The Effects of Surfactant on Combustion Characteristics of Emulsified Diesel Fuel

By

Muhammad Iskandar Bin Ismail

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Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

_____

(AP. Dr. 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.

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MUHAMMAD ISKANDAR BIN ISMAIL

ABSTRACT

Introduction of water into diesel mixture could be used as an alternative fuels to replace natural hydrocarbon resources that are nearly depleted. The emulsified diesel fuel is defined as emulsions of water in diesel fuel, mixed with a surfactant formulation. This emulsified fuel will be a new solution to the pollution and environmental problems. Problem arises when this emulsion tend to demulsify itself over time. In order to get a good and stabilised emulsion, a correct mixture of water and diesel fuel must be produced. Water in Diesel Emulsion (WiDE) is produced with proportion of 5% water content. The emulsions created will be tested for its stability and property compositions such as Carbon, Hydrogen and Nitrogen content, flame point and molecule composition. As the result, Oxygen content in emulsified diesel fuel is more than ordinary diesel fuel and this clearly shown that the emulsion can provide better combustion. Mixing speed provides more stabilised emulsion as compared to mixing time. Therefore, it is useful to apply mixing speed when preparing emulsified diesel fuel.

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ABBREVIATIONS AND NOMENCLATURES

1. CO: Carbon monoxide
2. CO_2: Carbon dioxide
3. HC: Hydrocarbon
4. NO_X: Nitrogen oxides
5. O/W: Oil-in-water
6. PM: Particulate matters
7. SO_X: Sulphur oxides
8. UTP: Universiti Teknologi PETRONAS
9. W/O : Water-in-oil

CHAPTER 1

INTRODUCTION

1.1 Background of Study

A diesel engine, also known as a compression-ignition engine is an internal combustion engine that uses the heat of compression to initiate ignition to burn the fuel that has been injected into the combustion chamber. This is in contrast to spark-ignition engines such as a petrol engine or gas engine, which uses a spark plug to ignite an air-fuel mixture. The diesel engine has the highest thermal efficiency of any regular internal or external combustion engine due to its very high compression ratio. Because of its very high compression ratio, diesel fuels that enter the engine will combust automatically when a sufficient pressure by piston is applied on it. Figure 1 below shows basic components of diesel engine.

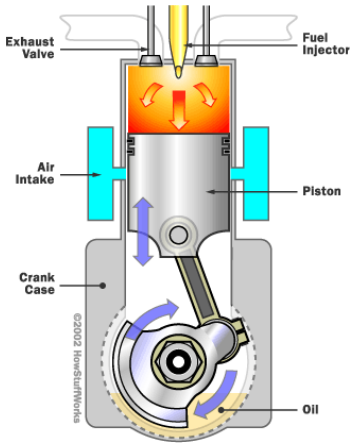

Figure 1: Two-Stroke Diesel Engine.[1]

Diesel engines offer better fuel to power conversion efficiency and due to their better fuel economy, diesel engines are the dominant class of engines in mass transportation, heavy industries and agricultural sectors. Increasing numbers of regulations of exhaust emissions contributed to the major research in engine

[1] Retrieved from http://auto.howstuffworks.com/diesel-two-stroke1.htm.

development and also into the formulation new fuel itself. One of the possible solutions to cater the above problem is to mix water and diesel and this can be achieved through the right formulation of the surfactants.

Emulsified fuels are emulsions composed of water and a combustible liquid, either oil or a fuel. Emulsions are a particular example of a dispersion comprising a continuous and a dispersed phase. Emulsion fuels can be either a micro emulsion or an ordinary emulsion. Emulsified fuels can be produced by the help of surfactant. Surfactants are compounds that lower the surface tension of a liquid, the interfacial tension between two liquids, or that between a liquid and a solid. Surfactants comprises of detergents, wetting agents, emulsifiers, forming agents, and dispersants (Wikipedia, 2013). For this experiment, surfactant is used to mix water and diesel in correct ratio as to produce a good and reliable emulsified diesel fuel. Emulsified diesel fuel is defined as emulsions of water in diesel fuel, mixed with very specific additives such as surfactants. The surfactant itself will help to stabilise the emulsion, so that the finely dispersed water droplets remain in suspension within the diesel fuel. Figure below shows on how the emulsified fuel can act as emission reduction. Water and fuel mixed together to form emulsions and because of rapid evaporation, water molecules that bind to fuel molecules breaks down fuel droplets to form a small one.

