EXPERIMENTAL STUDY OF THE EFFECTS OF EGG YOLK OIL (EYO) ON EMULSIFIED BIOFUEL PROPERTIES AND COMPRESSION IGNITION (CI) ENGINE PERFORMANCE IMPROVEMENT

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DECLARATION

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

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LIST OF SYMBOLS

ρ	Density
m_f	Mass flow rate
M	Mass
$\dot{V}$	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
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
RPO100EYO0	Refined Palm Oil 100% Egg Yolk Oil 0%
RPO70EYO30	Refined Palm Oil 70% Egg Yolk Oil 30%
USM	Universiti Sains Malaysia
WOT	Wide-open throttle
W/O	Water in oil emulsion

LIST OF APPENDICES

KAJIAN EKSPERIMEN KESAN MINYAK TELUR KUNING KEPADA SIFAT-SIFAT BAHAN BAKAR BIO TEREMULSI AND PENINGKATAN PRESTASI ENJIN NYALAAN MAMPATAN

ABSTRAK

Terdapat peningkatan minat para penyelidik untuk menggunakan bahan bakar bio dalam enjin nyalaan mampatan kerana ketersediaannya yang luas di serata tempat. Namun, penggunaan terus bahan bakar bio ke dalam enjin menyebabkan banyak masalah pada enjin disebabkan kelikatannya yang tinggi daripada diesel. Pelbagai masalah seperti penembusan bahan bakar yang lebih panjang, pengaburan dan pembakaran yang teruk, binaan karbon di dalam silinder, haus dan lusuh. Untuk mengurangkan kelikatan bahan bakar bio, teknik pencampuran atau dikenali sebagai emulsi komposisi bahan bakar bio memerlukan surfaktan dan air. Surfaktan seperti Span80 dan siri TritonX biasanya digunakan dalam proses emulsi bahan bakar bio untuk mengurangkan ketegangan permukaannya, tetapi dari segi kos, harganya adalah mahal. Dalam projek ini, minyak telur kuning yang lebih murah digunakan dalam penghasilan bahan bakar bio teremulsi untuk mengurangkan penggunaan surfaktan. Penambahan minyak telur kuning ke dalam bahan bakar bio teremulsi dengan variasi dari 5%, hingga 30% mengikut peratusan isipadu dengan kenaikan 5%. Kesan penambahan minyak telur kuning terhadap sifat-sifat bahan bakar bio teremulsi, ciri-ciri corak penyemburan bahan bakar dan prestasi enjin telah dikaji. Hasil kajian menunjukkan bahawa peningkatan penambahan minyak telur kuning dengan peratusan komposisi berbeza telah mengurangkan kelikatan dan nilai kalori bahan bakar bio teremulsi, manakala ketumpatannya meningkat. Corak semburan bahan bakar bio teremulsi dengan minyak telur kuning menggambarkan pengurangan yang

ketara terhadap panjang penembusan dalam corak penyemburan dan peningkatan sudut kerucut, dengan itu menandakan pengabungan bahan bakar yang lebih baik. Berdasarkan ujian prestasi enjin menggunakan bahan bakar bio teremulsi dengan minyak telur kuning, suhu ekzos berkurang dengan peningkatan penambahan minyak telur kuning. Walaupun begitu, hasil daya kilas dan kuasa yang dihasilkan oleh campuran bahan bakar bio teremulsi dengan minyak telur kuning adalah lebih rendah daripada bahan bakar diesel.

EXPERIMENTAL STUDY OF THE EFFECTS OF EGG YOLK OIL (EYO) ON EMULSIFIED BIOFUEL PROPERTIES AND COMPRESSION IGNITION (CI) ENGINE PERFORMANCE

ABSTRACT

There is a rise of interest among researchers in applying biofuel in compression-ignition (CI) engine due its wide availability locally. However, the direct use of biofuel into CI engine has led to many problems to the engine mainly due to its high viscosity than baseline diesel fuel. The problems include longer penetration, poor atomisation, poor combustion, carbon deposits in the cylinder, wear, and tear. To reduce the viscosity of biofuel, a proper blending known as emulsification of biofuel, require surfactant and water. Commercial surfactants such as Span80 and TritonX series are commonly used in the emulsification of biofuel to reduce its surface tension but in terms of cost, they are very expensive. In this project, an affordable egg yolk oil (EYO) has been explored and introduced to the emulsification of biofuel to reduce the consumption of the surfactants. The EYO addition into the emulsified biofuel (EB) was varied from 5%, to 30% by volume, with an increment of 5%. The effects of EYO addition to the emulsified biofuel properties, spraying characteristics and engine performance were studied. The results show that the increase of EYO addition by % composition reduces the viscosity and calorific value of EB whereas the density increases. The spray pattern of EBEYO depicted a significant reduction of the penetration length and increasing cone angle, thus, signifying a better atomisation of the fuel. Based on the engine performance test using EBEYO, the exhaust temperature reduces with the increase of EYO addition. Even though it is feasible, the torque and brake power performances are lower than the baseline diesel.

CHAPTER 1

INTRODUCTION

1.1 Overview

Diesel engines are widely found in industrial, transportation, and agricultural applications due to their excellent efficiency and reliability (Qi et al., 2010). Dr Rudolf Diesel introduced the diesel engine known as compression ignition (CI) engine in late 1900 based on peanut-oil based (H. Kumar et al., 2020). Diesel fuel is one of the available fossil fuels, associated with issues of depletion in the coming years, other than the emissions problems. Over the past decades, there were several improvements in engine performance and reduction of pollutant emissions. The diesel engine is one of the primary sources of pollution due to its emissions, black smoke, hydrocarbons (HC), nitrogen oxides (NOx), particulate matter (PM), sulphur dioxide (SOx), and carbon monoxide (CO) (Melo-Espinosa et al., 2015). This fossil fuel burning in vehicles results in profound environmental changes such as increasing global temperature, air pollution, acid rain, and climatic disorder (H. Kumar et al., 2020; Reham et al., 2015). Besides, the diesel engine's emissions also create respiration and cardiovascular diseases in humans (H. Kumar et al., 2020).

