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Effect of Mixture Formation of Biodiesel-water-air Rapid Mixing Derived from Crude Palm Oil and Waste Cooking Oil in Burner Combustion

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Key Words: Emulsified Biodiesel, Mixture Formation, Spray Penetration, Evaporation, Flame Development

Abstract The trade-off between NO_x and PM is a main issue in the observation of combustion characteristics, NO_x and PM are released from the combustion of biodiesel either in internal combustion engine or external burner system. Thus, the rapid mixing of biodiesel-water-air technique is one of the most significant approaches to the reduction of pollutant emissions from burner combustion. In this research, the relation between the mixture formation of biodiesel spray and the burning process was investigated in detail in order to understand the effects of the changes of fuel properties in fuel evaporation. In these experiments, different types of biodiesel fuel derived from the crude palm oil and waste cooking oil were used in the same nozzle characteristics of burner system. This study focuses on the observation of the real images of the spray characteristics together with equivalent ratio, water content, spray penetration length, spray angle and spray area. Water emulsion of percentage up to 15vol% and blending of biodiesel ratio was varied from 5vol%-15vol%. The diesel fuel has been compared with based analyzed of real spray images with the times change. The results show the percentage of biodiesel and shows the higher of water content due to the higher viscosity affects the higher penetration length and lower spray angle and influence the flame penetration.

Introduction

In the near future, the growth of economic and population have driven the use of energy and natural resources. However, natural resources such as fossil fuel, gasoline, coal and natural gas will exhaust toxic emissions when there are used as a fuel in the burner combustion. Diesel as one of the natural resources is being consumed heavily in the world demand. Diesel can be used in many applications such as automotive and burner system. These fuels will exhaust toxic emissions such as NOx, CO and particulate matters (PM) which causes environment problem[1],[8]. Therefore, in order to improve these emissions, a study in spray characteristic and formation is necessary before the combustion process started. The simplest method to control the emission is by adding water in diesel, which is diesel-water emulsion process[3–5]. It enhanced the air fuel mixing during the diffusion combustion phase, which allows combustion at lower global air fuel ratio while maintaining PM constant[10]. In addition, the water involves in the mixtures can reduce the flame temperature at the core region of the flame, hence the reduction of high temperature area will decrease the formation of NO_x[1],[3],[8].

Experimental setup

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. Figure 1 shows the setup of the experiment consists of an injector which has 8 holes with 1mm diameter, the characteristic of injector is shown in Table 3.

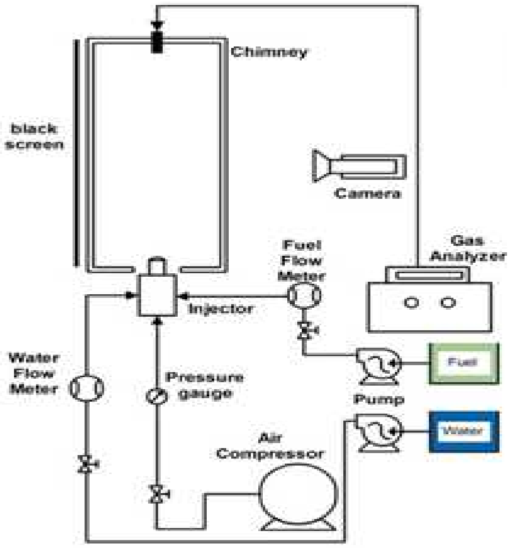

Figure 1: Schematic Diagram of experimental setup

Table 1: Properties of CPO at ambient temperature (45°C)

Fuel Type	Properties			
	Density (g/cm^3)	Kinematic Viscosity (cP)	Flashpoint (°C)	Water Content (ppm)
STD	0.833736	3	80	79.6
B5	0.837048	3	91.5	120.1
B10	0.837664	2.9	92	158.6
B15	0.840428	3	93.5	219
B20	0.841172	3.1	94.5	294.7
B25	0.841716	3	97	363.3
B30	0.845852	3.2	97.5	397.1
B35	0.844816	3.4	99.5	426.9
B40	0.848236	3.2	100	558

