Analysis of Emulsified Renewable Fuel Injector in Burner Combustion: An Overview

Mirnah Suardi[1,a], Norazwan Azman[1] , Dahrum Samsudin [1], Norani Mansor[1], Amir Khalid[1,b]

[1]Combustion Research Group (CRG), Centre for Energy and Industrial Environment Studies (CEIES), Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400 Johor, Malaysia.
[a]mirnahsuardi@yahoo.com, [b]amirk@uthm.edu.my

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Abstract
The use of energy and natural resources being increase due to the growth of economy and world population. One of the natural resources is being consumed heavily is diesel for transportation and burner combustion. However, the major product results from the combustions of diesel are NOx and PM emissions. This review paper focuses on the influences of the emulsified renewable biodiesel fuel such as crude palm oil and waste cooking oil with the concept fuel-air-water internally rapid mixing injector for the open burner system. Water is introduced directly into the combustion field. The concept of rapid mixing from biodiesel and water are controlling of the combustion process in order to minimize the emissions. The water content in the emulsified biodiesel fuels effectively in the reduction of NOx emissions especially the high blending biodiesel. Moreover, emulsion technology significantly reduced particulate matter (PM) emissions as compared to the standard biodiesel fuel combustion. The parameters include equivalent ratio, water content in biodiesel-water, and spray characteristics such as spray penetration, spray angle and spray area.

Introduction

As the environment pollution and diminishing supply of fossil fuels are the key factors the search of alternative sources of energy. Biodiesel now is the best choice for consumers and can occupy a great volume of the world's fuel sector. Biodiesel, as an alternative fuel of diesel, is described as fatty acid methyl or ethyl esters from vegetable oils or animal fats. It is renewable, biodegradable and oxygenated. Many researches had been concluded that biodiesel can reduce greenhouse gas emission [1]. In addition, the properties of biodiesel are similar to diesel fuels, but variation in fuel viscosity of biodiesel will cause poor atomization of the diesel engine as well as causing the clogging of the injector [6-8]. Some method had been used to decrease the viscosity of biodiesel like preheating the biodiesel and blending with lighter fuels such as diesel [13-18]. The researchers had studied that the performance of internal combustion engine fuel with preheated biodiesel like palm oil and the result is better because produce a better combustion and less deposits [2].

Experimental setup

The biodiesel used to be CPO and WCO biodiesel, which blended from Universiti Tun Hussein Onn Malaysia (UTHM) Automotive Laboratory and the particular of the tested fuel are detailed in Table 1 and Table 2. 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[21]. Fuel is initially rapidly mixed with fuel-water-air will then pumped by the fuel pump to inject, afterwards the injector sprays the mixtures out with very fine droplets [1-3][9].

Table 1: Properties of CPO at ambient temperature (45^{o}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 at ambient temperature (45^{o}C)

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

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, 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 [21].

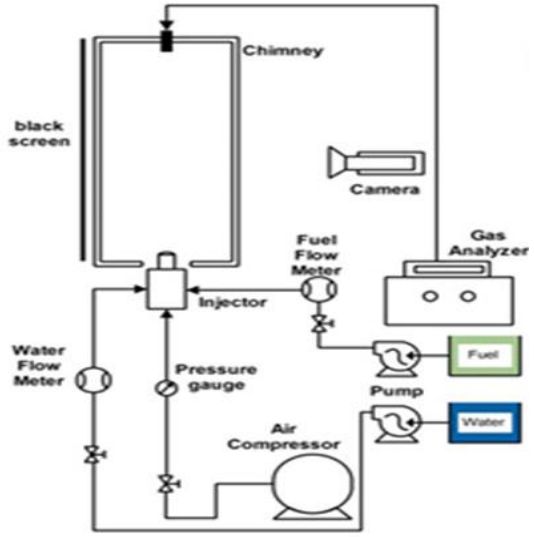

Figure 1: Schematic Diagram of

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

Result and Discussion

An effect of the biodiesel on mixture formation was firstly investigated. The time indicate in the images is referring to the time start of injection[5][21]. 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 interval between each image taken is 0.03s for every set. The spray of biodiesel 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 [6][9-11]. 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. The increment of equivalent ratio of 0.6 to 1.4. This indicates that the concentration of biodiesel in the mixture increases. Hence the spray area is affected by the penetration length only.

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.