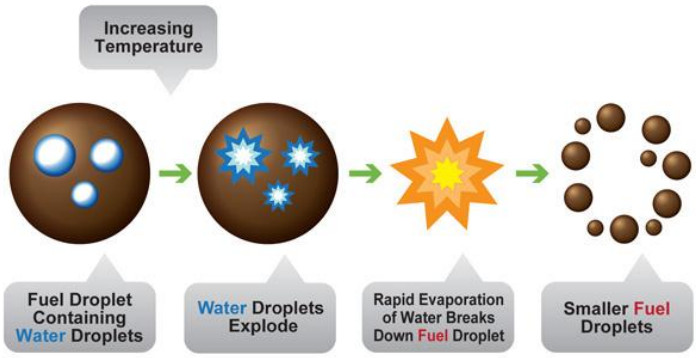

Figure 2: Formulation of fuel emulsions.[2]

Combustion is burning, a self-propagating oxidative chemical reaction producing light, heat, smoke and gases. This combustion consists of burning of wood in air,

[2] Retrieved from http://www.altpetrol.com/en/4a-tech-overview.html

natural gas in air, hydrogen with oxygen and others. Combustion is used for heating the surroundings, generating motion by means of heat engines, refrigeration by separating heat form liquid mixture and chemical transformations. Diesel is combusted by the assistance of compressed air, which means oxygen in the engine. Diesel combustion is characterised by lean Air to Fuel Ratio (A/F). A combustion characteristic is a comprehensive troubleshooting and problem-solving class covering the effects of operating conditions and control adjustments on engine combustion.

1.2 Problem Statement

Diesel fuel that is used nowadays contributed many environmental problems such as sooty exhaust and many other dangerous emissions as the results from its combustion. Water will be introduced into the mixture of diesel as to offer more complete combustion and reduces harmful pollutants to the environment. When an emulsion is produced, it tends to disseminate back to their original liquid form, which is water and diesel. In order to get a stabilised emulsified diesel fuel, a correct method to prepare the emulsions must be made known. After that, the proportion of diesel and surfactant must be tested and its composition must be determined.

1.3 Objectives

The main objectives of this study include:-

1. To study the method for preparing a correct proportion of water, diesel fuel and surfactant as to produce a stabilised emulsified diesel fuel.
2. To characterise emulsified diesel fuel by its stability and property composition determination.

1.4 Scope of Study

The project is divided into two parts, which are FYP 1 and FYP 2. Below are the scopes of study that will be done during the progress of the project:-

1. FYP 1 – To study about the suitable method to mix water and diesel as to offer a stabilised emulsified diesel fuel. During this period, the focus is more on the understanding on how surfactant can mix up water and diesel, what are the suitable proportion of surfactant, water and diesel in order to get a stabilised diesel fuel and lastly appropriate method to blend all those components.
2. FYP 2 – Combustion characteristics of emulsified diesel fuel will be tested. One industry-made emulsified diesel will be tested for its combustion characteristics. It comprises of percentage of emissions of pollutants such as nitrogen oxides (NO_X), particulate matters (PM), sulphur oxides (SO_X), unburned hydrocarbon (HC), and carbon monoxide (CO). Next, to test on the heat value of the emulsions. The result obtained will be analysed and compared, between industry-made emulsified diesel fuel and ordinary diesel fuel.

1.5 The Relevancy of the Project

Based on The European Union, the pollution caused by road vehicles is very high. As from the causes, they introduce strict limits on pollution emissions from road vehicles, especially emissions of nitrogen particulates and oxides. This shows that pollution from exhaust emissions is being taken seriously by the government. Many scientists had done researches in order to reduce dangerous emissions from combustion of diesel fuel.

1.6 The Feasibility of the Project

This project is done by means of two phases, FYP 1 and FYP 2. In FYP 1, the project is started by understanding the components of emulsified diesel fuel such as water, diesel and surfactant. Then, the methods of mixing of those components are made known by conducting literature review. In FYP 2, an experimental study has been conducted to identify the effects of surfactant on combustion characteristics of emulsified diesel fuel.