In overcoming the harmful environmental and health issues due to diesel-burning, biofuel has become the potential candidate to solve the problem. Biofuel is a type of fuel derived directly from a plant or indirectly from agricultural, commercialised, domestic or industrial waste with comparable physicochemical and fuel properties to diesel (Khan et al., 2015; H. Kumar et al., 2020). Straight vegetable oil (SVO) is one example of a basic lipid that could be used as a feedstock due to its widespread availability and environmental benefits (Zaharin et al., 2017). On the other hand, it is high in viscosity, creating low injection pressure and poor fuel atomisation compared with diesel (H. Kumar et al., 2020; Zaharin et al., 2017). However, nitrogen oxide (NOx) is still high since pure biofuel needs high temperatures to ignite, which has not fully solved biofuel's emission issue (Palash et al., 2013).

In producing an inexpensive and environmentally friendly engine fuel from renewable feedstock such as vegetable oils and animal fats, it is necessary to modify or change the characteristics of biofuels such as viscosity, surface tension, free fatty acids, odorants, and moisture content (Melo-Espinosa et al., 2015). Different methods were used previously, such as preheating, blending, dual fuel operation, transesterification, cracking/pyrolysis and emulsification (Melo-Espinosa et al., 2015).

The emulsification technique is also popularly named the viscosity reduction technique (H. Kumar et al., 2020). Emulsification is the process of combining two immiscible liquids, a viscosity modifier, and vegetable oil, biodiesel, or a mixture of vegetable oil/biodiesel/petroleum-diesel. Other components, such as surfactant and co-surfactant, are used to minimise the interfacial tension between these two liquid films and form a stable emulsion (Khan et al., 2015). In a brief, microemulsions are an anisotropic, transparent, and thermodynamically stable mixture of oil in water (O/W) or water in oil (W/O) that is stabilised using surface-active agents (surfactants and co-surfactants) (H. Kumar et al., 2020; Zaharin et al., 2017). Figure 1.1 shows the illustration of W/O type microemulsion. Emulsification is a cheaper procedure since there are no significant needs for problematic modifications to the original engine configuration and sophisticated equipment. Because only small amounts of surfactant, co-surfactant, and water are required, the emulsification formulation is also cost-effective. The selection of the surfactants to be used in emulsification must be studied since it affects the emulsion's stability and characteristics.

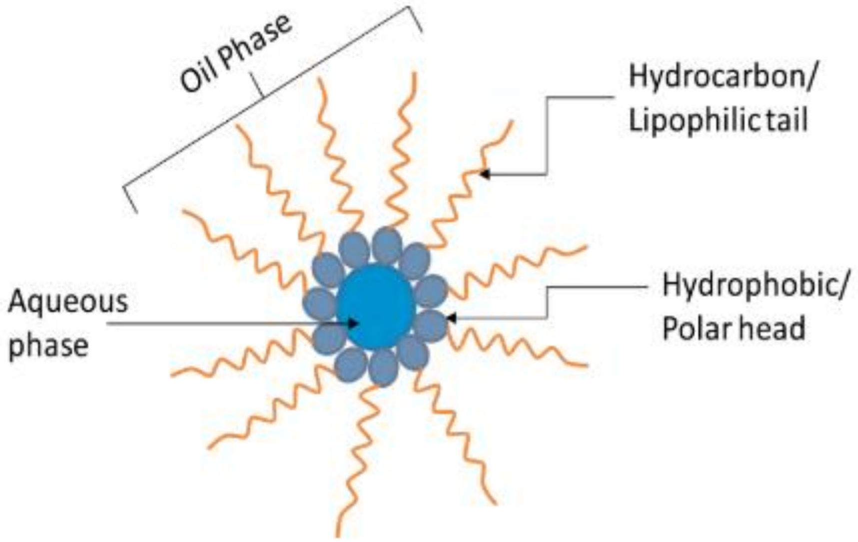

Figure 1.1 W/O type microemulsion (H. Kumar et al., 2020)

Recently, emulsified biofuel has become the centre of attention of researchers worldwide as it can improve combustion efficiency. Emulsified biofuel is a mixture of two or more immiscible liquids that exists as a droplet or scattered phase throughout the other liquids (Fingas, 2004). The emulsion is made by agitating a fluid with a surfactant agent, which reacts with the fluid and lowers the surface tension.

Another additional research is to cover the subject of the use of egg yolk. The aim is to reduce biofuel's surface tension by immersing tiny particulate water in the liquid biofuel system. Initially, the technique of double blending of surfactant is utilised. The egg yolk is not to be used as the surfactant during the process. Instead, after the emulsified biofuel's actual formulation is obtained, egg yolk is then added into the emulsified biofuel itself inside. The surfactant used is the Tween 80 and Span 80 mixture with the egg yolk addition at last. The hydrophilic-lipophilic balance (HLB) number plays an essential role in determining the surface tension of the surfactants and the emulsified biofuels (H. Kumar et al., 2020). It is expected that the resulting performance should be comparable to the diesel and biodiesel fuel by the standard of the American Society of Testing and Materials (ASTM).

This project aims to study and investigate the effect of egg yolk oil on the emulsified biofuel's physiochemical properties and the improvement of the compression ignition engine performance. The emulsified biofuel formulation needs to be developed by utilising various surfactants such as the Span80 series, Tween 80 series, and the addition of egg yolk oil. The properties of the EB and EBEYO will be compared with ASTM D6751 standard requirement and baseline diesel. These emulsified biofuels are tested in the engine and compared with the baseline diesel fuel.

1.2 Problem Statement

Biofuel, which is commonly used in diesel engines, is also widely used in industries. Researchers have made many changes to improve performance, such as improving the compression ratio to increase the combustion chamber volume and temperature to make the biofuel useable. With biofuel emulsification, enhancing the properties of the fuel and engine efficiency is another step forward. However, the selection of surfactant agents must be carried out cautiously and appropriately since specific issues, such as oil formation in water (O/W) solution, can occur due to excessive water content in the water in oil (W/O). Therefore, O/W is not suitable for fuel since the water content is high, since lesser oil content results in poor combustion during combustion, and water corrodes the engine parts (Reham et al., 2015). Besides, different properties and characteristics of other surfactants determine the characteristics of the emulsion.