Table 2: Properties of WCO

Parameter	Value
Viscosity at 40 °C (mm2/s)	47.66
Volume (kg/m3) at 15°C	903
Flash Point (°C)	310
Free Fatty Acid (%)	1.6
Acid Number (mg KOH/g Oil)	3.2
Saponification Value (mg KOH/g Oil)	182
Water Content (%)	0.6

Table 3: Experimental Condition

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%
	Equivalence ratio	0.6-1.4

Table 1 and Table 2 are the properties of biodiesel will be used. The air pressure of 0.35 bar 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. The mixture is then pumped by the fuel pump to inject, afterwards the injector sprays the mixtures out with very fine droplets. A black surface background will give a better spray image when it captures by Digital Single-Lens Reflex (DSLR) camera of EOS 550D. The camera aperture was set to f5.6, the shutter speed is at 1/80 Sec for the spray image. The spray characteristic which includes penetration length and spray angle is an analysis of by Solidworks software, only one hole from the nozzle will be analyzed. Few set of spray image which from different flow rates and water content being taken to be compared. This study is keeping the injection air pressure at 0.35 bar and ambient density of 300K, all the operating condition and equipment specification are summarized in Table 3.

Result and Discussion

Figure 2 and Figure 3 shows the spray formation of W0, W5, W10 and W15 in equivalent ratio 0.6 (lean), 1.0 (stoichiometric), and 1.4 (rich). The spray formation start from of time 0.03s until 0.12s, the interval between each image taken is 0.03s for every set. The spray of diesel fuel is sprayed upward from the injector when the supply mixtures are pumped into the injector, as vary with time, the volume of spray increases and it's drawn by the ventilation system. At high equivalent ratio, the spray image becomes clearer due to the increment of the flow rate of the mixtures. This indicates that more fuel is being injected into the injector and the spray contains more fuel compared to the spray of low equivalent ratio. As observed from the images, the spray is starting to expand at the time 0.06 second for all types of water content and equivalent ratio, thus it can be seen that after time 0.06s the overall diesel spray is becoming thicker. Furthermore, the penetration length shows an increasing trend with equivalent ratio for each type of water content, while the spray angles remain unchanged. Followed by the increment of equivalent ratio of 0.6 to 1.4, the color intensity of the spray increases as shown in Figure 2 for WCO and Figure 3 for CPO, this indicates that the concentration of biodiesel in the mixture increases. On the other hand, the spray angle is becoming narrower when the water content increase, but it does not give significant effect on the spray area since the differences of angle are small. Hence the spray area is affected by the penetration length only. The same happens on another equivalent ratio also.

Figure 4 and Figure 5 shows the graph of mixture formation which is penetration length, spray angle and spray area against equivalent ratio for water content of W0, W5, W10 and W15. From the figure, the penetration length is increasing with the equivalent ratio for different water content. At the same time, W15 has the highest penetration length among other water content, this is due to the viscosity of W15 is the highest, which the penetration length is directly proportional to the viscosity. W0, which is the pure biodiesel fuel, has the lowest penetration length with lowest viscosity. The viscosity of the mixtures is affected by the water content, as the water content of the mixture increases, the viscosity also increase. On the other hand, the spray angles for each water content with increments of equivalent ratio are about the same. However, it shows a decreasing trend when the water content is increasing, which W0 has the largest spray angle and W15 has the smallest spray angle. Therefore, it proves that the spray angle is inversely proportional to the viscosity as viscosity increase, the spray angle decreases. Furthermore, spray area is a dependent variable which it depends on the penetration length and spray angle. Penetration length will give more effect on the spray area which shows from the result. It can be seen that the spray area of W15 is the largest due to its penetration length is the longest, although its spray angle is small compared to others.

