

EXPERIMENTAL INVESTIGATION ON THE COMBUSTION  
CHARACTERISTICS OF PALM BIODIESEL-DIETHYL ETHER  
BLENDS

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**EXPERIMENTAL INVESTIGATION ON THE COMBUSTION CHARACTERISTICS  
OF PALM BIODIESEL-DIETHYL ETHER BLENDS**

By

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**ABSTRACT****EXPERIMENTAL INVESTIGATION ON THE COMBUSTION CHARACTERISTICS  
OF PALM BIODIESEL-DIETHYL ETHER BLENDS****Doresharan A/L Gangatharan**

Depletion of fossil fuel and particularly environmental pollution done by diesel fuel has driven an initiative to resource for an alternative fuel for diesel engines. Diesel fuel pollutes the environment by emitting carbon monoxide (CO), nitrogen oxide (NO<sub>x</sub>), particulate matter (PM) as well as unburnt hydrocarbons. This particularly degrades the environment as well possess threat to human health. This research focuses on biodiesel B7 combined with diethyl ether with specific percentage of 5%, 7% and 9% respectively. A combustion chamber was built to analyse the characteristic of a single fuel droplet. High speed video was taken to analyse the ignition delay, burning duration and micro explosion. The burning of diethyl ether blends with palm biodiesel has shown a constant rate, which indicates higher oxygen molecules allows for a clean combustion. Micro explosion also was seen as soon as the percentage of diethyl ether was added, which increases evaporation rate and improved the combustion properties of palm biodiesel.

## APPROVAL SHEET

This dissertation/thesis entitled “**EXPERIMENTAL INVESTIGATION ON THE COMBUSTION CHARACTERISTICS OF PALM BIODIESEL DIETHYL ETHER BLEND**” was prepared by DORESHARAN A/L GANGATHARAN and submitted as partial fulfillment of the requirements for the degree of Master of Engineering (Mechanical) at Universiti Tunku Abdul Rahman.

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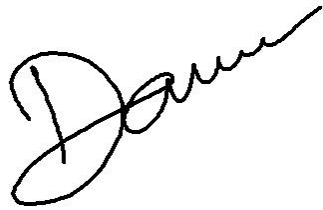


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**LIST OF ABBREVIATION**

ICE internal combustion engine

NO<sub>x</sub> nitrogen oxide

CO<sub>2</sub> carbon dioxide

HC hydrocarbons

CO carbon monoxide

PM particular matter

DEE diethyl ether

BOF fish oil biodiesel

EGR exhaust gas recirculation

CI compression ignition

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## CHAPTER 1

### INTRODUCTION

#### 1.1 General Introduction

It's a type of heat engine where only chemical energy from its fuel is discharged within an engine as well as utilised straight from chemical actions, unlike to an external combustion engine that requires an external burner to burn more fuel. Heat engine is a type of device which converts chemical energy from a fuel into thermal energy, which will then be utilised to generate mechanical activities. Heat engines are divided into two different categories.

An internal combustion engine (ICE) is a type of engine in which a fuel, usually fossil, is combusted in a combustion chamber with an oxidant known as air. The rise of high-temperature, high-pressure gases formed by combustion directly stimulates on internal combustion engine components such as pistons, turbine blades, or nozzles. This force causes those components to move over a distance, resulting in the usage of mechanical energy from the fuel.

Internal combustion engines, for example, the more prevalent four- and two-stroke piston engines, and versions like Winkle rotary engine, are often referred to as intermittent combustion engines. Continuous combustion gas turbines, jet engines, and most other internal combustion engines that works on the very same principles as the first are examples of a second type of internal combustion engine.

External combustion engines, including steam and Sterling engine, supply power to working fluids that just aren't combined, polluted, or mixed with combustion products. On the other hand, internal combustion engines provide power to working fluids that are not mixed,

mixed, or contaminated with combustion products. Working fluids, heat sources, and boilers can include air, hot water, pressured water, and sometimes even liquid sodium.

The internal combustion engine (ICE) is a type of engine wherein the air is compressed to something like a high enough temperature to ignite diesel fuel fed inside the cylinder, resulting in combustion as well as expansions that drive a piston. The efficiency of a diesel engine is one of its most notable features. The diesel engine isn't constrained by the pre-ignition difficulties that affect high compression spark ignition engines because it compresses air rather than employing an air-fuel mixture. As a consequence, diesel engines may be able to attain a rise in compression ratios than spark ignition engines, thus theoretical cycle efficiency can often be achieved if compared with something similar. It's a particular compression ratio that, the potential efficiency of a spark ignition engine was better than compression ignition engine. Compression ignition engines, on the other hand, can be run at higher compression ratios than spark ignition engines, resulting in higher efficiency. Moreover, diesel engines do not adjust power by limiting the intake of mixture. As a result, the idle and lowered power efficiency of a diesel engine is substantially better than that of a spark ignition engine.

One of the most significant disadvantage of a diesel engines will be the pollution they produce. When it is compared to spark ignition engines, most of the engines produce a lot of particulate matter called soot, as well as reactive nitrogen molecules like nitrogen oxide and odors. As a consequence, customer acceptability of smaller engines is low.

An external power supply is used to start a diesel engine until conditions are met that allow the engine to run on its own power. One simplest approach to get started is to feed air into each of the cylinders as they normally fire from a high-pressure source ranging from 1.7 to approximately 2.4 megapascal. The compressed air has a high enough temperature to ignite the



fuel. Equipment based on auxiliary starting methods usually includes supplying compressed air to an air stimulated motor geared to rotate a large engine's flywheel, providing electric charge to an electric starting motor geared to rotate the engine flywheel, as well as using a small gasoline engine geared to rotate the engine flywheel. An ideal starting approach is determined by the physical size of its engine to began, the nature of a linked load, and whether or not the weight can still be released even while the engine can be started.

Concerns have recently been made about the non-renewable fuels' long-term supply, as well as the negative effects connected with their combustion, which contribute to environmental degradation. As a result, it is prudent to generate replacement fuels as a precaution until the non-renewable fuel is totally depleted. Researchers have been looking into the creation of alternative fuels for diesel engines and have discovered that numerous viable fuels, such as biodiesel, butanol, producing gas, dimethyl ether, and hydrogen, are capable of replacing diesel (Kumar, et al., 2018).

Yet, hardly all of these fuels could meet the performance requirements for combustion systems, fuel supply, and long-term development to lessen negative environmental impact. As a result, further research is needed to find the best substitute fuels that meet these requirements. As a result, the primary goal of this study is to evaluate the combustion behavior of biodiesel-diethyl ether blends by using a time-based picture capture approach to undertake an experimental assessment of fuel droplet combustion.

## **1.2 Importance of Study**

Any such, this study is based on results of several experiments using a combination of Biodiesel and Diethyl ether. To reduce dangerous exhaust emissions from diesel engines, three main technologies are used. The initial method for reducing hazardous emissions improves

combustion by changing the engine and fuel injection system architecture, but this is an expensive and time-consuming technique. The next approach involves the use of catalytic converters and diesel particulate filters, among other exhaust devices. The usage of these gadgets, however, will have negative impact on the performance of diesel engines. Nitrogen oxides as well as particulates are the principal pollutants produced by diesel engines. In practice, reducing nitrogen oxide and particulate matter emissions at the particular time is quite challenging. The majority of studies have found that using a variety of other fuels, such as natural gas, biogas, and biodiesel, or using fuel additives with these alternative fuels or regular diesel, is the best strategy to reduce these emissions. As a result, combining the results of numerous alternative fuels or fuel additive research for practical applications is vital. The use of DEE as a gasoline additive is indeed the subject of this research. The research work looked at the impact of DEE on fuel qualities, injection, and combustion characteristics. In order to solve these environmental problems, many investigations have been conducted to develop alternative fuels. Several factors, such as the composition of and related combustion behavior, are important in determining its viability as an alternative fuel. A thorough understanding of the fuel characteristics is necessary so that the engine design and fuel composition can be improved.

In conclusion, the current research is critical in understanding the combustion behaviour of the Biodiesel B7 and diethyl ether blend. These experimental results can be utilised to identify the optimal Biodiesel B7 diethyl ether blend concentration that allows the combustion system to run at maximum efficiency.

### **1.3 Problem Statement**

Biodiesel is usually regarded mostly as fuel which is equivalent to diesel in internal combustion engines because of its beneficial properties such as reduced pollutant emissions and higher cetane value, non-toxic, etc. However, the poor low-temperature fluidity of biodiesel limits its application in internal combustion engines (Misra and Murthy, 2011). Although several studies have shown that adding low-viscosity fuels such as alcohol-based fuels to biodiesel can improve its physical properties. Its detailed combustion five characteristics have yet to be explored and understood. As a consequence, more research is needed, and the current project aims to study the impact of diethyl ether on palm biodiesel combustion properties.

### **1.4 Aim & Objective**

The primary goal of this study is to see how diethyl ether affects the combustion characteristics of palm biodiesel. The study's goal can be broken down into the following subcategories:

- To design and construct an experiment apparatus, specifically a combustion chamber, to study the combustion of a single fuel droplet.
- The goal of this study was to look into the droplet combustion properties of palm biodiesel-diethyl ether blends with various diethyl ether blending concentrations.
- To find the best palm biodiesel-diethyl ether blending concentration for improved combustion than palm biodiesel.

### **1.5 Scope & Limitation of Study**

This current research concerns heterogeneous liquid fuel combustion in air. Looking deeper into its practical application in a diesel engine, the research focuses on the combustion system's operating mechanism, which includes spray combustion and atomization. The burning of fuel droplets can be used to simulate the complex mechanisms in spray combustion. As a result, the scope is further reduced to liquid fuel droplet combustion. Finally, the current research looks into the combustion characteristics of a biodiesel-diethyl ether blend at various blending ratios.

