Experimental Study of Micro-Explosion Phenomena of Emulsified Fuel

By

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Dissertation submitted in partial fulfillment of the requirements for the

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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(MECHANICAL)

Approved by,

____
(Zainal Ambri Bin Abdul Karim)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ADAM MUHSEIN BIN AMIR ABDULLAH

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ABSTRACT

Water in diesel emulsion contributes to a better alternative fuel to reduce pollutant due to the secondary atomization of the diesel fuel droplets during combustion which is known as micro-explosion. It is significant to know the variables that affect the stability of the emulsified fuel and also the parameters that influence the development of micro-explosion. This study is to experimentally determine the onset of micro-explosion on various water in diesel blends and to establish the parameters influencing the development of micro-explosion. Several emulsified fuel been prepared with different percentage of water and different dosage of surfactant used. These variables are used to collect data about the stability of each emulsified fuel produced and also to observe the progression and behavior of micro-explosion for every emulsified fuel. Each of the water in diesel blends have different stability where the level of stability is observed from the amount of sedimentation produced at the bottle of each emulsions. After a period of time, emulsion with surfactant's Hydrophilic-Lipophilic Balance (HLB) value closer to 5 shows more stability compared to emulsion with higher surfactant's HLB value. Furthermore, emulsion with higher dosage amount of surfactant and higher percentage of water has a thicker sedimentation formed at the bottom of each bottles. The experiments result shows that each emulsion has different progression and behavior of micro-explosion where the time taken for micro-explosion to occur and the temperature at which micro-explosion occur differ for every emulsion. Emulsion with a higher dosage of surfactant has a shorter time taken for micro-explosion to occur and a higher micro-explosion temperature compared to emulsion with a lower dosage of surfactant. Apart from that, more water in an emulsion would increase the time taken for micro-explosion to occur. The phase changes throughout the experiment are observed to study the progression and also the colour changes from the beginning of the experiment until micro-explosion occurs. Several emulsions show no micro-explosion while most of the emulsions have micro-explosion phenomena.

KEY WORD: Micro-explosion, Water-in-diesel emulsion, Secondary atomization, Sedimentation, Hydrophilic-Lipophilic Balance (HLB)

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1.0 INTRODUCTION

1.1 Background of study

Diesel engine is a combustion-efficient engine as it provides better fuel to power conversion yield. Even though researchers and scientists had discovered a new source of energy with their intensive research, energy supply systems based on combustion still remain as the dominant source of worldwide energy [1]. Diesel engine is being widely used for many applications such as in mass transportation, heavy industries and agricultural sectors due to its most fuel efficient internal combustion engines. However, all of these advantages had covered up the deficit of its emission drawbacks where vehicles powered by a diesel engine are considered one of the primary sources of air pollution.

Some of the primary contaminations emitted from diesel engines are nitrogen oxides (NOx), sulphur oxides (SOx), carbon monoxide (CO), carbon dioxide (CO_2), particulate matter (PM), unburned hydrocarbon (HC) and black smoke [2]. These emissions had contributed to the enhancement of the greenhouse effect, acid rains, attenuate the ozone layer in the stratosphere, and affect the human respiratory health [4]. Due to that circumstances, a number of diesel engine tests have been experimented using various liquid fuels and emulsified diesel fuel is regarded as one of the possible alternative fuels to reduce the pollutants [1]. Emulsified fuel consists of base fuel and water with or without the trace content of surfactant. Water in diesel emulsion (WiDE) has been found to simultaneously reduce several emission constituents.

The reduction is due to the secondary atomization of the diesel fuel droplets during combustion which is known as micro-explosion [4]. During evaporation or combustion of the emulsified fuel droplet, dispersed water can reach a superheat temperature [7]. When the emulsion state of droplet is burning in, the mixed components with different boiling points will vaporize and the temperature of the components with higher boiling points will increase. When the temperature becomes higher than the limit of water, overheating and micro-explosion can occur [13]. The expanding vapor breaks up a whole droplet or sometime just a part of the droplet. This phenomenon is called micro-explosion where the whole droplet breaks up into small droplets quickly [6]. When a droplet is heated, the minute particles of mixed droplet can be overheated, but vaporization of water droplet is still suppressed by the fuel surrounding the droplet. At a certain point, the droplet can explode if this suppression is broken. This phenomenon is called a micro-explosion [13].

The parameters that influence micro-explosion are still at the preliminary stages and require further study. In this work, the investigation is on the combustion characteristics of emulsion droplets made of mixture of diesel, water and surfactant. The result will examine the temperature at which micro-explosion will occur, lifetime (the time required for a droplet to burn out after ignition), and the variable micro-explosion characteristics of the droplet according to the water mixture rate.

The progression of each droplet is observed in order to study the behavior of the droplets before explosion and after explosion. The propagation of droplets throughout experiment can show how fast the emulsion change its phases, how strong their explosion, and also at which time does it start to puff. Puffing is a brief sudden emission of vapour from the droplets throughout the experiment.

1.2 Problem statement

The usage of diesel engine especially in industrialized country had contribute to a major problem as they are considered one of the primary sources of air pollution. Combustion from diesel fuel had emitted bad products which are under stringent environmental regulation such as nitrogen oxides (NOx), sulphur oxides (SOx), carbon monoxide (CO), carbon dioxide (CO_2), particulate matter (PM), unburned hydrocarbon (HC) and black smoke which can lead to health problems [2, 4]. The effects of emulsified fuel has contradicting results on the engine performances where some researchers claimed emulsified fuel has nothing to do with engine performances while others stated that emulsified fuel lead to a phenomena called micro-explosion [3]. Micro-explosion is claimed to enhance the reduction of both oxides of nitrogen (NOx) and particulate matter (PM) due to the secondary atomization of the diesel fuel droplets during combustion. In order to verify the claims, study on the formation of micro-explosion and the parameters that influence micro-explosion are to be performed.

1.3 Objectives

i. To experimentally determine the onset of micro-explosion of various water in diesel blends
ii. To establish the parameters influencing the development of micro-explosion

1.4 Scope of Study

The scope of studies can be divided into two parts which are scope of study for Final Year Project 1(FYP I) and scope of study for Final Year Project 2 (FYP II). For FYP I, the experiment is expected to be able to determine the parameters that influenced the onset of micro-explosion of different water in diesel blends.

Under FYP I, scopes of studies to be covered include:

i. Size of the droplets of emulsified fuel that is believed to affect the evaporation of the fuel
ii. Blends of emulsified fuel that leads to micro-explosion
iii. The effect of hot plate temperature on the evaporation or combustion of emulsified fuel droplet
iv. The optimal set-up for visualization of micro-explosion

At the end of FYP 1, the concept for experimental setup is to be determined. Under FYP II, scopes of studies to be covered include:

i. Experimental matrix such as size of droplets, temperature of hot plate and blends of emulsified fuel are to be performed
ii. Data acquisition and analysis
iii. Validation with engine performance results

1.5 Relevancy and Feasibility of Project

This project is very relevant as it is one of the national agenda where the researchers have highlighted the significant of micro-explosion phenomena to improve engine performance. Apart from that, the proposed study serves PETRONAS as their reference or guide in improving their oil and gas industry. Furthermore, this project is also feasible as the cost of the project is reasonable as most of equipment is already available. Apart from that, the time frame to be able to complete all experiment are also within the semester. Last but not least, all results for the experiments are valid as this project involve expertise person in this topic.