CHAPTER 2

LITERATURE REVIEW

2.1 Components in Diesel Fuel

Diesel fuel is generally a fuel that is used in diesel engine. It offers better fuel efficiency and economy and thus, preferably the most usable fuel nowadays. Diesel fuel is the dominant fuel used by the commercial transportation, heavy industries and agricultural sectors. Diesel fuel comes in several different grades that depend on its usage [1]. Like gasoline, diesel fuel comprises of a mixture of various petroleum-derived components including paraffins, isoparaffins, napthenes, olefins and aromatics hydrocarbon. Despite their numerous advantages, diesel fuel also is the main pollution contributors to the environment. Primary pollutants released from emission of diesel fuel are particulate matters (PM), black smoke, nitrogen oxides (NO_X), sulphur oxides (SO_X), unburned hydrocarbon (HC), carbon monoxide (CO), and carbon dioxide (CO_2) [2]. The cleaner diesel fuel program significantly reduces sulphur content, producing healthy benefits and reduces harmful emissions. A 15 parts per million (ppm) sulphur specification, known as Ultra Sulphur Diesel (ULSD), was introduced for highway diesel fuel from 2006-2010 [3].

2.2 The Emulsified Diesel Fuel

The composition of diesel emissions varies depending on engine type, operating condition, fuel, lubricating oil and others. Researchers around the world have focused their experiments on how to reduce pollution based on diesel emissions. This is because they have found that prolong exposure to diesel engines pollutants above specific limits should be harmful to human health. One of the possibilities of reducing the pollution is by introducing water content into the diesel fuel. Diesel oil emulsions appear to be the most appropriate because they require no engine retrofitting. Research showed that emulsified diesel fuel can lead into reductions of NO_X emissions [4]. There are many advantages when emulsified fuel is possible, such as more complete combustion, cleaner burning of emissions and reduction of hazardous pollutants.

2.3 Method on Preparing Stabilised Emulsions

There are two basic forms of two phase emulsion. The first one is the oil-in-water (O/W) emulsion in which oil droplets are dispersed and trapped inside the water column. The second is the water-in-oil (W/O) emulsion in which droplets of water are dispersed and encapsulated within the oil [5]. Emulsions have found numerous applications of food and beverages, cosmetics, paints, printing, pharmaceuticals, polymerization, metal, wood processing and others. Figure 3 shows the concept of two-phase (W/O) and (O/W) emulsions.

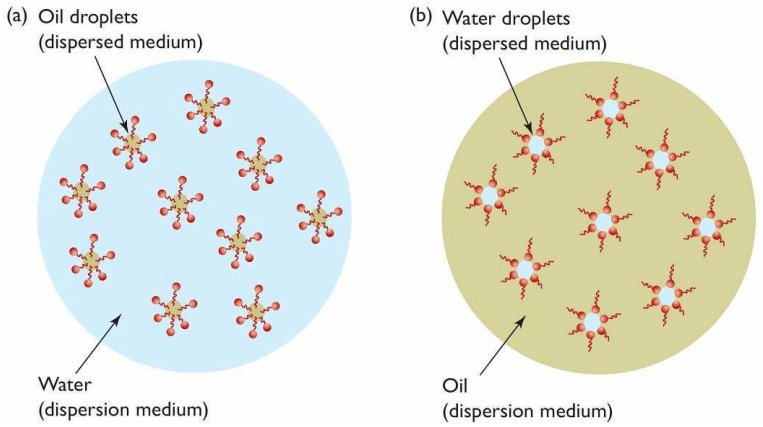

Figure 3: Concept of water and oil emulsions.

The two liquids must be immiscible or naturally insoluble to each other. An emulsifying agent, which is surfactant, is used to combine these two liquids. They are capable to form self-associated clusters, which normally lead to organized molecular assemblies of a mixture. A few researches has included a new concept of three phase emulsions and also the comparative studies on the effect of two phase and three phase emulsions on the engine performance [6]. Figure 4 shows the difference in composition of two phase and three phase emulsions.