Value determined using standard droplet combustion theory is an approximation rather than an exact conclusion. Some of the impacts of the chemical and physical interactions that occur during the combustion of fuel droplets have been overlooked as a result of the assumptions made when simplifying the solution to build the theory. The experiment is then limited to the surrounding environment in a self-made experiment chamber. Furthermore, another limitation would be due to the current pandemic situation. The research experiment was tough to be conducted as there was limited access to physical meetups with lecturers and sources from laboratory. The implementation of movement control order had reduced the access to source for fuels, materials and proper tools around Klang Valley and rural areas.

### **1.6 Outline of the Report**

The final report is broken into five chapters that are ordered in a chronological order to present the progress of the current study, starting with a general introduction to the current work and ending with conclusions and recommendations for future research. The following is a summary of the report's contents: The general introduction, importance of the study, problem description, key objectives, and scope and constraints of the study are all included in Chapter 1.

The current study's literature review is outlined in Chapter 2 which deals with the principle of liquid fuel combustion and the combustion characteristics of the fuel. The methodological section of Chapter 3 covers the setup of the experimental apparatus and fuel blends, as well as the design of the experimental strategy. The methods for analysing the data retrieved are also covered in this chapter. The main findings of the current investigation are presented in Chapter 4. The combustion properties are all graphically shown in the form of charts, graphs, and tables, along with explanations or descriptions of the findings. Chapter 5 summarises the key findings of the research and makes recommendations for how to enhance certain parts of the project. The recommendations are intended to serve as a guide for future study. Lastly, at the end of this chapter, all of the references and appendices used in the current study are listed.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

Combustion, often known as consuming, is an exothermic synthetic reaction involving the oxidation of a fuel, which releases energy that can be used for a variety of applications. Extremists are involved in the fast-paced reply. Combustion is a ubiquitous invention. It is used in the power generation industry, as well as land, sea, and air transportation, rocket propulsion, heating, material processing, and other developments. Modern heaters and boilers, smelting, furnaces, ovens, incinerators, motors, and domestic ovens, as well as mobile and stationary uses, are all affected.

Additionally, combustion is a chemical reaction that produces heat and light in the form of flame by combining two or more chemicals, commonly oxygen. The rate at which the reactants combine is rapid, partly due to the nature of the chemical reaction and partly due to the fact that more heat is produced than can escape into the surrounding medium, causing the temperature of the reactants to rise even faster.

Combustion encompasses a wide spectrum of phenomena with widespread application in industry, science, professions, and the home, and its application requires knowledge of physics, chemistry, and mechanics so that the interplay becomes obvious when dealing with flame propagation.

Combustion is one of the most significant chemical processes in general, and that it is the last step in the oxidation of specific materials. Although oxidation was once assumed to be restricted to the reaction of oxygen with any molecule or element, it has since expanded to include

any reaction wherein the atoms loss electrons and as such become oxidised. As previously stated, the oxidizer steals electrons from the oxidizable component in almost any oxidation reaction, getting reduced in the process known as gaining electrons. An oxidising agent can be any material. While these meanings are clear when applied to atomic structure to demonstrate chemical reactions, they are less so when applied to combustion, which is still a type of chemical reaction that uses oxygen as the oxidising agent but is based on the assumption that it includes other types of reactions and moves at an unusually rapid speed. Some flames, interestingly, have an area in their structure where reduction processes happen rather than oxidations. Notwithstanding that, the interaction of combustible material with oxygen is frequently the predominant event in burning.

### **2.1.1 Physical and chemical aspects of combustion**

#### *Chemical Reaction*

Combustion is, with few exceptions, a complex chemical process involving numerous phases that are dependent on the properties of the combustible ingredients. External elements such as heat, light, and ignites cause it. The reaction starts when the combustible solution achieves ignition temperature. Each point in the combustion layer serves as a source of ignition for the next adjacent layer, and so on, as combustion diffuses from the source of ignition to the adjacent gas mixture layer in turn. Combustion is complete when the total thermal energy of the reactants and the total thermal energy of the products are equal. Often these processes come to a halt when the energy of the reactants equals the energy of the products, which occurs when the energy of the reactants equals the energy of a product.

There is a connection between the ignition temperature as well as the mixture pressure under certain situations. Figure 2.1 depicts the interaction between hydrogen and oxygen mixtures. Whereas a temperature is associated with a certain pressure, a temperature may be associated with one or more pressures, known as the explosion limit. The explosion limit is determined by the reaction of mechanism. The reaction can only progress if each process in the reaction sequence is faster than the ultimate process. Therefore, the intensity of light or spark energy must exceed a specific minimum because combustion starts with light or spark.

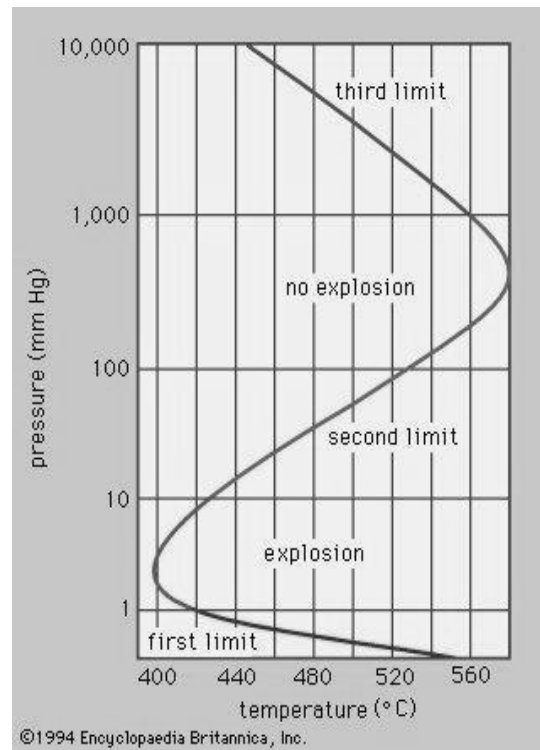


Figure 2.1 A hydrogen-oxygen mixture's explosion limitations.



### *Physical Process*

In addition to these chemical reactions, gas combustion involves the physical process of mass and energy transfer via diffusion or convection. The rate of diffusion of a component in the absence of external force is determined by the component's concentration, variations in pressure and temperature, and the coefficients of diffusion, which is a measure of the rate of diffusion. In combustion reactions, flames that are a gas mixtures, and solids or liquids, the diffusion process is vital. Heat transmission by diffusion across molecular media is governed by Fourier's law, which states that heat flux, or the amount of heat transferred, is proportional to the temperature gradient, or the temperature difference between two extreme temperatures. This proportionate coefficient, also known as heat conductivity, is measured or computed using kinetic theory of gases, similar to the diffusion coefficient.

#### **2.1.2 Combustion phenomena and classification**

Premixed and non-premixed combustion flames are the two types of flames.

- Premixed Flames

The combustion of the flame is pronounced more in pre-mixed fuel with any of the oxidants or oxygen or oxygen supplies for the reaction. With this mixture, the flame temperature is frequently several thousand times higher. Chemical reactions in such flames occur in the thickness of ornaments in a narrow area. The flame front is the term used to describe the combustion zone.

A temperature of a combustion mixture diluted with an inert gas, such as helium or nitrogen, is reduced, lowering the reaction rate. The flame was extinguished by a

significant amount of inert gas, and the material that eliminates the active species was introduced to the flame while it was being added to the flame. A flame must be attached to the burner nozzle or the combustion chamber under certain conditions. Many practical applications of combustion necessitate this placement.

The main quantitative properties of the flame are their normal or basic and combustion rates, which depends on chemical and thermodynamic properties of the mixture, as well as the temperature and temperature of the mixture, and the heat loss under circumstances, are all factors to consider. The combustion rate varies from a few millimetres over several tens of metres per second. In the fuel structure, there is a dependence on the combustion rate. which is known as a series of fuel phase mixtures that depend on the molecular structures that are the cause of fuel reactivity.

- Non-Premixed Flames (Diffusion)

Non-premixed flames, also known as diffusion, are a type of flame in which the components are not mixed before entering the combustion zone and move smoothly, laminarly, or turbulently. Gas mixing for this flame is caused by molecular or turbulent diffusion. In a laminar flame, the distribution of combustible chemicals and oxygen in each tie of the flame is regular, but in a turbulent flow, it becomes more difficult. Situationally, the transition from laminar to turbulent flame occurs at a certain point in the flow.

- Oxidizing and reducing flame

There will be a diffusion flame zone in addition to the flame zone when the premixed flame burns surplus fuel in the air. The diffusion of oxygen in the atmosphere

causes this. In the bunsen flame created by the burner, for example, the intake can be modified to change the extremely hot gas flow in which the majority of the fuel gas is burned. The fuel gas is oxidised to carbon dioxide and water at a low temperature flux, with the majority of the fuel gas just partially oxidised. A flame has two sections which is an inner core and an outer cone, where distinct chemical reactions, such as reduction and oxidation, takes place. An oxidising character of the outer cone is owing to abundant oxygen, as shown in Figure 2.2.

