Oxides (NOx) but it decreases the other gases. The improvement of diesel combustion with controlling of combustion process is urgently required. For that reason, the study in fuel-air mixing and spray characteristics are necessary before the combustion process takes place[1-4]. Therefore, the simplest method to control the emission is by adding water in diesel, which is also known as diesel-water emulsion process. Diesel-water emulsion is the simpler and cheapest way to reduce the emission of combustion [1]. This research investigates the effects of emulsified biodiesel on mixture formation, burning process and flame development in burner system. The purpose of water-fuel emulsion in the combustion process is to reduce the gas emission especially NOx, soot, flame temperature and flame phenomena. Many studies on emulsion fuels reveal that they have various benefits, including improvement in combustion efficiency and a reduction in particulate matter (PM) and nitrogen oxide (NOx) emissions. During this process, water can weaken the peak temperature of luminous flames during diffusion process thus decrease the NO_x emissions [5-7]. In addition, the fuel is vaporized to a small particular after the explosion of water droplets, this is named as micro-explosion phenomenon [2]. Micro-explosion is occurs during the mixing of water and fuel, it's made up of two or more liquids with relatively large differences between their boiling temperatures. Heat absorption by water vaporization causes a decrease of local adiabatic flame temperature and reduction of peak flame temperature that associated with lower the PM emissions and produces less toxic emission. Nevertheless, another effect of water emulsification is the influences on fuel properties and to increase the surface tension and viscosity of the fuel, which makes the fuel hard to break up. During burning process, emulsification enhanced air-fuel mixing and promotes the spray characteristics especially at diffusion combustion phase. The saturated methyl esters resulted has greater flame temperatures if compare with unsaturated methyl esters. It can reveal that shorter chained fatty acid methyl esters lead to higher flame temperatures as compared to its longer chained counterparts and higher tendency for thermal NOx formation [8-10]. With the increase in the degree of unsaturated, the fuel consumption rate increased. Water use independent of emulsification to reduce toxic emission.

This main purpose of this research is to investigate the effects of new concept of premixing injector in burner system and analyze the behavior of mixture spray formation during fuel-air premixing. In this research, the spray characteristic of the water-diesel mixture was investigated using the newly developed injector with the water-diesel content and equivalent ratio of the emulsified diesel. Spray characteristic such as spray angle and penetration length were investigated due to the important parameter influences in combustion process that will influences to the NOx and PM emission behaviors. It is expected that this work will provide knowledge to the effects of emulsified diesel and biodiesel fuel to the variation in the fuel-water that strongly influences to the mixture formation, ignition process and combustion characteristics

Table 1: Properties of tested fuels

Fuel type	Properties				
	Density (g/cm3)	Kinematic viscosity (Cp)	Flash point (°C)	Water content (ppm)	Acid value (mg KOH/g)
OD	0.83374	3	80	79.6	0.423
B5	0.84453	4	85	140	0.6732
B10	0.85229	4.1	85.5	146.1	0.7293
B15	0.85428	4.3	87	191.9	0.9537

