COMBUSTION ANALYSIS OF WATER-IN-BIODIESEL EMULSIFIED FUELS

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MECHANICAL ENGINEERING

UNIVERSITI TEKNOLOGI PETRONAS

JANUARY 2020

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by

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dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

____
(AP Dr. Zainal Ambri bin Abdul Karim)

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
January 2020

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.

MOHD NUR IZZWAN BIN MARTANG

ABSTRACT

Water-in-Biodiesel emulsified fuels is one of the options to address the problem of decreasing availability of conventional fuels, as well as to reduce the CO2 emissions of internal combustion engines. The present paper describes an experimental campaign carried out on a current production single-cylinder, 4-stroke diesel engine. Running on neat diesel fuel, B10 biodiesel engine and on 12 different of Water-in-Biodiesel emulsified fuels. 12 emulsion are blended using 11% and 13% of water, 7%, 8% and 9% surfactant dosage and with 2 HLB value which is 7 and 8. Performance, emissions, in-cylinder pressure and heat release rate were measured at 5 different loads ranging 0% to 100% with 25% increment at constant 2000 rpm. There are no significant changes on 0% - 50% thus it excluded from the report. It is found that at 75% load 7-9-13 has the highest premixed combustion peak and 8-8-13 has the highest secondary peak. At 100% load, 8-9-13 has the highest premixed combustion peak and 8-8-13 has the highest secondary peak. Heat release rate, the author found that at 75% load, 8-9-11 has the highest and shortest for peak of combustion and ignition delay if being compared to B10. At 100% load, 7-8-11 has the highest and shortest for peak of combustion and ignition delay if being compared to B10. The lowest emission of NOx is being produced 7-7-13. The author found that, in-cylindrical pressure does not affect NOx emission since 7-9-13 has the highest in-cylindrical pressure at 75% while 8-9-13 at 100% but 7-7-13 has the lowest value for NOx emission at 75% and 100% load.

ACKNOWLEDGEMENTS

Final Year Project allows student to handle a research study on their major field. This project is dedicated to those who have shared their ideas and knowledges for the completion of this research. Firstly, I would like to express my gratitude to Universiti Teknologi Petronas (UTP) for giving me this opportunity to enhance my knowledge and research experience.

Next, I would like to express my deepest gratitude to my supervisor, AP Dr. Zainal Ambri bin Abdul Karim who gave me guidance and advices while I encounter problems in this project. Furthermore, I would like to express my gratitude to Ms Hazira, who have been guiding and assisting me to complete the experiment. I would also like to thank Syed for giving me a helping hand throughout the project.

Lastly, I hope this research will provide further information and data relating to the research of Water-in-Biodiesel Emulsified Fuel (WiBE) for references

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

Diesel engine or mostly known as Compression Ignition (CI) engine works by compressing air until the temperature is high enough to atomise the diesel fuel. It is being widely use in mobile and power generations. Consumptions of fossil fuels is on its peak where new reserves are hardly to be found. Sustainable and renewable energy have become the main interest of researches so that the downsides from fossil fuels can be alleviated (Leng et al., 2018). Emission from combustion of diesel fuels are harmful to environment and human's health. There are four pollutant emission from combustion of diesel engine that are harmful; Carbon Monoxide (CO), Hydrocarbons (HC), Particulate Matter (PM) and nitrogen oxide (NOx) (Leng et al., 2018).

Even though there are a lot of research of greener power source but the demands on diesel fuel are rising day by day due to industrial revolutionary which requires high output in torque and power, low maintenance and cost effective. By using diesel engine, all the three requirements can be achieved. There are a lot of research that concentrating on reductions of emission from diesel engines such as the development of biodiesel fuels and emulsion fuels. Rather than using diesel for emulsion, biodiesel is an alternative fuel to reduce CO, HC and PM with an increasing in NOx (Patil, 2017). WiBE fuels is one of the candidates for alternative fuels that might be replacing neat diesel fuels as fuels without altering the engine. Altering fuels are cheaper than engine modification. The use of water-in-diesel emulsion fuels in existing diesel engines has been an active field of inquiry in the past decade (Vellaiyan & Amirthagadeswaran, 2016a). WiBE is the mixture or combination of water, biodiesel and surfactants. There are lots of benefits of using

WiBE fuel, such as to reduce NOx and particulate matter emission, fuel consumptions and alternative for commercial fuels. Biofuel has higher oxygen content which will leads to better combustion, thus will reduce the emission content of the engine.

1.2 PROBLEM STATEMENT

Past research has identified 12 samples of Water-in-Biodiesel emulsified fuels (WiBE) that are stable. 12 WiBE samples with compositions of water (11% and 13%), surfactant content (7%, 8%, and 9%) and HLB value of 7% and 8% and commercial biodiesel (B10) by using ultrasonic homogenizer. Micro-explosion of WiBE field did not always occur during laboratory investigation and might not be the main reason for the simultaneous reduction of NOx. In response to this problem, this project is to determine the combustion phases of these fuels will provide useful knowledge on the phenomenon of effects on engine performance and emission characteristic of WiBE.

1.3 OBJECTIVES

Objectives for this project have been defined and set up to obtain desired outcomes. The objectives are as below:

i. To ascertain the effects of WiBE on combustion analysis for combustion efficiency enhancement and compare the engine performance data with commercial fuels.
ii. To compare the occurrence of micro-explosion during combustion phase to the formation of the emission's product for emission control with commercial fuels.

CHAPTER 2
LITERATURE REVIEW

2.1 THEORY

Water-in-Biodiesel emulsion is an alternative that able to reduce the development of Nitrogen Oxides (NOx) and Particulate Matter (PM) and at the same time it can improve the combustion efficiency(Ithnin et al., 2018). Water-in-Biodiesel emulsion is widely known by having a unique structure with water in continuous phase of dispersion and diesel. Water molecule has lower boiling point than biodiesel. Hence, rapid evaporation and explosion in the surface heating environment and it is commonly known as micro-explosion(Wang et al., 2018). In the case of fuel spray, evaporation and micro-explosion of water is an advantage of emulsion fuel, since both evaporation and micro-explosion of water in the fuel spray can lead to increased droplet breakdown, accelerated full evaporation and fuel-air mixing, which can reduce soot production and improve thermal efficiency (Lin & Chen, 2008). By adding water to the emulsion, it will decreases combustion temperatures inside combustion chamber thus lowers NOx emissions simultaneously make it less harmful (Canfield, 1999),(Huo et al., 2014). Presence of water in the emulsion proves that to assist fuel atomization and mixing which are properties to droplet micro-explosions(Eng & Scarpete, 2013).

2.2 MICRO-EXPLOSION PHENOMENA

Water droplets have lower boiling point than diesel. Thus it will resulting in rapid evaporation and probably explosion on the surface heating element and it is commonly known as micro-explosion (S, 2014). Water-in-Biodiesel emulsified fuels is the mixture of water, biodiesel(B10), and surfactant. Suitable surfactant is necessary to reduce the surface tension between oil and water and to increase the interfacial free energy (Lin & Chen, 2008). Micro-explosion of water is an advantage of emulsified fuels, since both evaporation and micro-explosion of water in the fuel spray can increase droplet breakdown, accelerating fuel evaporation and fuel-mixing, which

2.3 STABILITY OF WATER-IN-BIODIESEL EMULSION FUELS

The stability of the emulsion is depending on emulsification technique, duration, concentration of water, surfactant concentration and stirrer speed. An increment on process duration, stirrer speed and biodiesel to water ratio, increases the emulsion stability (Chen & Tao, 2005). Increasing in process temperature could lessen the emulsion stability (Chen & Tao, 2005). According to Watanabe et al. (Watanabe et al., 2009) that the selection of surfactant and process duration has the importance role to the emulsion stability. Surfactant role in emulsification process is to reduce the surface tension between fuel and water, maintain the emulsion stability and reduce coagulation effect in the water phase (R. S. Kumar et al., 2018). Tween 80 and Span 80 are mainly used in stabilising diesel or biodiesel emulsion (Abdul Karim et al., 2020; Karim & Khan, 2018; Syafiq et al., 2016). Ghannam and Selim (Ghannam & Selim, 2009) recorded that increase in surfactant concentration, stirrer speed and process time is required for higher water concentration in the fuels.

Emulsion stability is recorded based on layer separation in scale test tube under constant conditions(Abdul Karim et al., 2020; Karim & Khan, 2018; Lin & Wang, 2004; Wong, 2019). Water-in-biodiesel are found stable with compositions of water (11% and 13%), surfactant content (7%, 8%, and 9%) and HLB value of 7% and 8% and commercial biodiesel (B10) by using ultrasonic homogenizer (Abdul Karim et al., 2020).

2.4 IMPACT OF EMULSIFIED FUELS ON ENGINE PERFORMANCE

Engine performance plays the important role on fuel modification methods. The improvement in performance will leads to economic feasibility in replacing the existing diesel fuel. Abu-Zaid (Abu-Zaid, 2004) and Alahmer et al. (Alahmer et al., 2010) recorded the increase in torque and engine performance are due to increment of water concentration in the emulsion. They added that this phenomenon occurs because of addition forces acts on top of the piston due to the pressure produced by the steam which resulting in improving engine power and torque. Increase in water concentration will resulting a drop in brake specific fuel consumption due to intensity of micro-explosion, higher premixed combustion, lower combustion temperature and more exhaust gas produced (Abu-Zaid, 2004). Water presence in the mixture will improve brake thermal efficiency (Abu-Zaid, 2004; Alahmer et al., 2010). They indicated that the increase in ignition delay leads to accumulating more amount of fuel, resulting in a higher heat release rate, higher fuel burning in the premixed stage and better brake thermal efficiency.

2.5 IMPACT OF EMULSIFIED FUELS ON EXHAUST EMISSION.

Water presence in diesel engine combustion chamber in the form of emulsified fuels has an influence on the exhaust gas. Heat absorption of water particle during combustion process will lower the local high temperature which will be resulting in reduction of NOx. Suresh and Amirthagadeswaran (Vellaiyan & Amirthagadeswaran, 2016b) stated that the NOx formation is reduced by 35% with the emulsion fuels. Efficient combustion will be indicated by smaller formation of soot and particulate matter. Studies reported that soot and particulate matter are reduced with increase in water concentration (Noge et al., 2015; Ochoterena et al., 2010). Incomplete combustion can be measured by the value of carbon monoxide and unburnt hydrocarbon. If there any reduction of the carbon monoxide and hydrocarbon emission probably due to micro-explosion phenomena which can lead to complete combustion (Attia & Kulchitskiy, 2014).

2.6 FUNDAMENTAL OF COMBUSTION PHASES IN DIESEL ENGINE

Combustion phases of diesel engines are mainly divided into three parts as shown in Figure 2.1.

