CHARACTERISTICS STUDY OF EMULSIFIED BIOFUEL AND EGG YOLK OIL (EBEYO) PROPERTIES AND ITS PERFORMANCE IN COMPRESSION-IGNITION ENGINE USING NEW FORMULATED SURFACTANTS AND COMPOSITION

MUHAMMAD RAFIQ BIN ALAUDEN

UNIVERSITY SAINS MALAYSIA

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By:

MUHAMMAD RAFIQ BIN ALAUDEN

(Matrix no.: 143977)

Supervisor:

Associate Professor Dr. Mohamad Yusof bin Idroas

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DECLARATION

This work has not previously been accepted in substances for any degree and is not being concurrently submitted in candidature for any degree.

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This thesis is the result of my investigation, except where otherwise stated.

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LIST OF EQUATION

LIST OF SYMBOLS

ρ	Density
m_f	Mass flow rate
M	Mass
V	Volume flow rate
Q	Calorific value
T	Torque
N	Engine speed

LIST OF ABBREVIATIONS

ASTM	American Society of Testing and Materials
BP	Brake Power
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
CI	Compression Ignition
CV	Calorific Value
CVCC	Constant Volume Combustion Chamber
Cp	Centipoise (Mpa.S)
EB	Emulsified Biofuel
EYO	Egg Yolk Oil
EBEYO	Emulsified Biofuel + Egg Yolk Oil
FC	Fuel Consumption
HLB	Hydrophilic-Lipophilic Balance
O/W	Oil in Water Emulsion
RPM	Revolution Per Minute
RPO	Refined Palm Oil
RPO1000EYO0	Refined Palm Oil 100% Egg Yolk Oil 0%
RPO95EYO5	Refined Palm Oil 95% Egg Yolk Oil 5%
USM	University Sains Malaysia
WOT	Wide-Open Throttle
W/O	Water in Oil Emulsion

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KAJIAN CIRI-CIRI SIFAT BAHAN BAKAR BIO PENGEMULSI DAN MINYAK TELUR KUNING (EBEYO) SERTA PRESTASINYA DALAM ENJIN NYALAAN MAMPATAN MENGGUNAKAN SURFAKTAN DAN KOMPOSISI FORMULA BARU

ABSTRAK

Peningkatan kos minyak dan inisiatif kerajaan untuk mengurangkan pelepasan gas rumah hijau telah menyebabkan peningkatan dalam permintaan untuk bahan bakar bio. Bahan bakar bio mempunyai kandungan oksigen yang tinggi dan pembakarannya di dalam enjin telah menambah baik pelepasan bahan bakar secara tidak langsung. Penggunaan terus bahan bakar bio pada enjin adalah dihadkan sama sekali kerana ia akan membahayakan enjin dengan menyebabkan deposit karbon, penyuntik tersumbat dan pembakaran yang tidak lengkap. Oleh itu, pengemulsi bahan bakar bio yang betul dengan penambahan surfaktan dan air diperlukan untuk menghasilkan sifat fizikokimia yang lebih baik seperti ketumpatan, kelikatan, dan nilai kalori yang setanding dengan bahan api diesel asas. Eksperimen sebelum ini menggunakan surfaktan Tween 80 dan Span 80 untuk pengemulsi. Manakala bagi projek ini, surfaktan (Triton X-100 dan Span 80) telah digunakan dengan komposisi 2% tetap, sukatan air yang sama dan penambahan minyak kuning telur dalam bahan bakar bio teremulsi dengan peratusan isipadu yang berbeza (5%, 10%, 15%, 20% dan 25%). Kesan campuran minyak kuning telur terhadap sifat fisikokimia dan prestasi enjin telah dikaji untuk dibandingkan dengan bahan api diesel. Bagi ujian sifat fisikokimia, keputusan menunjukkan penambahan dari 5% sehingga 25% isipadu minyak telur kuning ke dalam bahan bakar bio pengemulsi mengurangkan kelikatan sebanyak 4.53%, untuk ketumpatan sebanyak 1.27% dan meningkatkan nilai kalori sebanyak 0.3% berbanding EB (RPO100EYO). EBEYO 4 (RPO80EYO20) mempunyai ketumpatan terendah dengan penurunan 1.27% dan nilai kalori tertinggi dengan keuntungan 0.3% jika dibandingkan dengan bahan api EB. Perbezaan peratusan dalam kriteria prestasi antara EBEYO dan bahan api diesel asas ialah sebanyak 6.68% untuk ketumpatan, 87.2% untuk kelikatan dan 11.9% untuk nilai kalori. Berdasarkan ujian prestasi enjin, tork dan kuasa brek yang dihasilkan oleh sampel bahan api EBEYO adalah lebih rendah (29.2%) berbanding diesel asas kerana nilai pemanasan yang lebih rendah. Suhu ekzos untuk EB dan EBEYO adalah jauh lebih rendah daripada bahan api diesel asas yang mengakibatkan pelepasan karbon yang lebih sedikit, kandungan sulfur yang rendah, yang menyumbang kepada pelepasan yang kurang berbahaya. Selain itu, penggunaan bahan api untuk sampel EBEYO adalah lebih baik daripada bahan api diesel menyebabkan pengurangan penggunaan bahan api khusus brek (9.71%) dan peningkatan kecekapan haba brek (10.11%) apabila kelajuan enjin semakin meningkat. Secara keseluruhan, kajian ini menunjukkan bahawa EBEYO 3 (RPO85EYO15) aplikasi dalam enjin CI adalah bahan api yang paling cekap untuk digunakan dan telah dikenal pasti sebagai sumber biofuel baharu yang berdaya maju untuk penggantian bahan api masa hadapan.