2.0 LITERATURE REVIEW AND THEORY

The introduction of water into the combustion chamber has been recognized as the best economical solution that can reduces pollutant emission and at the same time improves fuel conversion efficiency. Use of diesel emulsions has been shown to give several interesting effects, such as (i) reduced nitrogen oxides (NOx) emission and also lower soot and particulate contents in the exhaust, and (ii) improved combustion efficiency [6]. Water can be introduced into combustion zone with four major approaches [7]: (i) Direct Water injection into the engine through Separate Injectors (DWSI); (ii) Hybrid injection, using a single injector or as a stratified diesel-water-diesel fuel injection by means of a specially modified nozzle (HDWI); (iii) Fumigating the Water into the engine Intake Air (FWIA); (iv) Diesel-water emulsions (DWE). Of all the methods proposed to introduce water into the combustion chamber, water-in-diesel emulsion appears to be the most suitable and appropriate fuel based solutions because they do not rely on hardware to control the combustion process and no engine retrofitting required [2, 7]. A comparison of the four methods of water addition in diesel engine vs. some technical and economical criteria is shown in Table 1.

Table 1: Comparison of water addition methods [7].

CHARACTERISTIC	METHOD	DWSI	HDWI	FWIA	DWE
Relative NOx reduction		Poor	Best	Poor	Good
Effect of PM emissions		Poor	Best	Poor	Good
Variability of water addition		Good	Poor	Good	Good
Lubricating oil dilution		High	Low	High	Low
Expenditure		High	Average	Low	High

Water-in-oil emulsion is regarded the second most important behavior of oil after evaporation by many researchers [3]. The emulsified fuels has proven to be able to provide clear effect on combustion process and were found to give lower amounts of polycyclic aromatic hydrocarbons in the flame, as well as reduced emission to the atmosphere [6]. In the emulsified fuel, the increase in water concentration in the emulsion results in significant increase in the ignition delay. The size of the fuel droplet and its volatility should significantly affect the ignition delay. Thus, the ignition delay of a single fuel droplet can be expressed by the evaporation and chemical reaction time [4]. This is where the heat absorption by water vaporization causes a decrease of local adiabatic flame temperature which in the end reduces the chemical reaction in gas phase to produce thermal NOx. It has been pointed out by Badran et al. [8] reviews on advances in the combustion of water fuel emulsion which consists of base fuel, water and surfactants. The surfactant is mainly used to stabilize water in diesel mixture. The stability of emulsified samples is crucial matter, and the use of unstable emulsion is harmful to the engine due to the separated water which are incombustible [8].

Surfactant reduces surface tension forces to permit two different densities liquids to mix with stable chemical composition. The surfactant consists of two parts Hydrophilic and Hydrophobic, hydrophilic moiety has tendency to react with water, on the other hand, hydrophobic moiety has tendency to react with oil [3, 8]. In the water-in-diesel emulsion, water remains embedded inside diesel droplets with the help of the surfactant [1]. Span 80 is a very hydrophobic surfactant and Tween 85 is a very hydrophilic surfactant. When used alone none of them is a good emulsifier but a mixture of the two is known to be efficient and is widely used for various emulsification purposes [6].

An experiment conducted by Mura et al. [14] shows a study of micro-explosion temperature of water in oil emulsion droplets during the leidenfrost effect where in this work, the influence of the size of the dispersed water droplets in the micro-explosion phenomenon is studied by the *hot plate* technique. In Mura et al. [14] research, the experimental setup consists of five main elements: the hot plate, the temperature and the image acquisition system, the synchronization system and the emulsions as shown in Figure 1.

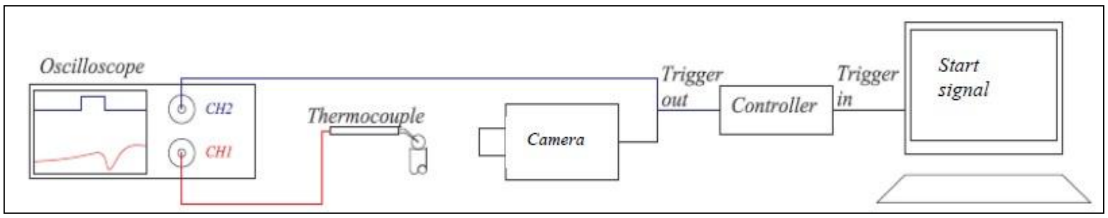


Figure 1: Experimental setup for hot plate technique

The experiment in Figure 1 begins with the thermocouple indicating a stable temperature of *296.5°C*. The droplet of emulsion is then approached to the thermocouple and placed on the hotplate. From the first contact between the droplet and the hot junction, the oscilloscope reads a significant drop in temperature: the temperature can drop to about *44 ° C* in a very short time (*0.12s*). This decrease is due to the fact that the emulsion sample is at room temperature (*18.5°C*). From that moment, the emulsion droplet begins to heat up. This heating phase is interrupted by the violent evaporation of the dispersed water droplets. The instant of the micro-explosion is followed by a sudden drop in temperature that, depending on the emulsion feature, is between *22* and *81°C*. When the thermocouple is discovered because of the spreading of the oil, the oscilloscope shows the temperature rising until reach the initial temperature. This phase lasts about *2.5* to *3* seconds.

Badran et al. [8] conducted an experiment on emulsified diesel fuels of 0%, 5%, 10%, 15% and 20% water-diesel ratios by volume were used in a diesel engine, operating at 1200–3300 rpm. His results indicated that the addition of water in the form of emulsion improves combustion efficiency. The engine torque, power and brake thermal efficiency increase as the water percentage in the emulsion increases. Kannan and Udayakumar [10] used commercial diesel fuel and diesel fuel with 10% and 20% water by volume. Their results showed that the water emulsification has a potential to improve brake thermal efficiency and brake specific fuel consumption where the average increase in the brake thermal efficiency for 20% water emulsion is approximately 3.5% over the use of diesel for the engine speed range studied [8, 10].

Numerous methods have been used to study the development of water-in-diesel emulsion in micro-explosion such as the used of horizontal steel and aluminum surfaces to study the evaporation of water-in-diesel and water-in-kerosene emulsion and the used of single droplet experiment where the emulsified droplet was suspended on a fine wire to study the breakup characteristics of a secondary atomization of an emulsion [3]. Most researchers use a water content of 5–10% but higher percentages have also been investigated. It has been claimed that the optimum water content for PM reduction is between 10 and 20% [6]. When this type of emulsion is sprayed on a hot combustion chamber, heat is convected on the surface of the fuel droplet. However, for combustion of emulsified heavy fuel oil it was found that the finer the water dispersion, i.e., the smaller the droplets of the water-in-fuel emulsion, the smaller the amount of water was needed to obtain good results in terms of reduced coke emission [6].