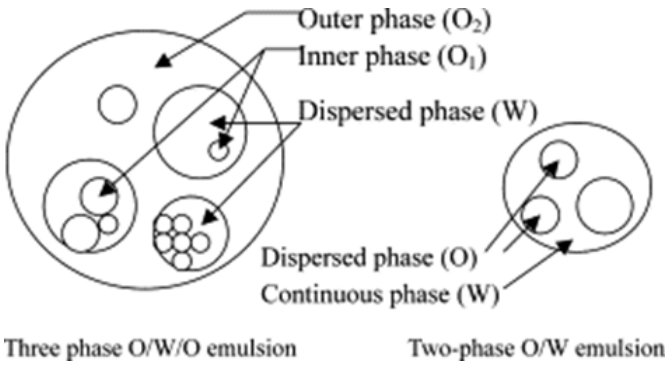

Figure 4: Composition of two phase and three phase emulsions.

The researches of intake oxygen-enriched combustion of internal combustion engine have begun since 1960s, and the original purpose was to reduce engine-out emissions. Mixing oxygen directly in engine intake air has been commonly used in oxygen-enriched combustion technology.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

Figure below shows the execution flowchart of the whole project.

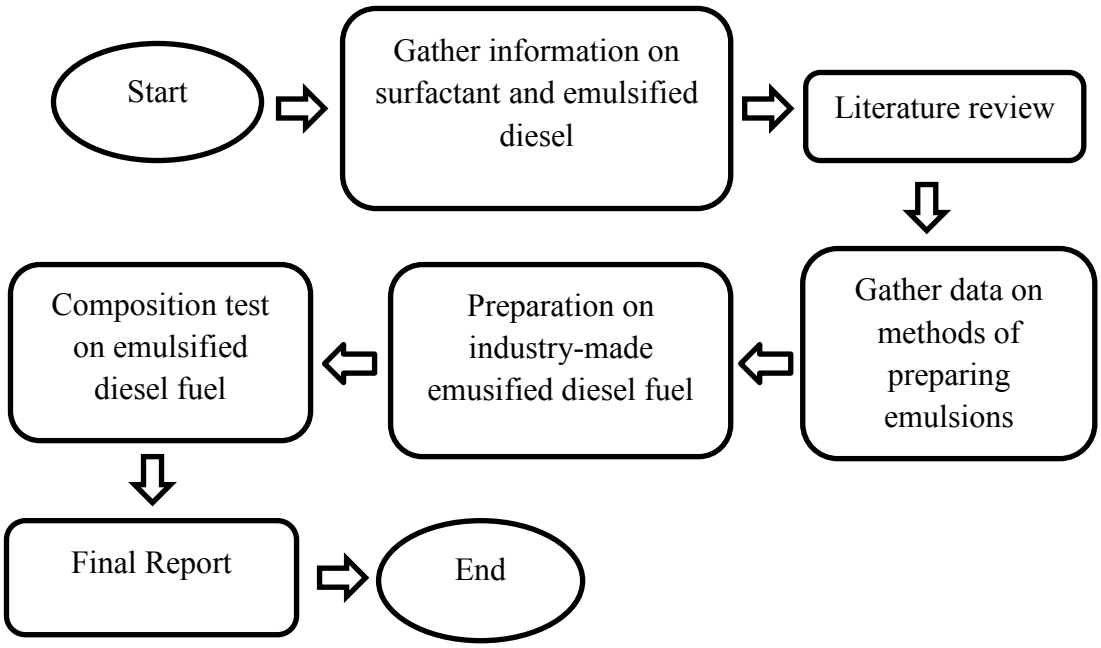

Figure 5: Execution Flow Chart

First, information regarding surfactant and emulsified diesel fuel are gathered according to criteria that have been specified earlier. Literature review is done on the subject matter as to increase the knowledge and understanding. This is very important as to close the gap of the experiment. The proposed experiment will be based on certain gaps that have been identified during this session. Then, methods for preparing s suitable emulsions are being compared to see which one provides most promising way in preparing the emulsions. Next, industry-made emulsified diesel fuel is made available. This emulsion is being tested according to the properties that have been setup. After that, the data of the experiment are being analysed and compared. Report will be produced and documented accordingly after the experiment.

3.1.1 Characterisation of Emulsion Properties

There are a few characterisations properties that can be tested on the emulsified diesel fuel. These properties are very important to be tested as they offer information on content of the emulsions. The contents of the emulsions are very useful in determining whether the emulsions are a good emulsion or a bad one. Table below shows the characterisation of emulsion properties.

