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EXPERIMENTAL STUDY OF THE EFFECT OF SURFACTANT AGENT FORMULATION TO THE SPRAY CHARACTERISTICS OF EMULSIFIED BIOFUEL

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ABSTRACT

The spray characteristics of an emulsified biofuel are assessed by its droplet size and velocity distribution within the spray, spray pattern, spray propagation, entrained air characteristic and spray volume distribution pattern. The spray characteristics of emulsified biofuel can be optimized by characterizing fuel type, formulation of fuel with water and surfactant, nozzle geometry, kinematic viscosity, density of fuels, pressure of liquid injected fluid and so forth. Formulation of fuel refers to an emulsification process where a mixture of two or more liquids which are normally immiscible is performed. The surfactant agent is introduced to stabilize the emulsion of water and oil. The surfactant is a chemical additive that works as a surface active agent to attract and to form the immiscible liquid into stable solution. The selection of a surfactant agent with particular HLB rating is a vital stage to ensure a correct form of emulsion has been developed as to whether the mixture is oil in water (O/W) or water in oil (W/O) basis. In this study, it is proven that the variation of surfactant agent formulation in emulsified biofuel has significantly influenced its spray characteristics to be comparable to the baseline diesel.

Keywords: biofuel, surfactant, spray characteristic, spray length penetration, emulsified biofuel.

INTRODUCTION

For decades, it is essential to concern that the process occurs in the combustion chamber phenomena is relative to a process of injecting an active fluid (diesel) to the thermodynamic behavior of the working fluid (air). Due to the technology enhancement, the investigation related to spray pattern characteristic is made easier via design optimization of nozzle for fuel utilization and conversion into an engine power output. The performance of engine power output is solely depending on nozzle performance due to its ultimate effect. The most common factor that influence the spray characteristic is the distribution of droplet size, droplet velocity, volume distribution pattern, entrained air characteristic and the microstructure of spray droplet (Miler *et al*., 2000).

The spray characteristic study was measured by two basic fundamental categories which are macroscopic and microscopic. Macroscopic category is a general study about spray cone angle, spray tip penetration and derivative on them (E. Delacourt *et al*, 2005),(R. Payri *et al*, 2008), (I. V. Roisman *et al*, 2007), (R. J. H. Klein-Douwel *et al*, 2007), (S. S. Sazhin *et al*, 2001), (J. M. Desantes *et al*, 2006), (H. K. Suh *et al*, 2007). Microscopic category is a general study involves droplet distribution, droplet diameter distribution, droplet velocity, air-fuel ratio distribution and so on (A. Doudou, 2005), (J. S. Hwang *et al*, 2003), (W. Ning, 2007). The investigation in the macroscopic spray characteristic study might be recorded and examined with medium hi-tech and inexpensive laboratory equipment rather than microscopic study that require sophisticated equipment and latest technology to zoom in analysis. Comparatively, the macroscopic study has been more trustworthy since been coarse size dimension and it facilitates a detectable result.

The design and optimization of nozzle geometry have become significant to study since the occurrence of an effect such as cavitation. This subject has been issued since most of diesel engine utilized high injection pressure with the application of the common rail injection system. The high pressure of nozzle flow has more inclination subject to cavitation forming. From the previous study has shown that the nozzle type and nozzle geometry (L/D ratio) have influence on fuel-air mixing process and cavitation (H. K. Suh and C. S. Lee, 2008) and (J. Benajes *et al*, 2008). Numerical and experimental study has shown that the sharp inlet nozzle purposely has greater axial velocity; these phenomena have potential to produce a low static pressure (cavity) thus initiate cavitation whenever a pressure drops below the fuel vapor pressure.

The area research on the spray mixing and characterization study is focused on more specific areas related to autoignition and the combustion process. Ignition delay period initially starts with either chemical or physical delay period until autoignition occurs. The physical delay period is commonly known as the process of fuel atomization, evaporation and interaction mixing with air. The chemical delay period is more tend related to the initial reaction gradually until initiate autoignition. There are several studies on new parameter to the ignition delay equation and effect of injection pressure and nozzle geometry. The ignition delay time will become a shorter influence by ambient pressure, ambient temperature and ignition pressure increase.