As water and diesel have different boiling temperatures, the evaporation rates of these two liquids will be different. As a result, the water molecule will reach its superheated stage faster than diesel creating vapor expansion breakup. It is at this stage according to [1, 2, and 5] the two phenomena; micro-explosion and puffing prevail. In puffing water leaves the droplet in a very fine size. Micro-explosion is a quick breakdown of droplets. It is believed that the micro-explosions promote oxidation of the hydrocarbons, possibly involving attack by hydroxyl radicals [6].

Based on one recent review, micro-explosion is mainly affected by volatility of the base fuel, type of emulsion and water content [3]. The study shows an increase in emulsifier content increases the micro-explosion temperature and waiting time. There have been many research conducted in the numerical predictions of micro-explosion phenomenon such as multi-component droplets with a major focus on mass and temperature distribution inside the droplets, the bubble growth in and break up process [3]. A study of micro-explosion temperature by Mura et al [5] shows that the temperature of micro-explosion is related to the distribution of the disperse water droplets. The time at which a micro-explosion initially occurs is generally unchanged, regardless of the number of droplets or the droplet spacing. The micro-explosion tends to become stronger as the water percentage increases [13].

3.0 METHODOLOGY

3.1 Project Execution Flow Chart

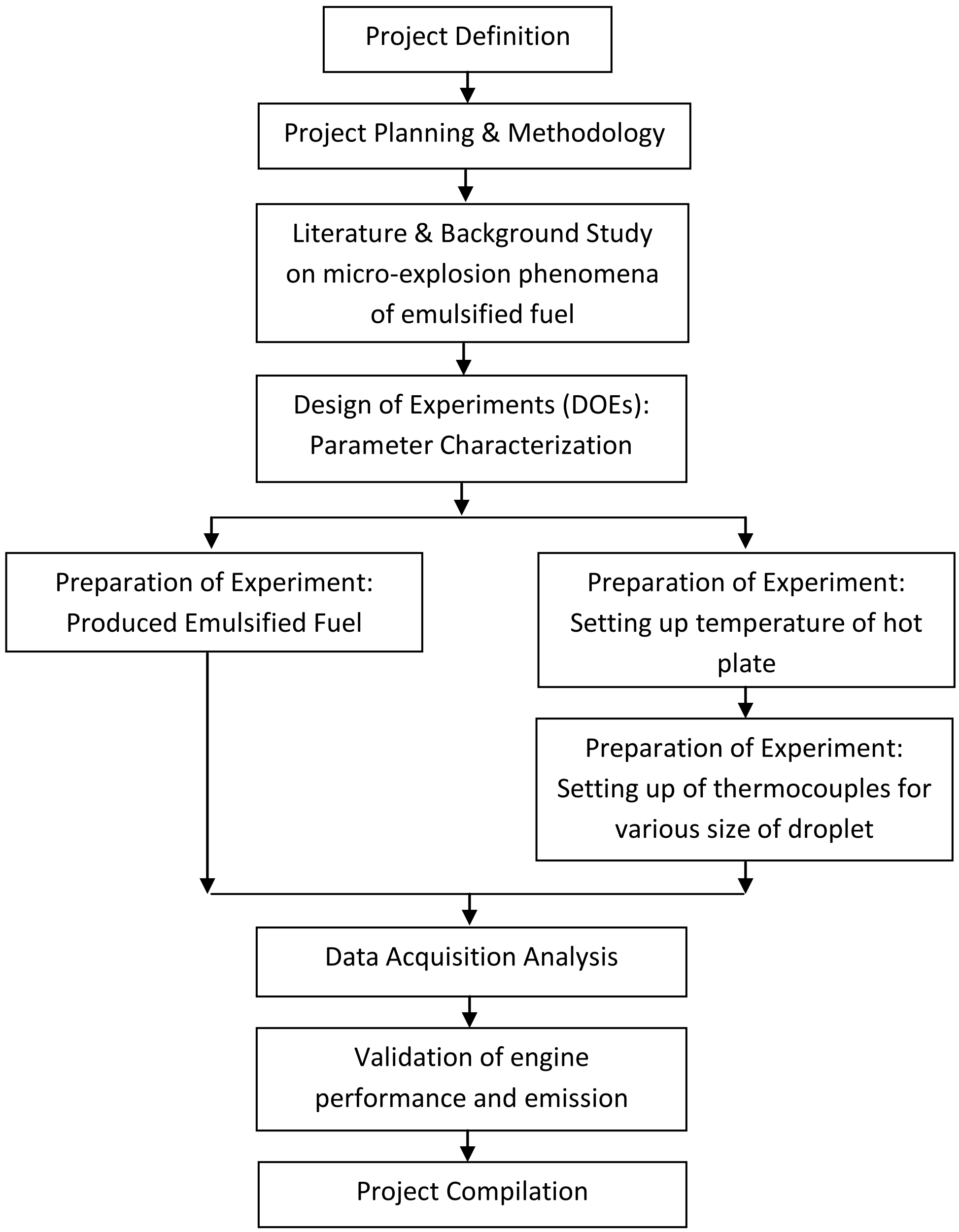


Figure 2: Project Execution Flow Chart

3.2 Preparation of Mixture Surfactant

Before preparing emulsified fuel, a surfactant consists of a mixture between Span 80 and Tween 85 is firstly prepared. Based on M.R Noor El-Din et al. [15], the HLB value for water in oil emulsifier is in between 4 to 6, hence 5 give the best stability. In order the mix the surfactants, a formula shown below is used:

$HLB_{AB} = (H_A \text{ x } W_A) + (H_B \text{ x } W_B)$ where,

H_A and H_B = the HLB value for surfactants,

W_A and W_B = the mass ratio of the surfactant (the mass ratio must equal to 1)

In this work, the HLB value for Tween 85 is 11 and for Span 80 is 4.3. To produce 50 ml of mixture surfactant, the total HLB value is calculated as shown below:-

i. Assuming the volume of Tween 85 is 10% out of 50 ml and Span 80 is 90% out of 50 ml, the mass ratio would be 0.1: 0.9 respectively. Thus,

   $HLB_{AB} = (11x0.1) + (4.3x0.9) = 4.97$ hlb

ii. Assuming the volume of Tween 85 is 30% out of 50 ml and Span 80 is 70% out of 50 ml, the mass ratio would be 0.3: 0.7 respectively. Thus,

   $HLB_{AB} = (11x0.3) + (4.3x0.7) = 6.31$ hlb

Hence, the volume of each surfactant for mixing is known. The procedure of mixing is as below:

1) Following (i) above, 10% out of 50 ml is 5 ml. Thus, 5 ml of Tween 85 is transfer into a glass bottle using transferpette.
2) Then 90% out of 50 ml is 45 ml. Thus, 45 ml of Span 80 is transfer into the same glass bottle using transferpette. The glass bottle is gently shaken to ensure the surfactants mix accordingly.
3) Step 1 and 2 is repeated using calculation of (ii) shown above.