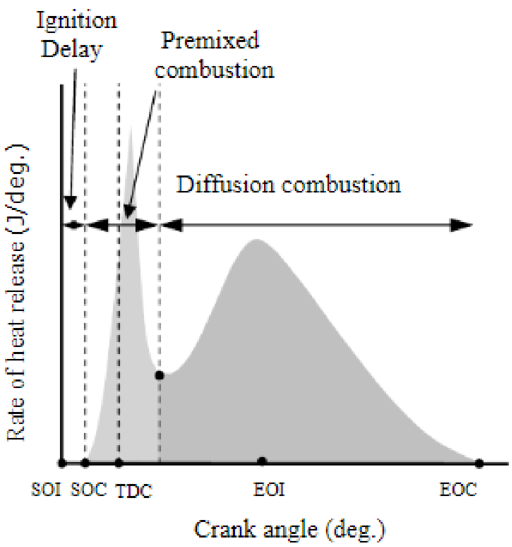

Figure 2. 1: Three phases of combustion in diesel engines (Satyanarayana & Rao, 2009)

First phase of the combustion is called as ignition delay, in which defined as the time interval between the start of injection and the start of combustion. Ignition delay period consists of (a) physical delay, wherein atomisation, vaporization and mixing of air fuel occur and (b) chemical delay attributed to pre-combustion reactions (Shahabuddin et al., 2013). The improved mixing also assists in the reduction in the NOx emissions from the diffusive burning portion of the combustion event as well as reducing the carbon formation. This effect, together with the chemical effect of the water, results in an increased ignition delay. By using piezoelectric pressure sensor and flame images recorded using a high-speed digital camera it is found that the ignition delay of the emulsified fuels is always higher than the standard diesel fuels (Ghojel & Tran, 2010). The next phases of combustion are called as rapid combustion or premixed combustion which can be considered as start of combustion. In this phase, the air-fuel mixture undergoes rapid combustion, therefore the pressure rise is rapid and releases maximum heat flux (Heywood, 1988). Peak pressure for water–diesel emulsion was found higher than that of diesel which was due to more fuel burned in premixed combustion phase during longer ignition delay period (N. Kumar et al., 2019). Period of controlled combustion is the third phase of the combustion where the fuel droplets injected during second stage burns faster with reduced ignition delay due to high temperature and pressure (Satyanarayana & Rao, 2009).

CHAPTER 3
METHODOLOGY

In this research, an experiment is being held to ascertain micro-explosion of 12 WiBE samples by doing combustion analysis. Insight into combustion phases will be done by using Yanmar L100V diesel engine test bed to gain useful knowledge on the phenomenon. There are two parameters that are being considered which are load and engine speed (RPM). Engine will run constantly at 2000 rpm while load start from 0% to 100% with 25% of increment.

To prepare the WIBE, Heilscher's UP100H Ultrasonic Homogenizer are being used to blend the emulsion. The configurations of the WiBE will affects the results in this experiment. The configuration includes HLB values, water percentage and surfactant content. All the substances will affect fuel chemical properties.

Finally, Kane Autoplus 5-2 will be used to measure and record the emission of the engine.

3.2 PROJECT FLOW CHART

In Figure 3.1 is a flow chart for the experimental work in this study. It is representing the process overview that takes place in this study

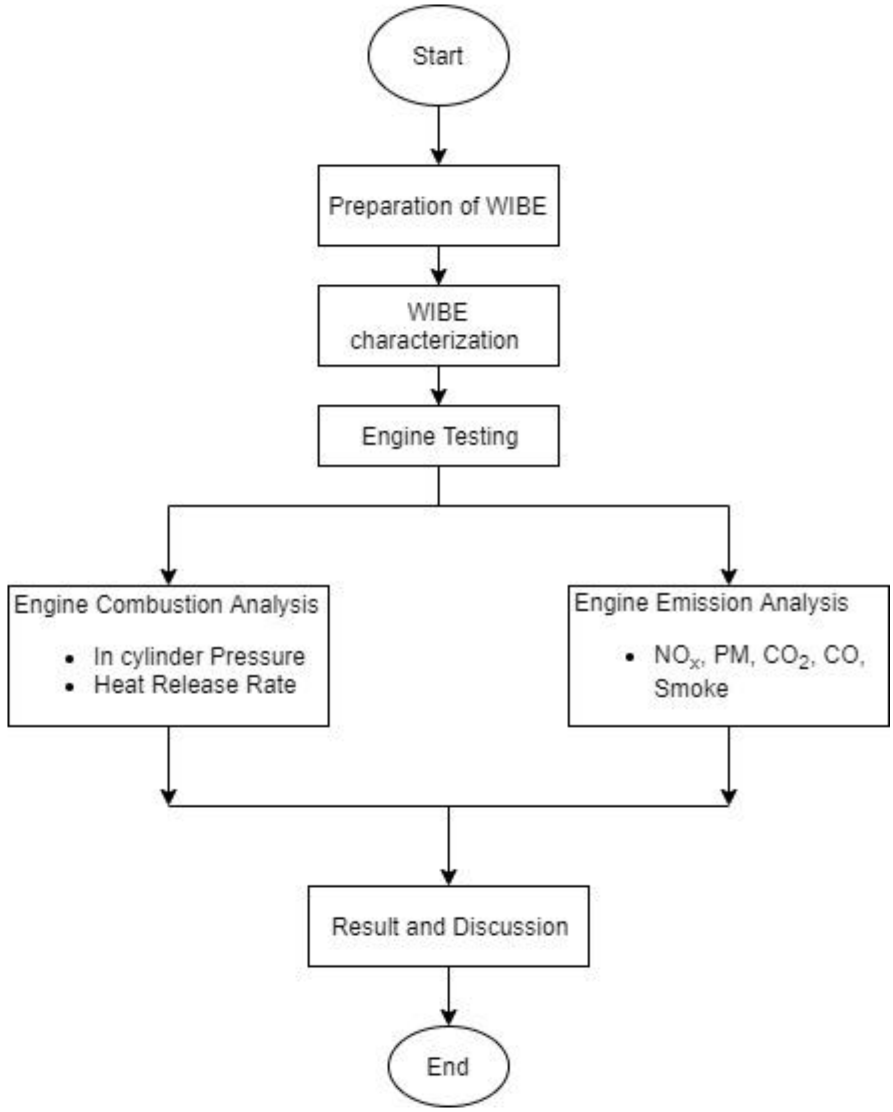

FIGURE 3.1: Final Year Project Experimental Flow Chart

3.3 PREPARATION OF WATER-IN-BIODIESEL EMULSION (WIBE)

To meet both objective of this research, WiBE needs to be prepared in the first hand. Figure 3.2 and Figure 3.3 shows the procedure of WiBE preparations. 12 WiBE samples are being produced by using ultrasonic homogenizer. Based on past research, 12 stable samples of WiBE are recognised as shown in Table 3.1. Composition of WiBE, equipment used, and list of variables are shown as below:

i. Composition of emulsions:
   a. Biodiesel B10
   b. Surfactant:
      - Tween 85 (Water)
      - Span 80 (Lipophilic)
   c. Distilled Water
ii. Equipment:
   a. Hielscher's UP100H Ultrasonic Processor (Ultrasonic Homogenizer)
iii. Variables:
   a. Hydrophilic-Lipophilic Balance (HLB) values: 7,8
   b. Surfactant dosage (%): 7, 8 and 9
   c. Distilled water (%): 11 and 13

TABLE 3.1: WiBE Composition

Sample ID	HLB value	Surf Dosage	Water Concentration (%)	Water Concentration (ml)	Tween 85 (ml)	Span 80 (ml)	Biodiesel B10 (ml)
7-7-11	7	7	11	110.00	3.100	4.600	882.30
7-7-13	7	7	13	130.00	3.670	5.430	860.90
7-8-11	7	8	11	110.00	3.550	5.250	881.20
7-8-13	7	8	13	130.00	4.190	6.210	859.60
7-9-11	7	9	11	110.00	3.990	5.910	880.10
7-9-13	7	9	13	130.00	4.720	6.980	858.30
8-7-11	8	7	11	110.00	4.250	3.450	882.30
8-7-13	8	7	13	130.00	5.030	4.070	860.90
8-8-11	8	8	11	110.00	4.860	3.940	881.20
8-8-13	8	8	13	130.00	5.740	4.660	859.60
8-9-11	8	9	11	110.00	5.470	4.430	880.10
8-9-13	8	9	13	130.00	6.460	5.240	858.30