In the past final year project, the objective was to develop the emulsified biofuels' best formulations with various surfactants of different surfactants used. The previous project has conducted the study of the EB. The viscosity of the emulsified biofuel reduces with the utilisation of different surfactants, but it was not in compliance with the ASTM standard to be compared with the diesel fuel. The stability period issue also incurred during the past project. Besides, the cost issues also came into consideration, where the surfactants are regarded as expensive. One of the methods to improve viscosity reduction is by introducing egg yolk oil. It is expected that the viscosity of the EB should reduce with the addition of the EYO. The addition of the egg yolk oil is expected to further improve the properties characteristics of emulsified biofuels. Then, it is compared with the baseline diesel fuel and ASTM D6751 standard findings from the viewpoint of physicochemical properties and combustion characteristics. The emulsified biofuel to be used in this project is based on palm oil.

1.3 Objectives

The objectives of this study are as follow:

1. To study the effects of egg yolk oil addition into emulsified biofuel formulation for the physicochemical properties' improvement.
2. To characterise egg yolk oil composition in emulsified biofuel formulation to optimise stability and physicochemical properties in compliance with ASTM D6751 standard requirements.
3. To study the effects of egg yolk oil addition into emulsified biofuel on the performance of compression ignition engines using EBEYO fuel.

1.4 Scope of the Project

The scope of this project covers mainly the experimental work and test. Refined palm oil is used as the base oil, with water, surfactants (Tween 80 and Span 80), and egg yolk oil (EYO) with different compositions. The emulsified biofuel with EYO addition, which is referred as EBEYO samples are prepared using an ultrasonic bath. The physicochemical properties of the emulsified biofuel are determined experimentally, such as viscosity, density, calorific value, stability time, among others. Besides, the spray pattern of the fuel in the injector is studied by using a high-speed camera. Lastly, the engine performance testing is conducted to acquire the engine performance curve compared with the existing baseline diesel fuel.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the overview of the emulsified biofuels by various research, selection of the surfactants, and various water percentages. Besides, it also includes the micro explosion phenomenon, with the stability of the emulsified biofuel with a different combination and the features and potential application of the egg yolk oil in the emulsified biofuel research. Besides, the purpose is to review how the other researchers experiment and how those differences in methodology affect the results.

2.2 Emulsified Biofuel as a Dispersed System

The dispersed system is a homogeneous system that occurs in an intermediate system between the heterogeneous macroscopic system and the molecular solution (Melo-Espinosa et al., 2015). Emulsified biofuel is defined as a mixture of two or more immiscible liquids and become a dispersed droplet. As for the dispersed droplets, it consists of two liquid immiscible stabilities, which are the internal phase and an external phase. Emulsified biofuels are dispersed water-in-oil (W/O) systems since water droplets (dispersed phase) are dispersed in the oils or fats (continuous phase), which is used as engine fuel.

Emulsified biofuels come in various of forms. It could be a water-in-oil (W/O) system, with water as the dispersed phase and oil as the continuous phase. Similarly, in the oil-in-water (O/W) type, the oil is the dispersed phase, while the water is the continuous phase. Besides, three-phase emulsified biofuels can also be made, such as water-in-oil-in-water (W/O/W) and oil-in-water-in-oil (O/W/O). For the W/O/W emulsion, water is the continuous and inner phase, while the oil is the dispersed phase.

The O/W/O emulsions follow the same idea, with the oil serving as the continuous and inner phase and the water acting as the dispersed phase. Figure 2.1 below shows the structures for both two-phase W/O emulsion and three-phase O/W/O emulsion. The hydrophilic-lipophilic balance (HLB) value of the surfactant agent affects whether the formation is oil or water-soluble, which is known as water-in-oil (W/O) or oil-in-water (O/W).

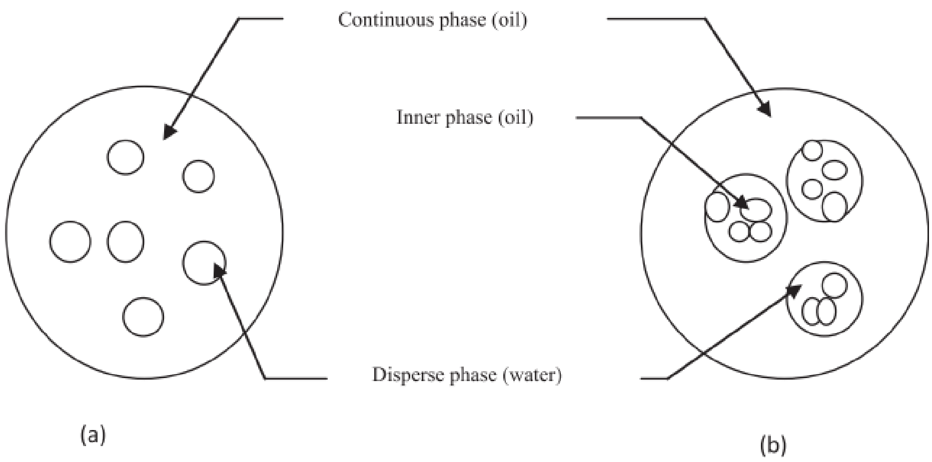

Figure 2.1 Physical structures of (a) two-phase W/O emulsion and (b) three-phase O/W/O emulsion (Mondal & Mandal, 2019)

However, emulsion and microemulsions have some significant differences even though they are in the same dispersed system. There are several dissimilarities of these two: the size of the drops of the dispersed phase and the thermodynamic stability (Ochoterena et al., 2010). The droplet size and distribution size influence emulsion properties such as stability, viscosity, density, specific gravity, and others (Melo-Espinosa et al., 2015). According to Yang et al. (2013), an emulsion is thermodynamically unstable, and the formation needs energy. It is because their Gibbs free energy (ΔG_f) is positive ($\Delta G_f > 0$), thus having the tendency of spontaneous phase separation or known as breakdown processes. This process can be delayed using surfactants and solvents since both components improve stability (Melo-Espinosa et al., 2015). The emulsion liquids are physically opaque and milky in colour (Yang et al., 2013). Melo-Espinosa et al. (2015) stated that microemulsions are spontaneously formed systems and having nano-dispersed structures. They have a large interfacial area, ultralow interfacial tension, and excellent transparency, as well as being thermodynamically stable. The Gibbs free energy (Gf 0) is negative or zero, and the drop size is substantially smaller than in an emulsion.