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ABSTRACT

Increasing fossil fuel price and government initiatives to cut greenhouse gas emissions have led to a rise in demand for biofuel. In contrast to fossil fuels, which are finite resources, biofuels are created from feedstocks that are continually replenished by nature. Biofuel has a high oxygen content and burning it in the engine has improve emissions indirectly. However, straight application of biofuel to the engine is absolutely restricted since it will harm the engine by causing carbon deposits, injector clogging, and incomplete combustion. Hence, proper emulsification of biofuel with the addition of surfactant and water is required to produce better physicochemical properties such as density, viscosity, and calorific value comparable to the baseline diesel fuel. The previous experiment uses surfactant Tween 80 and Span 80 for emulsification. While for this project, surfactants (Triton X-100 and Span 80) were used with constant of 2% composition and the egg yolk oil (EYO) addition with different percentages (5%, 10%, 15%, 20% and 25%) volumes in the emulsified biofuel (EB). The effect of the EB blend on the physicochemical properties and engine performance was studied. For the physicochemical properties test, the results show that the addition from 5% to 25% volumes of EYO into EB reduce the viscosity by 4.53%, for density by 1.27% and increase the calorific value by 0.3% compared to neat EB (RPO100EYO). EBEYO 4 (RPO80EYO20) has the lowest density with 1.27% drop and highest calorific value with 0.3% gain when compared to EB fuel. The percentage difference in the physicochemical criteria between EBEYO and baseline diesel fuel is by 6.68% for density, 87.2% for viscosity and 11.9% for calorific value. Based on the engine performance test by EBEYO fuel samples, the torque and brake power output were both 29.2% lower and the brake specific fuel consumption (BSFC) was 9.71% lower than with baseline diesel because of the lower heating value. Exhaust temperatures for EB and EBEYO's are significantly lower than baseline diesel fuel resulting in less carbon release, low sulphur content, which contribute to less harmful emissions. Besides that, the fuel consumption of EBEYO fuel samples is better than diesel fuel resulting in reduction of brake specific fuel consumption (9.71 %) and increment in the brake thermal efficiency (10.11%) as the speed of the engine increase. Overall, this study demonstrates that EBEYO 3 (RPO85EYO15) application in CI engine is the most efficient fuel to be used and has been identified as a viable new source of biofuel for the future fuel replacement.

CHAPTER 1

INTRODUCTION

1.1 Overview

A diesel engine is an internal-combustion engine in which air is compressed to a high enough temperature to ignite diesel fuel pumped into the cylinder, causing combustion and expansion to move a piston. It transforms the chemical energy in the fuel into mechanical energy that can be utilised to operate vehicles, huge tractors, locomotives, and ships. The Diesel Cycle is used to represent the diesel engine. Rudolf Diesel invented both the engine and the thermodynamic cycle in 1897. (Armstrong, 2021)

Nowadays, there are huge demand on diesel engine in application such as transportation, industrial and more. Diesels have a compression-ignition system that is highly efficient. The engine uses high compression to heat the air within the cylinders to create combustion. However, there are some disadvantages faced on usage of diesel engine such as harmful emissions which is oxides of nitrogen (NOx), particulate matter (PM) and other gaseous pollutants. The world is currently dealing with the depletion of fossil fuels and pollution resulted by fossil fuel combustion in vehicles. Burning fossil fuels discharges hazardous particles and greenhouse gases into the atmosphere, which have negative consequences for humans and the environment. Furthermore, NOx, SOx, CO, and CO2 are among the mutagens, carcinogens, and hazardous compounds found in diesel engine emissions. Additionally, lung cancer has emerged as a serious health concern in both animal and human. Studies on railroad employees and truck drivers who are occupationally exposed to diesel engine emissions have indicated that the risk of lung cancer increases with the number of years spent in the exposed employment (Low, 2017). The current context has enhanced the hunt for alternative fuels that offer a good relation with sustainable development, energy saving, efficiency, and environmental protection (Reham, 2015)

Biofuels is a revolution to replace the fossil fuels. Biofuel is frequently promoted as a cost-effective and ecologically friendly alternative to petroleum and other fossil fuels, especially in light of rising petroleum prices and growing concern about fossil fuels implications to global warming. However, researchers have found that there are some lacks of engine performance when using the biofuel such as incomplete combustion, affect in injector pump, and injector effect on fuel spray pattern. This is due to the high viscosity, density, molecular weight and other chemical properties that affect the engine performance.

Biodiesel typically contains 10 to 15% oxygen, which improves combustion efficiency and reduces PM, CO, and other gaseous pollutants emissions. However, because of the greater oxygen concentration, there will be more NOx formation at high combustion temperatures, which is roughly 10% more than fossil diesel. As a result, the goal of using biodiesel fuels is to minimise NOx emissions while maintaining performance. Using emulsified fuels containing biofuels in varied fractions to meet both restrictions is a potential option. In diesel engines, emulsified biofuels may be used in two ways. Emulsified fuel is created in the first step by mixing a certain amount of water with diesel fuel. This method is not widely used since it generates phase separation. In the second method, water is added to the vegetable oil via a surfactant additive, which aids in the bonding of water to biofuel fuel and therefore eliminates phase separation. Stabilized emulsified fuels are emulsified fuels that have been manufactured using this technique. By using emulsified biofuels, in-cylinder temperatures are reduced, and therefore significant reductions in NOx emissions are obtained. (Ayhan, 2013)

Additionally, delivered water in the biofuel increases atomization and mixture formation quality by creating micro explosions in the cylinder, resulting in lower NOx emissions and smoke emission formation during the diffusive combustion phase (Sahota, 2020). The interior water superheats, causing a micro-explosion, but an oil membrane must be formed around the droplet to prevent it from exploding. Once an oil membrane is in place, the inside water can become superheated, resulting in a micro-explosion (Sahota, 2020). Furthermore, certain adjustments to the biofuel's physicochemical features, such as emulsification has been tested by some researchers to improve its performance (Reham, 2015).

The process of emulsification is also known as a viscosity reduction technique. It involves mixing two immiscible liquids, a viscosity modifier and vegetable oil, biodiesel, or a combination of vegetable oil/biodiesel/petro diesel. To decrease the interfacial tension between these two liquid films and generate a stable emulsion, a surfactant and a co-surfactant are utilised (Attaphong, 2013). In a nutshell, emulsification is an anisotropic, transparent, and thermodynamically stable combination of oil in water (O/W) or water in oil (W/O) stabilised by surface-active agents (surfactants/co-surfactants).