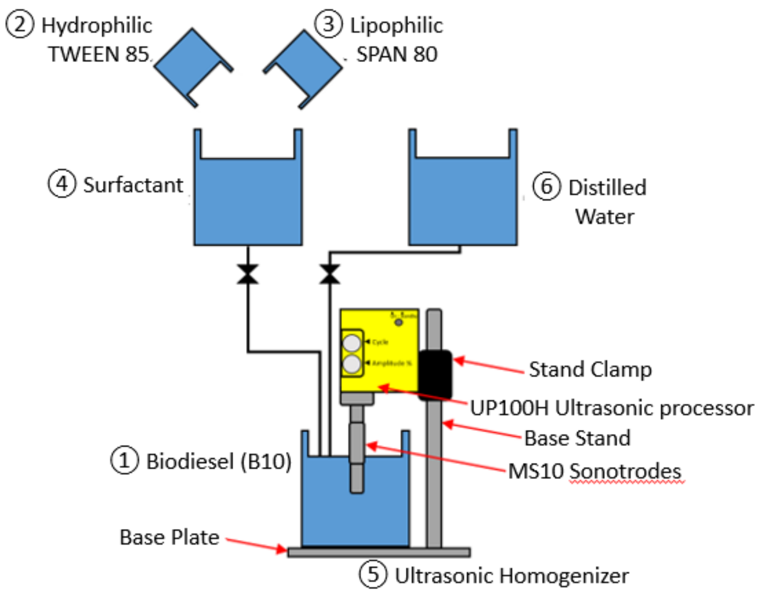

FIGURE 3.2: WiBE production's Schematic Diagram

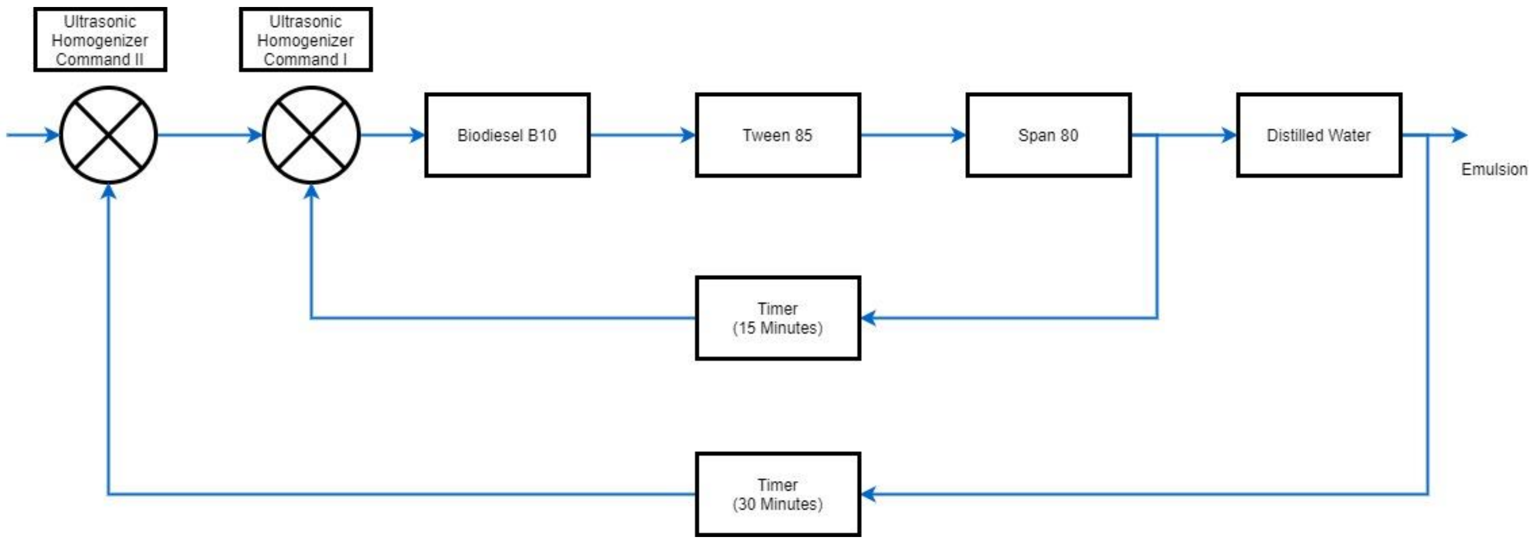

FIGURE 3.3: Process of WiBE Production

TABLE 3.2:Command for WiBE Production

Command I:	i. Biodiesel B10, Tween 85 and Span 85 are being put into the same beaker ii. Beaker going through direct sonication by Ultrasonic Homogenizer for 15 minutes. Optimum emulsification parameters are set to be 0.7 cycle and 50% amplitude.
Command II:	i. After 15 minutes direct sonication, distilled water is added into the beaker ii. Then, the emulsion will go through second direct sonication for another 30 minutes with the same optimum parameters.
Emulsion Command:	i. Command I and Command II are repeated to prepare 12 samples of WIBE with varies HLB value, surfactant dosage and distilled water content.

3.4 PERFORMANCE TEST AND EXHAUST EMISSION MEASUREMENT

Performance test are being performed on single cylinder 4-stroke Yanmar L100V diesel engine test bed. Schematic diagram of the experiment set up are being showed in Figure 3.4. Table 3.3 shows engine's specification. Table 3.4 shows emission analyser and smoke meter specifications. Diesel engine running constantly at speed 2000 rpm with ranging loads from 0% to 100% with 25% increments. The measured engine performance parameters are in-cylinder pressure(bar) and crank angle (°).

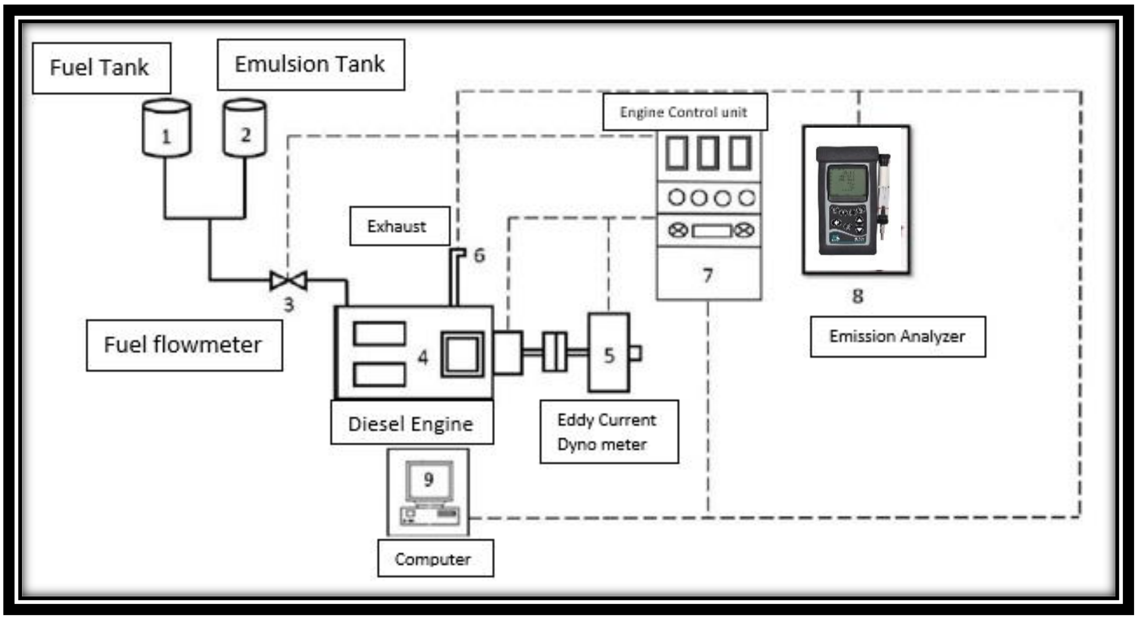

FIGURE 3.4: Schematic Diagram of Experiment Set up

TABLE 3.3: Yanmar L100V Diesel Engine Specification

Engine Model	Yanmar L100V
Engine Type	Air Cooled, 4 Cycle, Vertical Cylinder
Fuel	Diesel
Number of Cylinders	1
Bore x Stroke	86mm x 75mm
Combustion type	Direct Injection
Total Displacement	435 cc
Valves per Cylinder	2
Rated Speed	3600 rpm

TABLE 3.4: Kane Autoplus 5-2 Emission Analyser

Model: Kane Autoplus 5-2	Measures CO (0-10%), CO2 (0-16%), HC (0-5000ppm), O2 (0-21%), & Lambda (0.8-1.2) optionally NOx (0-5000ppm)
	Handheld & portable
	Can be used on Petrol/Gasoline, LPG, CNG & Diesel vehicles
	AC & 12v Chargers
	Up to 4 hours internal battery life
	Ideal for pre-compliance testing, vehicle diagnostics & servicing to manufacturers specification.

Exhaust emission analyser is a device to measure emitted substance to the in a form of gases or particulate matter. It is important to measure exhaust emission as it needs to comply with emission standards and regulations. In exhaust emission measurement of WiBE, diesel engine running constantly at speed 2000 rpm with ranging loads from 0% to 100% with 25% increments. Emission gases that are measured are nitrogen oxide (NOx), carbon monoxide (CO), and carbon dioxide (CO_2).

FIGURE 3.5: Emission Analyzer

3.5 EXPERIMENTAL PROCEDURE

Experiment set-up that are shown in Figure 3.6 are being used for engine performance test and exhaust emission measurement. Both information's will be taken at constant speed 2000 rpm with 5 varied loads ranging 0% to 100% with 25% load increment.

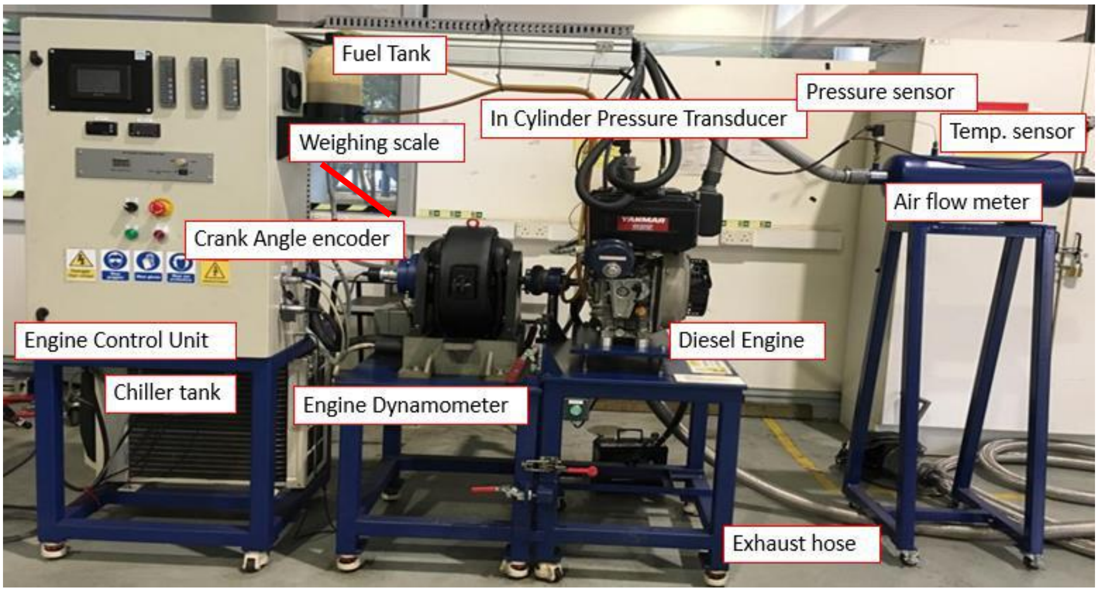

FIGURE 3.6: Experiment Set-Up

Firstly, diesel will be used to warm up the diesel engine. After warming up process, the excesses of diesel fuel will be disposed into the waste tank. Fuel tank will be filled up with WiBE fuels by using funnel. Engine speed (RPM) and loads will be controlled by using computer. In this experiment, all samples will be tested at constant speed of 2000 rpm and 5 varied loads. When the engine speed dropped, throttle actuator position will be adjusted so the engine will run constantly at 2000 rpm. After the speed is being sustained at 2000 rpm before taking the data, the timer in the computer well be turned on and engine will be left running for 60 seconds to acquire the engine in-cylindrical pressure. In Table 3.5 is shown in-cylindrical pressure data for each crank angle for WiBE 8-8-11 at 0% load. At each load, the emission analyser is being set-up to gain emission data. Engine in-cylindrical pressure, heat release rate and exhaust emission data are being taken as a baseline for comparison.