Table 1: Characterisation of Emulsion Properties

Emulsion Property	Testing Methodology
Stability Test	observation for phase separation over time
Density(Kg/m3)	by weighing a known volume of fuel
Viscosity	dynamic viscometer
Flame point temperature	Thermogravimetric analyser
Calorific Value	bomb calorimeter (MJ/Kg)
Surface tension measurements	Spinning drop tensiometer
Water droplet size(μm)	optical electron microscope(OEM)
Corrosiveness	Copper strip corrosion test tube bath
Sulphur content (ppm w) C (% w/w) H (% w/w) N (% w/w) O (% w/w)	CHNS analyser

Only some of the properties will be tested on the industry-made emulsified diesel fuel. There are, Carbon, Hydrogen, Nitrogen, Oxygen and Sulphur content as well as flame point temperature. Also, the size for molecule of the emulsions will be determined by using Scanning Electron Microscope (SEM).

3.1.2 Methods on How to Prepare a Stabilised Emulsions

Data on methods on how to prepare a stabilised emulsion are gathered and compared. These methods are being compared to see which one favours the most suitable method in order to prepare a stabilised emulsion. There are a few methods such as speed of stirring of blending and others. Most suitable method will be recommended for future research.

3.1.3 Establish Experiment

Experiment is done by using a number of equipment. All the equipment is used to determine the properties of the industry-made emulsified diesel fuel.

3.1.4 Data Collection

All data from the experiment are recorded and analysed. These data then will be compared to theoretical data and analysis will be done to see the differences and its significance to each emulsion properties.

3.1.5 Documentation

All details of the project will documented properly for future references. Any recommendations on how to do better on the research can be made known to others.

3.2 Project Activities

3.2.1 Expected Result

From the characterisation properties, a few selected properties will be tested on the emulsions. Table below shows the expected result of these properties.

Table 2: Expected Results for Characteristics of the Emulsified Diesel Fuel

Type of analysis	Expected results
Carbon, Hydrogen, Nitrogen, Sulphur (CHNS)	Amount of nitrogen, sulphur, carbon and hydrogen in emulsified fuel
Thermal Gravimetric Analysis (TGA)	Flame point temperature of emulsified fuel
Scanning Electron Microscope (SEM)	Molecule composition

With this approach, the determination of properties on the emulsions will be more in accordance in manner. Data that will be collected can easily be analysed and compared.

3.2.2 Emulsion Ratio

Real-time emulsion process was used to produce the emulsified diesel [7]. The real-time technique can prevent demulsification of emulsified diesel for long time acquisition. The water-emulsion ratio was calculated as follows:

$$\text{Water Emulsion Ratio } \% = \frac{V_{\text{water volume fraction}}}{V_{\text{water volume fraction}} + V_{\text{diesel volume fraction}}} \times 100\%$$

3.2.3 Emissions Calculation

The concentrations of the gaseous emissions form the engine exhaust can be calculated by using specific emissions equations. Specific emissions are the flow rate of pollutant per power output [8].

$$sNO_x = \frac{\dot{m}_{NO_x}}{P}$$

$$sCO = \frac{\dot{m}_{CO}}{P}$$

$$sHC = \frac{\dot{m}_{HC}}{P}$$

where $P = \text{Power}$, $\dot{m} = \text{mass flow rate of gaseous emissions.}$

3.2.4 Equipment and Apparatus

Below are identified lists of equipment and apparatus that will be used in the experiment:-

1. Diesel fuel from petrol pump
2. Water
3. Surfactant
4. Test tubes with cork stopper (30)
5. Test tube rack
6. Diesel engine
7. CHNS analyser
8. TGA instrument
9. Scanning Electron Microscope (SEM)

3.3 Gantt Chart

3.3.1 FYP 1

Table 3: FYP 1 Project Timeline

No	Details Weeks	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Title	■	■													
2	Preliminary Research Work and Literature Review		■	■	■	■										
3	Submission of Extended Proposal Defence							●								
5	Oral Proposal Defence Presentation									■						
6	Detailed Literature Review										■	■	■	■	■	■
7	Study on Methods to Prepare Stabilised Emulsions										■	■	■	■		
10	Preparation of Interim Report			■	■	■	■	■		■	■	■	■	■		
11	Submission of Interim Draft Report														●	
12	Submission of Interim Final Report															●

● Key milestones of the activities.