3.3 Preparation of Emulsified Fuel

An emulsified fuel is prepared before conducting the experiment of micro-explosion. There are several tools needed in order to prepare the emulsified fuel as shown in Table 2.

Table 2: Tools and materials used for emulsified fuel

TOOLS AND MATERIALS	PICTURE	FUNCTION
Stirrer Machine		To stir the mixture between diesel, surfactant and distilled water. There are 2 variable in this equipment which are the speed of the blade and the duration of stirring
Glass Beaker		A 100ml of glass beaker is used to store the emulsified fuel once stirring process has been done. A glass beaker is used because it can withstand high temperature liquid
Tranferpette		Tranferpette is a tool used to transfer surfactant from bottle into container in a very small amount accurately.
Diesel		Diesel is used as the fuel for the emulsion.

Distilled Water		Distilled water is used during emulsion to create emulsified fuel. The amount of water is differentiated into four amount which are 9%, 12%, 15% and 18%
Surfactants	 	Surfactant is used to ensure the water remains embedded inside diesel fuel droplet. The surfactant used is a combination of Span 80 and Tween 85
Stopwatch		Stopwatch is used to measure the duration of the stirring of the emulsified fuel
Syringe		Syringe is a tool used to transfer distilled water and diesel from bottle into container in a small amount accurately.

3.3.1 Procedure of preparing emulsified fuel

1) The stirrer's steel container is rinsed with water and left dried before conducting the experiment in order to prevent any impurities from entering the emulsified fuel.

2) Following standard percentage of water from France which are 9%-18%, 9% from the total volume of emulsion (100 ml) of distilled water which means 9 ml of water is measured using a syringe and then is poured into the steel container. This standard is used to compare similar percentage of water done by researchers in France.

3) Then, 5% from the volume of distilled water which means 0.45 ml of surfactant is poured into the same container using a tranferpette.

4) Then, the diesel is added into the container. The amount of diesel is calculated by subtracting total volume of emulsion (100 ml) with amount of distilled water and surfactant added before. In this case, the volume for diesel is 90.55 ml.

5) The speed of the stirrer machine is then turned into speed of 1500 rpm and the mixture is left to stir for 15 minutes. The duration of stirring is measured using a stopwatch.

6) The emulsified fuel is left for 2 minutes to let it cool down. Once it cools down, the emulsified fuel is transferred into 100 ml glass beaker.

7) The container is rinsed with water to remove any remaining emulsified fuel and is ensured dried to be use for the next preparation of emulsion.

8) Step 2 to 7 is repeated using different amounts of distilled water which are 12%, 15% and 18% and each bottle is labeled accordingly.

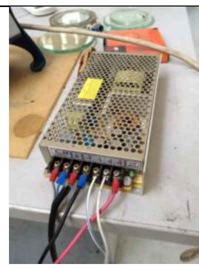
9) The emulsified fuel is left in a normal room temperature for several days to check its stability.

Figure 3: Preparation of emulsified fuel

3.4 Project Equipment for Micro-explosion experiment

Table 3: Type of equipment used for micro-explosion experiment

ITEM	PICTURE	FUNCTION
Light Source		*Light Source* – used to provide a direct light towards the droplets to catch a better and clearer image.
Hot Plate		*Hot Plate* – this part consists of a square aluminum piece which is electrically heated upon which the droplets are placed during the tests. The temperature of the hot surface is checked by a thermocouple arranged at the position under the center of the surface.
Thermocouple		*Thermocouple (Temperature acquisition system)* – two thermocouples is used to determine the temperature of aluminium plate and the temperature of droplets.
Camera		*Camera (Image acquisition system)* – the images are acquired by a High Speed Camera (CCD). The subject of the image is located in between the camera and the light source.

Computer		*Computer (Data acquisition system)* - used for a process of sampling signals that measure physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. This computer saved the images of micro-explosion using Photron FASTCAM Viewer software.
Trigger Controller		*Trigger* – used for triggering the camera to capture a perfect timing picture based on temperature limit setup before running the experiment.
Power Sources		*Power sources* – this device is used to provide power source to trigger controller.
Laptop		*Laptop (Data acquisition system)* – used to set up the trigger controller and also to record temperature of the droplets throughout the experiment using LabView software.

3.4.1 Procedure of micro-explosion experiment setup

1) First, the hot plate is placed on top of the table and an aluminium plate is put on top of the hot plate.

2) There are two thermocouples where one thermocouple is clamped by a clamper stand to determine the temperature of droplets at the

surface of the metal plate. The distance between the metal plate and thermocouple is 0.8mm. Another thermocouple is placed inside the metal plate which has a small hole at the center of the metal plate. The thermocouples are connected to a trigger controller.

3) A light source is placed on top of the table where the light is directed towards the metal plate.

4) The trigger controller is connected to a laptop where all the temperature readings is shown using LabView software.

5) A high speed camera is placed in front of the hot plate and the lens is aimed at the droplets. The camera is connected to computer to capture a good image of micro-explosion using Photron FASTCAM Viewer software.

3.4.2 Procedure of conducting micro-explosion experiment

1) All devices are switched on and the hot plate temperature is set up to 500 ˚C.

2) Emulsified fuel from sample 1 is sucked into a syringe. The triggering temperature is fixed to 140 ˚C for all samples.

3) The LabView software is run and a droplet of emulsion is drop on the surface of the metal plate.

4) All temperature readings and images of micro-explosion is saved.

5) Step 2 to 4 is repeated for all samples.

6) All data are recorded in a table.