TABLE 3.5: In-Cylindrical Pressure for WiBE 8-8-11

CA (deg)	P1	P2	Pave
106	0	0.04972	0.02486
107	0	0.23667	0.11833
108	0	0.50689	0.25345
109	0	0.7018	0.3509
111	0	0.77957	0.38979
112	0.07644	0.76381	0.42012

By obtaining in-cylindrical pressure at each crank angle data, heat release rate can be calculated based on formula that shown in Figure 3.8 which is obtained from the first law of thermodynamics during a cycle.

$$\frac{dQ_n}{d\theta} = \left(\frac{\gamma}{\gamma - 1} \times P \times \frac{dV}{d\theta}\right) + \left(\frac{1}{\gamma - 1} \times V \times \frac{dP}{d\theta}\right)$$

γ=Specific heat ratio

P=In−Cylinder pressure

V=Cylinder Volume

θ=Crank Angle

FIGURE 3.7: Heat Release Rate Formula

3.6 GANTT CHART

TABLE 3. 6: Gantt Chart for Final Year Project

Key Milestone		FYP1														FYP 2													
No	Task	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Literature Review on Diesel Engine, Combustion Phases and Emission	■	■	■	■	■	■	■	■	■	■	■	■	■	■														
2	Collect Results From Previous Study		■	■	■	■	■	■																					
3	Training on use of engine					■	■	■	■	■																			
4	Training on emission analyzer					■	■	■	■	■																			
5	Research proposal defense								■	■	■																		
6	Prepare WiBE											■	■	■															
7	Experiment Setup											■	■	■	■	■	■	■	■										
8	Interim Report														■														
9	Run Experiment																		■	■	■	■	■						
10	Analyse of Data																			■	■	■	■	■	■	■			
11	Validation of data with combustion analysis																				■	■	■	■	■	■	■	■	
12	Final Report																												■

3.7 KEY MILESTONES

TABLE 3. 7: Key milestone for final year project

No	Milestones	Date	Work Progress
1	Optimised Samples are identified	23rd Sept 2019	20%
2	Production of fuels for optimised samples are completed	11th Nov 2019	40%
3	Engine Performance Test and exhaust emissions measurement are completed	6th Dec 2019	60%
4	Analysis on result	16th Mar 2020	80%
5	Report and submission	30th Mar 2020	100%

CHAPTER 4
RESULTS AND DISCUSSIONS

For this experiment, analysis was being focused on 75% and 100% loads because there are no significant changes on in-cylindrical and heat release rate trends at 0%, 25% and 50% loads.

4.1 Combustion Analysis for Water-In-Biodiesel Emulsified Fuels.

4.1.1 In-Cylindrical Pressure (ICP)

Figure 4.1, Figure 4.2 shows that at 75% load, first peak decreases as water concentration increases. But as HLB value increases we can see that there are slightly increment for first peak. It also shows that secondary peak is increases for emulsion 7-8-11, 7-8-13, 8-8-11 and 8-8-13 as water content and HLB value increases. But at 100% load, those sample shows different behaviour as shown in Figure 4.3 and Figure 4.4. 11% water concentration tends to have higher first peak value than 13% water concentration and the secondary peak decreases as HLB increases for emulsion 7-8-11, 7-8-13, 8-8-11, 8-8-13, 7-7-11, 7-7-13, 8-7-11 and 8-7-13. An inconsistency behaviour occurs at 75% and 100% load for 7-9-11, 7-9-13, 8-9-11, 8-9-13 as shown in Figure 4.5 and Figure 4.6. We can observe that first peak and secondary peak increases as water concentration and HLB value increases. If we compare all the trend in Figure 4.1 – Figure 4.6, we can observe that 9% surfactant always exhibit highest first and secondary peak at 75% and 100% loads. Secondary peak increment probably indicating secondary combustion that occurs due to micro-explosion. We observe that, all emulsion has higher first and secondary peak than B10 fuel.