This paper presents the influence of surfactant agent on formulation spray nozzle length penetration.

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METHODOLOGY

A specific methodology for the preparation of emulsified biofuel of different compositions of water, oil and surfactant agent to the experimental setup of spray characteristics of the emulsified biofuel is discussed.

Emulsified biofuel preparation

Two biofuel emulsions were evaluated in this experiment which are SP21 and TP21. SP21 refers to a biofuel mixed with the surfactant agent of Span 80 at 1% composition and 2% composition of water by volume. TP21 refers to a biofuel mixed with the surfactant agent of Triton X-100 at 1% composition and 2% composition of water by volume. SP21 and TP21 have a number of hydrophile-lipophile balance (HLB rating) of 4.3 and 13.5, respectively. The HLB is rated from 0 to 20 for non-ionic surfactant and for ionic surfactant is greater than 20. The HLB value of the surfactant agent is an important indicator to determine whether the form of emulsion is (W/O) or (O/W). Low HLB number (<9) refers to a lipophilic surfactant (oil soluble) and high HLB number (>11) refers to a hydrophilic surfactant (water soluble). In this study, the biofuel emulsion using both low and high HLB number surfactant agents were prepared and tested. In order to produce biofuel emulsion, 500 ml beaker, measuring cylinder, syringe, ordinary tap water, surfactant agent and palm oil as a source of biofuel were prepared. The measuring cylinder was used to measure the volume of palm oil and the palm oil was poured into the 500 ml beaker. The emulsion was prepared using ultrasonic homogenizer. Ultrasonic homogenizer was set on continuous homogenize mode, 15min process time and 20 khz sound energy. After the emulsification process, the emulsified biofuel was tested for its chemical properties that include density, surface tension, viscosity and calorific value. The viscosity was measured by Brookfield DV-III ultra-programme viscometer. The Viscometer is designed for Newtonian and Non Newtonian fluid with an accuracy of ± 0.1 mg Centi-Poise. Viscosity is a measure of a fluid's resistance to flow and the working operation is derive with a spindle which immerse with a biofuel by a calibrated spring. The rotary transducer will measure a spring deflection. The viscosity measurement range of the DV-III (in centipoise or Cp) is determined by the rotational speed of the spindle. The density of the fluid was measured by pychometer, and using the equation below:

$$\rho = \frac{m}{v} \tag{1}$$

Where ρ is the density, *m* is the mass (kg) and v is the volume (m^3).

The density of emulsion was measured by weighting 25mL using a digital balance with an accuracy of ±0.1 mg.. While the calorific value was measured by the automatic bomb calorimeter model NENKEN type 1013-B. The equation was used to measure a calorific value as stated below:

Higher Calorific Value

$$CV = \frac{\{\mathrm{M_{cw}} + \mathrm{M_{wic}}\}\,\mathrm{x}\,\mathrm{T_{corr}}\,\mathrm{x}\,\mathrm{c_{p_w}} - (\mathrm{E_{rp}} + \mathrm{E_{nw}})}{\mathrm{M_s}} \tag{2}$$

Where:
M_{cw} = equivalent water mass of the calorimeter (g)
M_{wic} = mass of water in the innest cylinder (g)
M_s = mass of fuel (g)
E_{rp} = energy of rice paper
E_{nw} = energy of nichrome wire
T_{corr} = change in temperature
C_{pw} = Specific heat of water

Corective temperature

$$T_{corr} = T_c + r_2(c-b) - (T_a + r_1(b-a)) \tag{3}$$

Energy of Nickel wire used

$$SE\ of\ nw\ x\ L\ nw\ used\ x\ 4.184\ Jcal^{-1} \tag{4}$$

Energy of Rice Paper

$$E = \frac{Mass\ of\ rice\ paper}{1000}\ x\ specific\ energy\ of\ rice\ paper \tag{5}$$