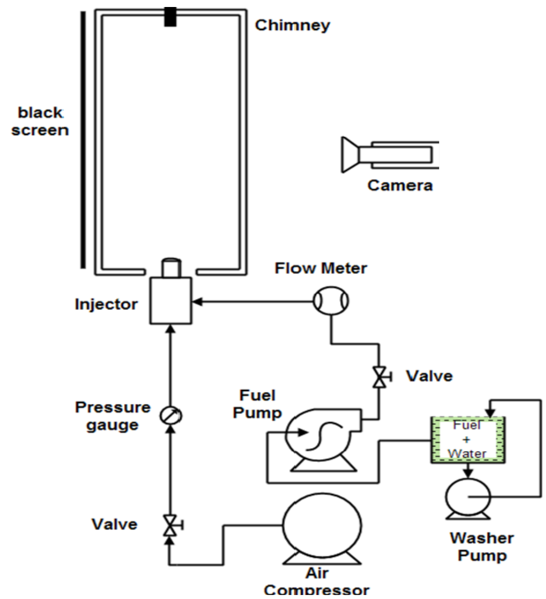


Figure 1: Schematic Diagram of experimental setup

Experimental Setup

The biodiesel used was Crude Palm Oil biodiesel which blended from Universiti Tun Hussein Onn Malaysia (UTHM) Automotive Laboratory and the particular of the tested fuel are detailed in Table 1.The fuel tested were grade II diesel and blends of 5(B5), 10(B10) and 15 vol%(B15) palm oil with the diesel fuel. The grade II diesel designated as ordinary diesel and also assume as standard fuel. The kinematic viscosity of palm oil blend was measured by Viscolite 700 model VL700-T15. The density properties measured by Metter Toledo Diamond Scale modeled JB703-C/AF. The water content in biodiesel sample is measured by Volumetric KF Tirator model v20. The flash point measured by Pensky–Martens PMA 4. The engine fuel consumption measured by Ono Sokki mass flow meter modeled FM2500. A schematic view of the experimental set up and the operating conditions including the nozzle parameter are shown in Fig. 1 and Table 2, respectively. As seen in Fig.1, the injector is equipped with one air compressor and two electrical pumps. Air flow rates and fuel flow rates are controlled by control valve and a voltage regulator respectively. The apparatus consists of an injector having 8 holes with 1mm diameter, the characteristic of injector. During operation, the air pressure from pressure gauge of 0.1bar was injected from the bottom inlet of the injector while side inlet is for fuel injection. Fuel is initially mixed with water in the tank by continuous recirculation through washer pump. Next, the fuel was pumped by fuel pump into the injector.

Table 2 Experimental parameter and operating conditions

Air Compressor	Model	PUMA XN2040
	Capacity, L/min	200
	Pressure, kg/cm^2	8
Washer Pump	Voltage, V	12
	Pressure, bar	3
	Flow rate, L/Hr	7.2
Fuel Pump	Model	CNY-3805
	Pressure, bar	3
	Flow rate, L/Hr	115
DC Voltage Regulator	Model	Teletron TC-1206A
	Current, A	64 (max)
Operating condition	Air Pressure, bar	0.1
	Air Density, kg/m^3	1.16
	Ambient Temperature, K	300
	Water Percentage	0-15%
	Equivalent ratio	0.6-2.0
Injector	Holes	8
	Hole Diameter, mm	1
	Volume, cc	5.9