2.3 Water in Emulsified Biofuel

One of the essential components used in formulating emulsified fuels is water. However, it comes at a cost where its presence in the engine system has negative impacts. Therefore, to stabilise emulsified fuels, particular attention must be paid to during the formulation, especially the salts content, since the formation of rust by fuel oxidation can lead to corrosion (Melo-Espinosa et al., 2015). The presence of water in the emulsified biofuel was meant to replace amounts of fuel. Its goal is to infuse more fuel and advance atomisation in the cylinder before the combustion process begins. It lowers the heating value of the fuel and lowers the total energy per unit mass of fuel. The formation of nitrogen oxide (NOx) in the combustion chamber also decreases since excessive water is present in the hot combustion chamber, which reduces the chamber's temperature (Melo-Espinosa et al., 2015). It also shows that water in emulsified biofuel has improved the engine's output curve similar to traditional fossil fuel (H. Kumar et al., 2020). Besides, Hamid et al. observed that the increasing water percentage also increases the viscosity and benefits during injection because of the different boiling points of auto ignitions.

There are some disadvantages as well, considering the previously stated benefits of water emulsified biofuels To begin with, the gasoline supply system is likely to corrode. Wang & Pan (2003) experimentally found that there was a metal loss when emulsified fuel was used at higher temperatures. The emulsion surfactants strip the fuel tank, fuel line deposits, and the fuel filters' plugging. Also, the acceptance of emulsified fuel by engine and equipment manufacturers is limited. Stability, power loss, torque loss, compliance with modern engine technologies such as common rail and EGRR are other problems with emulsified gasoline (Wang & Pan, 2003). The brake specific fuel consumption (BSFC) for emulsified fuel is also higher than for pure diesel (Fahd et al., 2013; Nadeem et al., 2006)

2.4 Micro Explosion Phenomenon

The emulsified fluid gets atomised into fine droplets inside the cylinder when sprayed through a nozzle. Water boils at a lower temperature than diesel fuel, therefore the former reaches its boiling point first after absorbing enough reaction heat (Debnath et al., 2013). The difference in water and fuel volatility mainly characterises the combustion of emulsified fuel droplets. Both convection and radiation heat transfer heat the water droplets, and the temperature reaches the superheated limit (Melo-Espinosa et al., 2015). In the droplet, it is followed by rapid bubble nucleation and the internal formation of vapour bubbles. The vaporisation of water causes the oil layer to rise and break up, forming smaller oil droplets. The micro explosion occurs when the surface to volume ratio of oil droplets increases as a result of this condition (Debnath et al., 2013). As shown in Figure 2.2, secondary atomisation forms the bulk of finer droplets after the micro explosion's succession. It quickly evaporates and disperses over a vast area, enhancing fuel/air mixing and overall combustion efficiency (Califano et al., 2014).

In smaller droplets and the contact surface area between fuel and air, water vaporisation increases fuel dispersion. As an outcome, combustion is becoming more efficient. Peak combustion temperatures are decreased when water absorbs heat in the form of latent heat for vaporisation. Fuel dispersion in smaller droplets and contact surface area between fuel and air increase when water vaporises. As a result, combustion efficiency improves. Peak combustion temperatures are reduced as water absorbs heat in the form of latent heat for vaporisation. The formation of particulate matter (PM) and nitrogen oxides (NOx) is reduced as a result of improved combustion and lower peak temperatures (Mondal & Mandal, 2019).

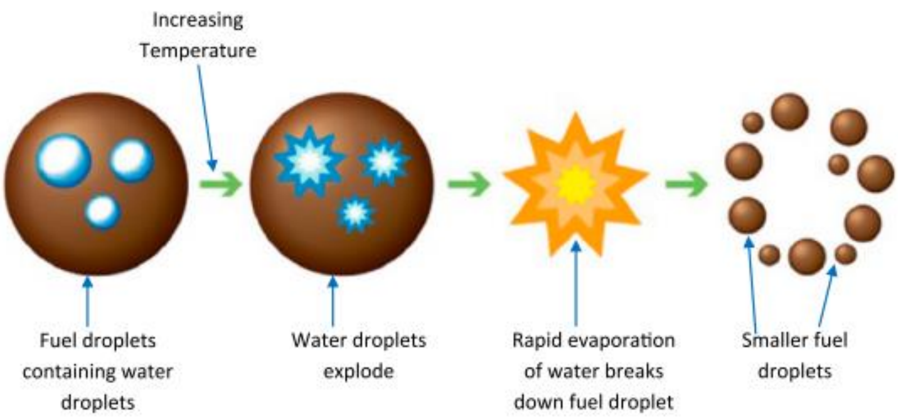

Figure 2.2 The mechanism of micro explosion phenomenon (Mondal & Mandal, 2019)

2.5 Stability of the Emulsified Biofuel and Relation with Surfactants

The stability of the emulsified biofuel is the prime concern to be able for domestic usage. If the emulsified biofuel destabilised during storage or engine operation, this would cause engine failure. Water co-exists with oil in four different states: stable, mesostable, unstable, and entrained water. The mesostable emulsion has the properties of stable and unstable emulsion. They are prominent for having insufficient stabilising materials than destabilising materials. Layers of oil and stable emulsion may form where these emulsions degrade (Fingas, 2004). After mixing within a few hours, unstable emulsion decomposes to oil and water in rapid succession. Its viscosity is less than 20 times greater than that of start-ups oil.

Currently, there are two stability test methods available which are gravitational or centrifugal stability tests. Reham et al. (2015) claimed that since the former is reasonably easy and can be performed within a shorter period. The stability of the emulsion depends on several factors such as type of emulsifier used (surfactant), emulsifier concentration, hydrophilic-lipophilic balance (HLB) number of the emulsifier, water concentration, and lastly, the type of emulsion prepared (Reham et al., 2015).

The surface-active agent, commonly known as surfactant, is used to lower the interfacial tension between two liquid layers (Reham et al., 2015). Various surfactants are utilised widely in the formulation of the emulsified biofuel, as in Table 2.1. The amount of surfactant employed in each range has a significant impact on the emulsion's stability. The emulsions are unstable because of oil droplet agglomeration at the lower concentration of surfactants. In comparison, rapid coalescence occurs at high concentrations. It destabilises the mixture due to the polydispersity of surfactant micelles produced at the W/O interface (Chow & Ho, 1996; Reham et al., 2015). Thus, the emulsion is best stabilised at an optimal level of surfactant concentration. Besides, as the emulsion is identified as a thermodynamically unstable system, breakdown processes are expected. By using surfactants and solvents, this process can be delayed as the system's stability is improved. Physical factors such as gravity settling, interfacial region drops, and the system's free energy all play a role in emulsion breakdown. In Figure 2.3, various breakdown processes in these distributed systems are depicted.