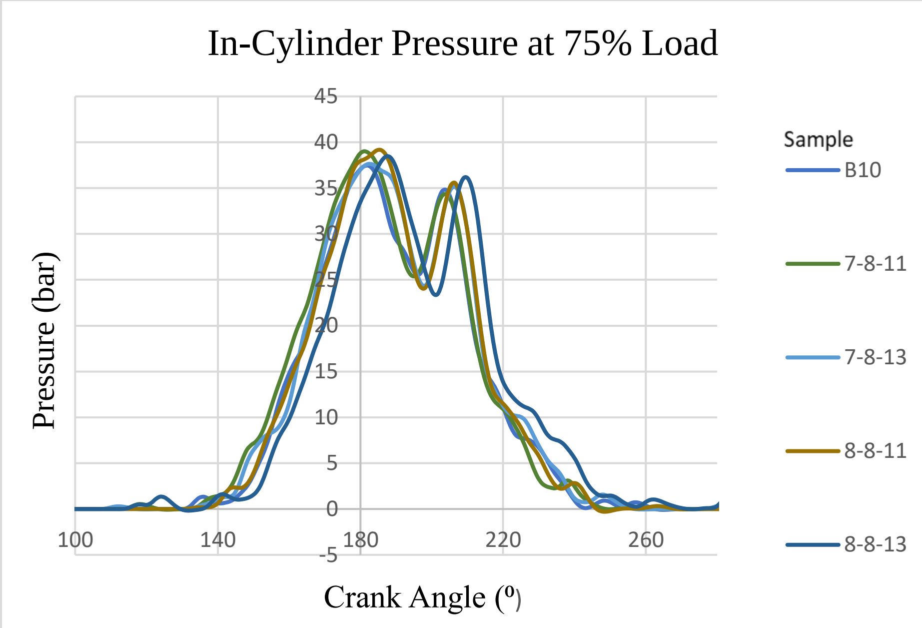

FIGURE 4. 1: In-Cylinder Pressure for 8% Surfactant Concentration at 75% Load

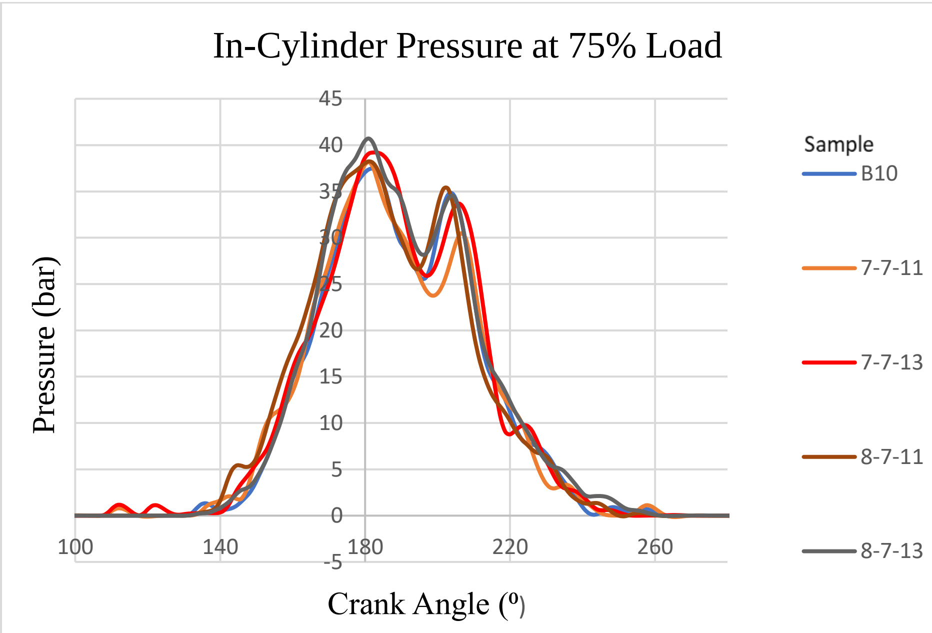

FIGURE 4. 2: In-Cylinder Pressure for 7% Surfactant Concentration at 75% Load

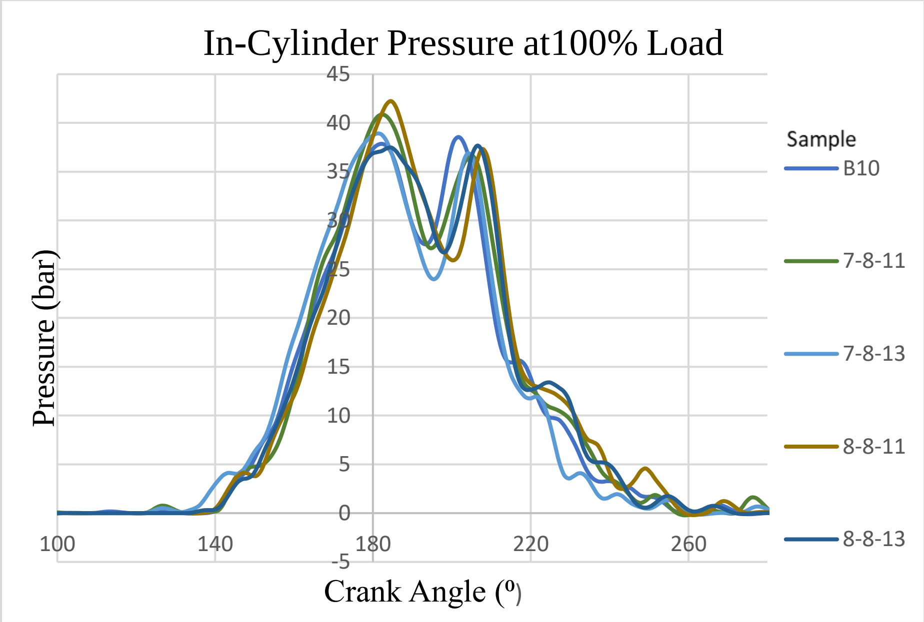

FIGURE 4. 3: In-Cylinder Pressure for 8% Surfactant Concentration at 100% Load

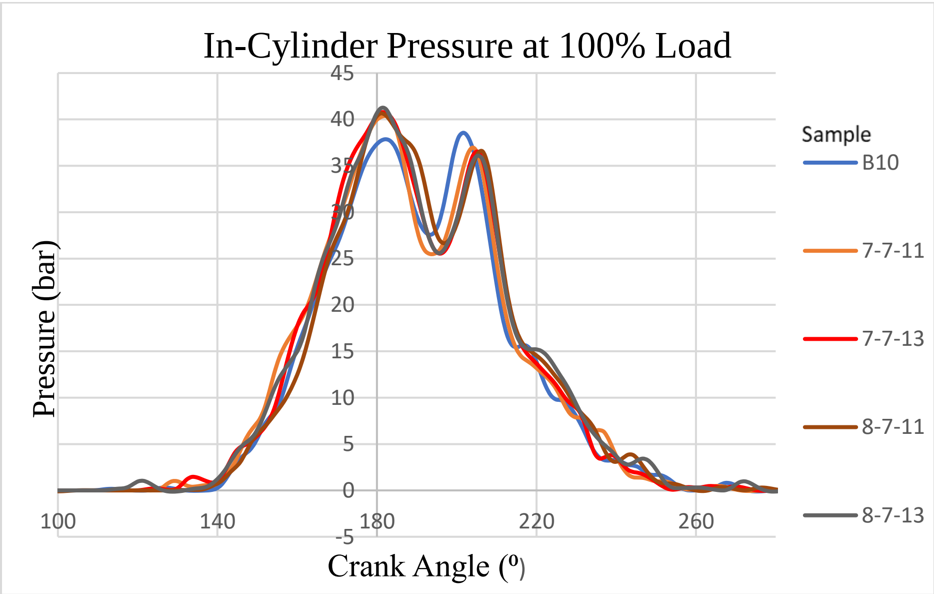

FIGURE 4. 4: In-Cylinder Pressure for 7% Surfactant Concentration at 100% Load

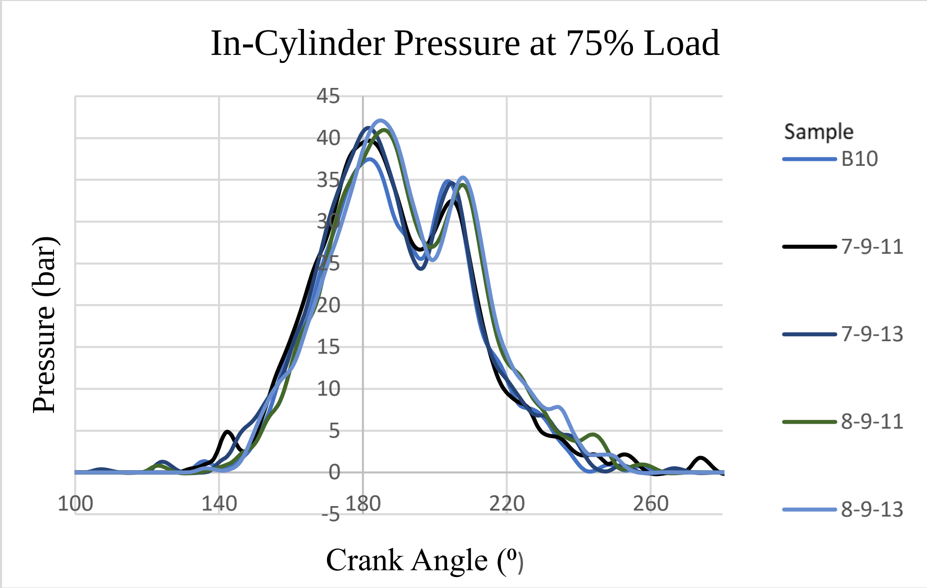

FIGURE 4. 5: In-Cylinder Pressure for 9% Surfactant Concentration at 75% Load

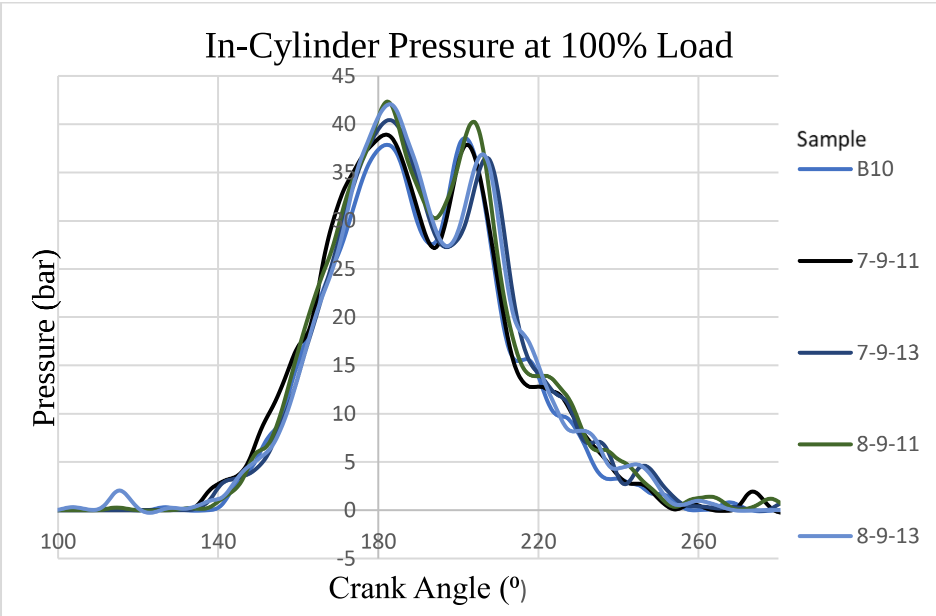

FIGURE 4. 6: In-Cylinder Pressure for 9% Surfactant Concentration at 100% Load

4.1.2 Heat Release Rate

Figure 4.7, Figure 4.8 and Figure 4.9 shows Heat Release rate for 8%, 7% and 9% surfactant concentration at 75% load respectively. In Figure 4.7 and Figure 4.8 we can observe that peak of combustion will increase as HLB and water concentration increases. The ignition delay will decrease in increment of HLB value in trend on Figure 4.7, Figure 4.8 and Figure 4.9. We also observe that emulsion with a constant value of surfactant concentration (7%, 8% and 9%) at 11% of water concentration will having longer ignition delay than 13% concentration of water at 75% load. In Figure 4.9 we learn that in increment of water concentration will improve peak of combustion for 7-9-11 and 7-9-13 while 8-9-11 and 8-9-13 acts oppositely. In addition, we observe that in increment of HLB value will improve peak of combustion and reduce ignition delay for emulsion 7-9-11 and 8-9-11 while emulsion 7-9-13 and 8-9-13 acts otherwise. In terms of increment surfactant concentration, we can observe that peak of combustion increases, and ignition delay reduced.

Figure 4.10, Figure 4.11 and Figure 4.12 shows heat release rate for 8%,7% and 9% surfactant concentration at 100% load respectively. Trend in Figure 4.7 shows that emulsion 7-8-11 has shortest ignition delay and highest peak of combustion. increment in water concentration will reduce peak of combustion for 7-8-11 and 7-8-13 while for 8-8-11 and 8-8-13 it occurs oppositely. Trend in Figure 4.11 shows that peak of combustion increases, and ignition delay decreases as water concentration and HLB value increases. Trend in Figure 4.12 shows a complex behaviour, for emulsion 7-9-11 and 7-9-13 as water increases it will reduce ignition delay while increasing peak of combustion, but it occurs oppositely for emulsion 8-9-11 and 8-9-13. We also can observe that as HLB value increases for emulsion 7-9-11 and 8-9-11 it will reduce the ignition delay and increase peak of combustion, while emulsion 7-9-13 and 8-9-13 behave oppositely. By comparing all the trends in Figure 4.10 – Figure 4.12 we observe that emulsion with 8% concentration will always exhibit highest peak of combustion and shortest ignition delay. Reduction of ignition delay indicate better atomization of the emulsion while increment of peak of combustion indicates higher intensity of micro-explosion occurrence.

We also observe that all emulsion has higher peak of combustion than B10 but only emulsion 7-8-11, 7-9-11, 7-9-13, 8-7-11, 8-7-13, 8-8-11, 8-8-13, 8-9-11 and 8-9-13 will has shorter ignition delay than B10 at 75% and 100% load.