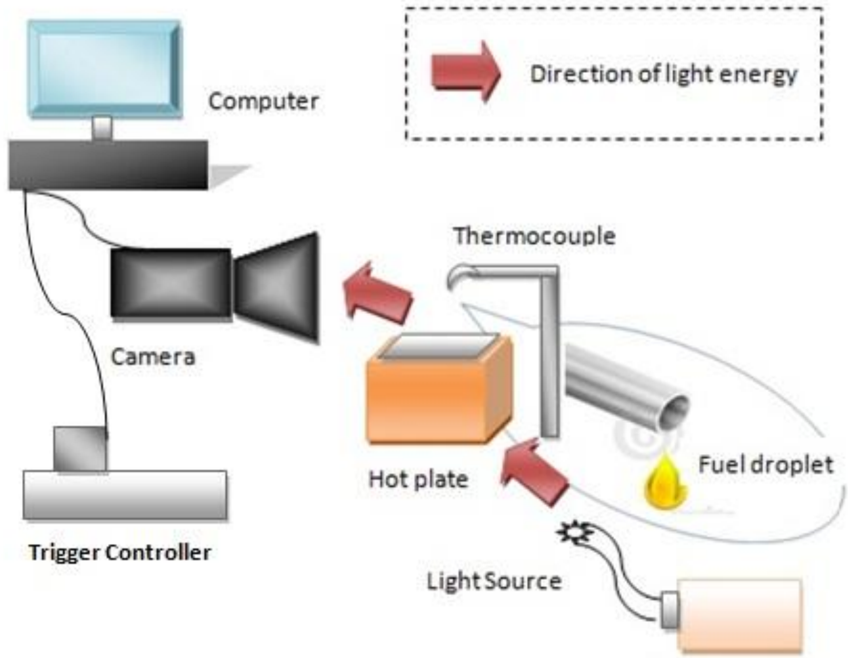


Figure 4: Final Sketch of Experimental Setup

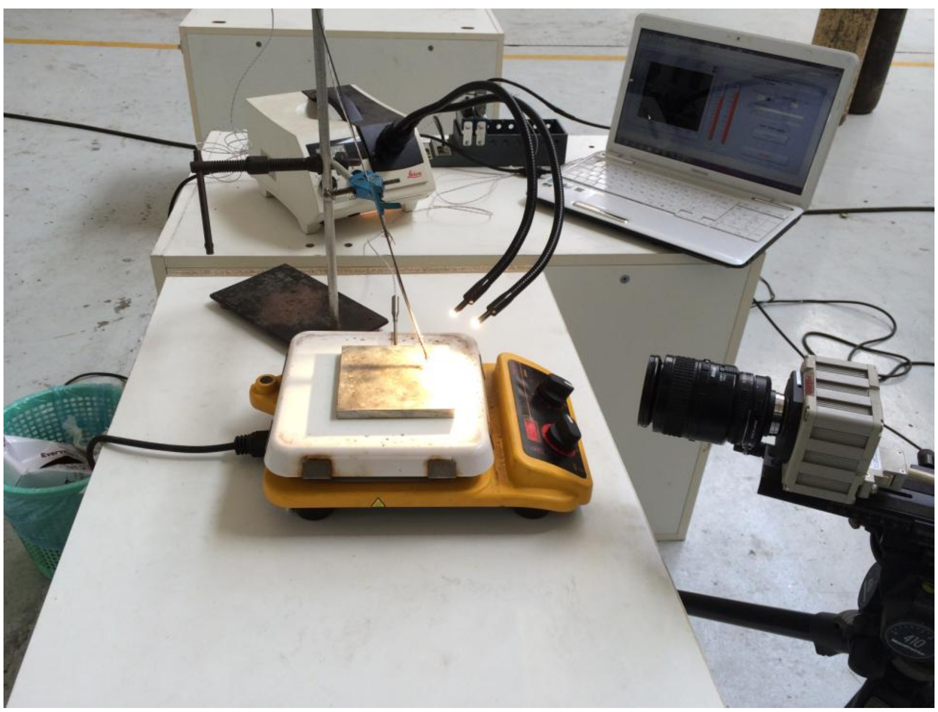


Figure 5: Final Experimental Setup

3.5 Project Gantt Chart

The completed Gantt Chart of final year project entitled ‘Study of Micro-explosion Phenomena of Emulsified Fuel’ is presented in Appendix Section.

3.6 Project Key Milestone

KEY MILESTONE	DATE
Mixture of surfactant has been produced	26/6/2014
Emulsion has been produced	1/7/2014
Stability of emulsion has been observed	3/7/2014
Thickness of sedimentation formed in emulsion has been observed	21/7/2014
Final experiment setup has been arranged	11/8/2014
Completed micro-explosion experiment for all samples	15/8/2014
Data analysis has been completed	20/8/2014
Dissertation has been submitted	26/8/2014

4.0 RESULT AND DISCUSSION

4.1 **Data for experiment of emulsion**

The emulsion produced can be divided into two groups where the first group is using a surfactant with HLB value equal to 4.97 and the second group is using a surfactant with HLB value equal to 6.31. A study of water in diesel emulsion stated that surfactant with HLB value of 5 is the most suitable surfactant that can be used to create a stable emulsion. Therefore, a surfactant with lower (4.97) and higher (6.31) HLB value is used to verify the claim. Each group of emulsion has different percentage of water and different percentage of surfactant. The percentage of water followed a standard from France where the standard percentage of water is 9%, 12%, 15% and 18%. The main reason that this standard is chosen is because all data of this experiment can be compared with several experiments completed by France researchers.

Table 4: Amount of volume used for each emulsified fuel using surfactant with HLB value equal to **4.97**

Bottle No.	Type of emulsion	Volume in ml			Speed of blade (RPM)	Duration of stirring (min)
		Diesel Fuel	Distilled Water	Surfactant (5% from H2O)		
1	9% H_2O	90.55	9	0.45	1500	15
2	12% H_2O	87.40	12	0.60	1500	15
3	15% H_2O	84.25	15	0.75	1500	15
4	18% H_2O	81.10	18	0.90	1500	15
Bottle No.	Type of emulsion	Volume in %			Speed of blade (RPM)	Duration of stirring (min)
		Diesel Fuel	Distilled Water	Surfactant (10% from H2O)		
5	9% H_2O	90.10	9	0.90	1500	15
6	12% H_2O	86.80	12	1.20	1500	15
7	15% H_2O	83.50	15	1.50	1500	15
8	18% H_2O	80.20	18	1.80	1500	15

Bottle No.	Type of emulsion	Volume in %			Speed of blade (RPM)	Duration of stirring (min)
		Diesel Fuel	Distilled Water	Surfactant (15% from H2O)		
9	9% H_2O	89.65	9	1.35	1500	15
10	12% H_2O	86.20	12	1.80	1500	15
11	15% H_2O	82.75	15	2.25	1500	15
12	18% H_2O	79.30	18	2.70	1500	15

Table 5: Amount of volume used for each emulsified fuel using surfactant with HLB value equal to **6.31**

Bottle No.	Type of emulsion	Volume in ml			Speed of blade (RPM)	Duration of stirring (min)
		Diesel Fuel	Distilled Water	Surfactant (5% from H2O)		
13	9% H_2O	90.55	9	0.45	1500	15
14	12% H_2O	87.40	12	0.60	1500	15
15	15% H_2O	84.25	15	0.75	1500	15
16	18% H_2O	81.10	18	0.90	1500	15
Bottle No.	Type of emulsion	Volume in %			Speed of blade (RPM)	Duration of stirring (min)
		Diesel Fuel	Distilled Water	Surfactant (10% from H2O)		
17	9% H_2O	90.10	9	0.90	1500	15
18	12% H_2O	86.80	12	1.20	1500	15
19	15% H_2O	83.50	15	1.50	1500	15
20	18% H_2O	80.20	18	1.80	1500	15
Bottle No.	Type of emulsion	Volume in %			Speed of blade (RPM)	Duration of stirring (min)
		Diesel Fuel	Distilled Water	Surfactant (15% from H2O)		
21	9% H_2O	89.65	9	1.35	1500	15
22	12% H_2O	86.20	12	1.80	1500	15
23	15% H_2O	82.75	15	2.25	1500	15
24	18% H_2O	79.30	18	2.70	1500	15

The amount of diesel fuel, distilled water and percentage for both Table 4 and 5 is the same. Speed of blade (RPM) and duration of stirring (min) are kept constant for all samples. Each table has 3 group consists of 4 samples with different percentage of water and different dosage of surfactant.