Furthermore, the physical state of the reactants can also be used to classify combustion, which is divided into homogeneous and heterogeneous combustion (Encyclopaedia of Hydrocarbons). The burning of fuel and oxidant that are in the same physical phase, such as bunsen burner flame, is referred to as homogeneous combustion. Heterogeneous combustion, on the other hand, refers to the burning of fuel and oxidants that are initially in distinct physical states, such as the combustion of liquid fuel in air. In fact, burning fuels in air is widely used in most combustion applications, indicating that the heterogeneous combustion of these solid and liquid fuels inherently occurs in heterogeneous combustion. Therefore, the heterogeneous combustion of liquid fuel in air is included in the scope of this study. More research on heterogeneous combustion is needed in order to gain a better understanding of the properties of the combustion and the reactions that occur during the process.

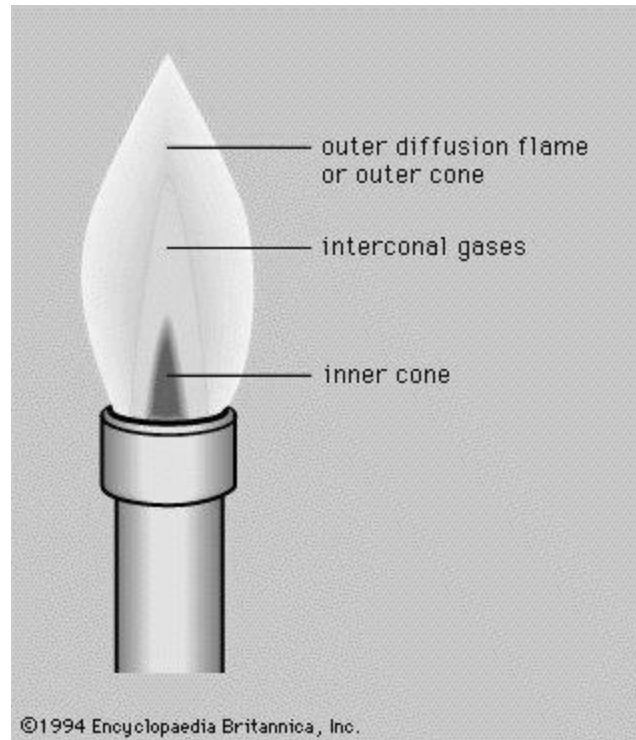


Figure 2.2 Cone of a Bunsen burner flame.

## 2.2 Liquid Fuel Combustion

According to SangChun Rah (1984), an atomizer injects liquid fuel into the combustion chamber to encourage the breakdown of the liquid into a spraying droplet. Whenever the fuel vapour burns near the droplets, the rate of evaporation increases. That reaction zone will surround each droplet in part or form in an area where the fuel or air ratio is below the flammable limit. The combustion process is quite sophisticated in most actual systems, and the sequence of physical and chemical processes involved can be described by the scheme depicted in Figure 2.3.

A comprehensive understanding of the single droplet combustion mechanism, any droplet interaction, and a statistical description of the size and spatial distribution of the droplets are required to gain a complete description of the spray combustion process. It is difficult to obtain thorough information about the combustion mechanism or rate of combustion through direct

research on spray combustion. Numerous experimental methods have been devised to explore the burning of isolated individual droplets under precisely regulated settings due to the challenges of these investigations. If only an isolated drop is considered, theoretical analysis and mathematical models are also very helpful.

It is not easy to apply the results of the single drop study to the problem of multiple drops of aerosol combustion, and it remains the basic problem of aerosol combustion.

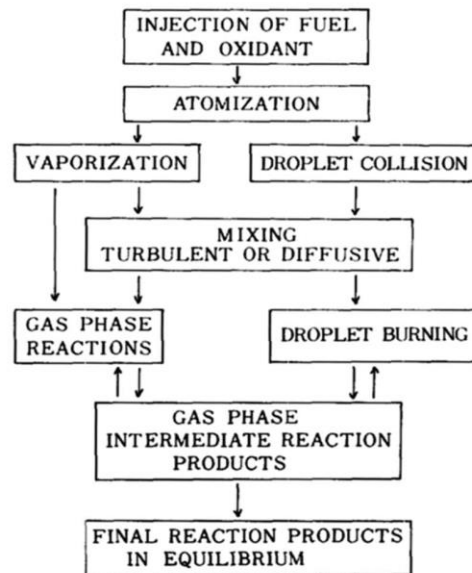


Figure 2.3 Combustion processes in a liquid fuel combustion chamber.

### 2.2.1 Spray combustion of liquid fuel

Spray combustion of liquid fuels is of considerable technical importance for various applications ranging from steam generation, furnaces, space heating and diesel engines to space rockets. Spray combustion alone accounts for a significant fraction of world's overall energy demand due to the importance of these applications. Spray combustion is an effective method of burning relatively non-volatile liquid fuels; in fact, even today, it is still the main method of

burning heavy oil, although they can be burned in a fluidized bed combustor. The basic process involved is the decomposition or atomization of liquid fuel to produce a spray of small droplets to increase the surface area, thereby greatly improving the heat and mass transfer rate during the combustion process. The difference between the fire aerosol and the premixed combustible gas system is that its composition is not uniform. The fuel exists in the form of discrete droplets, which can have a variety of sizes and can move in different directions at different speeds than the main gas flow. Due to the extreme inhomogeneity in the unburned mixture, the flame propagation through the spray is uneven, and the combustion zone is geometrically indeterminate.

According to the research of Warnatz, Maas and Dibble (2006), aerosol production, fuel evaporation, fuel mixture development, and mixture combustion are the four key processes for the combustion of liquid fuels. During the spraying procedure, the shearing force destroys the spray form, just as it does the gasoline blasted from the nozzle. The development of turbulent structures in the shear layer is analogous to this process (Clift et al., 1978). Liquid particles that aren't quite spheres are flung into the oxidants and combustion products' typical recirculating, turbulent flow environment.

Process of breaking down liquid fuel into droplets is called atomization. Atomization is an important part of liquid fuel combustion. Actually, liquid fuels must be atomized before combustion in most practical combustion systems, such as industrial furnaces as well as internal combustion engines. Due to the increased surface area to mass ratio of the fuel, atomization helps to increase the combustion efficiency of such systems, which leads to rapid evaporation and more uniform mixing with the oxidant, thereby improving heat and mass transfer mechanisms.

### 2.2.2 Atomization

Injecting liquid fuel into the combustion chamber via the sprayer allows the liquid to collapse to the droplet sprayer, which improves the transcribing process and uniform distribution of the majority of the liquid. The most feasible liquid fuel sprays have a wide range of droplet sizes with an average droplet diameter of 75-130  $\mu\text{m}$  and a size distribution in a wide range of droplet sizes (Bolle and Moureau, 1982).

The development of liquid, flow of the collapse induced by collision and friction of the tension of the collapse surface, and collapse owing to turbulent movement are the primary processes that make up atomization via spray (Stambuleanu, 1976). The atomization process of combining droplets and dividing owing to collision is carried out one step at a time, and the resulting droplets are unstable in the sense that they can be merged or divided. This droplet development instability can be a lively source of problem in the combustion chamber, leading to flame instability (Petela and Tysoska, 1982).

## 2.3 Combustion Characteristics of Fuel

This research involves the study of fuel combustion characteristics. Therefore, the combustion characteristics such as ignition delay, combustion rate constant, combustion duration and micro-explosion have been thoroughly reviewed. Many researchers have used the above parameters to discuss their experimental results. Therefore, the factors affecting these parameters were also reviewed.

- *Ignition delay*

Ignition delay is an important combustion parameter that has an impact on diesel engine performance and emissions. A shorter ignition delay period produces more diffuse

combustion than premixed combustion in the combustion process, resulting in less engine knock or noise, low nitrogen oxide (NO<sub>x</sub>) emissions, and high soot, whereas a longer ignition delay period produces more engine knock, high NO<sub>x</sub> emissions, and decreased dust and smoke (Haywood, 1988). To control diesel emissions, a blend of diesel and palm biodiesel can be used to balance these two extremes. The ignition delay was determined in this investigation by monitoring the time between the injection of heat from the glow plug and the droplet's ignition point. The longer igniting delay for gasoline combinations containing more palm biodiesel could be owing to biodiesel's reduced volatility and greater boiling point (Xue et al., 2011). Palm biodiesel takes longer to produce a combustible mixture of fuel vapour and air when heated to the same temperature. The existence of the double bonds in biodiesel molecules can potentially prolong the igniting process (Zhu et al., 2013). The greater ignition delay is usually not the first choice, because once the drop achieves ignite, the temperature gradient rises faster (Lapuerta et al., 2008). NO<sub>x</sub> development will be aided by the high combustion temperature. Nonetheless, because palm biodiesel has a higher cetane number, burning the fuel combination in a real engine can result in a shorter ignition delay (Canakci, 2007).

- *Burn Rate*

When a fuel burns at a faster rate, it undergoes more complete combustion. The term higher burn rate relates to how quickly the combustion process is completed and how complete it is. As a result, the heat created by the fuel is not lost to the combustion chamber when the combustion time is shortened. It is indeed advantageous for diesel engines to burn more fuel at a faster rate. Because the fuel will be recorded, the burn rate is one of the most important aspects of the diesel engine. Tall combustion, in general rate, shortens the time



it takes for the fuel to burn, which reduces heat dissipation through the motor wall and improves the motor's thermal efficiency (Ooi et al., 2017). Furthermore, the high combustion liquid is linked to the reduction of diesel emissions. Carbon monoxide and smoke emissions, for example (Heywood, 1988). The increased oxygen content of palm biodiesel can be linked to the rise in burns when it is introduced to the fuel mixture (Zhu et al., 2013).

