FINAL YEAR PROJECT: DISSERTATION

Experimental Study on the Influence of Water-in-Diesel Emulsion (WiDE) Characterization on Microexplosion Occurrence.

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ABSTRACT

Emission regulations continue to get more stringent, exacerbating the need to find a solution for the emission of gaseous pollutant and particulate matter from diesel engines. Various studies reported the success of Water-in-Diesel Emulsion (WiDE) in solving the emission issue through the microexplosion phenomenon. A study on the basics of this occurrence and its influencing parameters plays a major role in the combustion improvement. A very close attention was given to the changes in viscosity, density and water droplet size in this research due to their pronounced effect on the mixing process and injection system

Physical characterization tests was carried on 16 stable WiDE samples with various water content, HLB value and surfactant percentage, to determine the viscosity of the samples at 40°C, the density of the samples at 15°C and the water droplet size of each samples. Through these test, only a few of the samples satisfy the France or Italy Water/Diesel Emulsions fuel regulations or the CWA15145 requirements and test methods was selected to undergo microexplosion test through a visualization technique.

6 samples was analysed and a correlation between water droplet size to the microexplosion temperature and time can be observed. However, no direct correlation between viscosity and density to the microexplosion phenomena can be concluded.

ACKNOWLEDGMENT

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First of all, an appreciation to Dr. Zainal Ambri b. Abdul Karim in allowing the writer to undergo this golden opportunity to understand and learn practically in the field of automotive throughout the journey of this course. Apart from that, the writer would also like to show her gratitude to Mr. Mohamed Yahaya Khan and all the members in The Centre of Automotive Research and Energy Management (CAREM) team with their help and support throughout this course.

The writer hopes that this document will benefit its readers, in providing additional data related to the research of Water-in-Diesel Emulsion (WiDE) for future references and studies.

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CHAPTER 1
INTRODUCTION

1.1 Background Study

Compression ignition engines, commonly known as Diesel Engines, ignite the fuel using heat from compression. It has the highest thermal efficiency due to its high compression ratio and inherent lean burn which facilitates unpack gases to salvage waste heat [1]. Therefore, they require less fuel to operate. It is not a surprise that this type of internal combustion engine (ICE) would be selected to power engines in various industries. With the increase of awareness in saving the environment, concerns have raised as diesel engines has been regarded as a major air pollution source as they exhaust gaseous emissions and particulate matter [2].

Studies have been made in order to counter the problems faced in the use of diesel engines. Despite the fact that diesel engines offer higher efficiency and fuel economy, they emit pollutants, i.e. particulate matter (PM), nitrogen oxides (NOx), sulphur oxides (SOx), carbon monoxides (CO) and carbon dioxides (CO_2). Modern hardware-based solutions are common adopted to help reduce these pollutants. Examples of these technologies are exhaust gas recirculation (EGR) and selective catalytic reduction (SCR). However, not all of these technologies can be fitted to existing engines and are quite costly [3].

Another alternative to resolve this environmental issue is through fuel-based solutions. This includes introducing other solvents into the engine i.e. additives and water. Additive have been claimed to improve fuel economy and/or reduce emissions. However, there is no analytical studies to prove these claims [4]. On the other hand, the introduction of water into an engine has been proven to reduce emission through cooling effect. This is the basis for the use of fuel-water emulsion [4]. Not only does this alternative reduce exhaust emission, but it also saves fuel. This advantage however comes at the cost of engine power which is generally inversely proportional to the water concentration of the emulsion. In addition to the tendency of the water and fuel to be separated, this leads to engine corrosion due to direct contact of water with the engine [4]

This cooling effect is a result of the micro-explosion theory [4]. As the emulsion is dispersed into the combustion chamber, the water droplets distributed throughout the fuel, vigorously change into water vapour, shattering the diesel surrounding the water droplets into much smaller droplets. This phenomenon is commonly known as secondary atomization, which can be seen in Figure 1.1. Due to high surface area of the smaller droplets, the combustion efficiency is improved thus reducing the formation of PM [4].

Research into utilizing Water-in-Diesel Emulsion (WiDE) as fuel has reported the reduction of the emissions of NOx, SOx, CO, CO_2 and PM without impacting on the engine's performance [2]. There are numerous other benefits of using WiDE fuel as an alternative, such as better fuel economy due to the increase of complete combustion which also leads to cleaner emissions [3]. With the introduction of water in the emulsion, it produces an increase in ignition delay, due to heat absorption by water vaporization. This heat absorption causes a decreasing adiabatic flame temperature, thus reducing the propensity for chemical reactions that produce NOx [2].