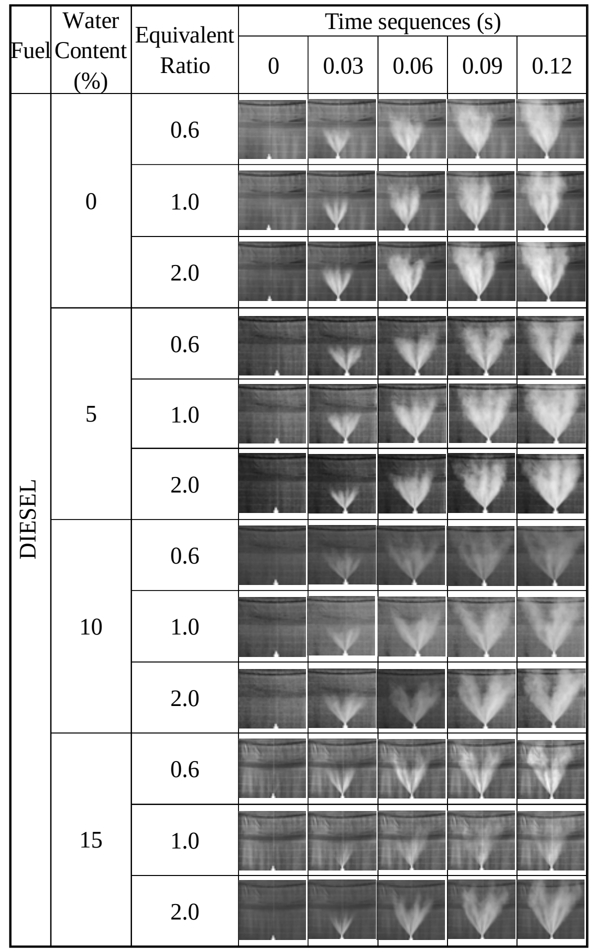


Figure 2 Mixture formation of diesel-water emulsified

Optical set up

The schematic diagrams of burner system of the burner system including the camera setup are shown in Figure 1.Measurements were made in an optical-accessible burner in order to observe the fuel-air mixing before start of the burning process. The optical visualization technique can be divided into several systems such as camera equipment, lighting system and background equipment. The mixture formation and flame development were captured with color images by A Digital Single-Lens Reflex (DSLR) Canon EOS 550D with 18-55mm lens. This model is recommended due its high image quality production compared to other type of camera. This camera settings of f/5.6 for the aperture value, 1/60s shutter speed value and the ISO value of 800 together black backdrop were used for all testing during the whole experiment of this study Real spray image which from different equivalence ratio and water content being taken to be compared. The spray characteristic which includes penetration length and spray angle is analyzed image processing technique and only one hole from the nozzle will be analyzed. In this study, the injection air pressure and ambient density are kept constant at 0.1 bar and 300 K respectively.