As a result, the  $D^2$  law can be used to define the rate of burns. The droplet size of the fuel will be lowered throughout combustion, and micro-explosions may occur right at the end of the burning process. The presence of micro-explosion in the burning process might increase the burn rate. For future research, plotting the graph of the ratio of droplet size against time could be used to calculate its fuel's burn rate constant (Javed, Baek and Waheed, 2015).

- *Micro-explosion*

During the combustion process, a droplet of fuel breaks down into even smaller droplets, causing such an occurrence. As a result, the whole droplet will finish burning at a quicker rate. The fuel's mixture components play a big role in the level of micro-explosion (Wang, Liu and Law, 1984). The incidence of micro-explosion is caused by the high concentration of fuel confined within the droplet as it shrinks.

- *Combustion Duration*

The duration of combustion is determined by the diesel engine's thermal efficiency. A shortened burn time is beneficial because it reduces heat loss through the engine's cylinder wall, enhancing thermal efficiency (Heywood, 1998). Between the commencement of

ignition and the end of the burning droplets, the duration of the flaming droplets was measured in this investigation.

## **2.4 Droplet Combustion**

Generally speaking, there are two main research methods of spray combustion. The first method depends on the interpretation of the actual combustion process through the idealized spray or the combustion of individual fuel droplets. The second method involves directly observing the combustion of the spray through experimental studies of various effects and related parameters such as radiation, stability, flame oscillation, and flame length.

There are generally two forms of droplet combustion, one-element droplet combustion and two-element droplet combustion. The first type describes the combustion of fuel which is known as monopropellants that does not require a separate oxidizer. Examples of monopropellants include hydrazine and its derivatives (Ambekar et al., 2014). Although the second type involves the burning of fuel droplets with the help of an oxidizer, it is more widely used in many industrial applications than the first type.

### **2.4.1 Classical $D^2$ Law**

Godsave and Spalding (1953) created the classical theory, is the original and most basic model for modelling droplet evaporation and burning is termed as the  $D^2$  law of droplet combustion. The classical theory demonstrates basic physics and offers a basic hypothesis concerning droplet regression rate. The fuel droplet in this model is subjected to a static oxidising atmosphere. In a non-premixed flame, each droplet evaporates at its surface, yet this generated vapour diffuses outwardly and reacts with the oxidizer that has been diffusing inwardly due to

circumstances. Mostly in the flame zone, the fuel vapour and oxidizer devour each other, just like in a stoichiometric reaction. Heat produced by the reaction is channeled inwardly into the droplet and outwardly into the surroundings. Thus, the heat directed at the droplet will provide the energy required to keep the droplet evaporating and the combustion running till the entire fuel droplet has been consumed. Conduction and radiation transmit the generated heat from the flame to the surroundings as well as the droplet surface. Figure 2.4 depicts the assumptions that were used to develop the classic  $D^2$  law.

I	Isobaric process.
II	Chemical reaction is infinitely fast with respect to diffusion.
III	Gas phase quasi-steadiness.
IV	Buoyancy is negligible.
V	Spherical symmetry.
VI	Constant droplet temperature.
VII	Ignores Soret effect, Dufour effect and radiation.
VIII	Constant gas phase transport properties and heat capacity.
IX	Isolated droplet in infinite medium.
X	Unity Lewis number for all gaseous species.
XI	Radiation is negligible.

Figure 2.4 Assumptions made in the classical theory of droplet combustion (Godsave, 1953).

The classic  $D^2$  law states that flame stand-off region, burning rate of droplet, as well as temperature flame remain unchanged during the droplet burning lifespan, as can be seen in Figure 2.4, and are specified by equations:

Burning droplet's mass burning rate can be calculated as below:

$$m_F = \frac{4\pi k_g r_s}{c_{pg}} \ln[1+B]$$

Equation 2-1

Temperature of flame is explained in terms of surface temperature of droplet, fuel characteristics, as well as stoichiometric fuel or air mixture:

$$T_f = T_s + \frac{q_i + h_{fg}}{c_{pg}(1+v)} [vB-1]$$

Equation 2-2

On the other hand, the radius of the flame is obtained by multiplying the radius of the droplet of flame's, which can be seen in equation (2-3). The flame stand-off ratio of droplet combustion is defined as ratio.

$$\frac{r_f}{r_s} = \frac{\ln[1+B]}{\ln\left[\frac{1+v}{v}\right]}$$

Equation 2-3

The mass fraction of fuel at the surface area of the droplet has been calculated as shown in the equation:

$$Y_{F,S} = \frac{B-(1/v)}{B+1}$$

Equation 2-4

The following is the definition of the Spalding transfer number (B):

$$B = \frac{(\Delta h_c/v)c_{pg}(T_\infty - T_s)}{q_i + h_{fg}}$$

Equation 2-5

In terms of fuel characteristics and transfer number, the burning rate constant of droplet combustion is calculated by using the following:

$$K = \frac{8k_g}{P_t c_{pg}} \ln[1+B]$$

Equation 2-6

It depicts the droplet size fluctuation's slope over time and is only true at the steady state. As a result, the general equation for fluctuating droplet sizes over time is:

$$D^2(t) = D_0^2 - Kt$$

Equation 2-7

The  $D^2$  law of droplet combustion is the name given to the equation (1-8). The overall droplet lifespan is then calculated by allowing for  $D^2(td) = 0$ :

$$t_d = \frac{D_0^2}{K}$$

Equation 2-8

The description of the classical theory of droplet combustion aided the estimation of burning rate of the droplet, temperature of flame as well as radius, and on-surface fuel concentration, is indicated in the equations above. The predictions, on the other hand, indicate approximations which are also known as instead of real values. That's because the theory was built using approximations, which streamlined the solution but left out the impact of certain physical and chemical processes that might occur during the combustion of actual fuel droplets. For instance, the quasi-steadiness assumption removes time dependent factors from conservation equations while also excluding transitory procedures like droplet heating, ignition, and flame

reduction. As a result, instead of precise calculations, the values predicted by the classical theory of droplet combustion could be employed as a first approximation.

## **2.5 Additives**

The additives are generally introduced into fuel to form multicomponent fuel for a particular purpose and can achieve the desired fuel properties that operate optimally for specific applications. There may be multi-component fuel or fuel in three different forms, such as a mixture, as a diesel mixture with alcohol, such as a mixture of carbon and water, or an emulsion, like an oil and a water chest. There most of the fuel in the market is used in the form of a multicomponent fuel instead for some reasons. Mainly, they are used to improve the performance of the combustion system from the point of view of the combustion efficiency when introducing fuel that has higher heating values. Next, it is used to minimize the emission of contaminants of harmful conventional fuels for the environment.

### **2.5.1 Biodiesel**

Biodiesel is a contemporary cleaning fuel made from fat, vegetable oil, as well as animal fat. The chemical structure is a fatty acid alkyl ester. Biodiesel is produced by the exchange of esters or the esterification of fatty acids having a short alcohol. The transesterification reaction consists of triglycerides such as methanol or alcohols such as ethanol, and catalysts such as alkali or acids, such as catalysts as byproducts (Hoydoncx et al., 2004). Chemical reactions according to the supercritical conditions have also been proposed without using a catalyst (Saka et al., 2001).

Biodiesel, particularly, has gotten a lot of interest as a diesel fuel substitute since it is biodegradable, non-toxic, and when burnt as a fuel, it can dramatically cut exhaust emissions and

carbon dioxide (CO<sub>2</sub>) emissions during the engine's full life cycle. Biodiesel use in diesel engines has been found in numerous studies to lower hydrocarbon (HC), carbon monoxide (CO), and particulate matter (PM) emissions while increasing nitrogen oxide emissions (NO<sub>x</sub>) (Agarwal et al., 2006; Avinash & Rajamanoharan, 2009). Because of the excessive oxidation of hydrocarbons, the oxygen content of biodiesel is an essential element in the generation of NO<sub>x</sub>, since it causes locally high temperatures. The higher the oxygen content, the higher the peak temperature during combustion and the more nitrogen oxide is produced (Ahmet et al., 2017; Raheman and Ghadge, 2007). Even in local fertile areas, a slightly higher cetane number, shorter ignition delay and thus lower temperature in the premixed combustion phase, and the absence of aromatics appear to help reduce NO<sub>x</sub> production, but these factors do not appear to compensate for the presence of oxygen increased fuel (Rakopoulos et al., 2008).

The advantages of biodiesel are few. It is, first and foremost, renewable. Biodiesel fuel can be produced in large quantities from a suitable culture of plants, algae, or bacteria. Second, it's also recycled. The majority of biodiesel sold today is made from discarded vegetable oils. Third, domestic production has lessened reliance on imported fossil fuels and boosted the agricultural sector in rural areas. Finally, when compared to petroleum-based diesel, it emits less pollutants, burns cleaner, and has no sulphur, therefore it emits no sulphur dioxide.

There are almost no disadvantages of biodiesel. First, because biodiesel manufacturing infrastructure is still lacking on a broad scale, it is now more expensive to generate than oil diesel. Moreover, biodiesel is prone to cold weather, therefore gelling as the temperature drops, which can be remedied by replacing the costly engine. Some diesel vehicle engines may run biodiesel with only minor adjustments or no adjustments at all, whereas biodiesel does not run-in regular

gasoline engines. Last but not least, biodiesel manufacturing raises food prices in both biodiesel-producing food crops and biodiesel-producing algae and raw materials for bacteria.

In-depth study of biodiesel types, palm biodiesel is a potential candidate for sustainable fuel that can be used in IC engines. Palm biodiesel provides economic advantages over biodiesel made from vegetable oils due to its energy production and lower pricing (Yap et al., 2019).