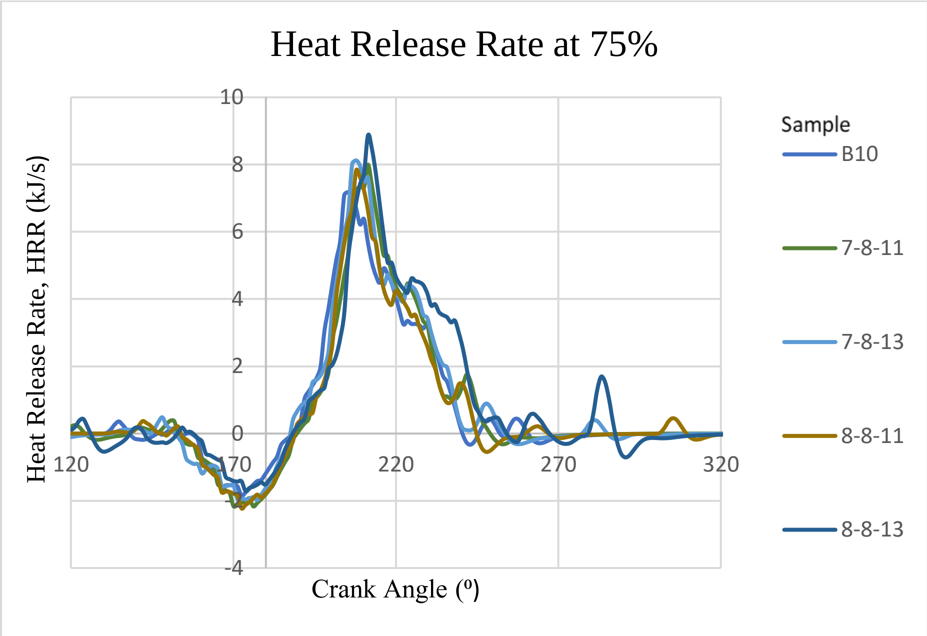

FIGURE 4. 7: Heat Release Rate for 8% Surfactant Concentration at 75% Load

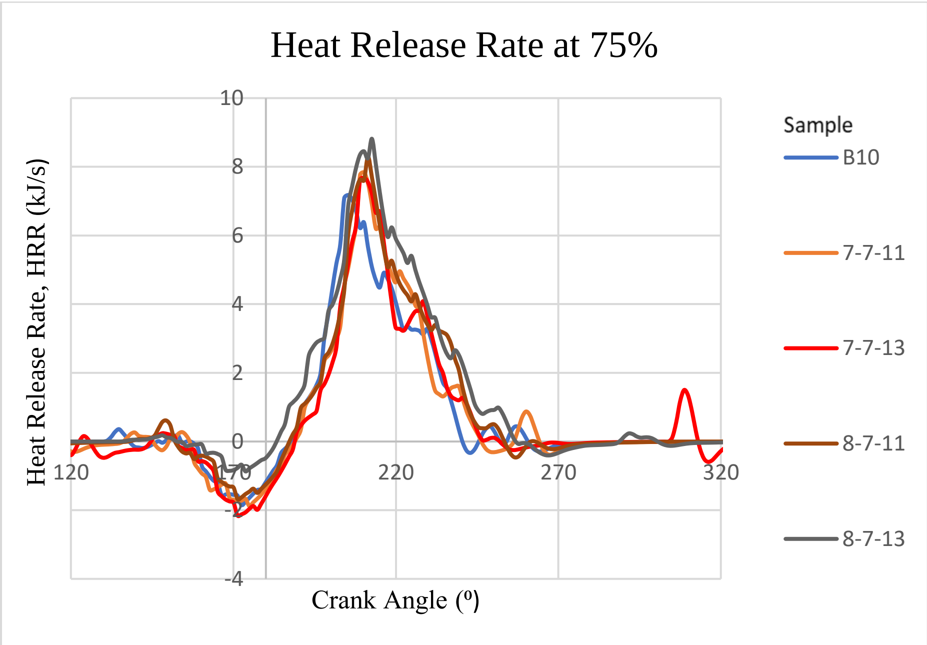

FIGURE 4. 8: Heat Release Rate for 7% Surfactant Concentration at 75% Load

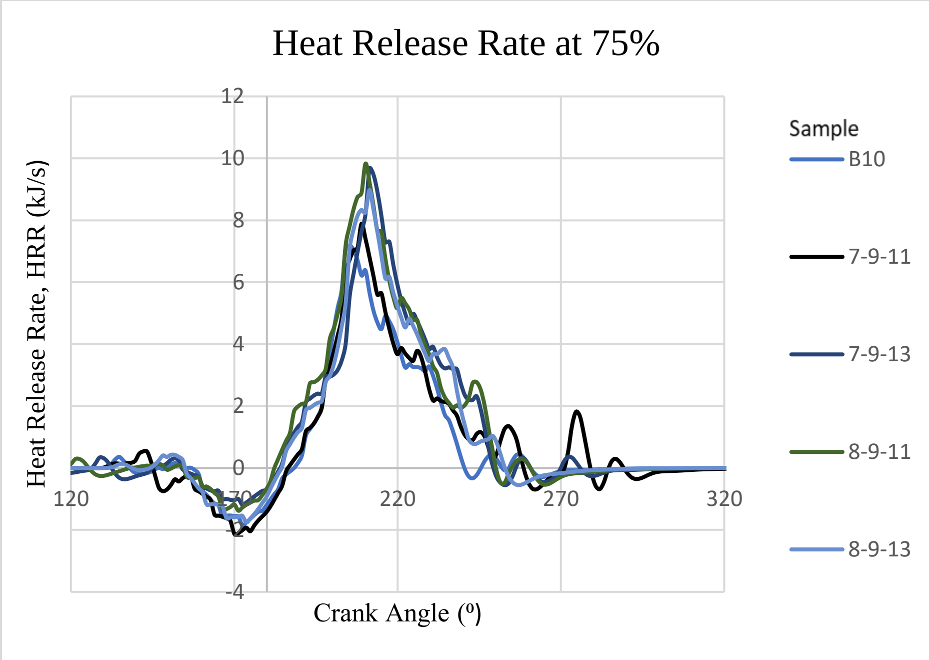

FIGURE 4. 9: Heat Release Rate for 9% Surfactant Concentration at 75% Load

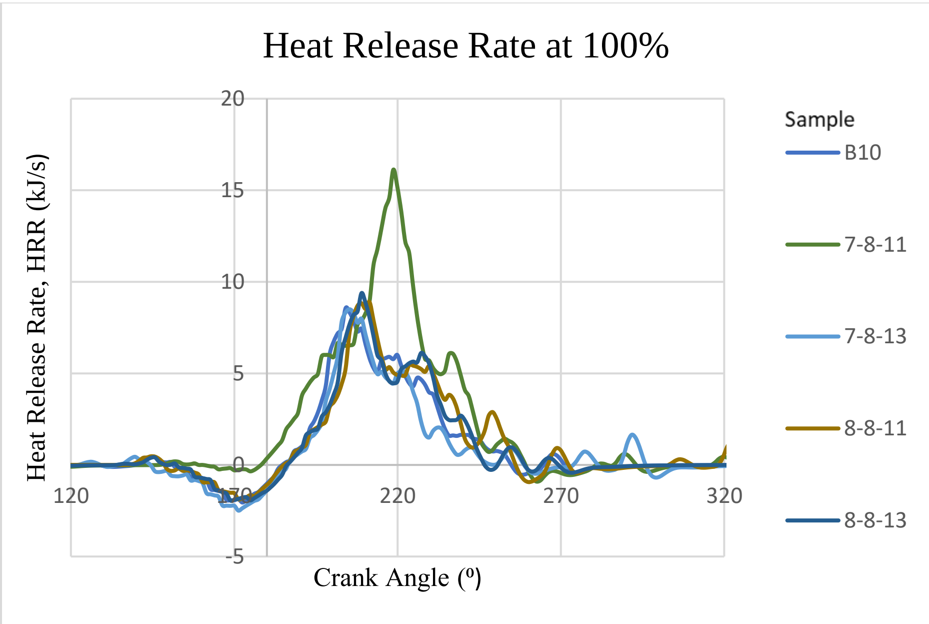

FIGURE 4. 10: Heat Release Rate for 8% Surfactant Concentration at 100% Load

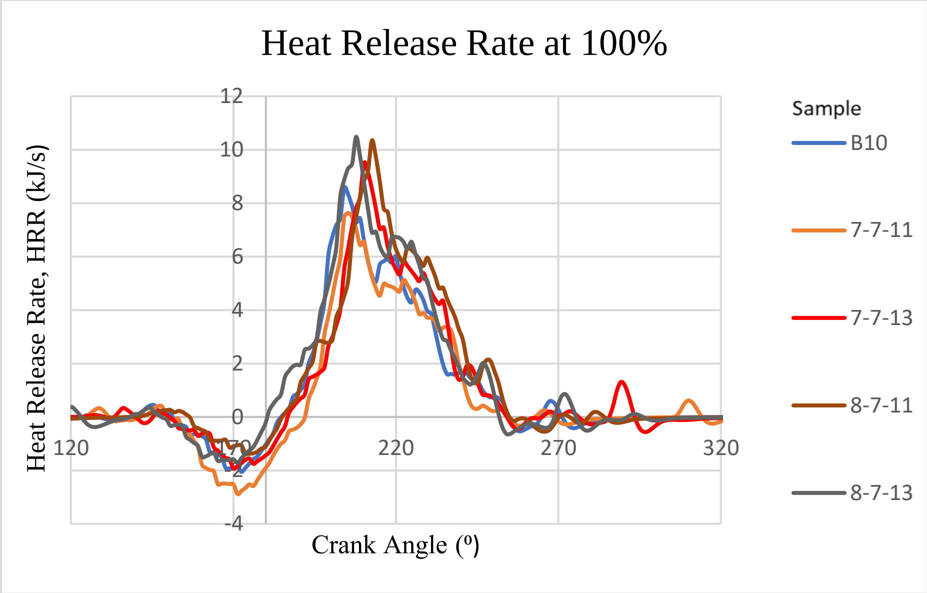

FIGURE 4. 11: Heat Release Rate for 7% Surfactant Concentration at 100% Load

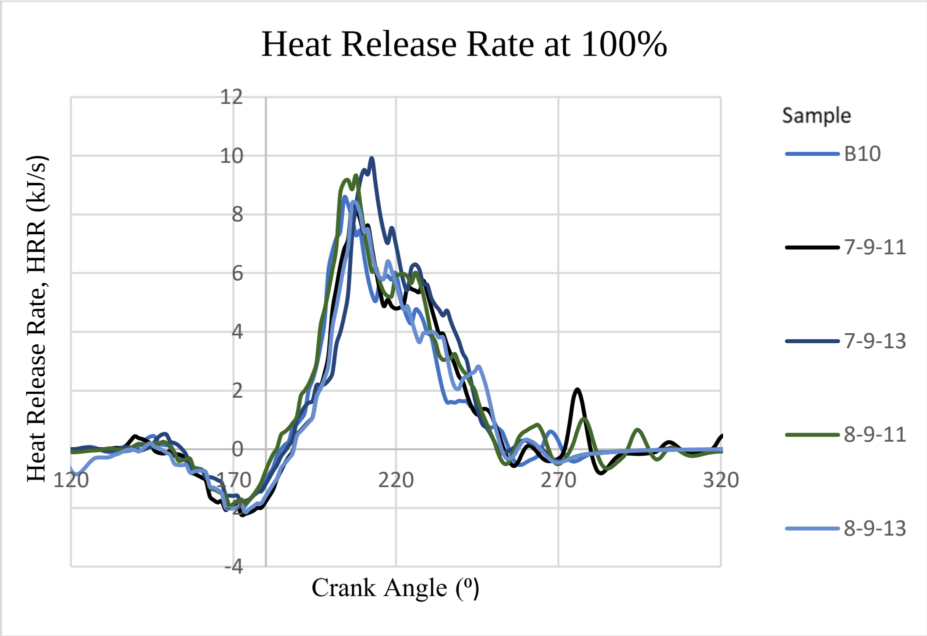

FIGURE 4. 12: Heat Release Rate for 9% Surfactant Concentration at 100% Load

4.2 Emission Analysis for Water-in-Biodiesel Emulsified Fuels.

4.2.1 Nitrogen Oxide (NO_x)

Figure 4.13, Figure 4.14, Figure 4.15 shows NO_x emission at each load for 8%, 7% and 9% surfactant concentration respectively. In Figure 4.13 7-8-11 and 7-8-13, shows that in increment in water concentration it will reduce NOx emission at 75% load while increasing NOx emission at 100% load. 8-8-11 and 8-8-13 shows that in increment of water concentration it will increase NOx emission at 75% and 100% load. Increment of HLB value for 7-8-11 and 8-8-11 will decrease NOx emission at 75% and 100% load while 7-8-13 and 8-8-13 will decrease NOx emission at 75% load but there were increment of NOx emission at 100% for 7-8-13 and 8-8-13.

In Figure 4.14, NOx emission at 75% for surfactant concentration 7% and HLB value 7 and 8 shows that as water concentration increase it will reduce NOx emission. As for HLB value increment we can observe that at 75% load, 7-7-11 and 8-7-11 will lessen NOx emission while 7-7-13 and 8-7-13 it will increase NOx emission. At 100% load, we can see that as water concentration increases NOx emission will be reduced while HLB increment will increase NOx emission.

In Figure 4.15, as water concentration increase for 7-9-11 and 7-9-13 it will reduce NOx emission while 8-9-11 and 8-9-13 it will increase NOx emission at 75% and 100% load. As HLB value increasing we can observe that emulsion 7-9-11 and 8-9-11 will reduce NOx emission while emulsion 7-9-13 and 8-9-13 will increase NOx emission at 75% and 100% load.

In Figure 4.16 we can observe that as surfactant concentration increasing for emulsion 7-7-11, 7-8-11 and 7-9-11 NOx emission will increase at 75% and 100% load. While emulsion 7-7-13, 7-8-13 and 7-9-13 as surfactant increasing, 7% surfactant concentration has lowest NOx emission while 8% surfactant concentration will have the highest at 75% and 100% load.

In Figure 4.17 we observe that as surfactant concentration increasing for emulsion 8-7-11, 8-8-11, 8-9-11 will reduce NOx emission at 75% and 100% load. While emulsion 8-7-13, 8-8-13, 8-9-13 as surfactant concentration increases at 7% surfactant concentration will has the highest NOx emission and 9% surfactant concentration has the lowest at 75% load. While at 100% load we can observes that 8% surfactant concentration will have the highest NOx emission and 9% surfactant concentration will have the lowest value.

We also can observe that all emulsion has lower NOx emission at 75% and 100% than B10. NOx formation due to high temperature in combustion that will resulting excesses oxygen that will form nitrogen oxides. The lowest emulsion that has NOx emission is 7-7-13 at 75% and 100% load.

We can observe that in-cylindrical pressure doesn't play role as in reducing NOx emission. The only emulsion that shows as in cylindrical pressure increases, NOx reduced are 8-7-11, 8-8-11 and 8-9-11.