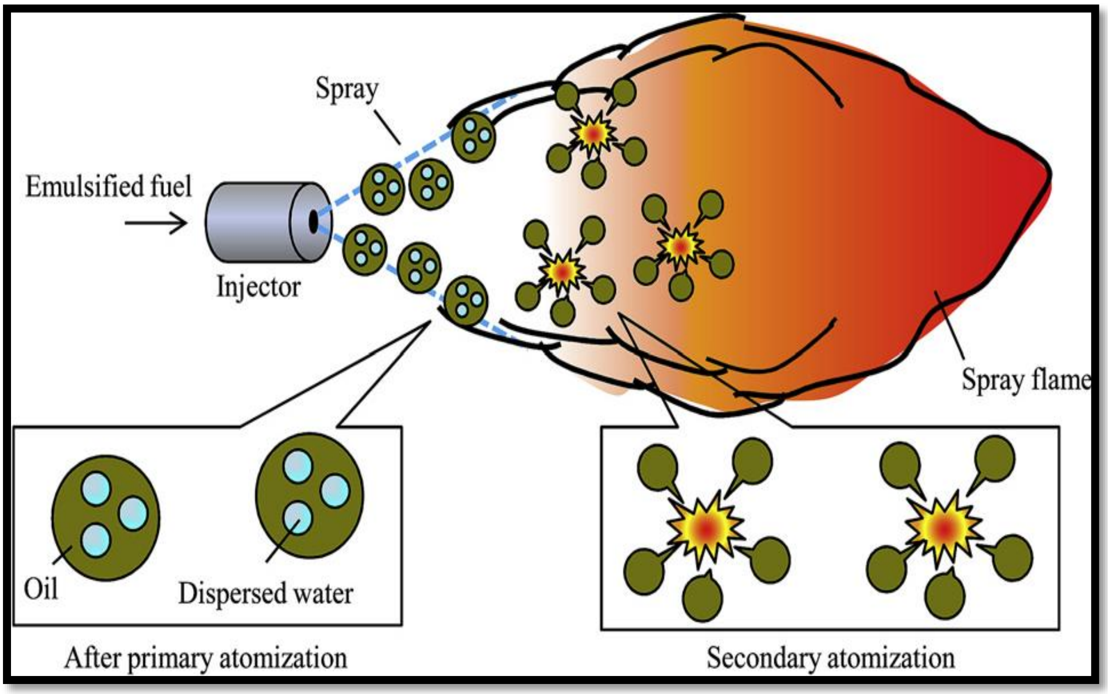


Figure 1.1 : Secondary Atomization [5]

1.2 Problem Statement

Diesel engines have been regarded as one of the main air pollution source and have been raising serious public concerns. Therefore, a more strict legislation on exhaust emission has been applied and increasing need to resolve the pollution problem. Research has showed the effectiveness of WiDE in reducing the exhaust emission [2]. It is claimed that microexplosion is the cause of the reduction of both NOx and PM. Physical characterization of the fuels, for example but not limited to the viscosity, density and water particle distribution, has a clear effect on the combustion process [2]. In order to verify these claims, an experimental study on the microexplosion and to optimise the selected parameters to ascertain the optimum WiDE formulation. The physical characterizations not only aims to obtain the ideal ratio, but also to comply with the standards and requirements.

1.3 Objective and Scope of Study

The objectives of this study was:

- To characterize WiDE through various laboratory investigations.
- To investigate the microexplosion phenomena occurrence in WiDE samples.
- To relate the characterization of WiDE with the microexplosion evolution principles and parameters that influences the occurrence of this phenomenon.

The Scope of Study was divided into two parts as follows Final Year Project 1 (FYP 1) and Final Year Project 2 (FYP 2).

Scope of work under FYP 1 involves:

- Characterization of the emulsified fuels made by using the instruments listed in Table 1.1 below:

Table 1.1 : WiDE characteristics and intruments used

WiDE Characteristics	Instruments Used
Water droplet size distribution	Optical Microscope
Density at 15°C	Density Meter
Viscosity at 15°C	Rheometer

FYP 2 scope of work includes:

- Visualization of microexplosion occurrence in WiDE
- Data acquisition and result analysis
- Ascertain optimal WiDE formulation

1.4 Relevancy

- World and National Agenda on reducing vehicles exhaust emission according to 10th Malaysia Plan (2011 – 2015)
- PETRONAS Corporate Sustainability Framework on monitoring, reporting and controlling GHG emission.

- PROTON has started initiatives in the development of hybrid electric vehicles. The project was initiated in September 2009 to adhere to the Malaysian Government's low carbon and green growth agenda.
- Various research has been done and concluded that microexplosion contributes to the reduction of exhaust emission. Therefore, it is important that studies on the factors that influence this phenomena should be carried out.

1.5 Feasibility

- Time – 7 months is enough to carry out all the experiments in this project. However, it is still dependent on the availability of the equipment.
- Material – All the samples are readily made and available. However, the amount of samples are limited, therefore, the samples should we used wisely as the samples is to be tested on all the experiments.
- Cost – No cost was needed in order to carry out the experiments or to purchase new equipment or materials.

CHAPTER 2
LITERATURE REVIEW AND THEORY

Mixtures of two or more immiscible (unblended) liquids, one present as droplets or dispersed phase distributed throughout the other liquid present in continuous phase, are known as emulsions [6]. The emergence of these two liquids can be made possible with the presence of emulsifiers or surfactants. Surfactant is a compound that reduces the surface tensions between two immiscible fluids. They contain both hydrophobic or lipophilic groups (their tail) and hydrophilic groups (their heads) [7]. This description can be visualize through Figure 2.1. Water in diesel emulsion is known as WiDE, is a type of emulsified fuel where the water, present as droplets, are encapsulated or distributed throughout the combustible fluid or in this case, diesel. Studies have been made on the utilization of WiDE as an alternative to diesel fuel and how it affects the engine performance and exhaust emission.

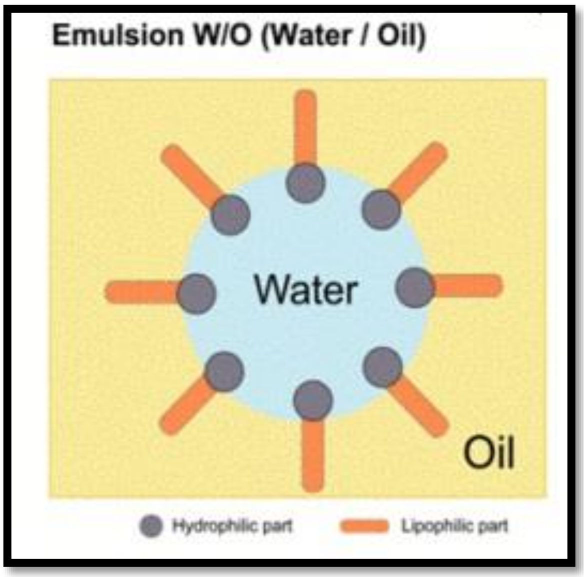


Figure 2.1 : Concept of oil-in-water emulsions [8]

Numerous research have been done on the stability of WiDE as a fuel for compression ignition (CI) engines. A good fuel for CI engines should acquire all the positive characteristics of diesel fuel i.e. short ignition timing, high cetane number, a suitable fuel viscosity and volatility [3]. These physiochemical characteristics greatly affect the fuel injection and combustion process in the engine for example, the density of fuel would affect the mixing process in the combustion chamber and the viscosity would then affect the injection system. By understanding the conditions of the fuel that would affect these processes will result a fuel that would improve the degree of efficiency of the injection and combustion mechanism [3].