Constant volume combustion chamber (CVCC) setup

The Constant volume combustion chamber was set up to visualize both spray and combustion characteristics of the emulsified biofuel. The complete setup of CVCC is as depicted on Figure-1. The Neat Diesel, SP21 and TP21 samples were loaded into the storage tank. The fuel pump was then switched on to deliver the emulsified biofuel through high pressure common rail system and the biofuel was in circulation condition. The controller unit was used to control the injection time at the interval of 0.5ms, 0.6ms, 0.8ms and 1.0ms and the injection pressure were set at 80, 90, 100, 120 and 140 Mpa, respectively. The test was conducted under room temperature and ambient pressure. The injector used in this experiment is BOSCH type injector. The hot air chamber is specifically functioned to preheat the CVCC for combustion characteristics study.

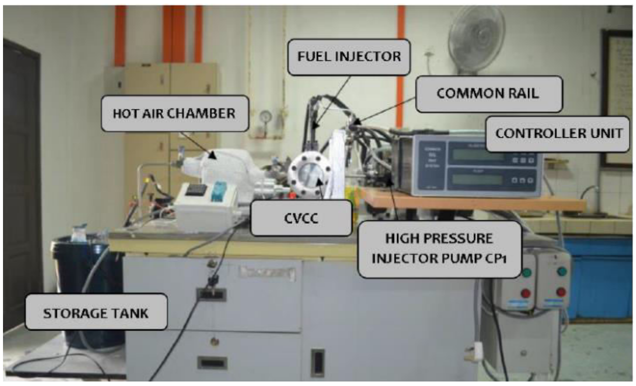

Figure-1. CVCC test setup.

RESULT AND DISCUSSIONS

Spray characteristics of the emulsified biofuel was visualized and compared to the spray characteristic of the baseline diesel with respect to the change of its chemical properties upon variation of surfactant agent formulation.

Viscosity

Based on the experiment, the viscosity of diesel fuel was determined as 4cP at the test temperature of 40 °C and the viscosity of TP21 and SP21 were determined as 32.00cP and 34.00cP, respectively. For the test temperature setting of 20 °C, their viscosities increased to 70.73cP and 66.87cP, respectively. Table-1 shows the increase of test temperature has resulted in the decrease of viscosity and the emulsified biofuel decreased on their shear rate value. The difference in percentage of emulsified biofuel viscosity between the test temperature of 20 °C and 40 °C is almost 50%.

Table-1. Viscosity values of neat diesel, TP21 and SP21.

Sample	Viscosity at 20 °C	Viscosity at 40 °C
Diesel	7.9	4
TP21	70.73	32.00
SP21	66.87	34.00

Surface tension

The surface tension was conducted in two condition temperature which is at 20°C and 40°C. For the 20 °C the temperature is equivalent to room temperature while at 40 °C, emulsified biofuel is preheated until 40°C and constant the temperature until the sample is led. The sample of surface tension is shown in the Table-2. From the surface tension result, can conclude that as a temperature increase, the surface tension decrease due to the movement of molecules disturb the imbalance force on the surface of the water.

Table-2. Surface tension of neat diesel, TP21 and SP21.

Sample	Surface Tension (dynes/cm)	
	20 °C	40 °C
Diesel	23.80	25.50
TP21	37.93	34.30
SP21	36.70	33.70

Density

Density is a mass of sample over volume and the density test was conducted in compliance with the standard operation ASTM D854. From the density result, it can conclude that the effect of surfactant and water composition itself on the emulsified biofuel, The SP21 is lower density compared with TP21 due to on their own concentration. Surfactant for SP21 is more concern of oil soluble rather than surfactant for TP21 which concern to water soluble.

Table-3. Density of neat diesel, TP21 and SP21.

Sample	Density (g/cm^3)
Diesel	0.828
TP21	0.905
SP21	0.901

Flash point

Flash point is conducted due to essential to determine as the lowest temperature at which it can vaporized to form an ignitable mixture in air. From the Table-4 have shown that emulsified biofuel has higher value of flash point compared to diesel fuel.

Table-4. Falsh point of neat diesel, TP21 and SP21.