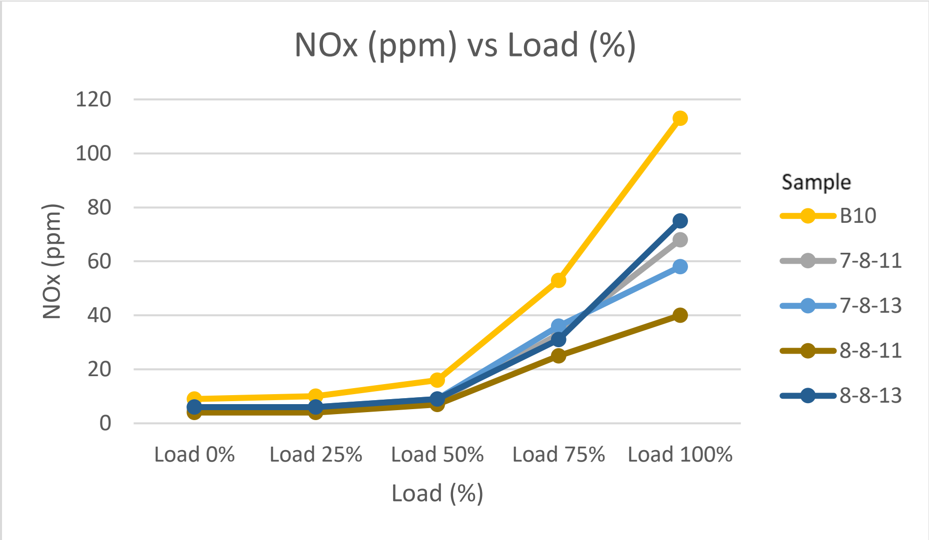

FIGURE 4. 13: NOx Emission for 8% Surfactant Concentration

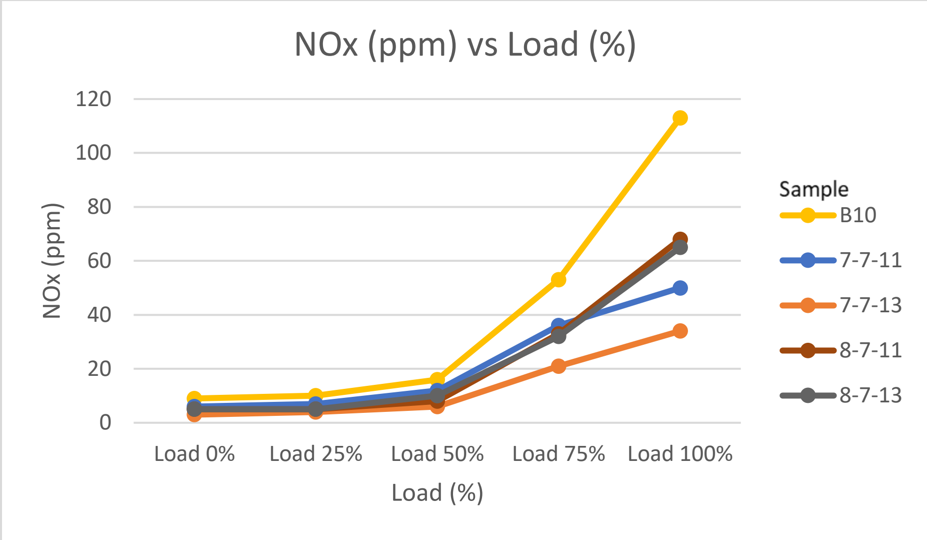

FIGURE 4. 14: NOx Emission for 7% Surfactant Concentration

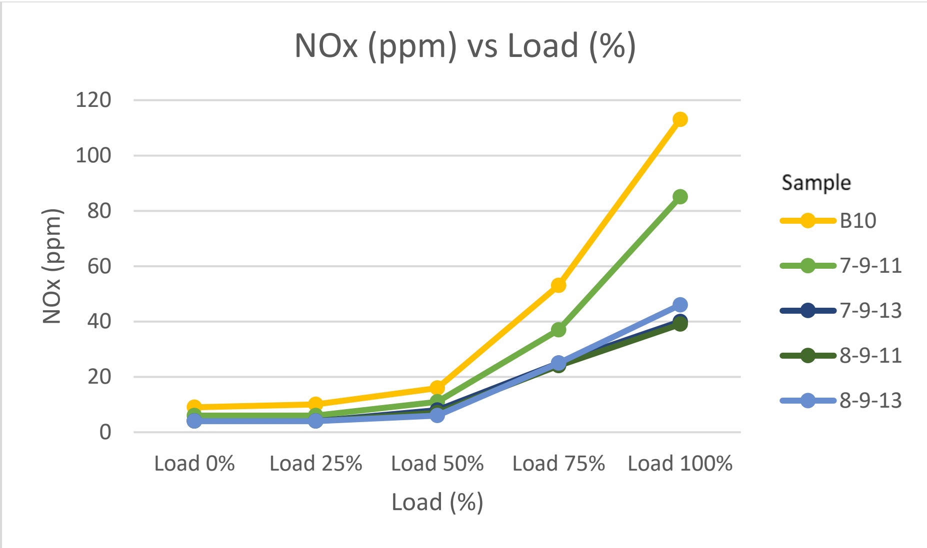

FIGURE 4. 15: NOx Emission for 9% Surfactant Concentration

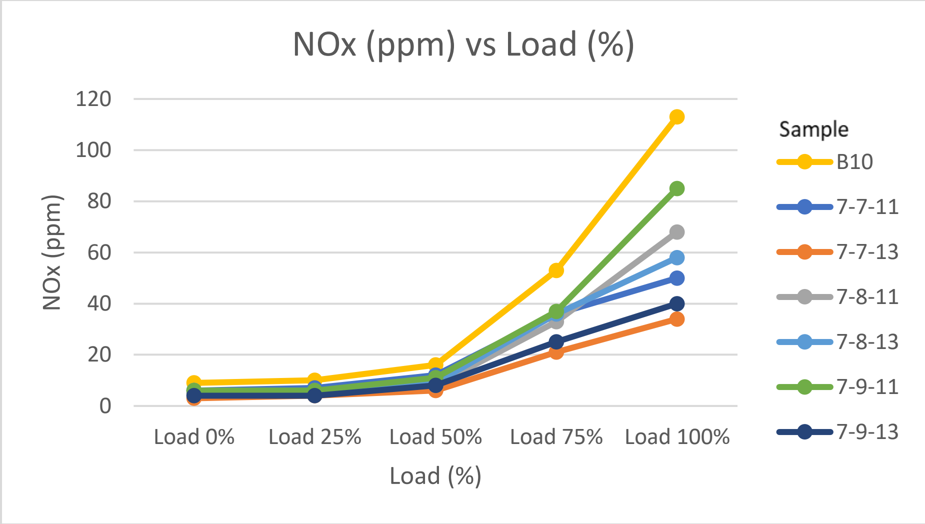

FIGURE 4. 16: NOx emission for increasing surfactant value at HLB value 7

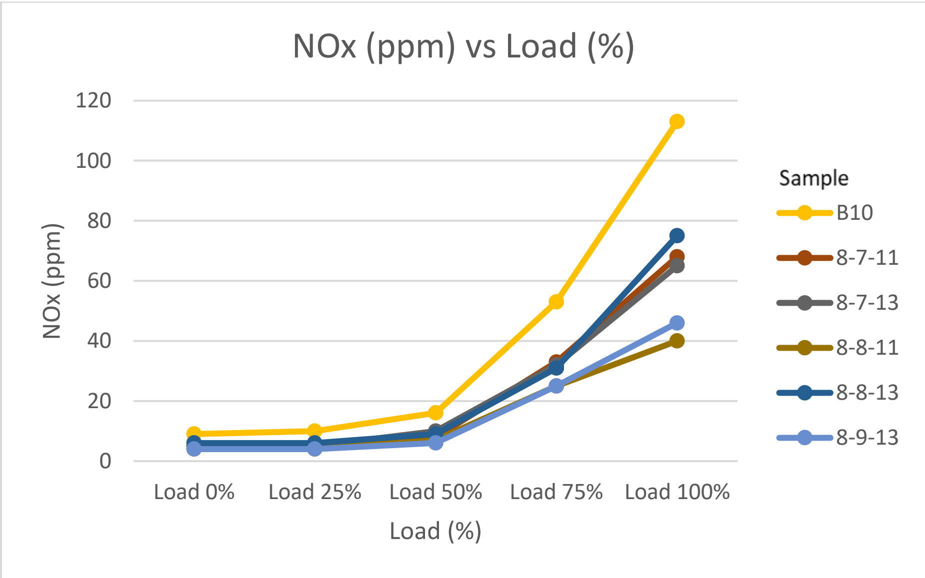

FIGURE 4. 17: NOx emission for increasing surfactant value at HLB value 8

4.2.1 Carbon Monoxide (CO)

In Figure 4.18 we can observe that CO emission decreases as water concentration increases at 75% and 100% load. We also can see there are no changes in CO emission as HLB value increases at 75% load but at 100% load CO emission will decrease.

In Figure 4.19 we can observe as water concentration increases for emulsion 7-7-11 and 7-7-13 CO emission decreases while for 8-7-11 and 8-7-13 increases at 75% load. At 100% load there are not changes for CO emission as water concentration increases. We can see that as HLB value increases for 7-7-11 and 8-7-11, CO emission increases but for 7-7-13 and 8-7-13, CO emission decreases at 75% and 100% load.

In Figure 4.20 we can observe as water concentration increases for emulsion 7-9-11 and 7-9-13, CO emission reduced while for 8-9-11 and 8-9-13 CO emission increases at 75% and 100% load. HLB value increases for emulsion 7-9-11 and 8-9-11 we can observe that CO emission decreases while for 7-9-13 and 8-9-13 CO emission increases at 75% and 100% load.

In Figure 4.21 we can observe that as surfactant concentration increases for emulsion 7-7-11,7-8-11,7-9-11,7-7-13,7-8-13 and 7-9-13, 8% surfactant tends to have highest CO emission and 9% surfactant concentration the lowest at 75% and 100% load.

In Figure 4.22 we can observe that as surfactant concentration increases for emulsion 8-7-11,8-8-11 and 8-9-11, 7% surfactant concentration tends to have highest CO emission and 9% surfactant concentration the lowest at 75% loads while at 100% load there are no changes in CO emission. For emulsion 8-7-13, 8-8-13, and 8-9-13 as surfactant concentration increases, 8% surfactant concentration emit the highest CO emission while 7% concentration emit the lowest at 75% and 100% load.

B10 still has the lowest CO value due to higher combustion efficiency. The nearest emulsion that has combustion efficiency to B10 is 7-9-13 and 8-9-11 at 75% and 100% load.