Microexplosion is the phenomena that explains the reduction in exhaust emission by improving the combustion process. Water droplets that are dispersed throughout the base fuel, reaches the superheated phase much faster compare to base fuel, resulting in a vapour expansion breakup [9] causing the fuel droplet to breakup into much smaller droplets and puffing , an occurrence of very fine mist of water escaping the droplet [10]. Due to this event, microexplosion causes fast fuel evaporation thus enhance air fuel mixing [3]. Through the understanding the basis of the microexplosion phenomena greatly benefit the study as it affects the combustion process positively.

The immiscibility and difference in volatility within WiDE droplets is the principle that made microexplosion possible. The vapour expansion breakup disrupts the primary droplets, subsequently causing expulsion of secondary droplets into the combustion chamber, improving combustion efficiency through the increase in fuel/air mixing [11]. It was reported that phase separation of the water droplets is an important factor that influence the microexplosion phenomena [11]. Small water droplets (due to low phase separation) will lead to longer or no microexplosion occurrence [9] [11] . The acceleration of phase separation due to the increase in mass transfer, causes a decrease in viscosity of the emulsion and the reduction of surfactant efficiency and when the emulsion is unstable enough, it leads to phase separation and microexplosion [11].

CHAPTER 3
METHODOLOGY AND EXPERIMENTAL WORK

3.1 Characterization Test for WiDE

Characteristics of a good CI engine fuel includes short ignition lags, a high cetane number, volatile within the engines operating temperature, suitable viscosity and free from wear and corrosion [3]. These features are determined by the physiochemical attributes of the fuel. Various test were conducted by previous researchers in order to investigate their physical properties, spray behavior and combustion characteristics in conditions similar to the engine's combustion chamber [3].

Tests was done to determine the sample's water particle size distribution, the density at 15°C, and viscosity at 40°C as these characteristics influence the injection, mixing and combustion process. However, tests was only carried out on stable samples determined through a standard stability test of observing the water layer formation of WiDE samples after two weeks. Stable WiDE samples would only form 2 layer, the WiDE and sediment layers while a clear layer of water would indicate that the WiDE sample is unstable.

3.1.1 Water droplet size distribution

Investigated through the Olympus BX61 Microscope displayed in Figure 3.1, the diameter of the dispersed liquid is related to the strength of the microexplosion. The fully motorized Olympus BX61 is a computer-controlled conventional wide-angle upright microscope. Equipped with a motorized stage and a high-resolution digital camera, this microscope can go up to 1000x magnification and can produce high definition images. This experiment aims to relate the size distribution of the dispersed liquid to the water content and the results is discussed in section 4.2.3.

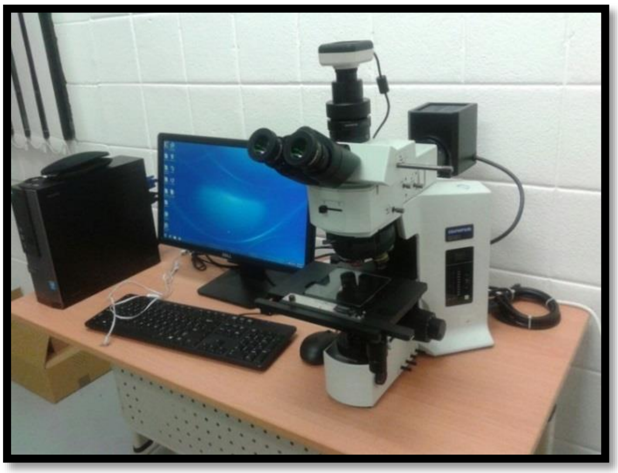


Figure 3.1 : Olympus BX61 Microscope

3.1.2 Density at 15°C

According to the France and Italy Water/Diesel Emulsion Fuel Regulations and the CWA15145 Requirements and Test Methods, the density of the samples at 15°C must comply with these standards. The density of the samples can be tested using the DA-645 Density Meter, which is displayed in Figure 3.2. This apparatus is capable of measuring density within a temperature range of 0 °C up to 90°C. The results from this experiment is discussed in section 4.2.1.

Figure 3.2 : KEM DA-645 Density Meter

3.1.3 Viscosity at 40°C

Viscosity is another property mention in the France and Italy Water/Diesel Emulsion Fuel Regulations and the CWA15145 Requirements and Test Methods. This property were examine as it could influence the spray characteristics of WiDE. Viscosity at 40°C of the sample can be tested using the DHR-1 Hybrid Rheometer. The equipment is displayed in Figure 3.3. The TA Instrument Hybrid Rheometer provides a convenient and versatile temperature control option with accurate data. The results for the viscosity of WiDE are discussed in section 4.2.2.