### **2.5.2 Palm Biodiesel - Diethyl Ether Blend**

Experiment that was conducted by Ali, et al. (2016) to study the spray characteristics of biodiesel-diethyl ether blend through the visualization of spray and analysis of droplet size. Several researchers tested a blend of diethyl ether (DEE) and biodiesel to reduce emissions. Engine performance and emission characteristics can be improved by using DEE and a lower amount of rubber seed biodiesel (Ramadhas et al., 2008). However, (Pugazhivadivu and Rajagopan 2009) experiments have shown that combining 20% DEE to Pongamia biodiesel and diethyl ether as a fuel is more conducive in lowering nitrogen oxide than other combinations. Similarly, according to Kannan and Marappan (2010), the 20% DEE blend offers higher performance and fewer emissions than other combinations when added to Thevetia Peruviana biodiesel, according to their research. Swaminathan and Sarangan (2012), on the other hand, stated that a mixture of fish oil biodiesel (BOF) and 2% DEE may reduce all damaging emissions and that running engines with exhaust gases recirculation (EGR) is the best alternative.

Generally speaking, biodiesel created from palm oil differs from other biodiesel and mineral diesel derived from other organic sources. Palm oil has a higher density and viscosity than mineral diesel (Pradeep & Sharma 2007). To assess the features of biodiesel when powered by traditional diesel engines, it is required to incorporate the physical characteristics data of biodiesel



and its mixed fuels. In compression ignition engines, the physical qualities of the fuel are essential elements in the atomization process. The quality of atomization of the fuel injection into the combustion chamber, the size distribution of the fuel droplets, and the homogeneity of the mixture are all influenced by viscosity. The disintegration of the liquid spray into smaller fuel droplets is also affected by increasing surface tension.

The characteristics of blended palm biodiesel fuel with diethyl ether additives were investigated and addressed in this study. All the properties provide critical information for future research into the performance, combustion, and emissions of engines that run on these fuels.

## **2.6 Experimental Approaches**

Normal gravity, microgravity, and freefalling are the three situations in which the droplet combustion experiment can be carried out. Kumagai and Isoda (1957) conducted the first microgravity-conditioned droplet combustion to test the  $D^2$  law's spherical symmetry assumption by neglecting the buoyancy effect and possibly even the effect of heat convection on droplet burning rate. A nearly perfect spherical droplet could be sustained throughout the burning time without gravitational disruption. The utilisation of a low-gravity environment is required for this procedure. Therefore, this research is important for investigating the burning behaviour of fuel for uses in outer space, such as spacecraft engines, where safety issues for fuel consumption in microgravity conditions are taken into account (Hu et al., 2012).

The next droplet combustion approach is to conduct the experiment in a free-falling environment, such as a flat-flame burner or a hot furnace chamber, where the fuel droplets are permitted to fall in a post-combustion region (Wang, Liu and Law, 1984). When a droplet approaches the combustion zone, it is able to ignite by itself. The combustion environment, and

perhaps even the condition of the droplets, can be modified in this situation. As an example, the size and velocity of the droplets, as well as the combustion temperature, can all be regulated.

Lastly, droplet combustion under normal gravity is the most easy and cost-effective way. The majority of studies have used the suspended droplet method to execute single droplet combustion under normal gravity conditions, in which the fuel droplet is suspended on a droplet suspender made of silicon carbide fibre, steel wire, or even the thermocouple wire. The interpretation of this single droplet combustion experiment should include assumptions for the classical  $D^2$  rule, such as quasi-steady state condition as well as spherical symmetry throughout the burning, as shown in Table 2.4 (Williams, 1990).

## 2.7 Summary

It's vital to know the burning characteristics before analysing the results of the experiment. When calculating the fuel's efficiency, ignition delay, burn rate, duration of combustion, and micro-explosion are all important factors to consider. B7 was employed as the base fuel, with diethyl ether added as an additive to investigate the improvements in burning behavior. Due to its capacity to depict the fuel droplet in the combustion chamber using the assumptions provided, the single droplet combustion experiment was utilised to analyse the test fuels. This experiment has a cheaper setup cost without compromising the quality of the fuel droplet burning behavior data. It is preferred to have a shorter ignition delay, a higher burn rate constant, a shorter combustion duration, and more micro-explosion events to improve the efficiency of a diesel engine. As a result, the experimental work and results are discussed in the following chapters. In Chapter 3, complete descriptions of the experimental setup, as well as the work plan, will be addressed, in addition to

image processing methods for analysing and computing the combustion parameters of palm biodiesel-diethyl ether fuel blends.

## CHAPTER 3

### METHODOLOGY AND WORK PLAN

#### 3.1 Introduction

The main objective of the experiment is to investigate the characteristic of the combustion characteristic of Palm Biodiesel Diethyl Ether Blends. The entire experiment is done on a self-built test chamber and distinguishes a single droplet of fuel throughout the flaming process. The entire burning lifetime process is captured on high frame per second image via a DSLR camera. There are several important criteria's to be focused on and will be further discussed. In section (3.2) which are equipment and materials used to conduct the entire experiment. Followed by section (3.3) the preparation of fuel is the key important aspect of the experiment. Next section (3.4) will be the configuration of the experiment apparatus. In section (3.5) the step and workflow of the experiment from beginning till the end.

#### 3.2. Constructing the Testing Equipment

There are several materials and tools needed to construct the test facility. For this experiment an electrical distribution board made of metal box was used which is safer and rigid. A 5W 5V light was used to illuminate and create the shadow effect of the burning flame. Next a 0.5mm wire is used and secured inside the DB box in the cross section where the midpoint will be the location to place the fuel. Alongside a DSLR Nikon D7000 were used to capture the flame. For powering up the test equipment, a 50Watt solar panel and solar controller were used, along with a 12V 60Ah battery to store the power. For the heat generation to light up the fuel, a Toyota 12V glow plug is used. A handheld temperature shooter used to capture the glow plug temperature.

On the other hand, a different range of syringe used to prepare the fuel, syringe 1ml, 3ml, 5ml, 10ml, measuring cylinder, Biodiesel B7, Diethyl - Ether blends.



Figure 3.1 Biodiesel B7 & Diethyl Ether

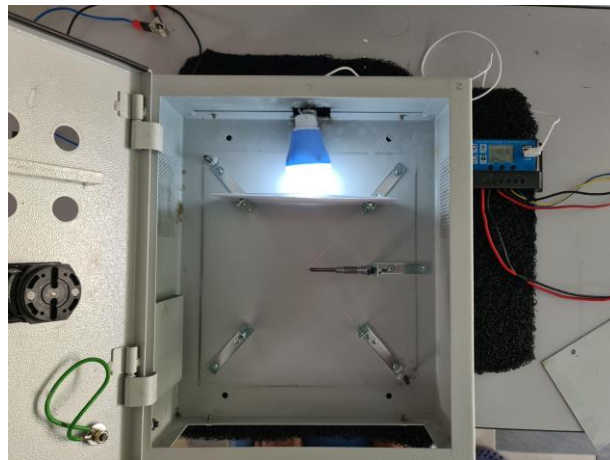


Figure 3.2 Self-made combustion chamber



Figure 3.3 Solar Controller - Charge battery and supply constant 12 V



Figure 3.4 Medical Syringe



Figure 3.5 Infrared Thermometer for ensure Glow Plug is producing expected heat



Figure 3.6 Glow Plug



Figure 3.7 12VDC 75AH Battery

### 3.3 Preparation of fuel

Since the whole experiment is on fuel characteristics it is very important to ensure the mixture of Biodiesel B7 and Diethyl - Ether is done with accuracy. All the mixture is measured in volume-to-volume ratio, as for example a 50ml of biodiesel will consist of 45% of Biodiesel added with 5% of Diethyl Ether. Fuel is measured by syringe and added into the measuring cylinder to ensure the amount is correct. In total there are four fuel samples in place, pure Biodiesel B7, Biodiesel B7 95% + Diethyl Ether 5%, Biodiesel B7 93% + Diethyl Ether 7%, Biodiesel B7 91% + Diethyl Ether 9%.



<b>FUEL SPECIFICATION</b>	
<b>Boiling point</b>	175.6°C - 370°C
<b>Viscosity</b>	1.90 cSt - 4.10 cSt (40°C)
<b>Explosion limit</b>	0.6 – 4.7% (V)
<b>Flash point</b>	52°C
<b>Ignition temperature</b>	257°C
<b>Specific gravity</b>	0.80 - 0.88 (15.6°C)
<b>Vapour pressure</b>	0.04kPa (40°C)
<b>Autoignition</b>	257°C

Table 3.1 Fuel Specification

<b>FUEL SPECIFICATION</b>	
<b>Boiling point</b>	34.6 °C (1013 hPa)
<b>Density</b>	0.71 g/cm <sup>3</sup> (20°C)
<b>Explosion limit</b>	1.7 - 36% (V)
<b>Flash point</b>	-40°C
<b>Ignition temperature</b>	180°C
<b>Melting Point</b>	-116°C
<b>Vapour pressure</b>	563hPa (20°C)
<b>Solubility</b>	69g/l

Table 3.2 Diethyl Ether Specifications

### 3.4 Self-made experiment equipment setup

A schematic diagram has been shown of the experiment setup (Figure 3.8). As per the schematic diagram, the power is delivered completely by natural resources. During daytime the Solar Panel is activated by sunlight, the cells in it produce current. The current is sent to the Solar controller which stores power in the battery and at the same time provides constant 12V to the experiment module. The experiment module has an opening at the bottom to allow light to pass in and for the camera to capture the image. The glow plug is placed close to the intersection where the metal wires meet. On the intersection the test fuel droplet is placed. Upon the fuel is

ignited the glow plug will be moved to capture the fuel burning image properly. The repetition test will be done after every 10 minutes, the time needed for the glow plug to cool down. A Nikon D7000 DSLR camera used to capture high resolution images.