Figure 6: Samples of Emulsified Fuel

Based on Figure 6, the emulsified fuel appeared to be in milky white color after stirring process has been done. Sedimentation (white color) seems to be appeared at the bottom surface of the glass bottle after a period of time. After leaving the emulsified fuel for 21 days (3 weeks), some of the samples have its water fully separated from the diesel. The separation is the result of the unstable emulsion produced where several variables such as percentage of water, dosage of surfactant and HLB value of surfactant used are not suitable in its combination. However, some samples do show a stable emulsion where after several weeks, the emulsion has no sedimentation showing that the water is fully mixing with the diesel perfectly. A total of 24 samples are placed in a safety box in a normal room temperature for next micro-explosion experiment.

4.2 Data Micro-Explosion

Table 6: Result for WiDE with HLB value equal to 4.97

Bottle No.	Type of emulsion	Surfactant (5% from H2O) (ml)	Micro-Explosion Occur	
			Time (s)	Temperature (˚C)
1	9% H_2O	0.45	1.132	166.35
2	12% H_2O	0.60	0.860	141.58
3	15% H_2O	0.75	0.780	130.75
4	18% H_2O	0.90	0.840	115.99
Bottle No.	**Type of emulsion**	**Surfactant (10% from H2O) (ml)**	**Micro-Explosion Occur**	
			Time (s)	**Temperature (˚C)**
5	9% H_2O	0.90	1.128	144.45
6	12% H_2O	1.20	1.134	143.30
7	15% H_2O	1.50	1.190	136.78
8	18% H_2O	1.80	1.432	132.21
Bottle No.	**Type of emulsion**	**Surfactant (15% from H2O) (ml)**	**Micro-Explosion Occur**	
			Time (s)	**Temperature (˚C)**
9	9% H_2O	1.35	0.894	166.97
10	12% H_2O	1.80	1.260	162.83
11	15% H_2O	2.25	1.678	143.24
12	18% H_2O	2.70	No Explosion occur	

From Table 6, there is only one sample out of 12 samples that did not encounter micro-explosion. However, another 11 samples shows a good explosion with different time taken for micro-explosion to occur and different temperatures at which micro-explosion occur.

Table 7: Result for WiDE with HLB value equal to 6.31

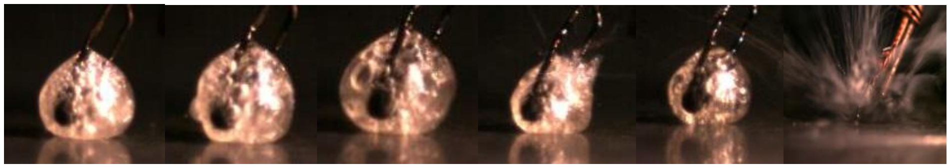
Bottle No.	Type of emulsion	Surfactant (5% from H2O) (ml)	Micro-Explosion Occur	
			Time (s)	Temperature (˚C)
13	9% H_2O	0.45	No Explosion occur	
14	12% H_2O	0.60	0.552	129.34
15	15% H_2O	0.75	0.608	132.55
16	18% H_2O	0.90	No Explosion occur	
Bottle No.	**Type of emulsion**	**Surfactant (10% from H2O) (ml)**	**Micro-Explosion Occur**	
			Time (s)	**Temperature (˚C)**
17	9% H_2O	0.90	0.686	150.66
18	12% H_2O	1.20	0.804	156.69
19	15% H_2O	1.50	1.212	189.44
20	18% H_2O	1.80	No Explosion occur	
Bottle No.	**Type of emulsion**	**Surfactant (15% from H2O) (ml)**	**Micro-Explosion Occur**	
			Time (s)	**Temperature (˚C)**
21	9% H_2O	1.35	0.848	152.74
22	12% H_2O	1.80	1.836	177.96
23	15% H_2O	2.25	No Explosion occur	
24	18% H_2O	2.70		

From table 7, there are several samples that do not encounter micro-explosion which are sample 13,16,20,23 and 24. Some samples show a very good explosion with a short time taken to explode and a low temperature of micro-explosion.

4.3 Image of Micro-Explosion

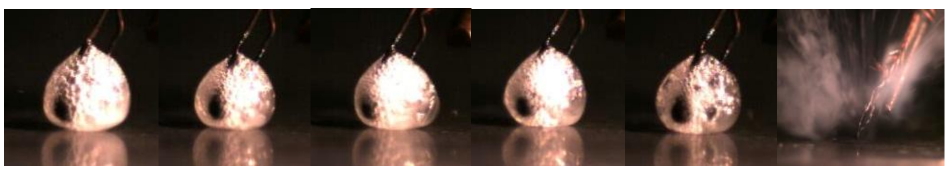
4.3.1 Comparison between different percentages of surfactant (HLB value of 4.97) but same percentage of water (9%)

<u>Sample 1 (5% of surfactant)</u>



0.014s   0.300s   0.478s   0.840s   1.040s   1.132s (166.35 ˚C)

<u>Sample 5 (10% of surfactant)</u>



0.014s   0.300s   0.580s   0.936s   1.090s   1.128s (144.45 ˚C)

<u>Sample 9 (15% of surfactant)</u>

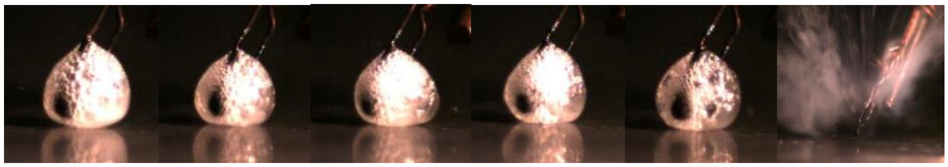
0.014s   0.300s   0.422s   0.610s   0.850s   0.894s (166.97 ˚C)

Figure 7: Micro-Explosion Images for Sample 1, 5 and 9

From the images shown in Figure 7, it can be seen that WiDE which has a higher percentage of surfactant has a shorter time for micro-explosion to occur while the temperature at which micro-explosion occur for WiDE with 10% of surfactant has the lowest value of temperature.