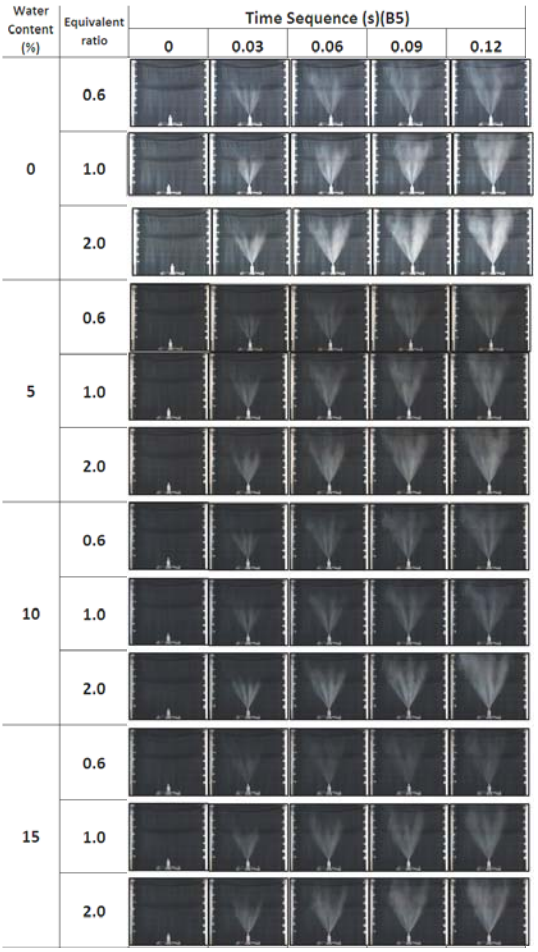


Figure 3 Mixture formation of B5 biodiesel-water emulsified

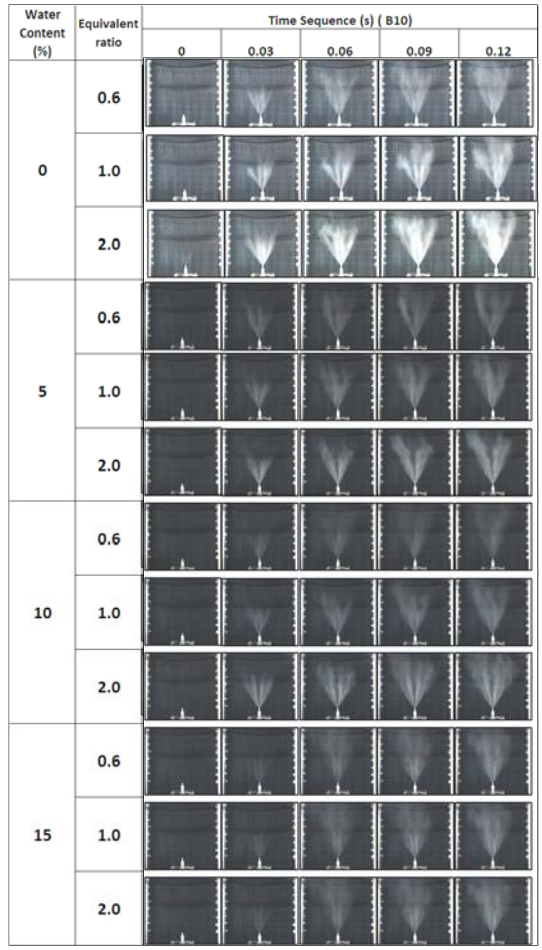


Figure 4 Mixture formation of B10 biodiesel-water emulsified

Result and Discussion

An effect of the diesel emulsified on mixture formation was firstly investigated. Figure 2 compares images of direct photographs with the time changes. The time indicate in the images is referring to the time start of injection. The direction of the spray of diesel fuel is upward from the injector when the supply mixtures are pumped into the injector. The experiments with real images photography was captured with avoided the combustion were conducted in order to observe the behavior of spray characteristics such as spray penetration, spray angle and spray interference. As seen in Fig. 2, the mixture formation were obtained under condition of W0, W5, W10 and W15 in equivalent ratio 0.6 (lean), 1.0 (stoichiometric), and 2.0 (rich). It is clearly shown that increasing of water content has an effect of promoting mixture formation and spray tip penetration especially under equivalent ratio of 2.0.

Figure 3 and 4 compares images of mixture formation of biodiesel with blending ratio of B5 and B10 with real time changes. It clearly demonstrates the increasing of water content under variant in biodiesel blending ratio does not give significant effect on the mixture formation since the differences of mixture formation and fuel-air premixing can be assumed to be similar with standard diesel condition. In addition, under the condition of different blending ratio and same equivalent ratio, the mixture formation trend has remained unchanged. It clearly seen that the equivalent ratio is not affected to mixture formation.

The trends of mixture formation in Fig. 3 and Fig.4 are analyzed by the imaging processing technique presented in Fig. 5 and Fig. 6. Figure 5 shows the graph variation of spray characteristics such as penetration length, spray angle and spray area against equivalent ratio of water content W0, W5, W10 and W15. As seen in Fig. 5, increase water content and equivalent ratio enhanced the penetration length and spray area. This behavior associated with the higher viscosity under W15 condition, and explains the proportionality between the penetration length and viscosity of the mixture. It seems that the viscosity of the mixture is dependent on the water content due to the W0 has the largest spray angle and W15 has the smallest spray angle. On the contrary, it decreases when the water content increases, which. In addition, W15 produced the largest due to its penetration length is the longest although its spray angle is small compared to other equivalent ratio. It seems that the penetration length will give more significant effect on the spray area.

Figure 6 compares the spatial distribution of spray tip penetration, spray angle and flame length for emulsified of biodiesel. As seen in Fig. 6, it can be observed that B5 biodiesel containing water produces longer spray penetration compared to the one without water content. The flame length of will increase with the equivalence ratio. While the smallest spray angle was produced from diesel fuel with 15% water content with the equivalence ratio of 0.8 at 7.26^0. It seems that the higher water content promotes the longer spray penetration that significantly with the decreasing of spray angle.