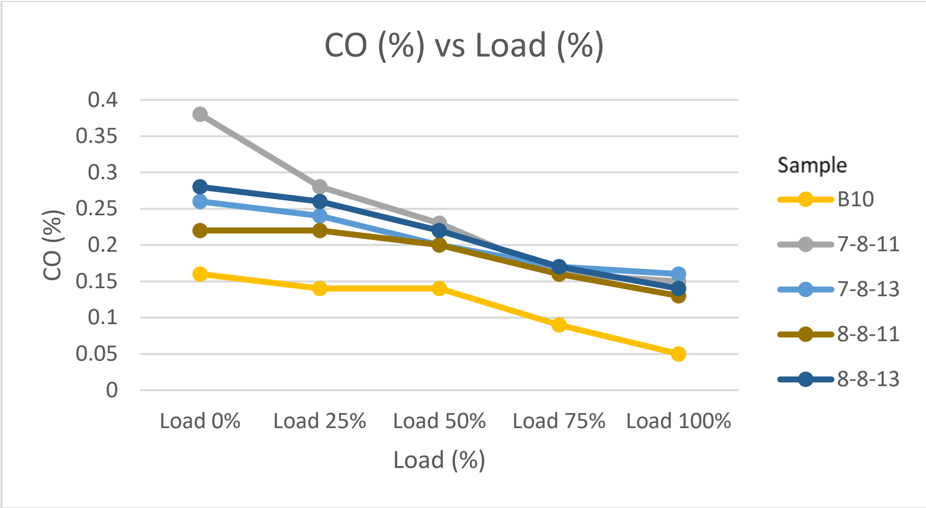

FIGURE 4. 18: CO emission for 8% Surfactant Concentration

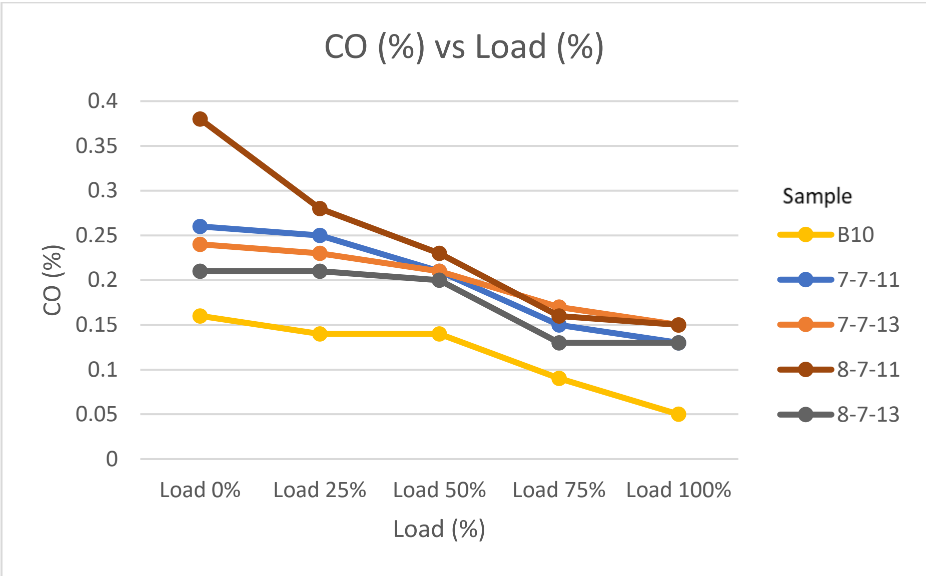

FIGURE 4. 19: CO emission for 7% Surfactant Concentration

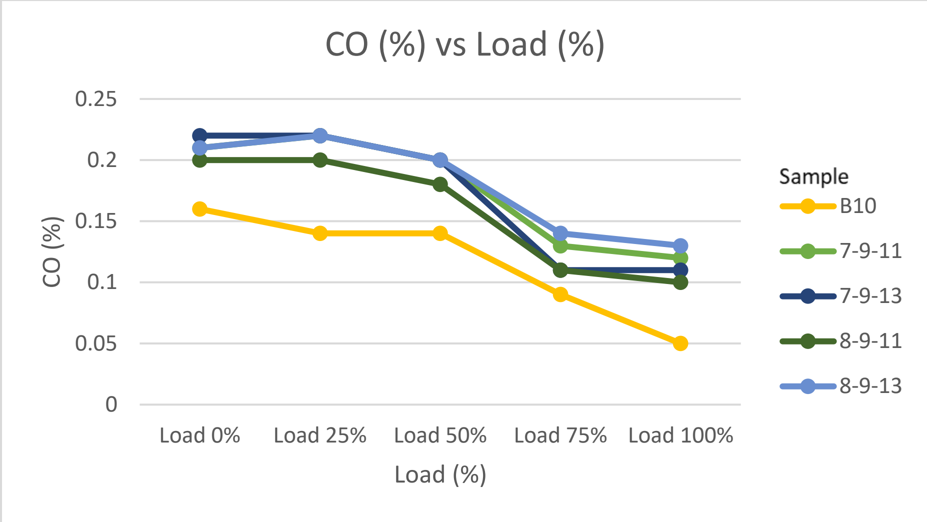

FIGURE 4. 20: CO emission for 9% Surfactant Concentration

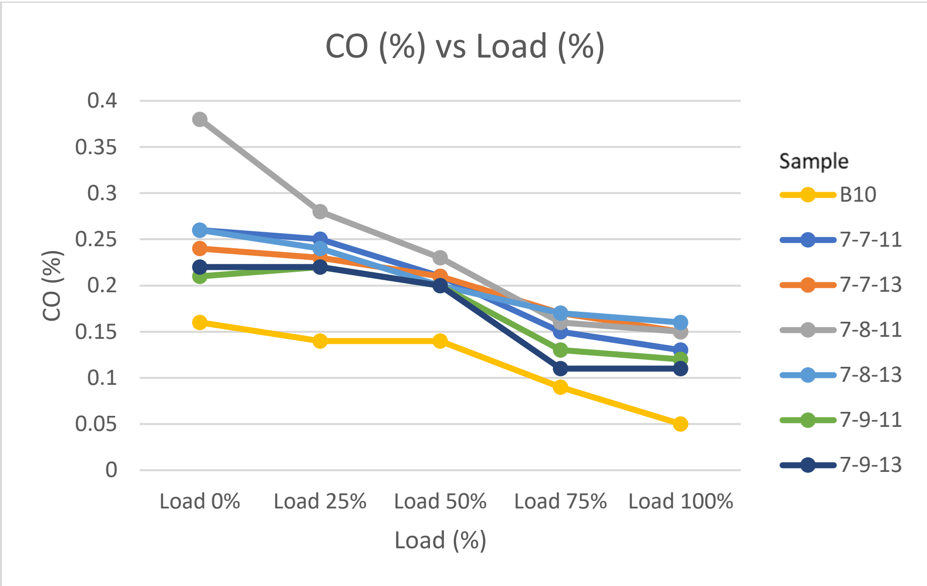

FIGURE 4. 21: CO emission for increasing surfactant value at HLB value 7

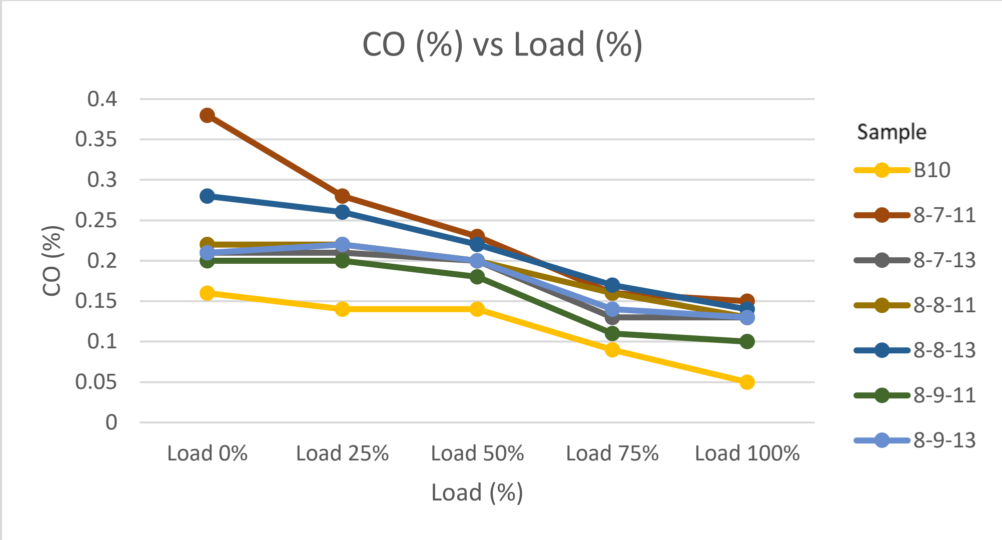

FIGURE 4. 22: CO emission for increasing surfactant value at HLB value 8

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The comparison of engine performance and emission of Biodiesel B10 and 12 WiBE emulsions produced by ultrasonic homogenizer method were completed. Micro-explosion occurrence in WiBE samples has been ascertained by increment of in-cylindrical pressure. At 75% load 7-9-13 showed 12% higher first peak pressure and 8-8-13 showed 3.85% higher secondary peak than B10. At 100% load, showed 8-9-13 11.8% higher and 8-8-13 4.28% higher for first and secondary peak than B10 respectively.

Micro-explosion occurrence in WiBE samples has been ascertained by increment of heat release rate. At 75% load, 8-9-11 showed the highest and shortest for peak of combustion and ignition delay if being compared to other emulsion and B10 biodiesel. At 100% load, 7-8-11 showed the highest and shortest for peak of combustion and ignition delay if being compared to other emulsion and B10 biodiesel. It is showed that, shorter ignition delay will increase atomization of the emulsion.

Micro-explosion occurrence in WiBE samples has been ascertained by reduction of NOx emission. When 75% load applied, 7-7-13 showed 60.38% lower NOx emission than diesel. When 100% load applied, 7-7-13 showed 35.85% lower NOx emission than diesel. Reduction of NOx emission indicate lower local combustion temperature. Not all WiBE emulsion that has NOx reduction are related to increment of in-cylindrical pressure but mostly due to its configuration.

We also can conclude that in-cylindrical pressure does not effecting NOx emission since 7-9-13 has the highest in-cylindrical pressure at 75% load while 8-9-13 at 100% load but emulsion 7-7-13 has the lowest value for NOx emission at 75% and 100% load.

5.2 RECOMMENDATION

To better understanding of micro-explosion phenomenon, a better emission analyser should be used that could measure hydrocarbon (HC) and Lambda value for diesel fuel. The author realised during higher engine body temperature and exhaust temperature; the emission of NOx increased. Thus, it should be considered that engine body temperature and exhaust temperature should be one of the parameters that being tested.

The combustion analysis and exhaust emission measurement of WiBE sample are done with constant speed at 2000 rpm with 5 varied loads ranging 0% to 100%. For the future experiment, it should be done with different engine speed and larger variation of loads so larger combustion analysis data and exhaust emission measurement of WiBE emulsion would be created for future references and studies.

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