Figure 6 shows the flame developments of crude palm oil with different water contents, as can observe from the figure, at an equivalent ratio of 1.0 (stoichiometric), the combustion can occur at this point for all fuels, but for W0 the flame is brighter and its flame height is higher than those diesel fuels that mixed with water. The biodiesel mixed with some water contents seem like having a lower flame height. It can be seen that for an equivalent ratio of 1.4 (rich) the flame height of W0 also higher than other diesel flames which due to inactive combustion that will lead high gas temperature occur[5]. Other than that, the flame area that produced from an equivalent ratio of 1.4 for all water contents have a larger flame area compared to other equivalent ratio. This is the point where the rich combustion takes place. In addition, at time 0.06 seconds after start of ignition, the flame structure for all fuels and all equivalent ratios seem like to be exploded and expand its flame area and then shrinking at 0.09 second and after that becomes constant and developed flame structure.

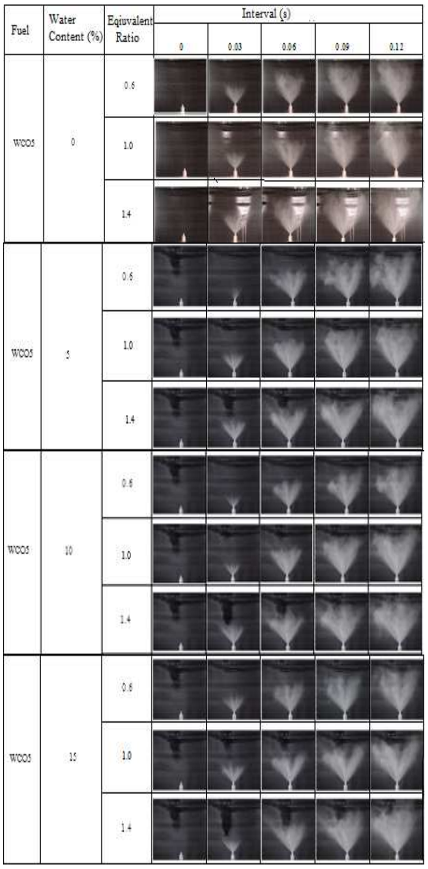

Figure 2: Mixture Formation for Biodiesel from WCO fuel

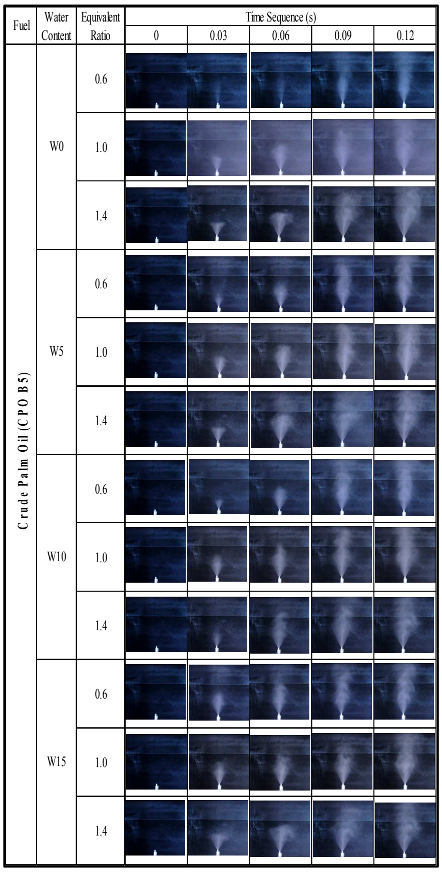