The surfactant used in this experiment are Tween 80 and Triton X-100 mixture with the egg yolk oil addition. The important property for selection of surface-active agents is its hydrophilic-lipophilic balance (HLB) value. Despite the fact that emulsifying agents must have both hydrophilic and lipophilic components, none can be excessively dominating. The chemical does not concentrate at the water–oil interface if the hydrophilic portion of the molecule is entirely dominant; it stays dissolved in the water phase. Similarly, if the lipophilic part of the material is too strong, the substance will remain dissolved in the oil (de Villiers, 2009).

Emulsified Biofuel (EB) is a mixture of two or more immiscible liquids. It is made by agitating a fluid with a surfactant agent, which reacts with the fluid and lowers the surface tension. Compression ignition (CI) engine will be used in order to investigate fundamental of engine performance using emulsified biofuels. The aim of this project is to investigate the performance characteristic of emulsified biofuel with respect to their physicochemical properties and engine performance in Compression ignition (CI) engine.

1.2 Problem Statement

The past final year project has dealt with experimental study of the effects of egg yolk oil (EYO) on emulsified biofuel properties and compression-ignition (CI) engine performance improvement. Despite of the failure of EB properties in terms of viscosity and density improvement to meet the ASTM D6571 standard requirement and (CI) engine performance, certain analysis still not compete with the baseline diesel fuel such as viscosity, density, and calorific value. The addition of different composition of surfactants and egg yolk oil (EYO) as an improved formulation for EBEYO properties is expected to meet the ASTM D6751 standard requirement and CI engine performance. Hence, the main objective of this project is to investigate the characteristics study of emulsified biofuel properties using different composition of surfactants and egg yolk oil (EYO). After that, the emulsified biofuel obtained will be analysed on engine performance test.

1.3 Objectives

The objectives of this study are as follow:

1. To investigate the formulation of emulsified biofuel with different types and compositions of surfactants to be tested in compression ignition (CI) engine for determining its performance.

2. To determine physicochemical properties of emulsified biofuel using different types of surfactants with respect to the baseline diesel fuel in compliance with ASTM D6751 standard requirement.

3. To compare the results obtained from the compression ignition (CI) engine performance test with respect to the baseline diesel fuel.

1.4 Scope of Project

The work involves preparation of the emulsified biofuel with different composition of egg yolk oil (EYO) and different types of surfactants. Then, the project continues with study of the chemical properties of emulsified biofuel using different types of surfactants in the range of 40^{0} C to 50^{0} C test condition and using rheometer for viscosity, bomb calorimeter for calorific value and pycnometer for density. Finally, the sample of emulsified biofuel will be tested in the compression ignition (CI) engine to determine the engine performance fuelled by EBEYO and compared with the baseline diesel fuel.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Various experiment has been undertaken over the past ten years for ensuring a proper formulation of emulsified biofuel and efficient combustion in diesel engine has been made with comparison of baseline diesel fuel. There are many aspects involve in formulation of EB and combustion in CVCC in order to achieve the objective. This section describes various experiment on characteristic study emulsified biofuels and combustion in CVCC commonly used. First the research reviews about characteristic study and application of emulsified biofuels blend. Next, the micro explosion phenomenon. Then, we will review on effect of surfactant on emulsified biofuel. Lastly, we will discuss the importance of using the CVCC to analysis an efficient combustion using emulsified biofuel and design configuration.

2.2 Emulsified Biofuel Blends

At this point in engine development, a thorough search for energy sources that can replace petroleum motor fuels is underway. Alternative fuels are getting increasingly popular. The first review is about the properties, emissions profiles, and performance of different biofuel blends that have been attempted for spark ignition and compression ignition engines.

Biofuel, with a greater oxygen content and controlled exhaust emissions, has been found to be an environmentally benign replacement for traditional diesel fuels. Biofuel, on the other hand, has a greater viscosity, density, and volatility. As a result, biofuel has a lower evaporation rate and does not mix well with the in-cylinder airflow during injection. When biofuel is directly applied to CI engines, this leads in decreased combustion efficiency, increased specific fuel consumption, and lower torque, all of which led to worse engine performance when compared to standard diesel fuels (Azad, 2015).

Altering the chemical composition of the biofuel via the transesterification process, emulsifying the biofuel with deionized (DI) water, blending biofuel with diesel at certain proportions, modifying the parameters of the piston-bowl, and adjusting the injection timing and pressure are the few methods presented by the researchers in order to mitigate the issues of higher viscosity and density plus lower volatility of biofuel when it is used in CI engines (Mat S. C., 2018).

According to (Holmberg, 2002), emulsions and microemulsions are distinguished not only by the size of the scattered phase droplets, but also by their thermodynamic stability Microemulsions are thermodynamically stable, whereas emulsions are thermodynamically unstable and will eventually split into two phases, however this separation may be postponed by using the right surfactants and polymers. In an emulsion, the droplets are 1–10 μm in size, however in a microemulsion, the drops are considerably smaller, 5–20 nm. (Ochoterena, 2010)

The emulsification of biofuel with a minor amount of water is a well-known method to improve fuel atomization and combustion via the water micro-explosion effect. Emulsified biofuel (EB) is obtained by blending biofuel (nonpolar liquid) and water (polar liquid) together with an emulsifier (surfactant agent) (Hamid M. F.). The emulsifier usually consists of two different surfactants with different hydrophilic-lipophilic balance (HLB) value in order to reduce the surface tension of the immiscible liquids and the the value of HLB is an important factor to choose suitable surfactant. The equation can be used to calculate the value (Bora, 2015): $B = 20 \times \frac{M_H}{M_H+M_L}$, where the M_H s the formula weight of hydrophilic portion of the molecule and M_L is the formula weight of lipophilic (hydrophobic) portion of the surface-active agent molecule. The HLB number indicates the two-phase emulsion formation, water-in-oil (W/O), or oil-in-water (O/W). With the addition of water to produce water in oil (W/O) emulsions, the performance of prospective fuels may be enhanced and NOx emissions can be lowered (Reham, 2015) (Sahota, 2020).