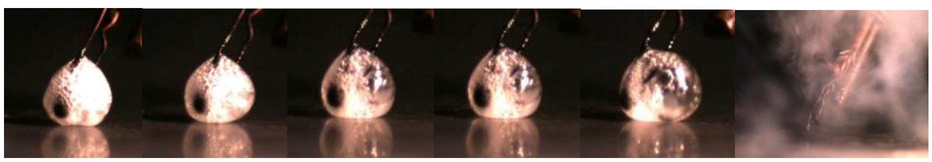
4.3.2 Comparison between different percentages of water but same percentage of surfactant (10% of surfactant with HLB value 4.97)

Sample 5 (9% of water)



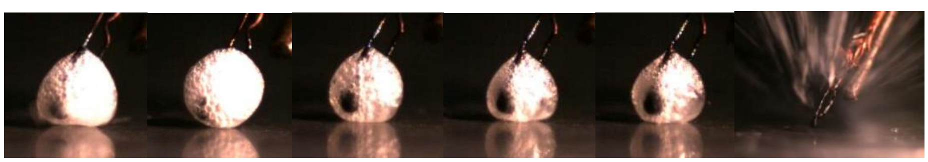
0.014s 0.300s 0.580s 0.936s 1.090s 1.128s (144.45 ˚C)

Sample 6 (12% of water)



0.014s 0.300s 0.786s 0.916s 1.072s 1.134s (143.30 ˚C)

Sample 7 (15% of water)



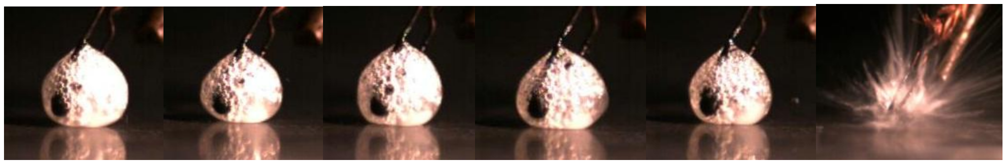
0.014s 0.300s 0.566s 0.788s 0.924s 1.190s (136.78 ˚C)

Figure 8: Micro-Explosion Images for Sample 5, 6 and 7

From the images shown in Figure 8, it can be seen that WiDE with a lower percentage of water has a shorter time for micro-explosion to occur. However, it has the highest temperature at which micro-explosion occur.

4.3.3 Comparison between different percentages of surfactant (HLB value of 6.31) but same percentage of water (12%)

Sample 14 (5% of surfactant)

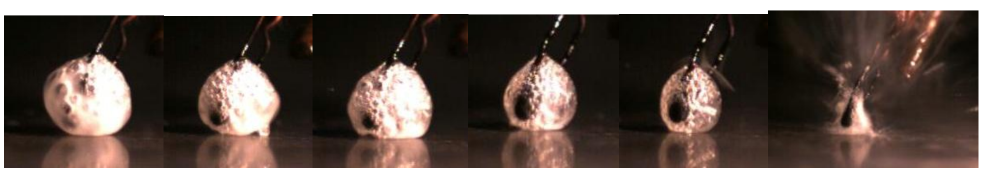


0.014s 0.206s 0.300s 0.432s 0.492s 0.552s (129.34 ˚C)

Sample 18 (10% of surfactant)

0.014s 0.184s 0.386s 0.450s 0.744s 0.804s (156.69 ˚C)

Sample 22 (15% of surfactant)



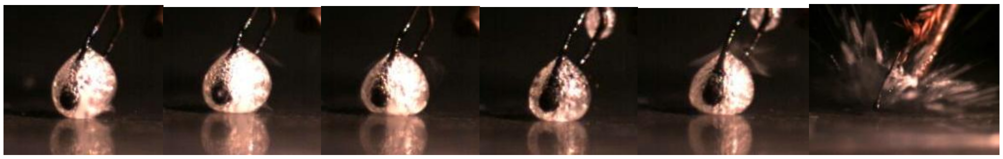
0.014s 0.302s 0.660s 1.288s 1.622s 1.836s (177.96 ˚C)

Figure 9: Micro-Explosion Images for Sample 14, 18 and 22

From the images shown in Figure 9, it can be seen that WiDE with less percentage of surfactant has a shorter time for micro-explosion to occur and a lower micro-explosion temperature which is opposite to samples which has the same percentage of surfactant but different HLB value.

4.3.4 Comparison between different percentages of water but same percentage of surfactant (10% of surfactant with HLB value 6.31)

Sample 17 (9% of water)

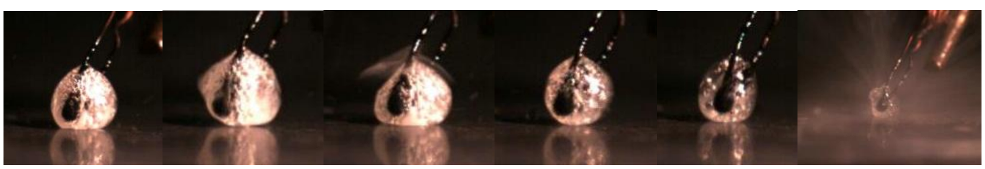


0.014s 0.110s 0.216s 0.508s 0.614s 0.686s (150.66 ˚C)

Sample 18 (12% of water)

0.014s 0.184s 0.386s 0.450s 0.744s 0.804s (156.69 ˚C)

Sample 19 (15% of water)



0.014s 0.300s 0.472s 0.784s 1.116s 1.212s (189.44 ˚C)

Figure 10: Micro-Explosion Images for Sample 17, 18 and 19

From the images shown in Figure 10, it can be seen that WiDE with less water has a shorter time for micro-explosion to occur and a lower micro-explosion temperature. It has the same behavior with other samples which has the same percentage of water but different HLB value. However, samples with HLB value have a shorter time for micro-explosion to occur and a higher micro-explosion temperature.

4.4 Discussion

In the preparation of emulsified fuel, the amount of water used in each experiment is varied to study the best percentage of water needed for micro-explosion. However, the surfactant and the amount of diesel fuel are fixed for every emulsion. Surfactant combination of Span 80 and Tween 85 is used to ensure water remains embedded to diesel droplets. Using Span 80 or Tween 85 alone as an emulsifier is not possible as each surfactant has different characteristic. Span 80 is hydrophobic means that it has a tendency to react with oil while Tween 85 is hydrophilic where it has more tendencies to react with water. Apart from that the HLB value for Tween 85 is 11 and for Span 80 are 4.3. A good emulsifier for water in diesel has a HLB value of 5. Thus, combining both of this surfactant would give a balance HLB value therefore produce a good emulsifier.

Based on the observation of the emulsified fuel sample, emulsion with more water seems to be more stable compared to emulsion with less water. It can be seen from the color of the emulsion where sample with more water is milky white in color which shows a good mixture while sample with less water are yellowish white in color which shows the diesel does not fully mix with water. Apart from that, a sample with more water seems to have thicker sedimentation form at the bottom of the glass bottle. When comparing sample which has the same amount of water but different percentage of surfactant, they have same level of sedimentation. However, sample with higher percentage of surfactant shows more stable emulsion. Last but not least, sample with higher amount of HLB value has a thicker level of sedimentation.

After conducting the micro-explosion experiment, it can be seen that some emulsions undergo micro-explosion while some others do not have explosion even thou the experiment is conducted for several times. From the comparison of samples shown in Figure 7 which has same percentage of water (9%) but different percentages of surfactant with HLB value equal to 4.97 (5%, 10% and 15%), it can be seen that WiDE which has a higher percentage of surfactant has a shorter time for micro-explosion to occur while the temperature at which micro-explosion occur for WiDE with 10% of surfactant has the lowest value of temperature. It can be seen that the emulsion with less percentage of surfactant has a very transparent colour compared to emulsion with higher percentage of surfactant. The reason that 5% and 15% of surfactant has a higher micro-explosion temperature would be that the samples would either have too less or too much of surfactant in its emulsion. Inappropriate amount of surfactant would affect the temperature of micro-explosion.