Sample	Flash Point (°C)
Diesel	70
TP21	330
SP21	328

Calorific value

The calorific value is measured by using bomb calorimeter. From the experiment, the calorific value for emulsified biofuel is lower than neat diesel at 9.3% percentage difference. Table-5 shows the calorific value of the fuel. The calorific value of the diesel is expecting higher rather than emulsion biofuel. The increase of water composition, the lowest of calorific value occur due to decrease a biofuel content. However, the different HLB value of every emulsion surfactant agent would give a significant effect and SP21 is seen much higher than TP21 due to the composition of W/O and O/W.

Table-5. Calorific value of neat diesel, TP21 and SP21.

Sample	Calorific Value (MJ/kg)
Diesel	44.00
TP21	38.64
SP21	39.07

Spray characteristics

In this experiment, Microscopic properties such as droplet velocity, droplet distribution, droplet diameter distribution, air fuel ratio distribution and macroscopic properties including penetration length, cone spray angle and spray width as shown in Figure-2 are discussed. For cone spray angle, it is defined as the angle formed by two straight lines that start from the depart orifice of the nozzle and tangent to the spray outline in a determined distance. The angle in a spray is formed by two straight lines that are in contact with the spray's outline and at a distance equivalent to 60 times the exit diameter of the nozzle orifice. This angle of spray normally in between 5 to 30 degrees (Simón Martínez-Martínez1 *et al*). This determines greatly the fuel macroscopic distribution in the

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combustion chamber. In the other hand, the increase in angle will decrease the penetration and effectiveness interference between sprays in the same chamber favoring the merging of droplets. In addition, an excessive penetration is favored when the angle decreases lower than certain values, causing the spray to collide with the piston bowl or the combustion chamber.

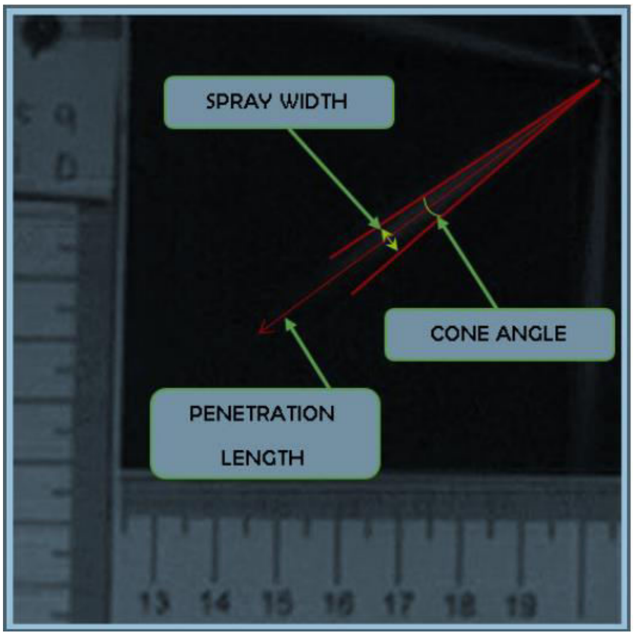

Figure-2. Measurement parameters of spray.

Spray characteristic study on preparing emulsified biofuel.

All the image was captured using high speed camera and 6000 frames per second and the time interval between two images is 0.167ms.

Spray penetration length at 80 Mpa.

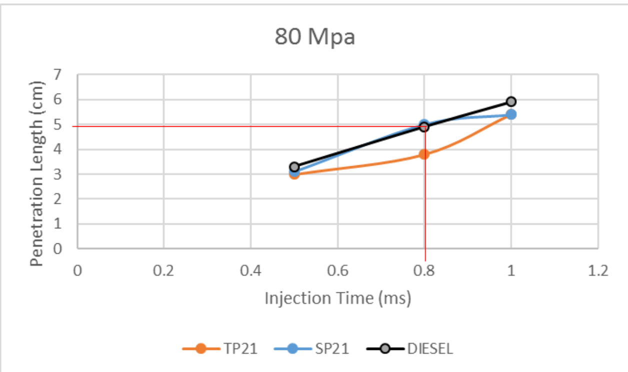

Figure-3. Penetration length against injection time at 80 Mpa injection pressure.