Figure 3: Mixture Formation for Biodiesel from CPO fuel

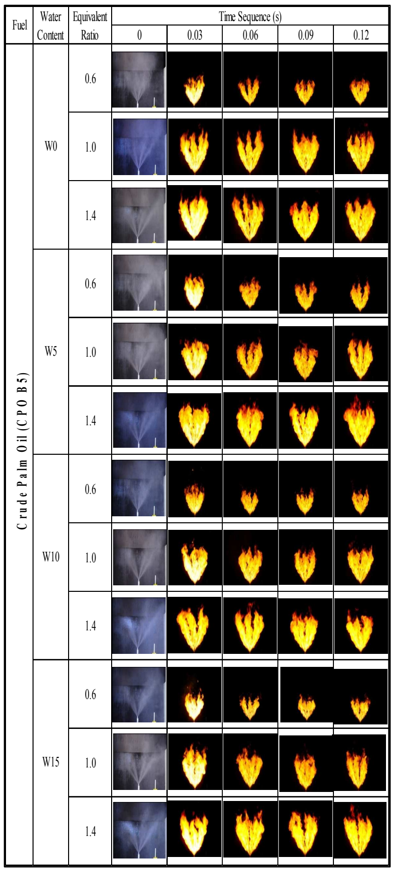

Figure 6: Biodiesel Flame Developement from CPO fuel

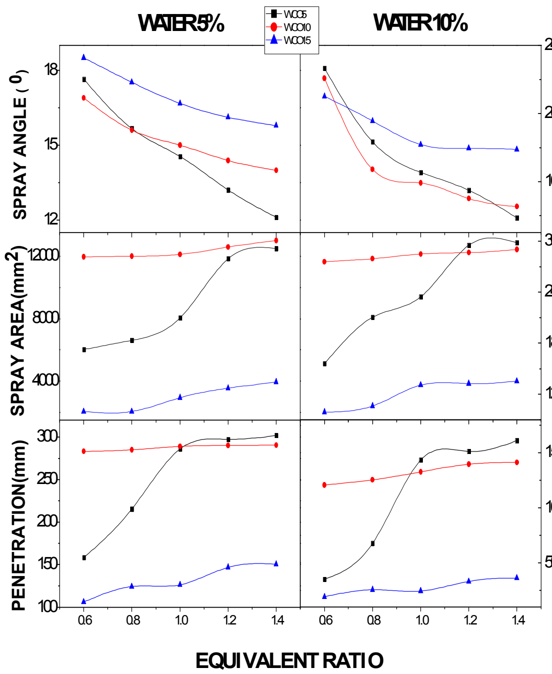

Figure 4: Effect of mixture formation derive from WCO fuel

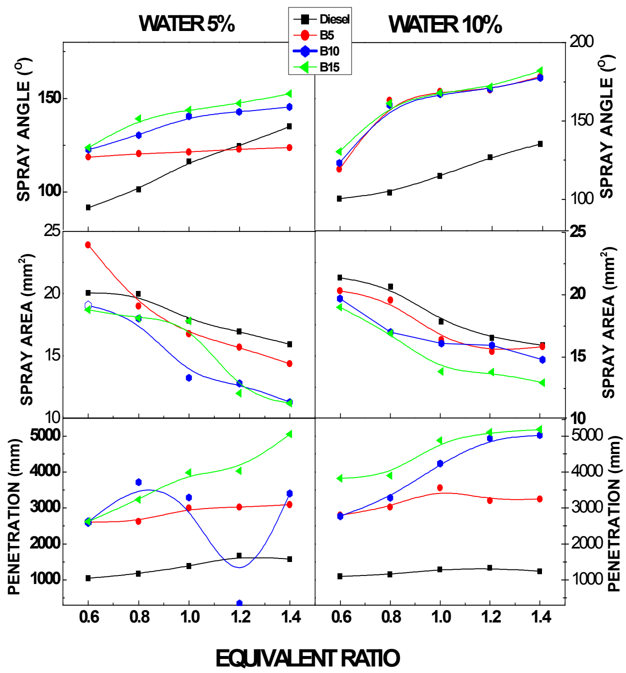

Figure 5: Effect of mixture formation derive from CPO fuel

CONCLUSION

High water content in the mixtures will result in longer penetration length and smaller spray angle. Penetration length is contributing in spray area, where longer the length will produce the larger area. There is no evidence to show that an equivalent ratio will give effect on the spray angle, however it does increase the penetration length as the equivalent ratio increase. In addition, flow rate makes the color intensity of spray increases with the increment of equivalent ratio, more fuel is being injected and hence the concentration of diesel fuel in the mixtures increases. Flame height of the combustion for pure diesel is higher than those biodiesel mixed with water, besides, the larger flame area is produced by a higher equivalent ratio, which the spray contains more fuel particles that makes the combustion process easy to take place.

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