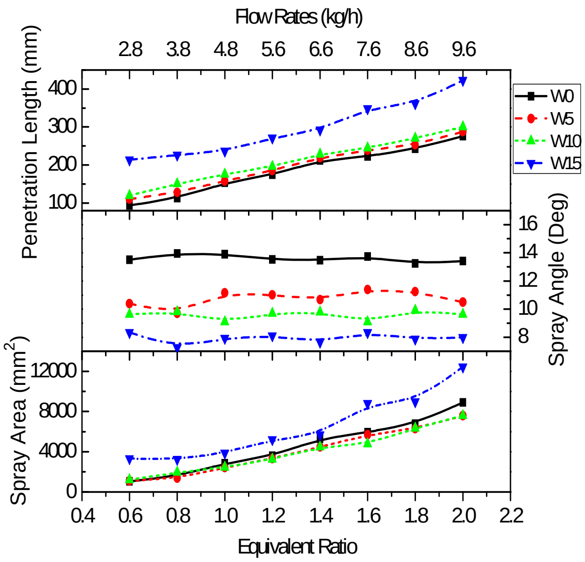


Figure 5 Effects of diesel-emulsified on spray characteristics

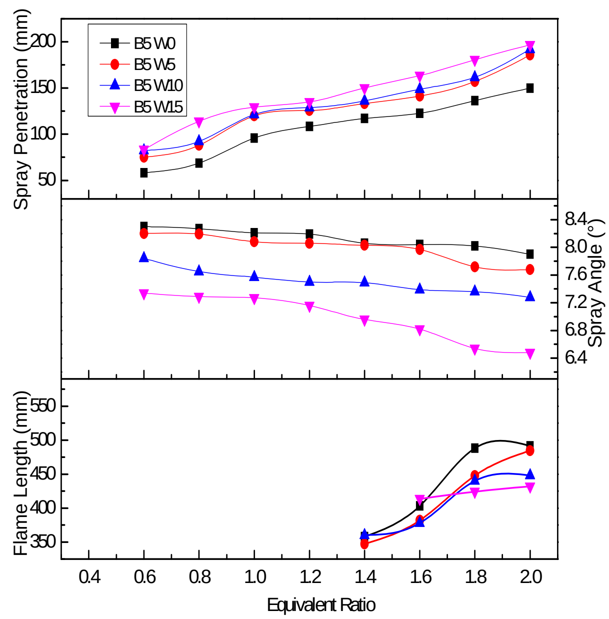


Figure 6: Comparison of spray tip penetration, spray angle and flame length for emulsified of biodiesel

Next, the influences of the water-emulsified on ignition point and flame development were investigated. Figure 7 shows the flame developments of emulsified diesel with different water contents. As seen in Fig. 7, the misfire occurs at the condition of equivalent ratio of 0.6 (lean) and for all of water content percentage, more obviously with the increasing of water content. In addition, the ignition point and flame development become slower under higher water content such as W10 and W15 and equivalent ratio of 1.0. During this stage, the flame cannot be established due to the low content of the combustible mixture thus predominantly influences to the slower of flame propagation. On the other hand, under W0, the flame is brighter and its flame height is higher compared than the emulsified diesel combustion. In addition, the bright flame area that produced from an equivalent ratio of 2.0 for all water contents have a larger flame area that significant with the rich combustion.