Table 2.1 Surfactants that are widely used in emulsified biofuel (Melo-Espinosa et al., 2015)

Chemical name	**Chemical formula**	**Hydrophilic-Lipophilic Balance (HLB)**
Sorbitan monooleate (Span 80)	$C_{24} H_{44} 0_6$	4.3
Sorbitan sesquiolate (Span 83)	$C_{66} H_{126} O_{16}$	3.7
Polyoxyethylene sorbitan monooleate (Tween 80)	$C_{64} H_{124} O_{26}$	15
Tetraethylene glycol dodecyl ether (Brij 30)	$C_{20} H_{42} O_5$	9.7
Oleic acid	$C_{18} H_{34} O_2$	1
1-butanol/2-butanol	$C_4 H_9 OH$	4

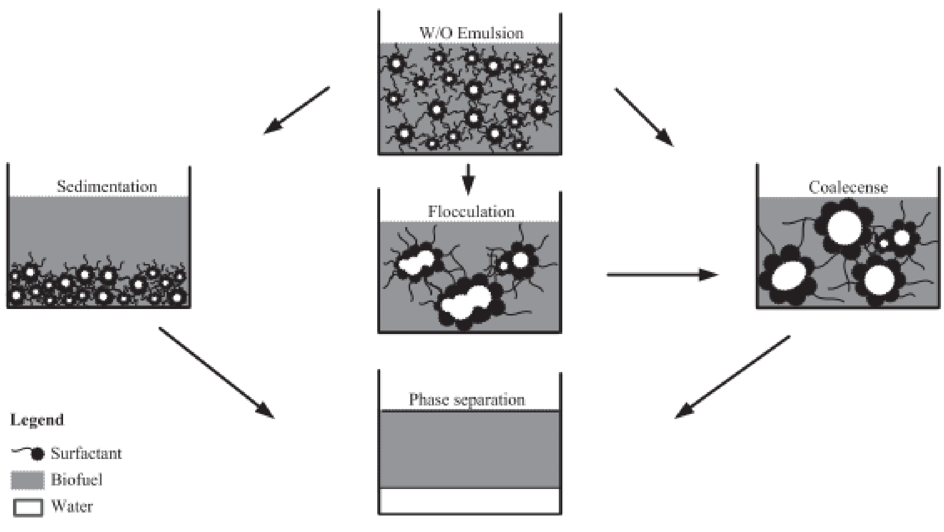

Figure 2.3 Various breakdown processes in W/O emulsions (Melo-Espinosa et al., 2015)

Besides, co-surfactants are primarily used to improve the stability of emulsions and reduce the amount of emulsifier usage. Synergism between the surfactant and co-surfactant is the main factor determining the co-surfactant emulsions and structure's stability (Sanatkaran et al., 2014). Another use of co-surfactant is to prepare microemulsions which are generally alcohol. Qi et al. (2010) used Span 80 for ethanol-biodiesel-water emulsion, and ethanol was selected as a co-surfactant. The type of alcohol to be used depends on its miscibility with the base oil. Ethanol has better mixing ability with waste cooking oil (base oil) over methanol (M. S. Kumar & Jaikumar, 2014). Other researchers discovered that the addition of methanol had an inverse relationship with the emulsion's stability. When compared to methanol, ethanol has a high miscibility with diesel, vegetable oils, and animal fats, as well as cleaner-burning properties and a high cetane number (He et al., 2003).

Bio-based surface-active agents have sparked researchers' interest since they are renewable, nitrogen-free, sulphur-free, and acid-free (Debnath et al., 2013). Recently, the reported bio-based surface-active agents are sorbitol monooleate, alcohol ethoxylate (hydrophobic), and polyisobutylene succinic anhydride ester monomethyl-capped polyethene glycol, glycerine, and polyethoxyester-based surfactants, 2-ethyl-1-hexanol, oleyl alcohol, and n-butanol (Bora et al., 2015). The hydrophilic-lipophilic balance (HLB) value is an important factor to consider when choosing surface-active agents. The equation can be used to calculate the value (Bora et al., 2015; H. Kumar et al., 2020): $HLB = 20 \times \frac{M_H}{M_H + M_L}$, where MH represents the molecular mass of the hydrophilic section and ML represents the molecular mass of the lipophilic section. The number ranges from 0 to 20, indicating the degree of hydrophilic and lipophilic variance. Water-in-oil (W/O) emulsions range from 3 to 6, whereas oil-in-water (O/W) emulsions range from 8 to 16 (Reham et al., 2015).

2.6 Egg Yolk Oil

Egg yolk oil (EYO) is extracted from the egg yolk, a part of the bioactive compounds of the egg. Egg yolk oil is widely used in the food industries, such as in mayonnaise making. Egg yolk and egg white contains much nutritional content, proteins, fats, and mineral (Suhag et al., 2021). Eggs are essential in food preparation, such as foaming, emulsification, and thickening. Egg yolk oil produced by solvent extraction from fresh liquid egg yolks specifically for experiment purposes (Kovalcuks et al., 2016).

The experimental work done by Kovalcuks (2014) was mainly on the viscosity reduction of the mayonnaise. Mayonnaise is regarded as the O/W (oil-in-water) emulsion, which has continuous and dispersed phases, containing interfaces film between the previously mentioned phases. The addition of the egg yolk is added in 1% to 7%, with an increment of 2% for each. It has been concluded that increasing egg yolk content decreases the viscosity of the mayonnaise.

Egg yolk oil (EYO) application is primarily found in the food industries, and not much of it was in renewable energy research, specifically emulsified biofuel research. Therefore, it is interesting to see if using the egg yolk oil in the emulsified biofuel research would reduce the viscosity as in the mayonnaise.