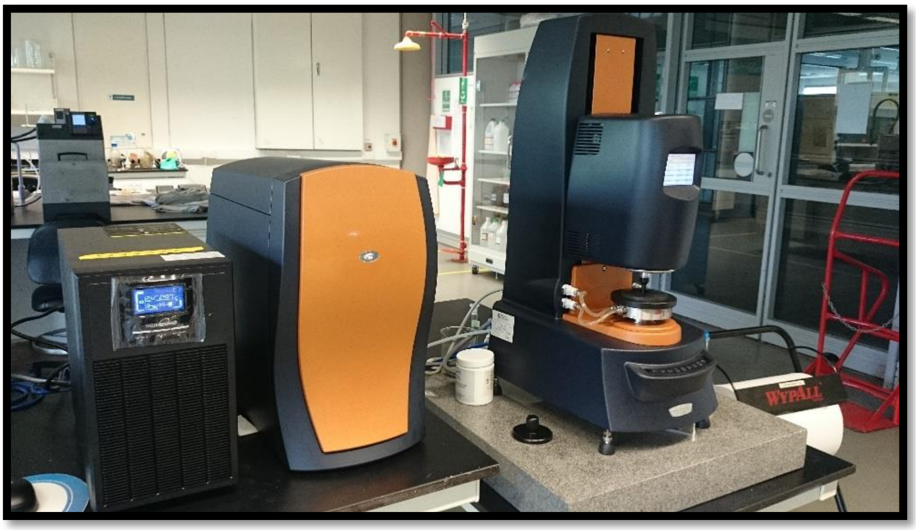


Figure 3.3 : DHR-1 Hybrid Rheometer

3.2 Microexplosion Test for WiDE

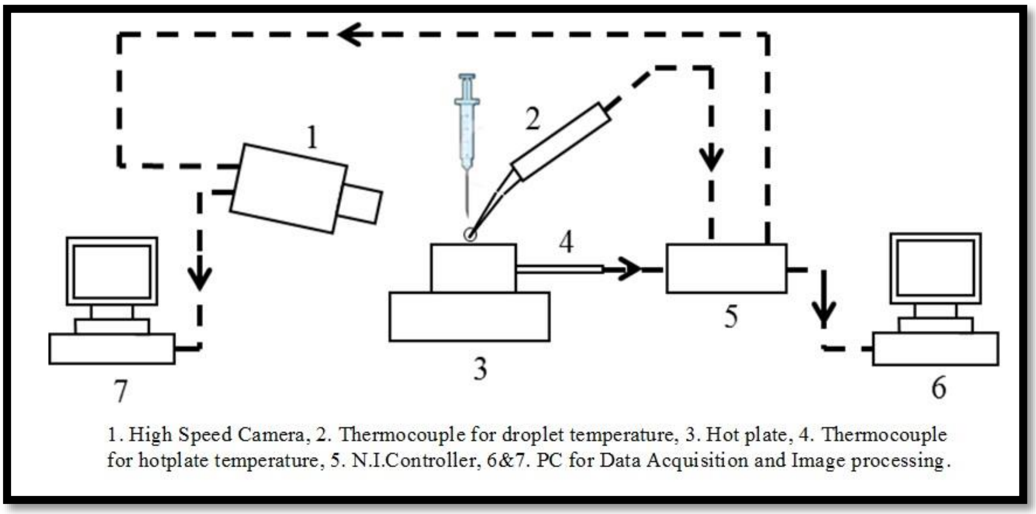


Figure 3.4 : Schematic diagram of the experimental setup for microexplosion visualization technique. [5]

Evolution of the microexplosion phenomenon was observed through a visualization technique which includes and arrange as shown in Figure 3.4. WiDE droplets was suspended on a thermocouple wire, approaching close to a 500°C hot plate. The whole phenomenon was captured through a PHOTRON FASTCAM-X 1280PCI high speed camera and analysed using the PHOTRON FASTCAM Viewer 2.4. The temperature reading and images of the micro-explosion was saved and discussed in section 4.3.

3.3 Project Management

3.3.1 Flow chart

Flow chart are used in displaying the basic flow of the project. It shows processes that needs to be done first in order for the following task to commence. Figure 3.5 shows the flow chart for the whole final year project (FYP) process. The first step of the experimentation would be doing a background study and literature review of WiDE and the microexplosion phenomana and the parameters that influence them. It is important that these studies are made to have a better understanding of the topic and to predict the result produced.

Once the topic has been understood, the parameters of the study was identified and the characterization experimentations begun. The samples undergo density, viscosity and water distribution test. Samples that violates the fuel regulations was eliminated and the remaining samples undergo the microexplosion test. The data obtained from the test was then analyzed to see the correlation between the physical characteristics of WiDE with the microexplossion occurrence.

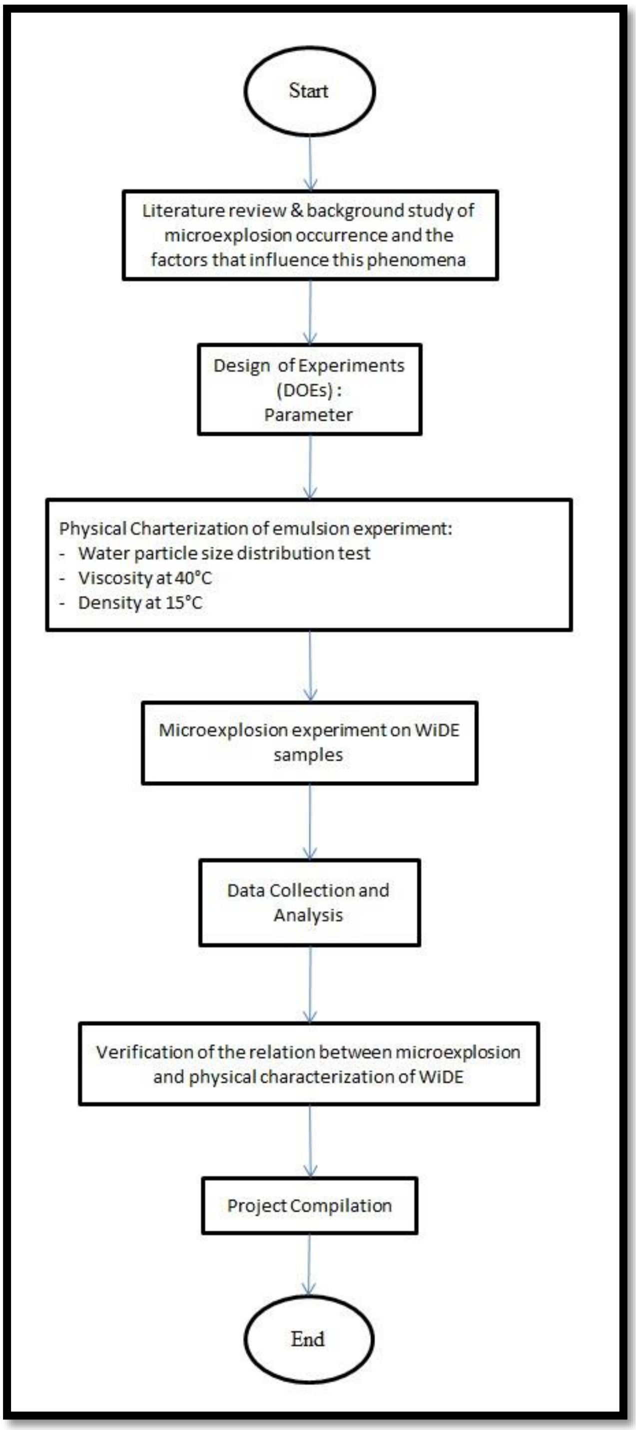


Figure 3.5 : Project Flow Chart

3.3.2 Gantt chart

Gantt charts are excellent tools in scheduling and forecasting any projects. It displays the key milestones in a project and provide the estimated time frame for each task. Gantt chart are also helpful in keeping track of progress. Table 3.1 displays the academic gantt chart for the whole FYP course. All the task are within a time frame of 8 months are listed in the chart below:

Table 3.1 : Academic gantt chart

No	Task	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR
1	**Literature Review**								
	Journal								
	Articles								
	Books								
	Review Paper								
	Completion of Literature Review								
2	**Submission of Extended Proposal**		*	*					
3	**Proposal Defence**								
5	**Preparation of WiDE (Physical Characterization of WiDE)**								
	• Water particle size distribution test								
	• Viscosity at 40°C								
	• Density at 15°C								
6	**Submission of Interim Report**				*				
7	**Experimental Work**								
	• Microexplosion occurrence								
	• Data collection, analysis and compilation								
8	**Oral Presentation**								
9	**Final Report Submission**								*

3.3.3 Key milestones

1. Characterization of WiDE completed: 20th February 2015
2. Microexplosion occurrence analysis completed: 5th April 2015
3. Analysis completed: 7th April 2015
4. Dissertation submission : 26th April 2015

CHAPTER 4
RESULTS AND DISCUSSION

4.1 The WiDE Samples

A total of 24 samples were made previously with water percentage of 9%, 12%, 15% and 18%, Hydrophilic and Lipophilic Balance (HLB) Value of 4.97 and 6.31, and Surfactant percentage of 5%, 10% and 15% as shown in Table 4.1. All of these samples were prepared at a fixed stirring speed of 1500rpm for duration of 15 minutes to reduce variables.

Only 16 samples were observed as stable and undergo characterization testing. The stable WiDE samples are highlighted in blue in Table 4.1. The stability was tested by observing the formation of clear water layer due to phase separation after duration of 2 weeks. The sedimentation of WiDE was also observe and displays and increase in sedimentation as the water percentage increases. A part from studying the physical characterization of WiDE, these test acts as screening process to narrow down the amount of samples to be analyzed. The characterization of WiDE should comply with the French or Italy Water-Diesel emulsion specifications or the CWA 15145 emulsion fuel requirements and test methods

According to the French and Italy Water-Diesel Emulsion Specifications, the water to fuel percentage is between 9-15%. However, a much higher percentage of water was also set as there are literatures recording higher water content up to 40%.

Stated by [10], HLB value ranges from 1 to 20. However, HLB value must be less than 10 if to react to higher oil content. The type of surfactant used is Tween 85 (HLB 11) and Span 80 (HLB 4.3) and the formula for mixed surfactant is as below:

$$\boldsymbol{HLB_{TS} = HLB_T(W_T) + HLB_S(W_S)} \qquad (1)$$

HLB_T = HLB value of Tween 85

HLB_S = HLB value of Span 80

$W_{T\ or\ S}$= percentage of surfactant volume of Tween 85 or Span 80

Assuming the volume of Tween 85 is to be 10% and Span 80 to be 90%, the HLB value would be:

$$HLB_{AB} = 11(0.1) + 4.3(0.9) = 4.97 \qquad (2)$$

By increasing the volume of Tween 85 to 30% and Span 80 is to be 70% in order to set the HLB value as variable, the HLB value would be:

$$HLB_{AB} = 11(0.3) + 4.3(0.7) = 6.31 \qquad (3)$$

Table 4.1 : WiDE sample specifications

Sample	% H_2O	HLB Value	Surfactant % From H_2O	Stability
1	9	4.97	5	
2	12		5	
3	15		5	
4	18		5	
5	9		10	
6	12		10	
7	15		10	Stable
8	18		10	Stable
9	9		15	Stable
10	12		15	Stable
11	15		15	Stable
12	18		15	Stable
13	9	6.31	5	
14	12		5	
15	15		5	Stable
16	18		5	Stable
17	9		10	Stable
18	12		10	Stable
19	15		10	Stable
20	18		10	Stable
21	9		15	Stable
22	12		15	Stable
23	15		15	Stable
24	18		15	Stable

4.2 Characterization of WiDE Samples

4.2.1 Density at 15°C

Table 4.2 : Density of WiDE Samples

Sample	% H_2O	HLB Value	Surfactant % From H_2O	Density@15°C (kg/m³)
7	15	4.97	10	876.32
8	18		10	882.13
9	9		15	865.36
10	12		15	871.84
11	15		15	879.28
12	18		15	881.97
15	15	6.31	5	876.12
16	18		5	880.40
17	9		10	868.48
18	12		10	873.55
19	15		10	878.04
20	18		10	883.95
21	9		15	868.37
22	12		15	875.90
23	15		15	879.27
24	18		15	884.76

Samples selected for next characterization

Density is the mass per unit volume of a substance. As water has a higher density than diesel, it is for certain that the higher the water content, the higher the density. Although the surfactant dosage effects the density as it increases as the surfactant percentage increases, the difference is not as much as how water content influence the density. This can be observed in all the WiDE samples in Table 4.3 and Table 4.4 However, according to CWA 1545 Emulsion Fuel Requirements, the density of fuel at 15°C must be within the range of 828 kg/m³ to 880 kg/m³. All of the samples comply with this regulation are highlighted in blue in Table 4.2, with the exception of samples with 18% of water, which are samples 8, 12, 16, 20, 24. This is expected, as CWA15145 regulation also states that the percentage of water must be within the range of 8% to 15% of water. This narrows down the amount of samples to undergo other testing to 11 samples.