Emulsified biofuels are dispersed in water in oil (W/O) phase since water droplets dispersed in the oils. The size of water droplets generated in W/O emulsions has been reported to be affected by the homogenisation method used to emulsify oil and water. Mechanical homogenisation and ultrasonication are two emulsification processes that are frequently contrasted (Mondal, 2019). Ultrasound-induced emulsification has a number of benefits over traditional approaches, including the ability to create sub-micron-sized particles, a narrow particle size distribution, and more stable emulsions, all while using less energy than mixing-based devices (Patil, 2018). Ultrasound-induced emulsification is a two-step process in which the Rayleigh-Taylor instability drives the formation of dispersed phase drops in the continuous phase, and then the shock waves created by transient cavitation induced by the passage of ultrasound break the generated drops into tiny droplets in the second step. In the case of traditional or ultrasound-assisted methods, a variety of operational parameters, including the presence of surfactant, impact the production of the droplets and their final size (Patil, 2018).

Moreover, a group of researchers has studied a novel biofuel called Melaleuca Cajuputi oil, also known as MCO, was blended with refined palm oil (RPO) to analysis the various important parameters of the blends, such as dynamic viscosity, calorific value, and density, were tested and compared to the biodiesel standards based on ASTM D6751 (Mat, 2017). The most important characteristics of less viscous biofuels are outlined in Table 2.1, where they are compared to the criteria established by the biodiesel standards by ASTM D6751. It was found that combining these biofuels with diesel or biodiesel in a mix was able to lower the blend's viscosity while simultaneously increasing its energy content value (CV). It would appear that the viscosity, calorific value, and density of the blended fuel are the most important parameters that need to be examined in great detail to guarantee their suitability as an engine fuel.

Table 2.1 Various properties of less viscous biofuel *(Mat, 2017)*

Property	**Eucalyptus oil**	**Pine oil**	**Camphor oil**	**Diesel**	**ASTM D6751**
Kinematic viscosity at 40^0C (mm^2/s)	2	1.3	1.9	3 - 4	1.9 - 6.0
Gross Calorific value (MJ/kg)	43.27	42.80	34.65	42.7 - 44.8	-
Density at 15^0C (kg/m^3)	890 - 895.5	875	894.2	822 - 880	880
Flash point (^0C)	54	52	50	50 - 74	93 min.
Boiling point (^0C)	175	150 - 180	-	150 - 180	-

2.3 Micro Explosion Phenomenon

The research paper has studied on the vaporization of water in emulsified biofuel reduce the combustion temperature which then reduce the NOx emissions. These phenomena were called micro explosion. The micro-explosion process was first discovered by Ivanov and Nevedov in 1965. They discovered that after combustion, the suspended droplets of leftover W/O emulsion spontaneously exploded, and thus came up with the term "micro-explosion" to describe the process. As a result, there has been a lot of study interest in this phenomenon all around the world to look into it more thoroughly.

When the emulsion is heated under high temperature condition, the water droplet enveloped. As a result, greater surface area of the small droplets may be exposed to the air, resulting in a better fuel and air mixing process. As a result, the efficiency of combustion will improve (Ithnin, 2019)

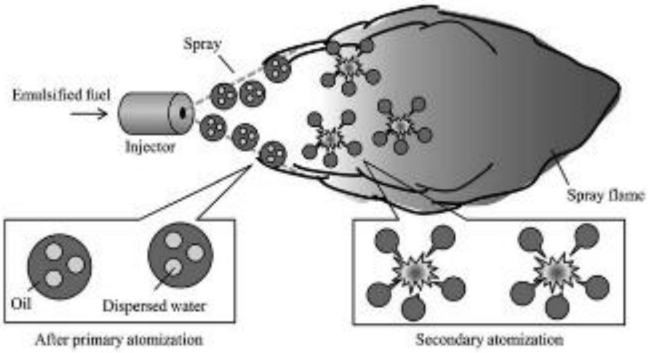

Figure 2.1 Micro explosion Phenomena *(Ithnin, 2019)*

In this paper, the author has discussed some of the technique to investigate the micro explosion phenomena. The first one is by using the single emulsion droplet method, the droplet is put on a hot plate in which the temperature can be measured and controlled, and then the vaporization process of emulsion and the occurrence of the micro-explosion is captured by a high-speed camera and presented as a shadowgraph. Other than experimental studies, many numerical researches have been conducted, predicting the onset, behaviour and strength of the micro-explosion. Furthermore, the strength of micro-explosions is also influenced by the droplet size of the emulsion during fuel spray into the combustion chamber. According to the study, if the water concentration in the emulsion is too low, the nucleation storage energy is reduced, resulting in weak micro-explosions (Ithnin, 2019).

The effects of ambient pressure on the micro-explosion process have been studied in a few research. Pressure has no direct influence on the micro-explosion process, according to (Fu, 2002). Nonetheless, the authors argue that increasing the pressure will raise the boiling point of the heavy component, making micro-explosions more likely. The authors went on to say that when the pressure rises, the gas's solubility rises as well, hastening the occurrence of the micro-explosion. (Tanaka, 2006) Concur with this conclusion, they discovered that the incidence of the micro-explosion occurs faster when the ambient pressure is higher, as well as when other parameters, such as the base fuel's saturation temperature, the water content, and the surface temperature, are increased.

Based on the water in fuel emulsion research, we can conclude that it is an alternative fuel with the potential to be marketed globally due to its capacity to improve combustion efficiency while lowering hazardous exhaust emissions. The micro-explosion phenomenon is crucial to improving such measures because it can explode a fuel droplet into a small particle, increasing the air-fuel mixing process and produce an efficient combustion.