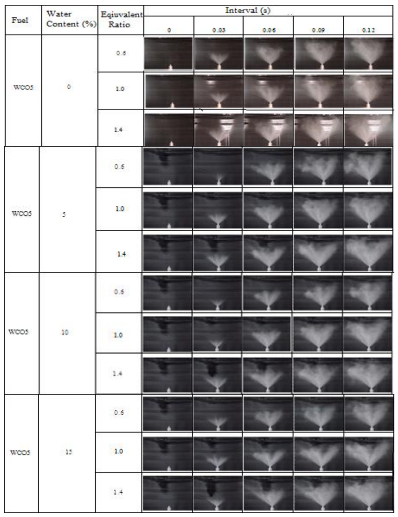

Figure 2: Mixture Formation for Biodiesel from WCO fuel

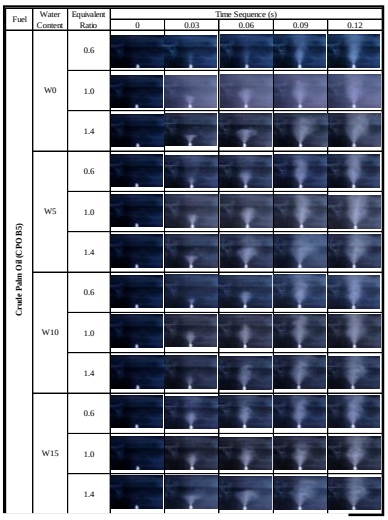

Figure 3: Mixture Formation for Biodiesel from CPO fuel

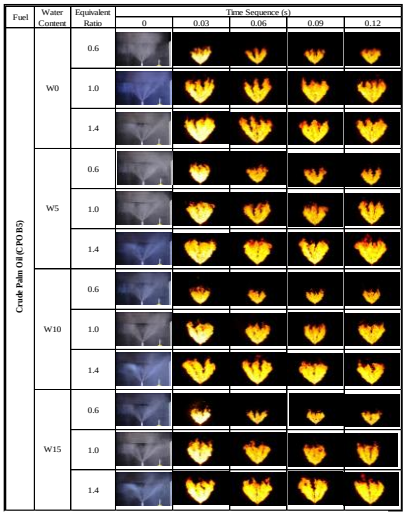

Figure 6: Biodiesel Flame Developement from CPO fuel

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.

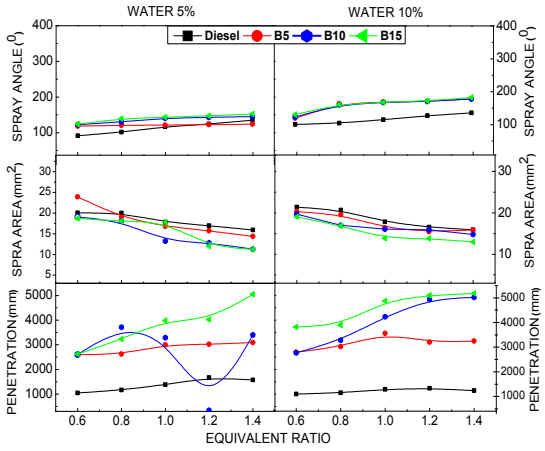

Figure 4: Effect of mixture formation derive from CPO fuel

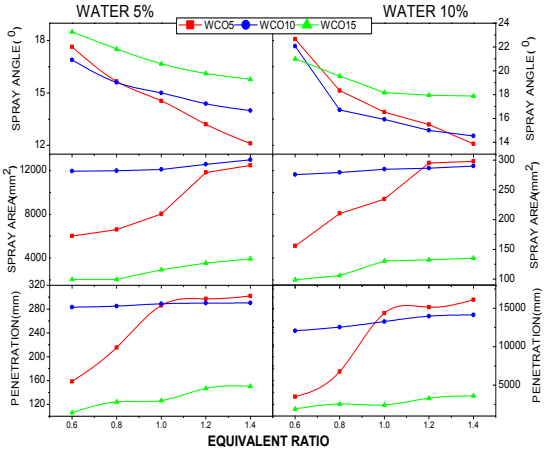

Figure 5: Effect of mixture formation derive from WCO fuel

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 to 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 due to the viscosity of W15 is the highest, which the penetration length is directly proportional to the viscosity [4-5]. W0, which is the pure biodiesel fuel, has the lowest penetration length with lowest viscosity[25-28]. The viscosity of the mixtures is affected by the water content, as the water content of the mixture increases, the viscosity also increase [8][21]. Therefore, it proves that the spray angle is inversely proportional to the viscosity as viscosity increase, the spray angle decreases.

Conclusion

In this research, a fundamental study on the emulsified renewable fuel injector process and burning process was carried out using a burner system. 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. An equivalent ratio will give effect 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. 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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