2.7 Summary

The emulsified biofuel can be produced with various types of oil from the literature review, including palm oil, jatropha oil, and canola oil, among others. The selection of surfactants affects the physicochemical properties of the emulsified biofuel produced, such as the viscosity, density, calorific value, and others. Therefore, the engine performance test using various oils and surfactants yield different engine performance results. Since the egg yolk oil application in the emulsified biofuel research is still in the elementary phase, it is interesting to see the effect of adding the egg yolk oil into the emulsified biofuel. It is expected that the addition of the egg yolk oil would reduce the viscosity of the emulsified biofuel. The engine performance of the emulsified biofuel with egg yolk oil is predicted to have adverse effects since the physicochemical properties of the emulsified biofuel now have changed.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Chapter 3 presents the details of the experimental procedures and the equipment and materials for each test. Firstly, the preparation of the emulsified biofuel samples with various percentages of the egg yolk addition is explained. Besides, the physicochemical properties of the emulsified biofuel samples are described, such as viscosity, density, and calorific value only. Next, the engine testing methodology procedure includes the fuel spray pattern and the engine performance testing only. The general workflow chart of the project is shown in Figure 3.1 below.

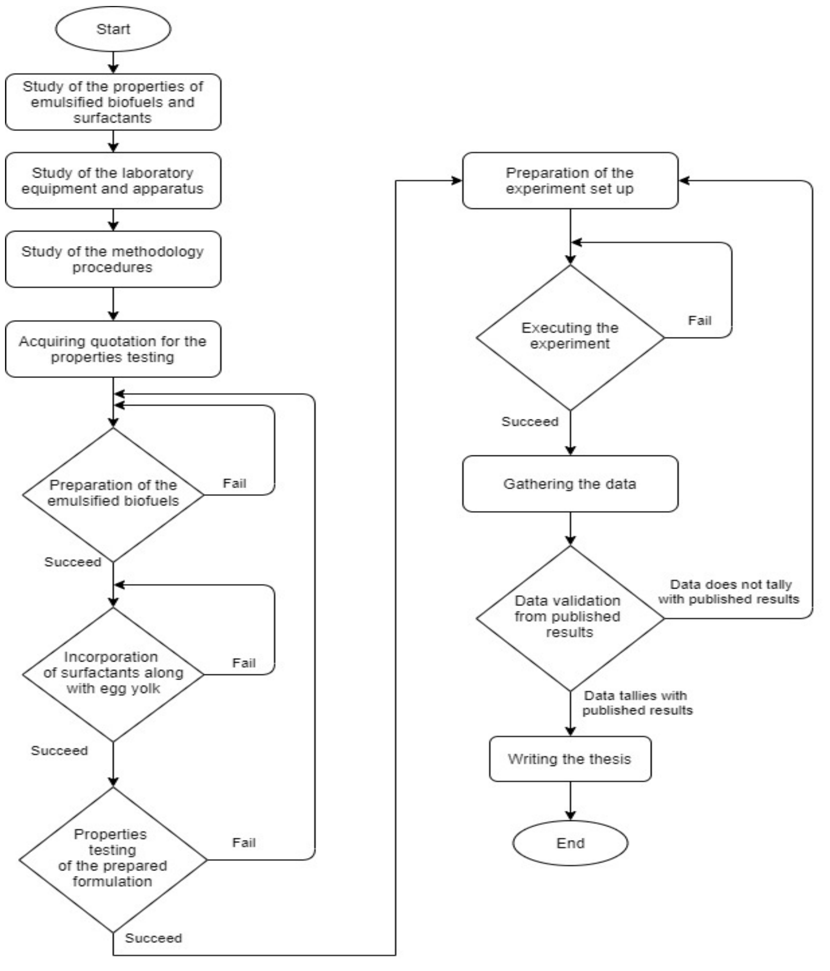

Figure 3.1 Workflow chart of the project

3.2 Emulsified Biofuel Samples Preparation

This step describes the preparation of emulsified biofuel samples with various percentages of EYO addition. A proper characterisation of EYO composition in the emulsified biofuel formulation is expected to exhibit significant variation or improvement of EB physicochemical properties. The details of procedures and apparatus are explained in the following paragraphs.

The apparatuses needed are a syringe, beaker, ultrasonic bath, stopwatch, measuring cylinder. The materials are refined palm oil, egg yolk oil, surfactants (Tween 80 and Span 80) and water. The HLB number for homogeneous palm oil is 8, Tween 80 is 15, and Span 80 is 4.3. Therefore, Tween 80 and Span 80 are regarded as Surfactant A and Surfactant B, respectively. The following equation is the surfactant formulations in the emulsion (H. Kumar et al., 2020):

$$\%A = \frac{100 \times (X - HLB_B)}{HLB_A - HLB_B} \qquad \text{Equation 3.1}$$

$$\%B = 100 - \%A$$

The calculation was made based on the equation above, and percentage of the Surfactant A is 35% while Surfactant B is 65%. The total surfactant percentage is only 1% by volume out of each sample. The amount of water to be added is set at 5% by the volume of each sample.

Throughout the writing, the specific code is used for the emulsified biofuel sample. Since the refined palm oil and egg yolk oil volume is different, the specific code is introduced. Meanwhile, the percentages of the surfactant and water are constant at 1% and 5% by volume, respectively, for all samples. Due to this reason, they are not included in the code. The detail of the code is explained in the following Table 3.1.

Table 3.1 Explanation of the specific code of the emulsified biofuel formulation

Emulsified biofuel code	Detail
EB (RPO100EYO0)	100% RPO and 0% EYO
EBEYO 1 (RPO95EYO5)	95% RPO and 5% EYO
EBEYO 2 (RPO90EYO10)	90% RPO and 10% EYO
EBEYO 3 (RPO85EYO15)	85% RPO and 15% EYO
EBEYO 4 (RPO80EYO20)	80% RPO and 20% EYO
EBEYO 5 (RPO75EYO25)	75% RPO and 25% EYO
EBEYO 6 (RPO70EYO30)	70% RPO and 30% EYO

The pure EB (RPO100EYO0) sample preparation begins by measuring 1000 mL of refined palm oil using a measuring cylinder. Then, the water is measured to 50 mL by using a beaker, and the surfactants are 3.5 mL Tween 80 and 6.5 mL Span 80 by using the syringe. All the previous materials are put into the ultrasonic bath. The ultrasonic bath temperature is set at 40°C to 50°C, while the frequency is fixed at 45 kHz. The stopwatch starts counting to 20 minutes. In the end, EB (RPO100EYO0) emulsion produced is milky in colour, the texture is a bit thick, just like the sweetened condensed milk with palm oil scent, as shown in Figure 3.2.