From the Figure-3 shows that the penetration length increases as the injection time increase. From the graph above, there have been clear that the penetration length of SP21 and neat diesel is seen similarly, except at 1ms which 7% difference with diesel length penetration. But TP21 for the initial are quite seem similar and have a far different approximately 20% difference between diesel and SP21. This is expected due TP21 is tend to promote oil soluble due to Triton X-100 have a 13.5 HLB number, thus yielding high interfacial tension and a week interface film.

Spray penetration length at 100 Mpa

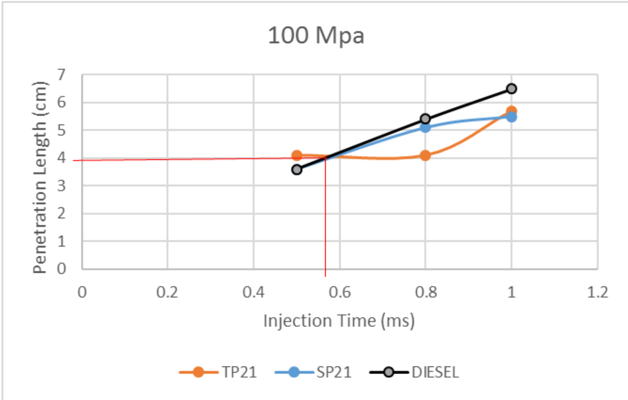

Figure-4. Penetration length against injection time at 100 Mpa injection pressure.

From Figure-4 shows the penetration length between neat diesel, TP21 and SP21 at pressure 100 Mpa. From the graph above represent the penetration length increase as the injection time increase. At this stage TP21 is initially higher rather than other fuel as 14% total difference, but far lower at 0.8ms injection time, which total difference as 37.5% with neat diesel and 36% with SP21. However the trend of TP21 is seem constant rate from start injection from 0.5ms to 0.8ms. This is because of the oil soluble formulation that are probably increasing spray drift and retard the spray length propagation. SP21 length penetration seems like quite similar with neat diesel profile, but a quite different at injection time 1 ms with a total difference approximately 16%. At a higher injection time seem like the neat diesel profile length penetration is performed rather than oil soluble and water soluble.

Spray penetration length at 120 Mpa

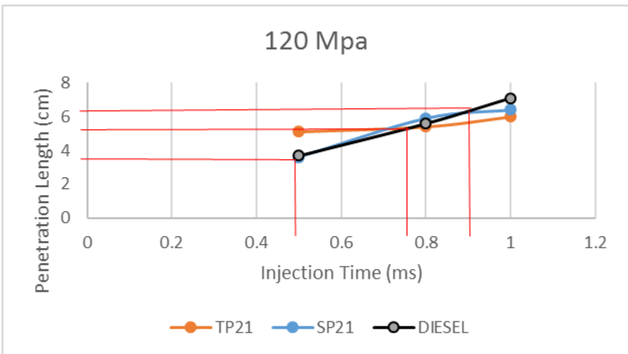

Figure-5. Penetration length against injection time at 120 Mpa injection pressure.

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From Figure-5 depecticted the penetration length between neat diesel, TP21 and SP21 with a variation of injection time. From the graph above illustrate that the penetration length increase with injection time increase. From the graph can see that the TP21 at 0.5ms is lead toward 22% difference higher than the other fuel and being similar at 0.8ms and a little difference at 1ms. Neat diesel and SP21 show a good in agreement as similar at 0.5ms and 0.8 but a tiny slight approximately 5% total difference with each fuel at 1ms. From this injection pressure, a penetration length is a quite similar with other fuel exclude TP21 which demonstrate the advance penetration at 0.5ms injection time.