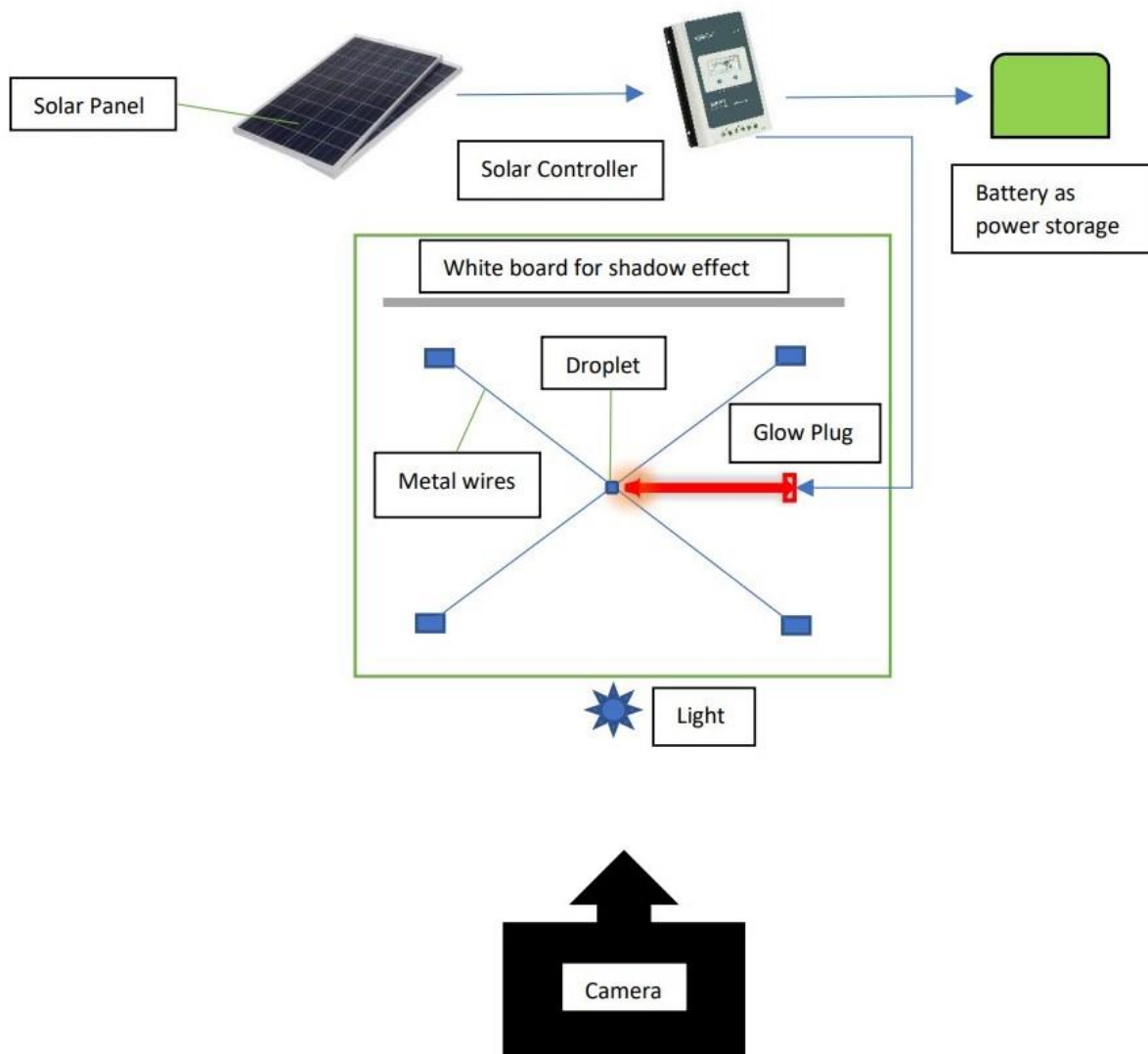


Figure 3.8 Schematic Diagram Experiment Chamber

### 3.5 Procedure for the Experiment

Since the experiment chamber has some openings and in a way, it has direct influences from outside temperature a few control measures were taken. Considering fuel and other potential fire threats are involved, the whole experiment was set on an open space, in order to get a constant result the surrounding temperature will be measured before the experiment took place. Only when the surrounding temperature measures between 27 to 28 °C, experiment will be started. During daytime the Solar panel will be able to generate power to charge up the battery and the solar controller able to produce constant 12V for the glow plug to function.

New fuel mixture will be done every time a new experiment is made. The fuel mixture will be transferred to a Syringe with a needle. A small drop of fuel will be placed where the intersections of wires meet.

Next the internal lamp will be turned on to the minimal lumens and observed via DSLR camera if needed camera setting will be done for capturing the perfect shot. Once the camera starts to roll and other conditions are satisfactory, the glow plug will be powered until it reaches red hot. The heated glow plug will be moved towards the fuel droplet at a gap of 4 to 5mm distance. As soon as the fuel ignited glow plug will be removed to void the continuous heat source.

This process will be repeated throughout the experiment, there will be a 10minutes time gap for each experiment. Two significant reasons are, one for cooling down the glow plug and another is to clean up the wire which contains soot and debris.

## CHAPTER 4

### RESULTS AND DISCUSSION

#### 4.1 Introduction

This experiment as a whole is to identify and tabulate data by igniting fuel droplets and capturing the entire process by high speed camera. Fuel mixtures as explained earlier on Chapter 3.3, will be placed on a crossed wire, the fuel will be ignited with a heat source from a glow plug. The heat source will be removed right after the fuel has been ignited. The high speed camera is placed to capture the process, where later when the video is played in a lower frame by frame image, the condition of the fuel and characteristics will emerge. The findings are crucial to identify burning rate, ignition delay and micro explosion.

#### 4.2 Micro-explosion

Micro-explosion seems to be a critical combustion behavior that allows fuel droplets to break into tiny droplets, allowing them to burn more quickly and cutting down on combustion time. Evaporation and fuel-air mixing may also be aided by the smaller fuel droplets. Heterogeneous nucleation at the droplet surface is the primary cause (Yap, et al., 2019).

The subsequent atomization of the original spray induced by the rapid evaporation of liquid present in an oil drop is also known as micro-explosion (Ballester, et al., 1996). The liquid in the emulsion fuel is positioned in the emulsion's internal phase for a clear statement. As the emulsion fuel is sprayed into such a high-temperature environment, like the combustion chamber, heat will be directly supplied to the surface of the emulsion droplet. Liquid and diesel liquids, on the other hand, have varying volatility and boiling temperatures. Due to the incredibly slow diffusion velocity of a liquid, this diesel fuel would form mostly on the droplet's surface,

enveloping as well as trapping the dispersed liquid droplet inside. Rapid bubble nucleation happens when the temperature of the liquid on the inside of the emulsion droplet reaches superheat, resulting in the liquid droplet expanding and exploding. As a result, the droplet is shattered into tiny fragments (Hagos Rashid, Isa, 2011). As a consequence, more of the fine droplets' surface area can be exposed to the air, which improves the fuel and air mixing technique. Consequently, the efficiency of combustion will improve (Ocampo, et al., 2001).

Depending on the beginning and degree of micro-explosion, On the diesel engine, the influence and effectiveness of liquid/diesel emulsion fuel may vary. The onset of the micro-explosion is the time between when fuel will be injected and when micro-explosion will get started. The intensity of the explosion is done by comparing the droplet's explosive, which breaks and ejects tiny particles as can be seen in shadowgraph.

A variety of factors influence the onset and intensity of the micro-explosion process. First, size of the dispersed liquid component may have an impact on the micro-explosion's strength. With increasing particle size, the emulsified liquid's ability to disperse the oil droplet rises. Whereas if the liquid is dispersed in very small particles all throughout oil, the droplet only experiences a minor explosion, according to the authors. Furthermore, From the main droplet, only a very few fuel particles are expelled. As a result, droplet is still present after the rest of the liquid has evaporated, but it has lost little of its bulk. According to the researchers, far more liquid would evaporate if the particle size is large, leaving inadequate liquid. Therefore, the explosion's strength will be affected.

Second, the severity of the micro-explosion is affected by the size of the emulsion droplets employed to spray fuel into the combustion chamber. Because of the remaining liquid mass is insufficient or will disappear before the droplet reaches saturation temperature, a mild

micro-explosion occurs (Zeng and Lee Chia, 2007). The size of the initial emulsion droplet influences the commencement of the micro-explosion process. As the droplet size grows bigger, the micro-explosion happens sooner. This is because the mass fraction differential between the middle and the surface is bigger for larger droplets. As a result, the superheat zone is easier to develop, allowing for a faster micro-explosion.

Then there's the emulsion's liquid content. The onset and strength of the micro-explosion are influenced by the percentage of liquid in the emulsion. The nucleation storage energy is lowered when the liquid content in the emulsion is too low, according to the study, resulting in mild micro-explosions (Fu, et al., 2002). Followed by ambient temperature. The superheat temperature just before micro-explosion, according to Watanabe et al. (2010), has a substantial impact on the micro-explosion technique. Once the ambient temperature is too low, micro-explosion does not occur, according to Sheng et al (1995). Micro-explosion would happen once the ambient temperature gets higher. The reason seems to be that ambient temperature has the impact of speeding up the micro-explosion activity. The ambient pressure will be the final factor to consider. A few studies have looked into the impacts of ambient pressure on the micro-explosion process. Pressure has no significant impact on the micro-explosion process, according to W.B. Fu (2011). Nonetheless, the authors suggest that increasing the pressure will boost the heavy component's boiling point and increase the likelihood of micro-explosions. The researchers went on to note that as pressure rises, so does the gas's solubility, hastening the onset of the micro-explosion.