2.4 Effect of Using Surfactant Agent

Surfactants are employed in the emulsification process to aid in the formation of a homogeneous mixture of immiscible liquids such as oil and water. This is accomplished by lowering the liquid-liquid surface tension (Sahota, 2020), (Kumar, 2014). The consumption of surfactants dependent on a number of elements, one of which being the surfactant's emulsifying ability, in addition to the characteristics of the polar and nonpolar phases. Because various surfactants have varying degrees of hydrophobicity and, thus, differing capacities for water solubilization (Leng, 2019). The balance of the HLB value will be produced by the combination of the two surfactants in their optimal proportions. The quantity of surfactant in the emulsion can range anywhere from 0.5% to 2% of the total volume. However, as the amount of surfactant increases, the emulsion's stability decreases due to the rapid coalescence that occurs (Kapadia, 2019).

The authors in this paper, has proven that variation of surfactant agent formulation in emulsified biofuel has significantly influenced its spray characteristics to be comparable to the baseline diesel (Hamid, 2016). There are two basic fundamental categories to measure the spray characteristic which are macroscopic and microscopic. Macroscopic spray characteristics include spray cone angle and spray penetration length analysis. Spray penetration length gives idea about fuel-air mixing, which is further used to study momentum exchanges of fuel and air. Spray cone angle depend on injector orifice dimensions and operating conditions. Microscopic spray characteristics such as droplet size distribution provide information about atomization, vaporization, and air - fuel mixing. Relatively finer droplets form homogenous mixture which reduces PM emissions and improve engine performance as compared to coarser droplets (Sonawane, 2020)

An experimental setup on preparation of emulsified biofuel of different composition of water, oil, and surfactant agent has been made by (Mohamad Yusof et al..2016). Two sample have been prepared which is SP21 and TP21. SP21 refers to a biofuel mixed with the surfactant agent of Span 80 at 1% composition and 2% composition of water by volume. TP21 refers to a biofuel mixed with the surfactant agent of Triton X-100 at 1% composition and 2% composition of water by volume. Both samples have been tested in the constant volume combustion chamber to visualize both spray and combustion characteristic of the emulsified biofuel. The result of the spray characteristic has been compared with the baseline diesel fuel respect to the change of its chemical properties such as viscosity, flash point, surface tension, calorific value, density and spray characteristic. Then, the spray penetration length has been observed.

From my understanding of this experiment, usage of Span 80 and Triton X-100 of surfactant agent will produce oil soluble and water soluble based on their hydrophile-lipophile respectively. This are the same surfactant agent that I will be use in my project. The difference HLB in emulsion will affect the physical properties of the spray liquid that is equivalent to doubling the flow rate through nozzles. Besides, higher HLB number of surfactant agent is found to have penetration length in advance of 0.5ms at the high injection pressure of 100-140Mpa while for the lower number HLB of surfactant agent has poor spray length penetration at injection pressure of 800-100Mpa at the injection time of 0.8ms (Hamid, 2016).

2.5 Constant Volume Combustion Chamber (CVCC) Analysis and Design Configuration

Constant volume combustion chambers (CVCC) are typically used in order to investigate fundamental aspects of combustion phenomena such as premixed ignition, diffusion flames, laminar flame speed, turbulent flame speed, auto ignition, injection strategies, and emissions formation by (Morovatiyan, 2018). (Kuszewski, 2017) conducted an experiment on use of the constant volume combustion chamber to examine the properties of auto ignition and derived cetane number of mixtures diesel fuel and ethanol. (Jackson) has proven that the use of a 20% addition of ethanol to diesel fuel resulted in a reduction of CO and NOX emissions relative to the diesel fuel. But there are some elements must be considered in usage of ethanol in diesel such as a long ignition delay period is undesirable because a considerable quantity of fuel accumulates in the combustion chamber prior to ignition, causing a rise in peak combustion pressures. Constant volume combustion chambers are an alternate means of measuring the autoignition properties of fuel. When employing the CVCC technique, the idea of derived cetane number is employed to separate it from measurements using a test engine. Cetane number is an indicator of the combustion speed of diesel fuel and compression needed for ignition.

Constant volume combustion chambers are frequently used to study the phenomenon of autoignition of fuel. Examples include test results provided by Hu et al. regarding autoignition of n-heptane and iso-octane. The observed pressure in the combustion chamber was utilised to calculate the ignition delay duration. Comparing the design of CVCC in this research with my project, there are some of the elements added in this design such as the cooling system. Below, Figure 2.2 shows the image of the CVCC use for the Diesel-ethanol analysis. (Munsin, 2013)

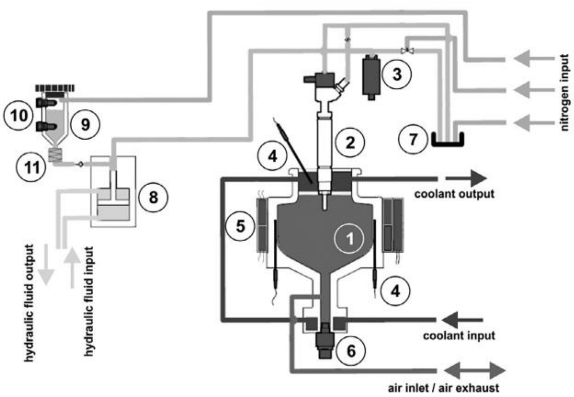

Fig. 5. Simplified diagram of the test device (based on Manual of CID510), 1-constant volume combustion chamber, 2-injector, 3-pressure sensor, 4-temperature sensor, 5-two circuit clamp heater, 6-dynamic pressure sensor, 7-waste bottle, 8-multipler, 9-sample vessel, 10-level sensors, 11-filter.

Figure 2.2 Design of CVCC *(Munsin, 2013)*

The cooling system's aim is to keep the injector and dynamic pressure sensor from overheating and causing damage. The air supply system's aim is to deliver synthetic air from the bottle into the chamber. The suitable value of the starting pressure in the chamber is determined by a static pressure sensor and valve venting (Kuszewski, 2017)

Another research paper has analysis on design of constant volume combustion chamber (cvcc) with pre-combustion technique for simulation of ci engine conditions.