Spray penetration length at 140 Mpa

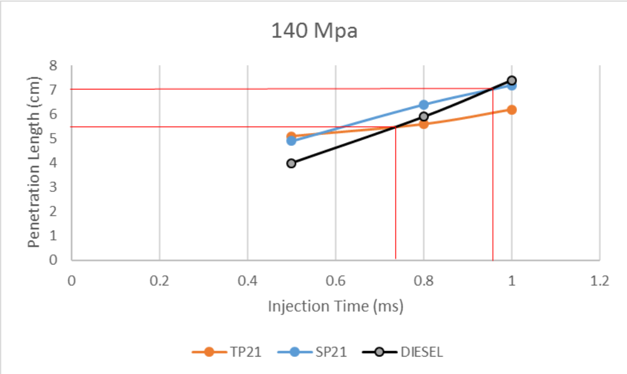


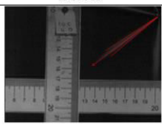
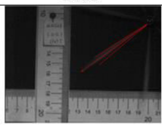
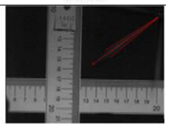
Figure-6. Penetration length against injection time at 140 Mpa injection pressure.

From the Figure-6 illustrate that the penetration length between neat diesel, TP21 and SP21 with a variation of injection time. In this stage of injection pressure, there are promoted to the higher length penetration between all the injection pressures. From the graph can see that the profile of SP21 and TP21 is quite similar at initial injection time 0.5ms and difference with neat diesel approximately 20%. SP21 is lead at injection time at 0.8ms but TP21 and neat diesel is quite similar profile and for the injection time of 1.0 ms the SP21 and neat diesel is lead to the performance curve. This is shown that at the initial spray penetration length was higher with biofuel, but at the 1.0ms injection time was lower as oil soluble.

The fine spray characteristics emulsified biofuel sample paralleled with neat diesel profile

Table-6 shows the finest spray characteristic of TP21 and SP21 which are prepared by using Ultrasonic Homogenizer and compared with baseline neat diesel. The best spraying characteristic of baseline diesel obtained is at the injection pressure of 1000 bar and injection time of 1.0ms with the spray penetration length of 84mm, spray width of 8mm and cone angle of 7.8°. For TP21, the best spraying characteristic is obtained at the injection pressure of 140Mpa and injection time of 1.0ms with the spray penetration length of 80mm, spray width of 8mm and cone angle of 8.0°. Whereas for SP21, the best spraying characteristic is obtained at the injection pressure of 140Mpa and injection time of 1.0ms with the spray penetration length of 82mm, spray width of 7mm and cone angle of 8.0°C.

Table-6. The fine spray characteristic of neat diesel, TP21 and SP21.

Sample	Diesel	TP21	SP21
Image of sample			
Injection pressure	100 Mpa	140 Mpa	140 Mpa
Injection time	1.0 ms	1.0 ms	1.0 ms
Penetration length	84mm	80mm	82mm
Cone angle	7.8 °	8.0 °	8.0 °
Spray width	8mm	8mm	7mm

CONCLUSIONS

The experimental study that focussed on the macroscopic characterization with high injection pressure has been conducted on neat diesel, TP21 and SP21 of the emulsified biofuel. The results of emulsified biofuel were compared with neat diesel in order to validate and to enhance the understanding of fuel spray development, spray performance characteristic, the influence of high pressure injection, air-fuel mixing process of emulsified biofuel and its blend. Significant findings of the spray characteristics of emulsified biofuel are as follow:

i. The difference of formulation between TP21 (oil soluble) and SP21 (water soluble) has a significant effect on fuel spray penetration length. Such difference affects the physical properties of the spray liquid that is equivalent to doubling the flow rate through nozzles.
ii. Spray pattern of different compositions of the emulsified biofuel indicates a change in orientation and cavitation inside the hole of injector nozzle is one of the possible contributing factors.
iii. At the high injection pressure of 100-140 Mpa, TP21 is found to have the penetration length in advance of 0.5ms but the penetration is similar to other fuel samples at the injection pressure of 800 bar.
iv. Spray angle and mass of air entrained within the spray shows that TP21 has poor spray length penetration at the injection pressure of 80-100 Mpa at the injection time of 0.8ms. This is visualized by the narrow spray angle and high penetration.

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