■ Process

3.3.2 FYP 2

Table 4: FYP 2 Project Timeline

No	Details / Weeks	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Establishment of Experimental Set Up and Procedures	■	■	■	■	■	■	■									
2	Conduct Experiment and Data Collection									■	■	■	■				
3	Results Analysis												■	■			
4	Submission of Progress report							●									
5	Pre-SEDEX Poster presentation											●					
6	Submission of Draft Report												●				
7	Submission of Dissertation (Soft Bound)													●			
8	Submission of Technical Paper													●			
9	Oral Presentation														●		
10	Submission of Project Dissertation (Hard Bound)																●

● Key milestones of the activities.

■ Process

The key milestones for this project are divided into two parts which are FYP 1 and FYP 2. There are listed as follows:-

1. FYP 1
    - Submission of Extended Proposal – 22nd February 2013
    - Submission of Interim Report – 22th April 2013
2. FYP 2
    - Composition Test – August 2013

CHAPTER 4

RESULT AND DISCUSSION

4.1 Emulsified Diesel Fuel

Figure 6: Water in Diesel Emulsion (WiDE)

The figure above shows the Water in Diesel Emulsion (WiDE) with 5% water content.

4.1.1 Characterisation of Emulsified Diesel Fuel (WiDE)

Table 5: Comparison between WiDE and Diesel

Fuel	Diesel	Emulsified Diesel Fuel
C (%)	86.120	77.510
H (%)	12.970	12.780
N (%)	0.060	0.054
S (%)	-	-
O (%)	-	8.900
Flame point temperature (K)	483	479

Based on Table 5, the emulsions have oxygen molecules in its molecules. This offers better combustion because oxygen molecules in the emulsions will help the carbon to combust effectively. Surfactant lowers the amount of carbon in the emulsions. Unburned carbon will contribute to the pollution. Flame point temperature for emulsion is lower than diesel because of the oxygen content and also reduced in carbon content.

4.2 Methods on Preparing a Stabilised Emulsified Diesel Fuel

There are a few methods on how to prepare a stabilised emulsion. A stabilised emulsion is the emulsion that can be used for a long period of time. It is important to know about the difference in methods of preparing the emulsion.

4.2.1 Mixing Speed

The main criterion for a stable emulsion is the presence of only one phase. If more than one layer is found in the mixture, it must be considered to be an unstable emulsion which means it lacks of stability. It is important to determine the operating conditions required to maintain a stable emulsion for a reasonable period of time to cover the different stages of preparation, storage, transportation, and consumption (M. T. Ghannam, M. Y. E. Selim, 2009). Several mixing speeds of different mixing times were examined to prepare the emulsions. M. T. Ghannam and M. Y. E. Selim have prepared the samples of emulsion then were placed into graduated glass cone containers to measure the amount of water separated over time.

Figure below shows the result of varying mixing speed method.

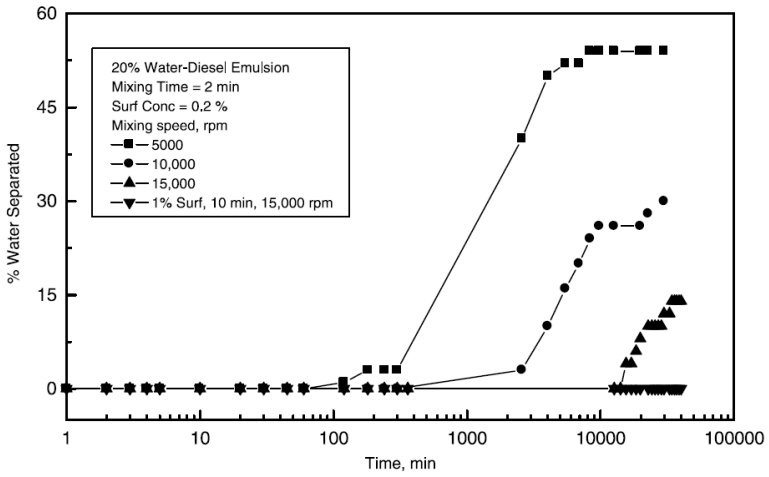

Figure 7: Effect of Mixing Speed on the Stability of the Emulsion.