Table 4.3 : Effects of water percentage on density

HLB Value 4.97			
Sample	**% H_2O**	**Stability**	**Density@15°C (kg/m³)**
15% Surfactant From H_2O			
9	**9**	Stable	865.36
10	**12**	Stable	871.84
11	**15**	Stable	879.28
12	**18**	Stable	881.97

HLB Value 6.31			
Sample	**% H_2O**	**Stability**	**Density@15°C (kg/m³)**
10% Surfactant From H2O			
17	**9**	Stable	868.48
18	**12**	Stable	873.55
19	**15**	Stable	878.04
20	**18**	Stable	883.95
15% Surfactant From H_2O			
21	**9**	Stable	868.37
22	**12**	Stable	875.90
23	**15**	Stable	879.27
24	**18**	Stable	884.76

Table 4.4 : Effects of surfactant percentage on density

HLB Value 6.31			
Sample	**Surfactant % From H_2O**	**Stability**	**Density@15°C (kg/m³)**
H_2O 15%			
15	**5**	Stable	876.12
19	**10**	Stable	878.04
23	**15**	Stable	879.27
H_2O 18%			
16	**5**	Stable	880.40
20	**10**	Stable	883.95
24	**15**	Stable	884.76

4.2.2 Viscosity at 40°C

Table 4.5 : Kinematic Viscosity of WiDE samples

SAMPLE	% H_2O	HLB Value	Surfactant % From H_2O	Kinematic Viscosity (mm^2/s)
7	15	4.97	10	10.47830358
9	9		15	5.745115808
10	12		15	7.523222237
11	15		15	11.16266784
15	15	6.31	5	11.41491613
17	9		10	6.955985171
18	12		10	7.384755097
19	15		10	8.055749816
21	9		15	6.349121551
22	12		15	7.65820407
23	15		15	7.314683379

Samples selected for next characterization

Kinematic viscosity is defined as the ratio of dynamic viscosity and density. This characterization express the resistance of a fluid to shearing flow. Referring to the France or Italy Water/Diesel Emulsions Fuel Regulations, the kinematic viscosity of the samples at 40°C should be within the range of 2.5 - 7.0 mm^2/s or 2.0 - 7.0 mm^2/s. According to those range, samples with 9% of water fulfil these specifications, cutting down the number of samples to 3, which are samples 9, 17, and 21, that are highlighted in blue in Table 4.5.

Displayed in Table 4.6 and Table 4.7, both water percentage and surfactant percentage plays a role in influencing the viscosity of WiDE samples. We can see in Table 4.6. , as the water percentage increases, the viscosity increases. This may result from the amount of sedimentation formed which is directly proportional to the water content. It is also observed that the increase in surfactant dosage results in a decrease of kinematic viscosity. This contradicts to the study made by [5] and [12].

Table 4.6 : Effect of water percentage on viscosity

HLB Value 4.97			
Sample	**% H_2O**	**Stability**	**Kinematic Viscosity (mm²/s)**
15% Surfactant From H_2O			
9	**9**	Stable	5.75
10	**12**	Stable	7.52
11	**15**	Stable	11.16

HLB Value 6.31			
Sample	**% H_2O**	**Stability**	**Kinematic Viscosity (mm²/s)**
10% Surfactant From H_2O			
17	9	Stable	6.96
18	12	Stable	7.38
19	15	Stable	8.06
15% Surfactant From H_2O			
21	9	Stable	6.35
22	12	Stable	7.66
23	15	Stable	7.31

Table 4.7 : Effect of surfactant percentage on viscosity

HLB Value 6.31			
Sample	**Surfactant % From H_2O**	**Stability**	**Kinematic Viscosity (mm²/s)**
H_2O 15%			
15	**5**	Stable	11.41
19	**10**	Stable	8.06
23	**15**	Stable	7.31

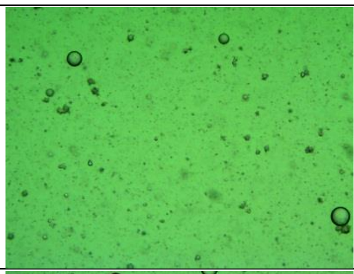
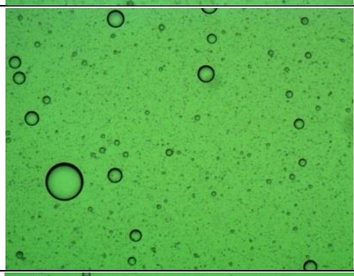
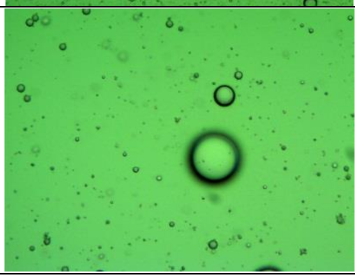
4.2.3 Water droplet size distribution

It can be seen in the images of the samples at 50 times the magnification in Table 4.8 that the water droplet distribution are uneven and with variation in size. Therefore the average particle size is expressed in terms of Sauter Mean Diameter, d_{32} (SMD) equation as below:

$$\boldsymbol{d_{32}} = \frac{\sum \boldsymbol{n_i D_i^3}}{\sum \boldsymbol{n_i D_i^2}} \qquad (4)$$

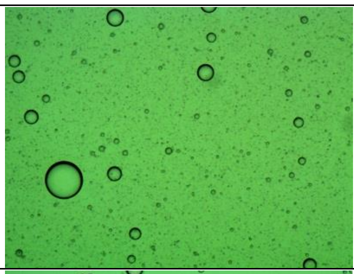
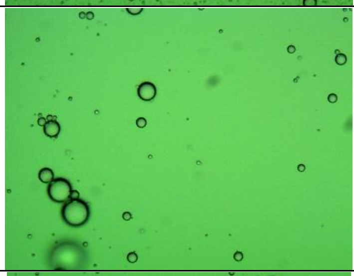
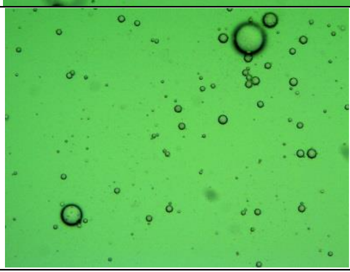
D_i is the diameter of the water droplet measured by the Olympus BX61 Microscope and n_i is the number of droplets with similar diameter value. The SMD calculated are displayed in Table 4.8.