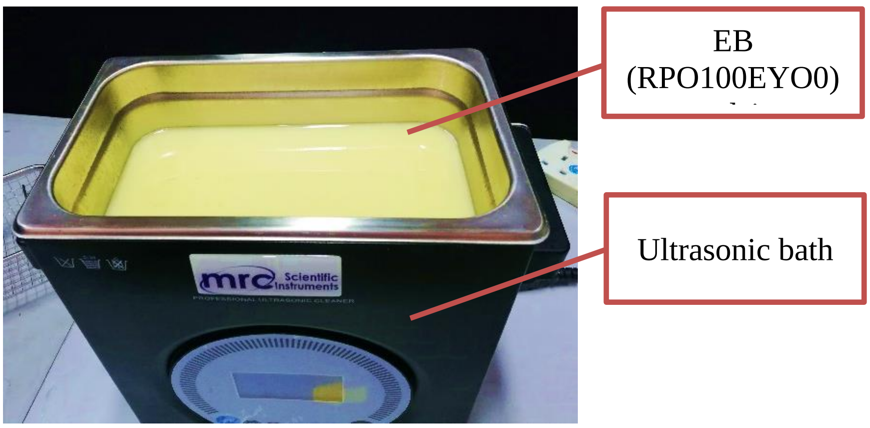

Figure 3.2 EB (RPO100EYO0) emulsion in the ultrasonic bath

Then, the next step is the addition of the egg yolk oil. The various number of the EYO is added to the emulsion as the following percentage by volume (%v/v): 5%. 10%, 15%, 20%, 25%, and 30%. The EYO is added during the material preparation step. All the process of the sample preparation in the previous paragraph is followed exactly. For each sample, there are various EYO percentages added to the EB. After finishing the material preparation step, all the samples are poured into the containers and labelled accordingly, as in Figure 3.3.

Figure 3.3 Labelled containers with different compositions of RPO and EYO

3.3 Physicochemical Properties Testing

The physicochemical properties testing of the samples is limited to viscosity, density, calorific value, surface tension, and stability test. The other testing, such as cetane number, flash point, and elemental analysis, could not be done due to several constraints. The following subtopics discuss the formerly mentioned and available properties tests.

3.3.1 Viscosity

The objective of the testing is to determine the viscosity of the various percentage of the egg yolk oil incorporated. The predicted results are that the viscosity of the emulsion reduces with an increasing percentage of egg yolk oil added.

The test equipment includes a water bath, rheometer, spindle, syringe, water-bath jacket, and stopwatch. The materials are the samples of the emulsified biofuel with various percentages of egg yolk oil.

The procedure of the testing starts by switching on the water bath and rheometer. The water bath temperature is set to 40°C according to the ASTM D6751 and ASTM D445 standards (ASTM D445 - 21, 2021; ASTM D6751 - 20a, 2020). The next step is to zero the rheometer. Put the spindle number 21 onto its place soon after the zero calibration has completed, leaving the spindle hanging. Then, lock the water-bath jacket onto the designated place by turning the screw. The first sample, EB (RPO100EYO0), is inserted into the tube using a syringe for approximately 7 mL. The tube is then tucked-in inside the water-bath jacket and locked accordingly. The apparatus setup is let to freely run for about 15 minutes for the sample to reach pre-set temperature 40°C, as in Figure 3.4. The motor is turned on, and the rotation per minute (RPM) of the spindle is set to 20, 40, 60, 80, and 100. The viscosity reading shown on the screen of the rheometer is recorded. The whole steps are repeated for the other samples, namely EBEYO 1 until EBEYO 6.