In current times, it has been identified that not much research or studies have been conducted on micro-explosion using the diethyl ether. However, there are several studies on micro-explosion that were conducted using ethanol and butanol. As an example, Chai Shen et al. (2011)

conducted a micro-explosion experiment utilising biodiesel and ethanol/butanol. According to the results of droplet properties at the commencement of micro-explosion for ethanol/butanol-diesel/biodiesel fuel blends, micro-explosion will be possible under engine operation circumstances. For micro-explosion to occur, the droplet size and ambient conditions must be just right. Therefore, to get a bigger perspective and view of outcomes, the usage of multiple and various liquids shall be used such as diethyl ether would be one of them.

Based on the experiment micro explosion is noticeable, and the greater DEE mixture the greater Micro - Explosion. This happens as DEE is higher on volatility, when the heat source is being delivered DEE becomes superheated to convert to small particles ejecting itself from the fuel drop placed on the wire.

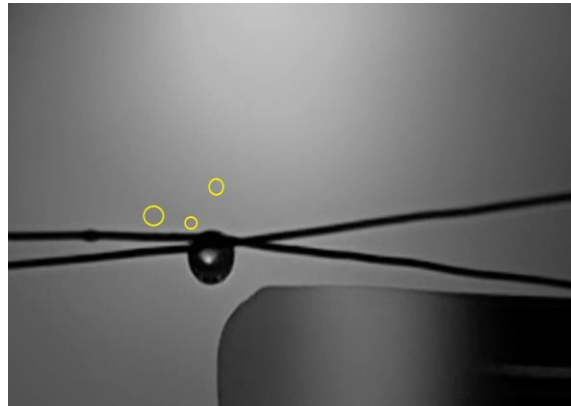


Figure 4.1 Pure Diesel Micro Explosion



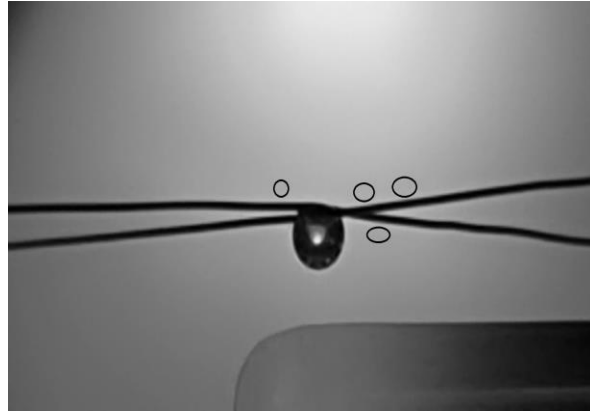


Figure 4.2 7% Micro Explosion

From the experiment it is noticed the moment the fuel source was set close to fuel drop, the fuel ignited much more faster than the rest. Micro-explosion was not able to be seen as the fuel ignited also instantaneously.

### 4.3 Ignition Delay

During the preheating phase, ignition delay is an important combustion feature to analyze. The ignition delay in this study refers to the time between adding heat to the fuel droplet as well as the initiation of droplet ignition. In a nutshell, it's the amount of time it takes for a fuel droplet to absorb enough heat from a spark plug to begin burning. Shorter ignition delays are favoured for diesel engines because they allow for even more diffusion burning all throughout complete combustion rather than premixed burning, which results in decreased engine knock and nitrogen oxide emissions.

Almost the majority of the research found that a biodiesel-diesel mixture ignites more quickly than diesel fuel. The ignition delay decreased under all loads as the proportion of diethyl ester biodiesel in the blend increased, according to a research. This is due to oxygen concentration of diethyl ester biodiesel, wherein improves ignitability by splitting the larger fatty acid molecules

present in diethyl ether biodiesel into even a smaller compound, resulting in more volatile matter and, as a result, it causes early ignition. According to Jafari et al. (2019), longer ignition delays as well as greater engine speeds can enhance the nucleation of certain emissions. As the oxygen content rises, aggregate compactness of unburned carbon rises. Fuel oxygen concentration reduces the particle mass as well as amount of soot particles.

The factors that influence the delay process can be divided into two categories. Engine design parameters and fuel characteristics are what they are;

Let's start with the design parameters for the engine. The injection time, pressure, as well as temperature in combustion chamber during fuel injection all affect the ignition delay. With advanced as well as retarded fuel injection timing, longer and shorter delay times were reported, respectively. Injection pressure, injector nozzle hole size, nozzle variety, and geometry all influence drop size, injection velocity, and injection rate. At normal engine circumstances, changes in nozzle type like multihole, pintle, and pintaux had no significant effect on delay (Heywood 1989). As a result, this variable's effect is ignored. The compression ratio decreases delay duration as the temperature rises. The temperature as well as pressure of air in the cylinder, and thus the ignition delay, are directly impacted by the bore, stroke, and clearance volume of an engine. The delay will decrease nearly linearly as the engine load increases. Because the load increases, both the remaining gas temperature and the wall temperature will rise too. As a result, the injection air temperature is higher, reducing the ignition delay.

Next, fuel characteristics. Fuel characteristics determine the chemical delay of ignition delay, hence their impact on ignition delay is critical. The cetane number would be used to determine how well compression ignition (CI) engine fuel ignites. As the cetane quantity rises, the ignition latency falls almost linearly. In fully or partially warmed up engines, the physical

properties of the fuel have no effect on the ignition delay. In testing employing fuels with various front-end volatility and dramatically different front-end ignition quality, there were no discernible differences. A 2.5-fold change in fuel viscosity was also investigated, but no discernible effect was detected. In a warmed-up engine, differences in fuel atomization, spray penetration, and evaporation rate don't appear to have a significant impact on the duration of the delay period.

In the experiment Biodiesel combined DEE, the data from the Table 4.1 clearly shows gradually decreasing of ignition delay as more of DEE percentage were added into Biodiesel.

Fuel Type	Time to Ignite
Biodiesel	1s 500ms
Biodiesel + DEE 5%	960ms
Biodiesel + DEE 7%	880ms
Biodiesel + DEE 9%	325ms

Table 4.1 Time taken for fuel to ignite

#### 4.4 Burn Rate Constant

Another key combustion characteristic in CI engines is the burn rate constant, which determines how rapidly the combustion process occurs. In general, a higher burning rate suggests a shorter combustion time, which aids in limiting heat losses through the combustion chamber wall and, as a result, boosting the engine's thermal efficiency (Ooi, et al., 2017).

The combustion rate is one of the key parameters of diesel engines, because it determines the combustion rate of the fuel. Generally, a high combustion rate will reduce the

duration of fuel combustion, as a result, heat dissipation through the cylinder wall of the engine is greatly reduced, enhancing the engine's thermal efficiency. Furthermore, the high combustion rate can also be attributed to clean diesel emissions such as reduced carbon monoxide and smoke emissions.

There are four factors that affect the rate of combustion. The first is pressure in the combustion chamber. Since grain is burned in the combustion chamber, rate of combustion is generally affected by the pressure in the combustion chamber. Since the pressure at the lower end of the pressure range has a low sensitivity to burn rate, the high pressure index is undesirable. For these reasons, there may be difficulties in starting the engine. This means that the combustion is proportional or linearly proportional to the pressure in the combustion chamber. Second, the temperature. Temperature affects the rate of chemical reactions, so the initial temperature of the propellant grains affects the rate of combustion.

The next factor is the speed of the combustion gas. The increase in the propellant burn rate is caused by the high velocity flow of gas from the combustion chamber onto the surface of the burning propellant. Increasing the burning rate is achieved by increasing the burning rate of the gas. This improvement process is called erosive combustion. Aggressive combustion increases the mass flow and therefore also increases the pressure and thrust of the combustion chamber in the early stages of combustion. Since the propellant is consumed more quickly during the erosion combustion process, flow and thrust are reduced at the end of combustion. The last factor that affects the rate of combustion is the acceleration and rotation of the engine. In vehicles where the rocket motor rotates around the longitudinal axis or has high lateral or longitudinal acceleration, an increase in the rate of combustion can be expected, which usually occurs in anti-missile rockets. The accelerated combustion behavior of propellants for new engine designs is often determined

by small engines. Embedding metal wires or other forms of good metal heat conductors in the propellant particles can also increase the burning rate.

Based on experiment Biodiesel + DEE 9% has better burn rate the fuel droplet was spherical in shape throughout the burning process. From the very second the fuel was ignited till the burning completion, the period was taken shorter compared to the rest fuel ratio.

A line drawn between two points of known distance from the image of burning fuel. The measurement is at first will be given in pixels since the image is on RAW format. Multiple points of measurement taken in order to get an appropriate data. The known data entered to convert the pixels reading into mm readings. The figure 4.3 shows each and every droplet of fuel measured using Image J software.