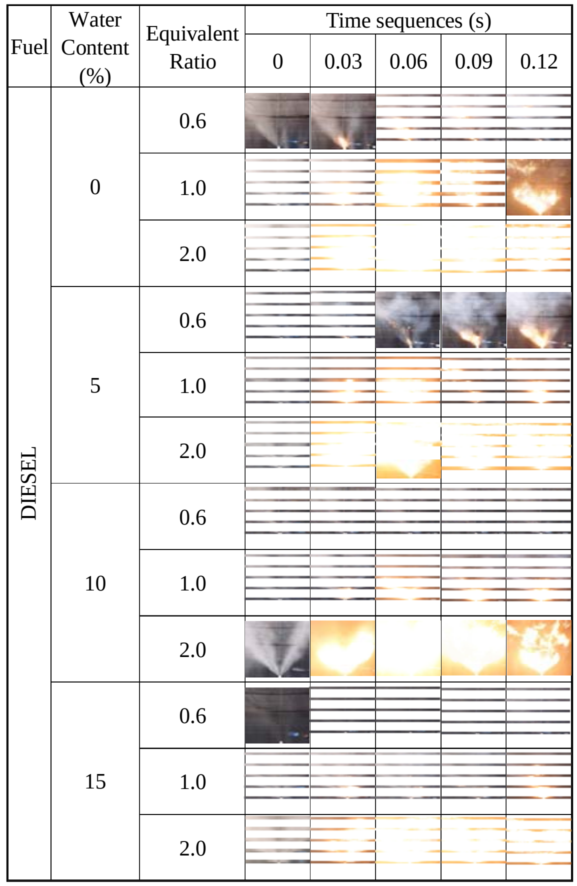
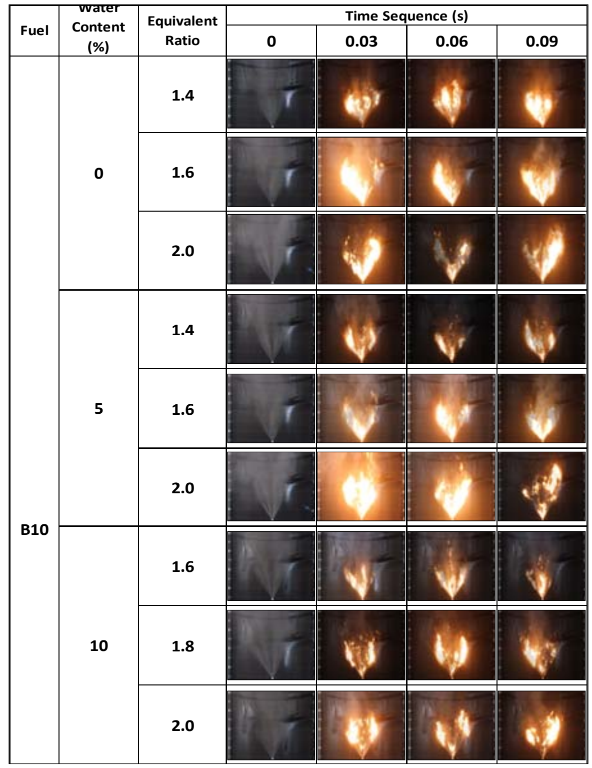


Figure 7 Effects of water-emulsified on ignition point and flame development

Figure 8 compares the spatial distribution of the emulsified biodiesel burning process on mixture formation and flame development. Higher blending ratio of B10 thus produces small region of bright flame. It means the reduction of bright flame region or globally lean combustion is influenced by the fuel characteristics. On the contrary, under blending ratio 5vol% of B5, high equivalent ratio the bright flame covers relatively wider region, which seems influences from the rich combustion during the fuel-air mixing of combustible mixture. It seems that the oxygenated content in high blending ratio biodiesel causes rich combustion. High luminosity flame can utilize high-density oxygen distributed and develops toward the chamber. In addition, the increment of equivalent ratio from 0.6 to 2.0, the color intensity of the spray increases and could be indicates the concentration of fuel in the mixture increases. In addition, the spray penetration and flame length keep increasing from low to high equivalence ratio; the spray angle is narrower with the addition of water in the fuel.

Next, images of the mixture formation and spatial distribution of natural flame luminosity are analyzed using image processing technique in order to provide qualitative information on progression of the mixture formation and flame distribution with time changes. Two types of real images were analyzed, one is noncombustional monochromes images of mixture formation and the other is combustion images.