For the design of the combustion chamber, both spray characteristics and structural strength are considered. Every criterion in terms of size and material selection for design a CVCC must done precisely in order to get an ideal combustion. Several tests have been done in this research such as strength analysis and flow analysis in the solidwork to get an accurate data of the CVCC. (Munsin, 2013)

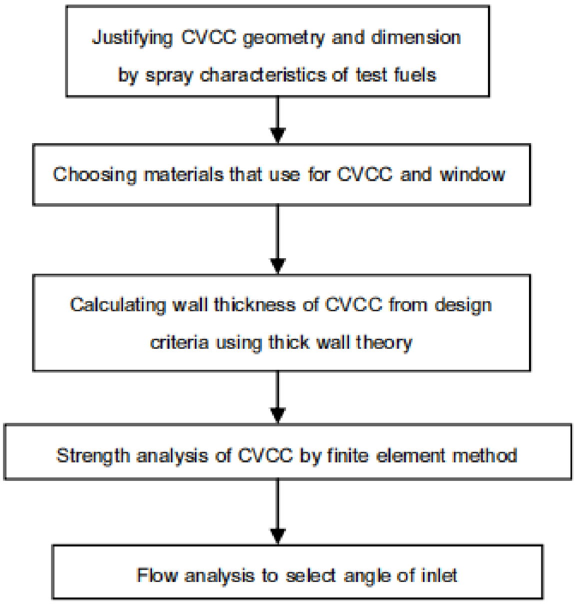

Figure 2.3 Design Procedure *(Munsin, 2013)*

In my case, the CVCC is already designed by the previous student but need to take the accurate details of the CVCC design such as the measurement. Hence, this author has briefly described the right method to design and analysis the CVCC and in order to get a good result in combustion, various simulation has been done before build the CVCC (Munsin, 2013)

Biofuel has a high oxygen content and burning it in the engine has improved emissions indirectly. Straight application of biofuel to the engine is absolutely restricted since it will harm the engine by causing carbon deposits, injector blockage, and incomplete combustion. This difficulty may be solved in two ways which is by improving the engine hardware system or by improving the chemical qualities of biofuel (Dhinesh, 2018).

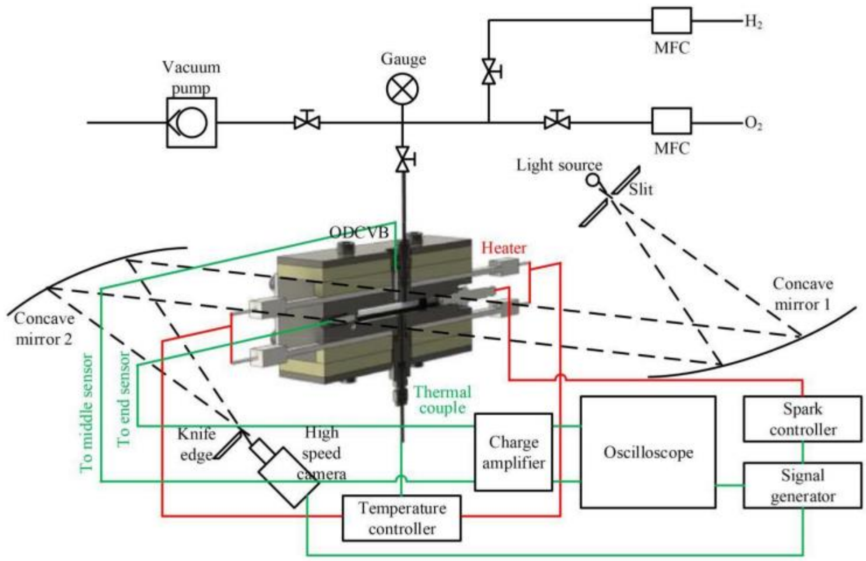

Figure 2.4 CVCC Assembly as used by *(Yu, 2015)*

End gas auto ignition and detonation development in a closed chamber employing a combination of hydrogen and air in a CVCC were investigated by (Yu, 2015). End gas combustion featured three types, according to their 1D simulations: regular flame propagation without auto ignition, auto ignition without detonation, and detonation development. They saw high amplitude pressure oscillations close to super knock as the detonation progressed. They also discovered that raising the initial pressure, temperature, or chamber size can aid detonation development. The end gas's reactivity also influences whether the end gas autoignites or detonates (Yu, 2015)

(Dingle, 2014) Demonstrated that by systematically injecting oil droplets into the combustion chamber, they were able to cause pre-ignited deflagration with an optical engine. They discovered that the production of enflamed zones by oil droplets is consistent with newly presented super knock ideas. The engine worked in pre-ignited knocking combustion, which is similar to super knock, when they tested it with a lower octane mix gasoline.

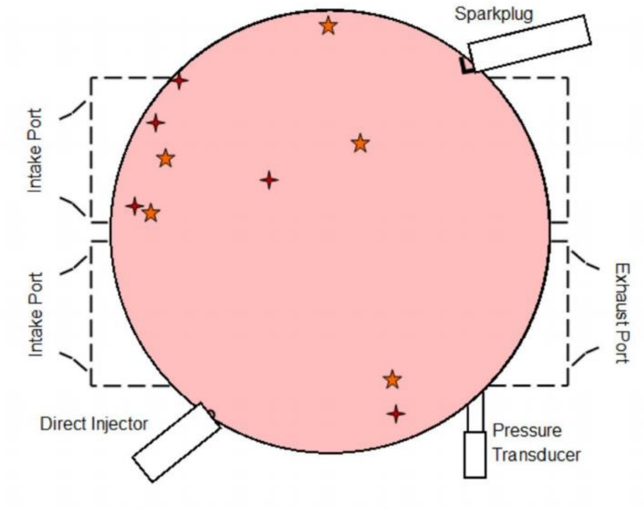

Figure 2.5 Locations of lubricant droplets as shown by *(Dingle, 2014)*

They also discovered that the majority of auto igniting occurrences happened at the intake port, and they concluded that this was due to a higher quantity of visible oil droplets and the presence of oxygen near the intake port.

(Hamid M. F., 2020) conducted an experiment on numerical investigation of the characteristics of the in-cylinder air flow in a compression-ignition engine for the application of emulsified biofuels. The author has briefly explained about the specification of the CI generator diesel engine model YANMAR L70AE installed with a four-stroke vertical single cylinder, one intake valve, and one exhaust valve that available in our lab. Hence, I can compare the specification and the combustion characteristic using the CVCC analysis.