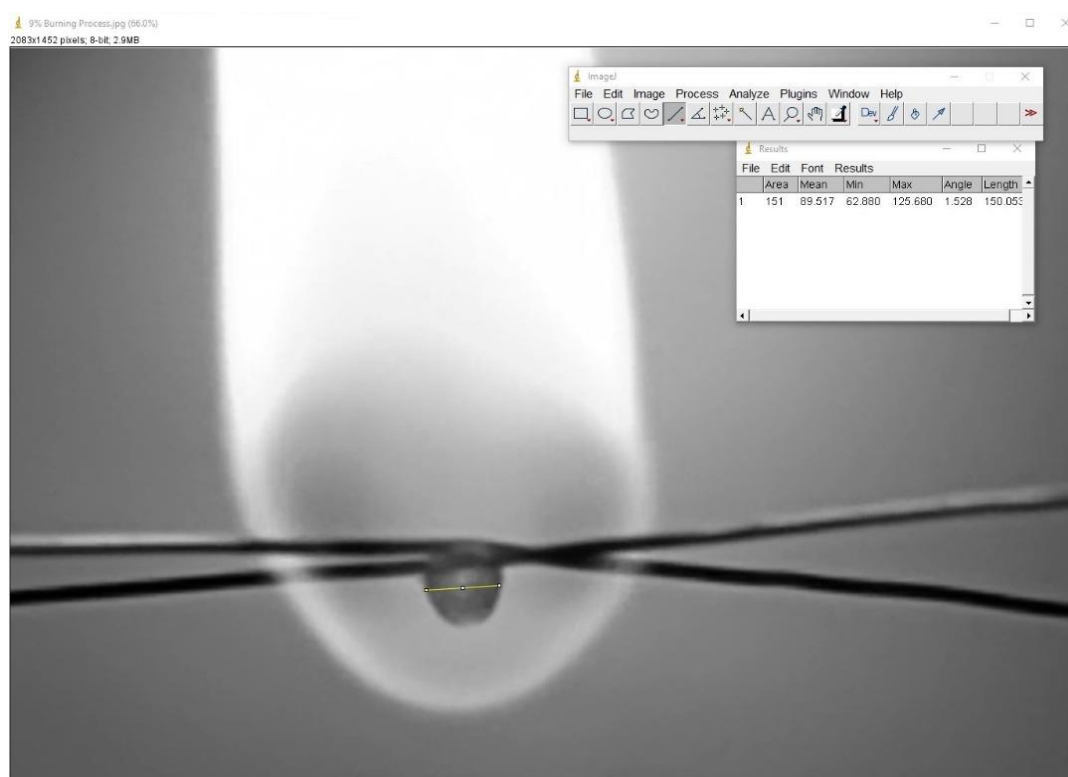


Figure 4.3 Image J software measurement of single droplet fuel

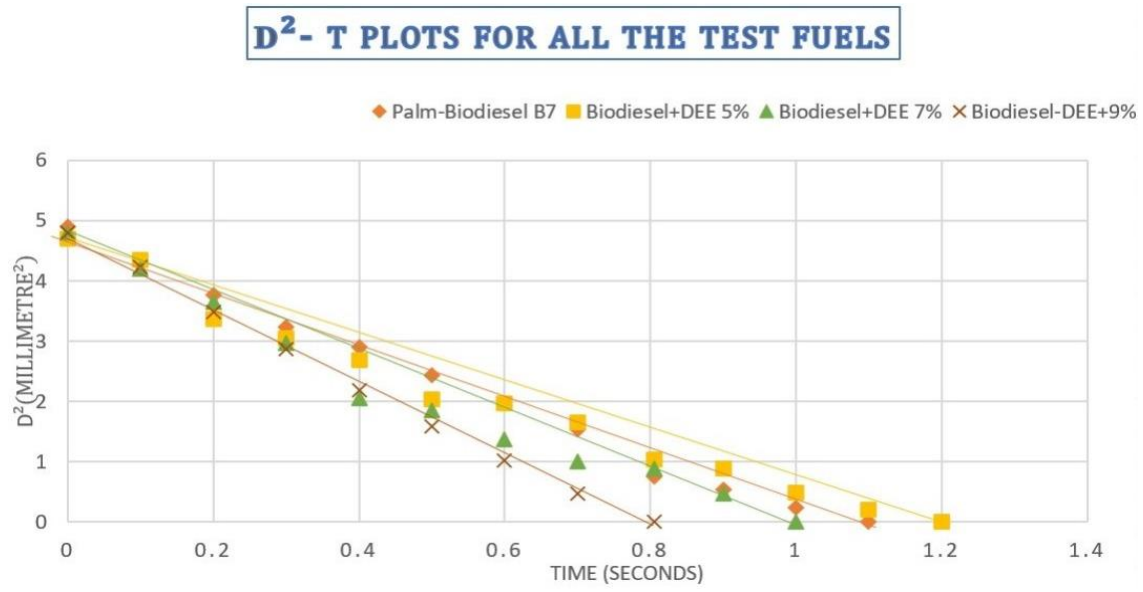


Figure 4.4 D<sup>2</sup>-t plots for all the test fuels

The results of the burn rate constant for all of the test fuels are shown in Figure 4.4. From the graph is visible that the burn rate is improving with the mixture of DEE increases with palm biodiesel B7. The pure biodiesel has the lowest burn rate subsequently by 5%, 7%, and 9% mixture of DEE. The most obvious improvement shows when the droplet of 9% tested. The graph line resulted in a constant burn rate. The reasons are due to volatility and evaporation of DEE is faster thus the overall combustion process is improved with 9% mixture.



Figure 4.5 Heat is applied

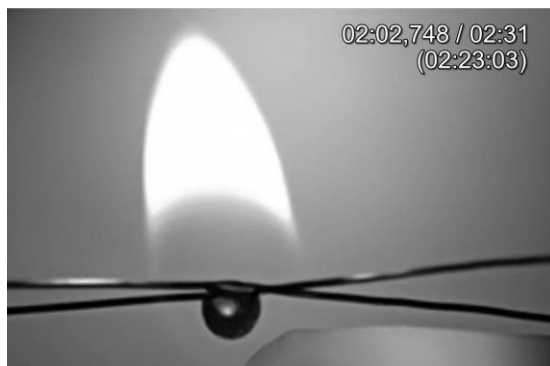


Figure 4.6 Ignition has started

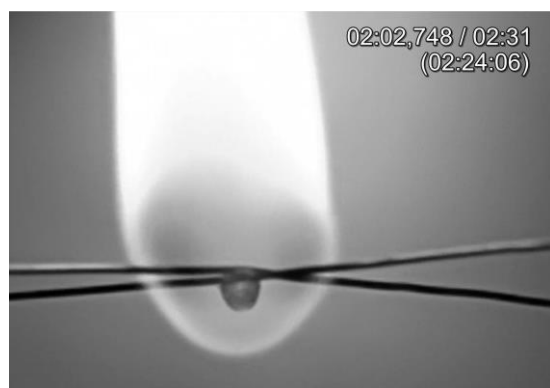


Figure 4.7 Fuel is burning and the shape is spherical

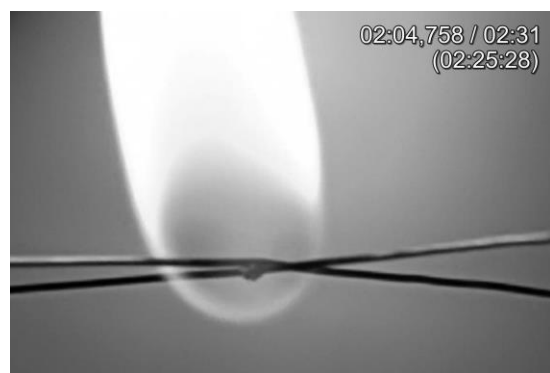


Figure 4.8 Towards the end of the burning life of the fuel

When compared to pure Biodiesel, the ignition was delayed and the flame period was longer compared to Biodiesel + DEE 9%. This relatively due to more oxygen is when added with 9% of DEE, thus increasing flaming and providing constant burning compared to the rest. Another significant result was the combustion duration was the shortest among all, helping better for CI engines.



## CHAPTER 5

### CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 Conclusions

As the world requires better and alternate fuel sources, it is necessary to constantly perform research to provide the needs of replacement of fossil fuel. In the interim fuel additive also plays a major role in consuming less fossil fuel. As per the experiment adding DEE with Biodiesel B7 has shown many positive improvements. Referring to micro-explosion, it is a crucial mechanism which will dramatically improve the evaporation process and shorten the combustion process. While shortening the combustion process, the fast evaporation process enhances air - fuel mixture and provides better and cleaner combustion every time. The mixture of 9% of DEE with biodiesel shows relatively lower ignition delay, this could be as the percentages of DEE increases the micro explosion thus enhances the burning as soon the heat source was given. Overall, the burning rate of the DEE 9% combination has shown a great combustion characteristic among the other ratios tested throughout the experiment. By the data collected for the burning rate, DEE 9% has shown more to a constant rate than the rest too. To conclude the experiment, it is clearly shown that Biodiesel B7 + DEE 9% has a better combustion characteristic and will perform better and then pure Biodiesel B7, however a more thorough study is always advised to be done where the actual experiment could be done on a real engine where the data may vary than obtained.

## 5.2 Recommendations for future work

Even when the experiment was carried out with adequate control, there is still space for improvement, particularly in the test chamber's construction. There is still some interference from the outside temperature, humidity, etc. Having a completely closed cubical to work with is where the fuel is not influenced by other factors may show significant results. Having a cubicle will also help to install a ventilation fan which will be able to pull out the soot created by the burning fuel. The camera used would only provide a max of 250FPS, cameras producing more than 1000FPS may show a more detailed view of the fuel droplet character where it will be able to identify the cavity and other details too. Finally fuel mixture may show a positive result overall, however when the fuel is injected to the engine the result may vary due to heat produced by the engine itself. It is recommended to perform the experiment with CI engine. Since the fuel is tested with engine power, torque, even the heat produced by the engine will be able to be calculated and precise data will be produced.

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