Table 4.8 : SMD of WiDE samples

Sample	% H_2O	HLB Value	Surfactant % From H_2O	SMD	Droplet Distribution Images
9	**9**	**4.97**	**15**	9.79	
17	**9**	**6.31**	**10**	11.52	
21	**9**		**15**	11.03	

It can be observed that the average water droplet diameter for sample 17 is slightly higher compare to sample 21 with much higher surfactant dosage. A higher SMD was also observed in a higher HLB value when samples 9 and 21 with similar surfactant and water percentage but different HLB value was compared. The influence of water to the SMD cannot be observed through this remaining set of data. Therefore, for academic purpose, a set of data with similar surfactant percentage and HLB value was observe in order to observe the correlation between water percentage and SMD. It is to be reminded that sample 18 and 19 violated the fuel regulation for viscosity.

Table 4.9 : SMD of WiDE samples of different water percentage but similar HLB value and surfactant percentage.

Sample	**% H_2O**	**HLB Value**	**Surfactant % From H_2O**	**SMD**	**Droplet Distribution Images**
17	**9**		**10**	11.52	
18	**12**	**6.31**	**10**	11.06	
19	**15**		**10**	6.78	

As the water percentage is increased, the SMD was observed to decrease in Table 4.9. It can be concluded that the increase in water percentage, surfactant percentage and decrease in HLB value would reduce the water droplet size.

From all these characterization experiments, it can be concluded that the increase in water percentage increases the density and viscosity while reduces the water droplet size. The increase of surfactant percentage however, increases the density while reducing the viscosity and water droplet size. The HLB value is observe to cause an increase in density and water droplet size while reducing the viscosity.

4.3 Microexplosion Occurrence of WiDE Samples

Table 4.10 : Microexplosion time and temperature occurrence with respect to physical characteristics

Sample	HLB	Surfactant % From H2O	Stability	Density @15°C (kg/m³)	Kinematic Viscosity @40°C (mm²/s)	SMD	Micro-Explosion Occur	
							Time (s)	Temp (°C)
9	**4.97**	**15**	Stable	865.36	5.75	9.79	0.894	166.97
17	**6.31**	**10**	Stable	868.48	6.93	11.52	0.686	150.66
21		**15**	Stable	868.72	6.16	11.03	0.848	152.74

Sample 9

0.014s 0.230s 0.850s 0.894s

Sample 17

0.014s 0.110s 0.508s 0.686s

Sample 21

0.014s 0.220s 0.818s 0.848s

Figure 4.1 : Microexplosion images for samples 9, 17 and 21

Table 4.11 : Microexplosion time and temperature occurrence with respect to physical characteristics of WiDE samples that violated the fuel regulation

Sample	% H_2O	HLB	Stability	Density @15°C (kg/m³)	Kinematic Viscosity @40°C (mm²/s)	SMD	Micro-Explosion Occur	
							Time (s)	Temp (°C)
17	**9**	**6.31**	Stable	868.48	6.96	11.52	0.686	150.66
18	**12**		Stable	873.55	7.38	11.06	0.804	156.69
19	**15**		Stable	878.04	8.06	6.78	1.212	189.44

Sample 17

0.014s 0.110s 0.508s 0.686s

Sample 18

0.014s 0.184s 0.744s 0.804s

Sample 19

0.014s 0.300s 1.116s 1.212s

Figure 4.2 : Microexplosion images for samples 17, 18 and 19

Table 4.10 displays samples with the similar percentage of water which is, nine percent. Table 4.11 displays samples with similar surfactant percentage of 10 percent. According to the results displayed in Table 4.10, the increase in viscosity and reduction of water droplet size increases the microexplosion time and temperature while there was no trend that can be displayed when microexplosion is related to the density. Figure 4.1 displays the microexplosion occurrence for samples 9, 17 and 21. In Table 4.11 recorded that the increase in both density and viscosity increases the microexplosion time and temperature while the increase in droplet size reduces the microexplosion time and temperature. Density shows inconsistency to the microexplosion phenomena. The microexplosion occurrence for samples 17, 18 and 19 are shown in Figure 4.2.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

An experimental study on the characterization of 16 WiDE samples and it's correlation with the microexplosion theory. All of the 16 samples undergo tests in determining its density at 15°C. Five out of samples violated the water/Diesel Emulsion Fuel Regulation and only 11 samples undergo the viscosity test at 40°C. Eight samples was eliminated due to the fuel regulation violation and the remaining samples was tested to determine its water droplet size and undergo microexplosion. Two samples that violated the fuel regulation was included in the experiment for academic purposes.

The factors that influence the physical properties (density, viscosity and water droplet size) was analyse. Density increase when water percentage, surfactant percentage and HLB value was increase. Viscosity increases as the water percentage increases but decreases when both surfactant percentage and HLB value was increases. A decrease in water droplet size was observed when the water percentage and surfactant dosage was increase and an increase in water droplet size when the HLB value increases.

An attempt in relating the microexplosion phenomena to the physical properties was made and the observation shows a correlation between the water droplet size in influencing the microexplosion time and temperature. The density and viscosity however displays inconsistent results in influencing the time and temperature of the microexplosion occurrence.

A lot of factors should be considered in order to formulate a fuel that could cause short ignition timing, high cetane number, a suitable fuel viscosity and volatility. To ascertain the optimum WiDE would be a challenge as there are many factors to be considered. For example, from the experiment, a successful microexplosion would involve high viscosity and water droplet size. A higher viscosity would affect the injection characteristic however, a lower viscosity would result in smaller water droplets which would result in longer or no microexplosion occurance hence, effecting the mixing process.

The remaining samples should undergo engine testing in order to correlate microexplosion to the exhaust emission of the diesel engine. Although there are a lot of studies that displays the positive effect of WiDE to the emission and engine performance, there are reports of conflicting results, sometimes generating results that are even worse than base fuel. For future research, the WiDE samples should be tested in a diesel engine and a comparison of engine performance and exhaust emission between base fuel and WiDE should be made.

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APPENDICES 1

Italy: Water/Diesel Emulsions

Water-diesel emulsions which comply with the following specification were eligible for a reduced excise duty rate in Italy, effective 200.10.1 through 2005.12.31. The emulsions were allowed for use in medium- and heavy-duty vehicles, and were available only at commercial sites not open to general public.