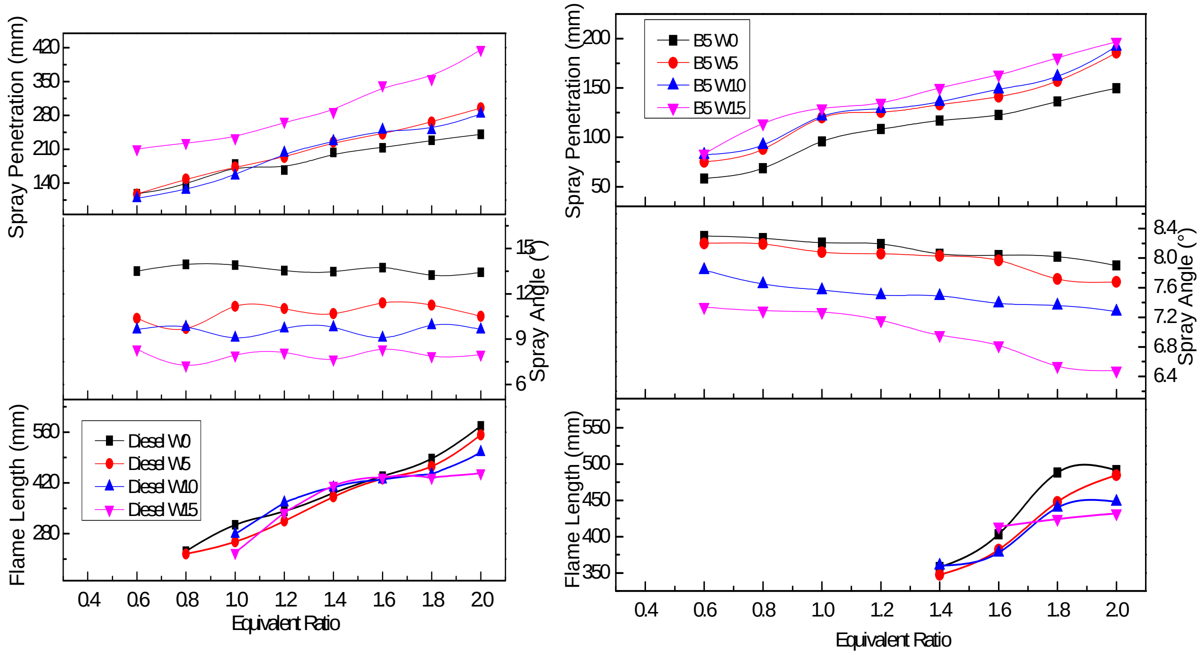
(a) Biodiesel B5



(b) Biodiesel B10

Figure 8: Effect of emulsified biodiesel on mixture formation and flame development

Figure 9 compares spray characteristics which are spray penetration and spray angle against equivalent ratio for water content of W0, W5, W10 and W15. As seen in Figure 9(a), the penetration length is increase with the equivalent ratio for different water content. The smallest spray angle can be observed in the graph is the B5 biodiesel with 15% water content and equivalence ratio of 2.0. It can be seen clearly that the difference in equivalence ratio will affect the spray angle, where higher value of equivalence ratio produces smaller value of spray angle. As seen in Fig. 9(b), it can be observed that B5 biodiesel containing water produces longer spray penetration compared to the one without water content. The flame length of will increase with the equivalence ratio. While the smallest spray angle was produced from diesel fuel with 15% water content with the equivalence ratio of 0.8 at 7.26^0. Therefore, the higher water content produces smaller spray angle. Higher content of water in the diesel fuel produces longer spray penetration.



(a) Diesel and emulsified diesel (b) Biodiesel and emulsified biodiesel

Figure 9: Comparison of spray tip penetration, spray angle and flame length for emulsified of diesel and biodiesel.

Conclusion

In this research, a fundamental study on the characteristics of ignition process and burning process of emulsified diesel and biodiesel combustion was carried out using a burner system by changing water content and equivalent ratio. Discussions were made on relation between water-emulsified into mixture formation and flame development during burning process. Results are summarized as follows;

1. Increased the equivalent ratio does not appear beneficial in physical fuel-air mixing but improves the chemical reaction and promotes the greater quantity fuel prepared for combustion due to higher luminosity flame area. However, high equivalent ratio and lower blending ratio biodiesel causes rich combustion and high luminosity flame covers relatively wider area due to higher oxygenated content.
2. Higher water content in the mixture will result in longer penetration length and smaller spray angle. Penetration length will affect the spray area, where longer length will produce larger spray area. Increased of flow rate makes the diesel intensity of spray increases. The increment of equivalent ratio, more fuel is being injected and hence the concentration of diesel fuel in the mixture increases.
3. Flame penetration of the combustion for pure diesel is higher than other diesel-water mixtures. Apart from that, when larger flame area produced by higher equivalent ratio, as this may be employed as a qualitative measure of the enhancements of fuel-air mixing.

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