Design Concept of Biodiesel Direct Injection Constant Volume Combustion Chamber by (Srichai, 2012). This research presents the conceptual design procedure of a constant volume combustion chamber (CVCC) with remark on important equipment, such as gas mixing tank, gas supply system and safety requirement for observation and combustion from computer simulation data. The researcher has obtained the lean limit, premix gas composite, and regulate partial pressure for proper ignition and combustion to simulate the diesel ambient condition. They also validate the wall thickness, material, shape and position for equipment tools to withstand the high pressure of combustion chamber and mixing tank.

Another research paper has briefly explained about the design parameters of CVCC design and mention about the important parts which is design of combustion chamber, viewing windows, gland and gaskets (Vinod, 2018). I have compared the design with the CVCC available in our lab and should run more simulation to obtain the real data because all parts of CVCC must be resistant to high pressure during combustion process estimated from simulation results. Then, careful disassembly and assembly of the quartz disc during cleaning must be observed to avoid any minute damage.

2.6 Compression ignition (CI) engine performance using emulsified biofuel (EB)

In recent years, an increasing number of researchers have begun to concentrate their attention on EB inquiry, engine performance, engine durability, and gas exhaust pollution, all of which are prospects to replacing fossil fuel. When compared to conventional diesel, the use of vegetable oils, blends of vegetable oil, and its derivatives has been proven to be more cost-effective as well as competitive, according to the findings of the trials that have been carried out by a number of different researchers (Muralidharan, 2011). Because of their high viscosity and poor evaporation, vegetable oils lead to a decline in the quality of fuel injection, atomization, and the production of fuel-air mixtures, which in turn leads to a decrease in the efficiency of combustion. Moreover, the formation of coke and deposits in fuel injector systems is enhanced, and carbon deposition may be seen in the combustion chamber when these oils are utilised in diesel engines. In spite of this fact, research into the optimal biofuel blend continues to increase engine performance in terms of braking power (BP), torque, brake specific fuel consumption (BSFC), brake thermal efficiency and a variety of other parameters. (Markov, 2021).

(Prakash, 2015) conducted research to evaluate the similarities and differences between the performance and combustion characteristics of diesel engines that were fuelled with biodiesel and bio-oil based emulsified fuels. According to the findings of the research, the brake thermal efficiency with biodiesel and bio-oil based emulsified fuels is superior to that of diesel when the vehicle is operating under full load conditions. This is because the kinetic rate of combustion is quicker, and the existence of oxygen content in the emulsified biofuel resulted in increased positive work done on the piston. Both of these factors contributed to the acceleration of the combustion process.

In the subject of low viscosity biofuel applications in diesel engine under various operating circumstances, fewer researchers made important discoveries. Lemongrass (Cymbopogon flexuosus) oil (LGO) was used in the experiment that (Alagumalai, 2015) conducted to study the combustion behaviour of a partly pre-mixed charge compression ignition engine. It was brought to our attention that the untreated LGO may be utilised in compression ignition engines as a single fuel without the need for any pre-treatment operations such as pyrolysis or transesterification.

Other than that, Biofuel viscosity may be reduced by preheating the fuel before it is injected into the combustion chamber, for example in a study conducted by (Chauhan, 2010), the impact of fuel input temperature of jatropha oil on the performance of a single-cylinder diesel engine was investigated while the engine rpm was held constant. The emissions of CO, HC, and soot were decreased, but the emissions of NOx were increased owing to higher combustion temperature induced by enhanced fuel atomization and evaporation. The brake thermal efficiency (BTE) of the engine was increased when the temperature of the jatropha oil was raised.

Recently, (Markov, 2021) studied an investigation of the Performances of a Diesel Engine Operating on Blended and Emulsified Biofuels from Rapeseed Oil (RO). According to the findings of the experimental tests, it has been determined how effective it is to use a mixture of biofuels derived from RO as a fuel for diesel engines. It has been shown that the presence of water in emulsified multicomponent biofuel has a more substantial impact on the amount of NOx emissions that are reduced as compared to the presence of RO in the biofuel.

Minimising fuel consumption, emissions of dangerous chemicals, and dominating operating modes while simultaneously optimising the composition of blended biofuel is something that has to be taken into consideration when trying to achieve optimal results. When a diesel engine is used with vegetable oils and fuels that are based on vegetable oils, it is also a good idea to take steps to enhance the quality of the fuel injection, atomization, and fuel-air mixture production processes. Emulsification of biofuel is one example of such a measure; this involves the usage of mixtures of biofuels that have been mixed with water. When these emulsions are injected into the combustion chamber of a diesel engine that is operating at elevated temperatures, rapid (explosive) evaporation of water from fuel droplets is observed. This results in additional turbulence of fuel jets, an improvement in the quality of the process of mixture formation, more complete combustion of fuel, and an improvement in emission characteristics (Markov, 2021).

2.7 Egg yolk oil (EYO)

Egg yolk oil (EYO) is extracted from the egg yolk, a portion of the bioactive compounds in the egg yolk. Egg yolk oil is a prominent emulsifying agent that is utilised in a wide range of food items, including mayonnaise and salad dressings, amongst others. In terms of surface activity and emulsifying capabilities, several research have reported on the technological and bio functional qualities of egg yolk and its components (Gmach, 2019).

(Kovalcuks, 2016) has studied on the effect of egg yolk oil on the chemical, physical and sensory properties of mayonnaise. Mayonnaise had an addition of EYO at the following concentrations, 1%, 3%, 5%, and 7% respectively. Lipid and protein contents are unaffected by the presence of EYO at the amounts that were tested; nevertheless, the mayonnaise's viscosity is reduced when the amount of EYO present in the mixture is increased. Mayonnaise is a type of an oil-in-water emulsion (O/W), and as such, it contains a dispersed phase as well as a continuous phase, along with the interfaces that exist between the two phases.