Table 1
Water-Diesel Fuel Emulsion Specification (April 2001)

Fuel Property	Unit	Limit		Test
		Min	Max	
Appearance		Milky		Visual
Density.@15°C	kg/m^3	835	870	ISO 3675, ISO 12185
Water content	% m/m	12.0	15.0	ISO 8534
Stability, by centrifuge (4200 rcf, 5 min)*				
- phase separation	% v/v	-	9.0	UNICHIM 1548
- free water		Pass		
Viscosity @40°C	mm^2/s	2.0	7.0	ISO 3104
Sulfur	% m/m	-	0.031	ISO 14596, EN 24260
Sulfated ash	% m/m	-	0.01	ISO 3987
Total contaminants	mg/kg	-	24	EN 12662
Copper corrosion, 3h @50°C		Class 1		ISO 2160
Flash Point	°C	55	-	ISO 2592, EN 22719
Total nitrate content†	mg/kg	750	-	ISO 13759
Lubricity (corrected wear scar diameter, wsd 1.4 @60°C)	µm	-	460	ISO 12156-1
CFPP‡	°C	-	W: -10 S: 0	EN 116

* Sample must be taken immediately upon delivery
† Expressed as 2-ethyl-hexyl-nitrate (EHN)
‡ Antifreeze additives are allow ed for w inter grade, provided the total w ater content is unchanged

Furthermore, the following requirements apply:

APPENDICES 2

DieselNet: Fuel Regulations

France: Water/Diesel Emulsions

Water-diesel emulsions which comply with the following specification were eligible for a reduced excise duty rate in France.

Table 1
Water-Diesel Fuel Emulsion Specification

Fuel Property	Unit	Limit		Test
		Min	Max	
Density @15°C	kg/m^3	835	870	NF M 07-096
Water content	% m/m	9.0	15.0	NF M 07-104
Stability, by centrifuge				NF M 07-101
- phase separation (after 5 min)	% v/v	-	9.0	
- (% sediment after 15 min - % sediment after 5 min) / 10	% v/v/min	0.3	-	
Viscosity @40°C	mm^2/s	2.5	7.0	NF M 07-097
Sulfur	mg/kg	-	*	NF M 07-100
Copper corrosion, 3h @50°C		Class 1		NF M 07-098
Flash Point (Cleveland)	°C	70	-	NF M 07-102
Lubricity (corrected wear scar diameter, wsd 1.4 @60°C)	µm	-	460	NF M 07-103
CFPP†	°C	-	W: -15 S: 0	NF M 07-099

* Sulfur = S (100 - y) / 100, where S - sulfur (mg/kg) in EN 590 conforming diesel fuel, y (% m/m) water content of the emulsion
† Antifreeze additives are allowed for winter grade, provided the total water content is unchanged

APPENDICES 3

The test methods listed in Table 1 have been shown to be applicable to emulsion fuels in interlaboratory test programmes. Precision data from these programmes are given in normative Annex A, where these were found to be different from the precision data given in the test methods for petroleum products.

NOTE 2 Revision of EN 116 and EN 12662 by CEN/TC 19 is awaited before further precision data will be obtained.

Table 1 — Requirements and test methods for emulsion fuel

Parameter	Units	Grade A		Grade B		Test method
		Min	Max	Min	Max	
Density	kg/m^3	828	880	825	865	EN ISO 12185
Water content [a]	% (*m/m*)	≥ 8	15	5	< 8	NF M 07-104
Stability at production (fcr 4200, 5 min), sediment	% (*V/V*)	-	9	-	7	M.U. 1548
Free water	% (*V/V*)	absent		absent		-
Viscosity at 40°C	mm^2/sec	2,00	5,50	2,00	5,50	EN ISO 3104
Sulfur content	% (*m/m*)	-	[b]	-	[b]	EN ISO 20884 EN ISO 20846
Total contamination	mg/kg	-	24	-	24	EN 12662 [c]
Copper strip corrosion (3h at 50°C)	index	Class 1		Class 1		EN ISO 2160
Flash point (Cleveland)	°C	70		70		EN ISO 2592
Total nitrate (2-ethyl-hexyl-nitrate) EHN	% (*V/V*)	0,070		0,050		EN ISO 13759
Lubricity, corrected wear scar diameter (wsd 1,4) at 60 °C	µm	-	400	-	400	EN ISO 12156-1
CFPP	°C	according to local EN 590				EN 116 [d]

NOTE Users are made aware of the fact that initial work at low sulfur levels has indicated matrix-effects for both sulfur test methods.

a The water portion of the emulsified fuel shall be demineralized to a maximum conductivity of 3 mS/m according to EN 27888.

b See 4.8 for maximum sulfur (S_{max}) determination.

c Use of an appropriate alternative filter is required.

d The recommended mode is manual, as some automatic instruments need manual sensitivity adjustment for emulsion fuels

4.6 Climatically dependent requirements and test methods

For climatically dependent requirements options are given to allow for seasonal grades to be set nationally. The options are for temperate climates six CFPP (cold filter plugging point) grades and for arctic or severe winter climates five different classes. Climatically dependent requirements for summer and winter grades are according to those specified in national publications of EN 590. When tested by EN 116, emulsion fuel shall be in accordance with the limits specified in EN 590.

4.7 Stability

The emulsified fuel shall be fit for purpose for a minimum period of three months from manufacturing.

4.8 Sulfur

The maximum amount of sulfur (S_{max}) depends on the required limit of sulfur in the diesel component (S_d) according to the current EN 590 (see 4.4) and the maximum water content (wc) as indicated in Table 1. It is derived following the equation:

$$S_{max} = \frac{S_d(100 - wc)}{100} \tag{1}$$

NOTE Revision of the referenced sulfur test methods is awaited before further precision data will be obtained.

5 Storage

For storage of the emulsified fuel, the user should regard the directions given by the supplier and the local regulations in relation to the storage conditions.

6 Precision

All test methods referred to in this Workshop Agreement include a precision statement. In cases of dispute, the procedures for resolving the dispute and interpretation of the results based on test method precision, described in EN ISO 4259 [4], shall be used, having due consideration for the stability of the emulsion fuel (see 4.7)