From the figure above, M. T. Ghannam and M. Y. E. Selim have concluded that all emulsions that being tested are remained stable for at least 6.5 hours. Varying in mixing speed enhances the stability when only emulsion with proportion of 20% of water-in-diesel has the stability up until 4 weeks. This condition is also supported by the presence of 1% of surfactant in the emulsion whereas the others only have 0.2% surfactant in their mixture.

4.2.2 Mixing Time

M. T. Ghannam and M. Y. E. Selim have carried out the stability investigation for the 30% emulsion using a mixing speed of 15,000 rpm, 0.2% surfactant concentration, and a mixing time of 2 minutes. The 30% emulsion was only stable for 5 hours. The water was gradually separated until 32% of the water separated within 1 week. As higher mixing times of 10 and 20 minutes were examined, the stability profile was slightly enhanced. For 20 minutes of mixing time, the emulsion was stable for 8.5 hours, and 11% of the water was separated within 1 week as shown in Figure 8.

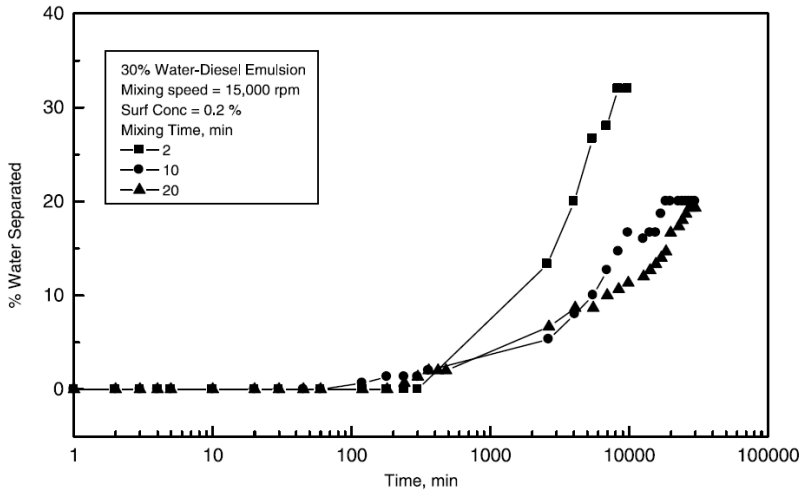

Figure 8: Stability Profile for 30% Emulsion for Different Mixing Time

4.2.3 Comparison between Methods of Preparation

Based on these two figures, it is clearly shown that mixing speed favours more stable mixture as compared to mixing time. In mixing speed, the time taken for the emulsion to separate is about four weeks as compared to mixing time, it takes only within one week.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

As a conclusion, all objectives are achieved. There are two methods that are being compared, mixing time and mixing speed. Based on the comparison, mixing speed provides more stability on the emulsion as compared to mixing time. This is because the emulsion will blend more perfectly when a fast mixing speed is applied. As a result, 20% water-in-diesel emulsion can be produced with stability about four weeks' time. The surfactant that is being used to create industry-made emulsified diesel fuel, Water-in-Diesel (WiDE) gave significant impact on the properties of the emulsion. The surfactant that is introduced in emulsified diesel fuel can help to reduce carbon content as to minimise the unburned carbon. The addition of oxygen in the emulsion can help to combust the carbon effectively and this contributes to a cleaner emissions. The flame point of the emulsion is not affected much, thus it can be used as widely useable fuel.

5.2 Recommendations

There are a few recommendations for future project on emulsified diesel fuel. The recommendations are listed as follows:-

1. Consider applying a mixing speed when preparing an emulsified diesel fuel. The mixing speed gives significant impact as it can help to blend the mixture more perfectly and also can increase stability of the emulsion.
2. Consider preparing an in-house emulsion by applying 5% to 10% of water into diesel, water-in-diesel emulsion. By referring to the WiDE, the in-house made emulsion can apply water of the said range as to determine which is more stable and can provide better reduction in exhaust emissions.`

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