From the comparison of samples shown in Figure 8 which has different percentages of water (9%, 12% and 15%) but same percentages of surfactant (10% of surfactant with HLB value of 4.97), it can be seen that WiDE with a lower percentage of water has a shorter time taken for micro-explosion to occur. However, it has the highest temperature at which micro-explosion occur. This means that more water in a diesel would take a longer time for it to have micro-explosion as more molecules of water need to be heated up before the water can reached its superheated temperature. Nevertheless, the positive side of emulsion which has a higher percentage of water has a lower micro-explosion temperature. This is because the superheated temperature of water is lesser than the diesel. Therefore, with more water in an emulsion, the total superheated temperature of emulsion would reduced thus leads a to lower micro-explosion temperature.

From the comparison of samples shown in Figure 9 which has same percentage of water (12%) but different percentages of surfactant with HLB value equal to 6.31 (5%, 10% and 15%), the results show an opposite behavior compared to samples in Figure 7. For the samples in Figure 7, the percentage of surfactant increases, the time taken for micro-explosion to occur decreases. However, for samples in Figure 9, the time taken for micro-explosion to occur increased when the percentage of surfactant is increased. This shows that surfactant with HLB value of 6.31 has a higher time taken for micro-explosion to occur compared to surfactant with HLB value of 4.97. Throughout the 3 samples in Figure 9, a lower percentage of surfactant (5%) also has the lowest micro-explosion temperature compared to 10% and 15%. This is because a higher percentage of surfactant would result in a stronger bond between water and diesel. In order to break the bond, it needs a higher temperature causing micro-explosion temperature to be higher.

From the comparison of samples shown in Figure 10 which has different percentages of water (9%, 12% and 15%) but same percentages of surfactant (10% of surfactant with HLB value of 6.31), the time taken for micro-explosion to occur for samples in Figure 10 and samples in Figure 8 shows a same behavior where WiDE with a lower percentage of water has a shorter time taken for micro-explosion to occur. However, the micro-explosion temperatures are opposite where samples in Figure 10 show an increment of temperature as the percentage of water increases. The reason would be that a higher dosage of surfactant (6.31 HLB) would require a higher temperature compared to emulsion with lower dosage of surfactant (4.97 HLB).

5.0 CONCLUSION

A water-in-diesel emulsion (WiDE) with more water creates a better emulsified fuel. Every sample which has the highest percentage of water shows a stable emulsion regardless different amount of surfactant and type of surfactant used. The main stability mechanism for the emulsions has been found to be the value of HLB of the surfactant used in the mixture. Even with a same amount of water percentage used in emulsion, a surfactant which has a HLB value near to 5 provide a better emulsifier. Referring to the observation made on every sample, emulsion with surfactant of HLB value equal to 4.97 looks more stable compared to emulsion with surfactant of HLB value equal to 6.31. This has clarified that WiDE which has a HLB value near to 5 has a better emulsifier. Each emulsion shows a different duration of sedimentation formation where variables such as percentage of water, HLB value of surfactant and dosage of surfactant affect the formation of sedimentation.

For micro-explosion, emulsion with a higher dosage of surfactant (6.31 HLB) has a shorter time taken for micro-explosion to occur and a higher micro-explosion temperature compared to emulsion with a lower dosage of surfactant (4.97 HLB). A higher micro-explosion would be because emulsion with higher HLB value has a stronger bond between water and diesel. Thus, it needs a high temperature to break the bond. Apart from that, more water in an emulsion would increase the time taken for micro-explosion to occur. This is because more water molecules need to be heated in order to reach superheated temperature.

As for the recommendations, this experiment should be continued however with a different variable to be use such as different percentage of water and surfactant. Apart from that, all data and should be kept properly so that these data can be used for reference and comparison in the future. Last but not least, the experimental setup can be improved by using a different arrangement to get a clearer image of micro-explosion phenomena.

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<u>APPENDIXES</u>

NO.	Subject	Allocation	1	2	3	4	5	6	7	8	9	10	11	12	13	14
			Semester 1 (FYP 1)													
1	**FYP Topic Selection**	N/A	■													
2	**Project Introduction**	23/1/2014		■												
3	**Extended Proposal Preparation**	29/1/2014			■											
	Project Methodology Planning	3 Weeks			■	■	■									
	Project Gantt Chart & Milestone Preparation	3 Weeks			■	■	■									
	Literature Reviews	3 Weeks				■	■	■								
4	**Preliminary Work**	19/2/2014						■								
	Familiarization with materials and equipments used for experiment	1 Week						■								
	Listing up equipment specification required for experiment	1 Week						■								
	Understanding the flow setup of equipment for experiment	1 Week						■								
5	**Preliminary Data Analysis for Familiarization Experiments**	1 Week						■								
6	**Proposal Defense Preparation**	2 weeks						■	■							
7	**Consumables Purchasing**	3 Weeks							■	■	■					
8	**Phase 1 : Determining the suitable parameters and variables for experiment**	4 Weeks									■	■	■	■		
	The temperature of hot plate - Leidenfrost Effect	1 Week										■				
	Percentage of water in diesel - Emulsified fuel	1 Week											■			
	Droplets size of emulsified fuel - Thermocouples	1 Week												■		
9	**Preliminary Data Analysis for Phase I Experiments**	1 Week													■	
10	**Submission of Interim Report**	20/4/2014														■

			Semester 2 (FYP 2)													
NO.	Subject	Allocation	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	**Phase II : Setup equipment for experiment**	1 Week	■													
	Check whether each equipment functions as required	1 Week		■												
	Prepare materials for experiments	1 Week			■											
2	**Preliminary Data Analysis for Phase II Experiments**	1 Week			■											
3	**Preparation of Progress Report**	1 Week						■								
4	**Project Finding Interpretation & Analyses**	6 Weeks				■	■	■	■	■	■					
	Comparative Analyses on the different blend of Emulsified Fuel	1 Week				■										
	Comparative Analyses on the different droplets size of Emulsified Fuel	1 Week					■									
	Establishment of Recommended Operating Conditions for Effective Micro-Explosion Phenomenon	1 Week						■								
	Cost Engineering Analyses (if required)	1 Week							■							
	Compilation of Project Findings Interpretation & Analyses	1 Week								■						
5	**PRE-SEDEX**	1 Week										■				
6	**Preparation of Draft Report & Technical Paper**	4 Weeks									■	■	■	■		
7	**Submission of Draft Report**	1 Week											■			
8	**Submission of Technical Paper**	1 Week												■		
9	**Submission of Dissertation (Soft Bound)**	1 Week												■		
10	**Oral Presentation / Viva**	1 Week													■	
11	**Submission of Project Dissertation (Hard Bound)**	1 Week														■