Hence, the reduction of the viscosity in the mayonnaise using EYO is proven, while in the biofuel application, there is not much study has been published regarding EYO usage. It is expected that the EYO could decrease the viscosity in the emulsified biofuel based on the EYO properties.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In chapter 3, the details of the experimental procedures, the equipment and materials for every test are elaborated. The first experiment begins with the preparation of the emulsified biofuels samples with various percentage of egg yolk oil added. Then, the physicochemical properties of the emulsified biofuel samples such as density, viscosity, and calorific value are explained. Next, the engine testing methodology procedure for engine performance testing. The general work flow chart of the project is shown in Figure 3.1 below.

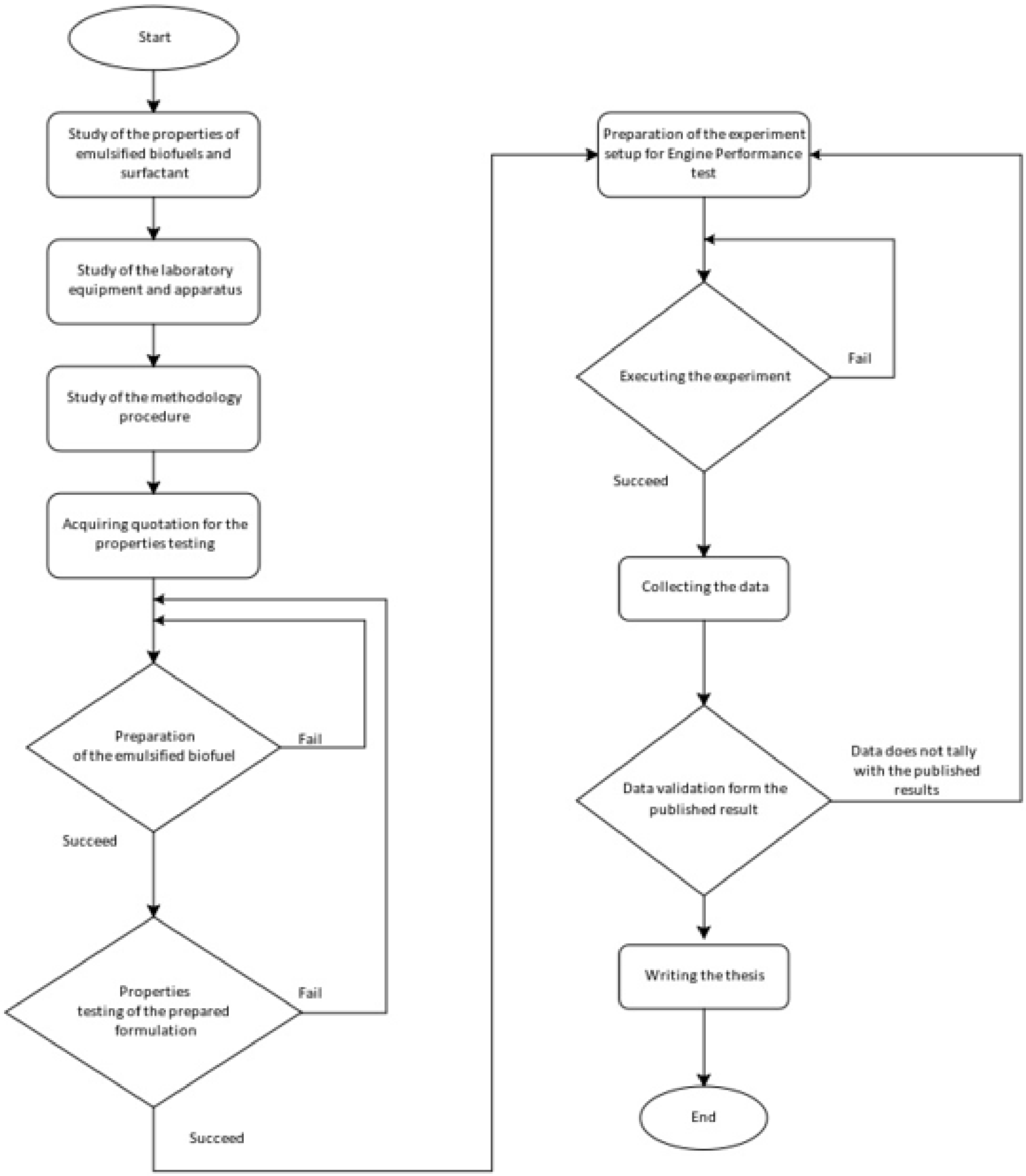

Figure 3.1 Workflow chart of the project

3.2 Emulsified Biofuel Preparation

The preparation of emulsified biofuel samples contains with different percentages of EYO addition. EYO composition with a proper characterisation in the emulsified biofuel formulation is likely to make improvement of EB physicochemical properties. Ultrasonic bath has been used in this experiment for a better emulsion of biofuel. Ultrasonic homogenization has been known as a rapid and efficient method for producing tiny, evenly sized particles (Debnath, 2015). Utilizing an ultrasonic bath (indirect sonication), in which ultrasonic waves travel from the bottom of an oscillating tank (bath) containing piezoelectric transducers, through the bath liquid, and through the emulsion container's wall before reaching the emulsion. The cavitation process is formed when ultrasonic frequency is converted into mechanical oscillations, resulting in small bubbles in the emulsion (Karim, 2020).

The apparatus needed are beaker, a syringe, ultrasonic bath, stopwatch, and measuring cylinder. The materials are refined palm oil, egg yolk oil, surfactants (Triton X-100 and Span 80) and water. The HLB number for homogenous palm oil is 8, Triton X-100 is 13.4 and Span 80 is 4.3. Hence, Triton 100 and Span 80 are classified as surfactant A and surfactant B respectively. The following Equation 3.1 is the surfactant formulations in the emulsions.

$$\%A = \frac{100 \times (X - HLB_B)}{HLB_A - HLB_B}$$

$$\%B = 100 - \%A \qquad \text{Equation 3.1}$$

The calculation was made based on the equation above, and percentage of the surfactant A is 41% while surfactant B is 59%. The total surfactant percentage is only 2