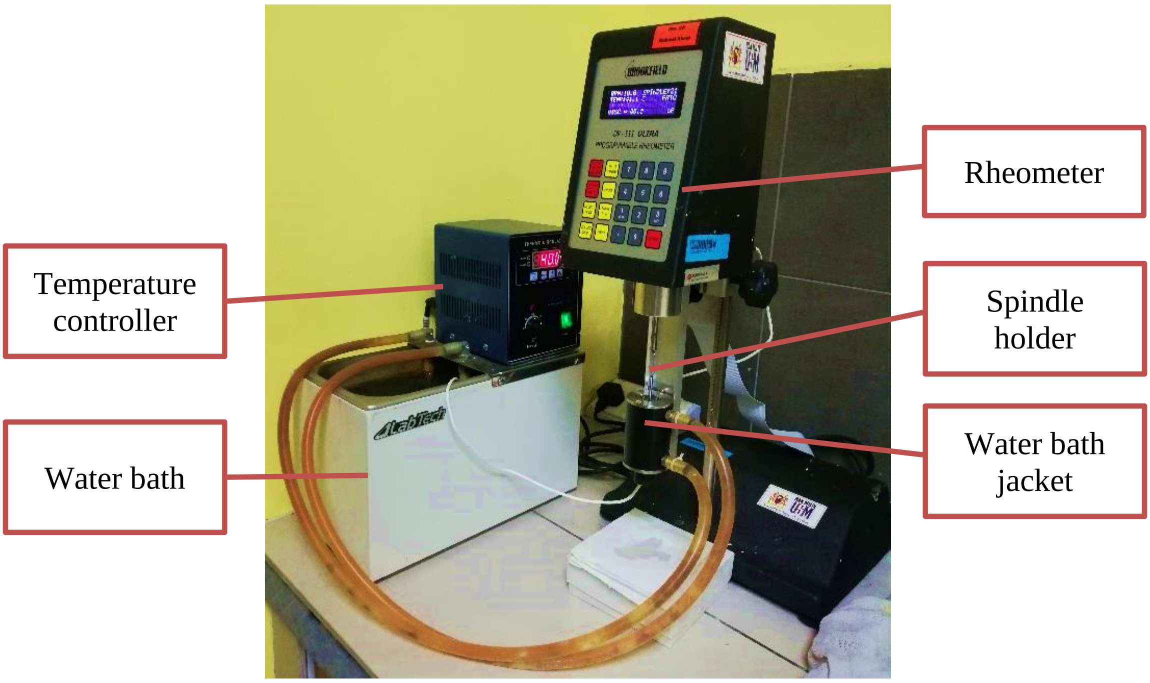

Figure 3.4 Apparatus set up for viscosity test

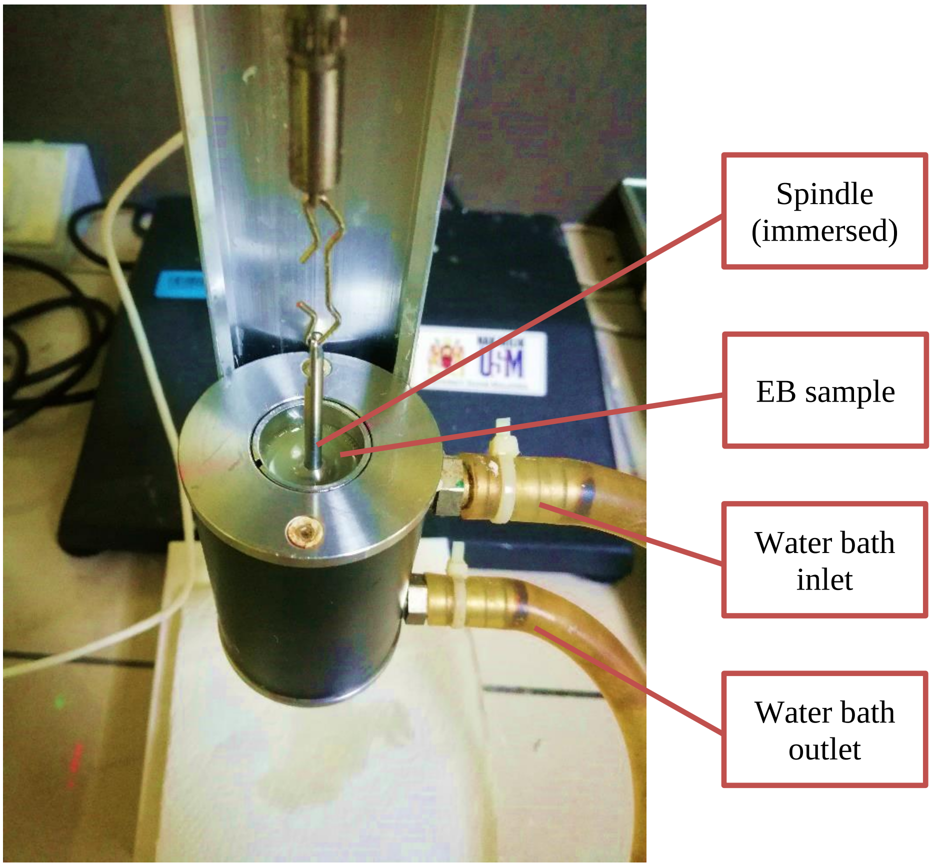

Figure 3.5 Close-up view of the viscosity testing

3.3.2 Density

This test aims to determine the density for each sample with the different numbers of the egg yolk oil added. The expected results are the increment of density concerning the increasing percentage of the egg yolk oil-infused.

The apparatuses for the experiment are a pycnometer, weighing scale, water bath, syringe, and stopwatch. The materials are the emulsified biofuel samples with varied egg yolk oil added.

Firstly, the empty pycnometer is weighed on the weighing scale. The reading is recorded as the mass of the air (M_air). Then, the first sample, EB (RPO100EYO0) is filled into the pycnometer until brim. The close-fitting glass stopper with a capillary tube through it is placed, making the air and sample inside the bottle escape via the capillary Figure 3.6. The residue of the sample is cleaned and wiped. The pycnometer is then immersed into the water bath at the set temperature of 25°C, which follows the ASTM D1217 standard (ASTM D1217 - 20, 2020) as in Figure 3.7.

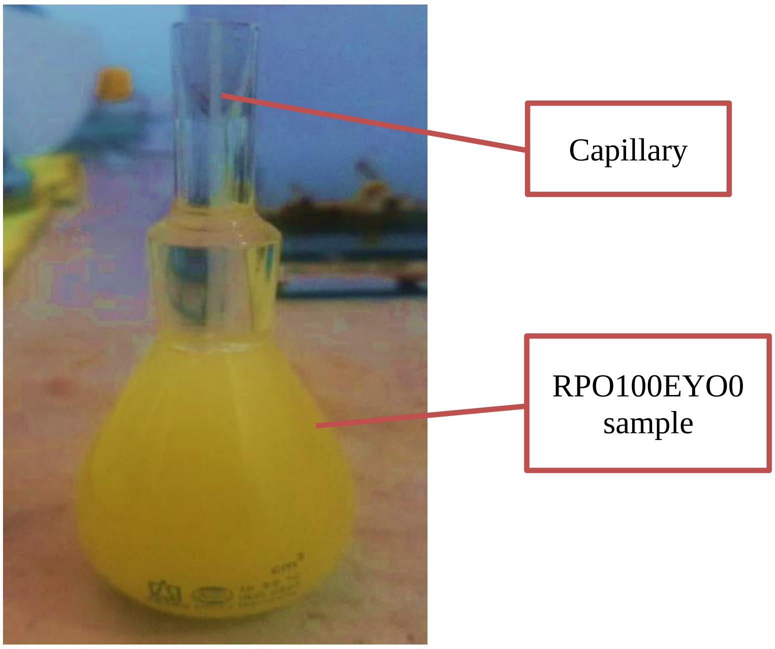

Figure 3.6 Pycnometer (note that the capillary is full)

Figure 3.7 Immersed pycnometer of RPO100EYO0 sample in the water bath at 25°C

The sample is left for 15 minutes to reach an equilibrium temperature. Since the temperature drops, the volume of the sample reduces as well due to fewer particles in the liquid move around when it is cooled and take up less room, and the sample must be topped up using a syringe until the capillary is full again. After 15 minutes, the pycnometer is weighed again after excess water has been wiped out. The final mass of the pycnometer is regarded as the mass of the sample (M_{sample}).

Another density testing is conducted at room temperature. The previously mentioned water bath step is skipped. After the sample is filled inside the pycnometer and the glass stopper is put into place, the sample is weighed. It is regarded as the mass of the sample (M_{sample}) in Figure 3.8. The previous steps are repeated for other samples. Equation 3.2 is used to calculate the density of the sample:

$$\rho = \frac{M_{sample} - M_{air}}{Volume} + \rho_{air} \qquad \text{Equation 3.2}$$