Study on Combustions Characteristics of Diesel-Vegetable Oil Blended using Industrial Fuel Burner

by

Nur E'zzati binti Wahi

A Project Dissertation Submitted in Partial Fulfillment of
the requirement for the
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CERTIFICATION OF APPROVAL

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Mechanical Engineering Department
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Approved by,

____

(Ir. Dr. Suhaimi bin Hassan)
Project Supervisor.

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK.
SEPTEMBER 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by specified sources or persons.

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(Nur E'zzati binti Wahi)

ABSTRACT

Combustion characteristics of diesel-vegetable oil using industrial dual fuel burner at different ratio have been experimentally investigated. Diesel was blended with vegetable oil at 0%, 20%, 40%, 60%, 80% and 100% volume ratios. Initially, diesel-vegetable oil blends properties which included kinematic viscosity, density and calorific value, were analyzed.

Combustion Unit C491 was used to burn the blends and the combustion characteristics were observed from the observation ports. In the experiments, the burner burnt liquefied petroleum gas (LPG) until the temperature reached 400^{o}C. After that, diesel-vegetable oil blend was fed to the burner. LPG flow rate and fuel flow rate were remained constant throughout every experiment. Data were recorded using High Speed Camera (Software Phantom) and standard camera.

It was observed that flame length reduced as the ratio of vegetable oil in the blends increased. Meanwhile, time to blow-off decreased as the ratio of vegetable oil in the blends increased. The longer time to blow off indicates that the combustion is more stable.

This is mainly due to higher viscosity, higher density and lower calorific value of vegetable oil compared with diesel fuel. Based on critical analysis of the results, the 20% vegetable oil with 80% diesel mixture is the best-suited blend for the dual fuel burner. Therefore, the experimental results indicate that vegetable oil can be used as an alternative to diesel in industrial fuel burner.

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CHAPTER 1

INTRODUCTION

1.1 Background

In the process of generating steam in power plant, the furnaces or burner systems provide controlled, efficient conversion of the chemical energy of fuel to heat energy which, in turn is transferred to the heat-absorbing surfaces of the steam generator [1]. The flame produced must have certain geometric shape and dimensions that suit the hearth or working space of a furnace. Failure to optimize these parameters is bound to lower the furnace efficiency, shorten the service life of refractories, pollute the environment and cause other undesirable effects [2]. One of the commonly used burner systems is industrial dual fuel burner and this burner burns light oils such as diesel.

Diesel is among the three most important fuels, apart from gasoline and jet fuels, that are fueling the growth in transportation. [3] It is expected that diesel demand and utilization will increase more in the next few decades. However, it is proven that diesel is not environmental-friendly as the combustion of diesel will emit high amount of sulfur and particulate matters [4].

Along with increasing price of the petroleum-based fuels, interest has been shifted to alternative fuel development for securing the supply of future fuels and cleaner emission. One of the alternative fuels, namely biodiesel is produced through tranesterification of diesel and vegetable oil [5] in order to reduce the emission of sulfur. In heavy duty vehicle applications, it is often blended with diesel [6].

Nevertheless, few studies have been done to use straight vegetable oil as fuel without converting it into biodiesel [7]. However, vegetable oils alone are not considered acceptable fuels for large-scale or long-term use. A major problem with the use of straight vegetable oils is their high viscosity, which causes poor fuel atomization and inefficient mixing with air in combustion chambers [8]. There are three popular methods to handle the problem and among them is blending vegetable oil with diesel [9].

1.2 Problem Statement

Diesel-vegetable oil blend uses less energy to produce and is more environmental-friendly compared to petroleum-based fuels. Besides, the advantages of bypassing the conversion process substantially reducing the cost of fuel [10].

Few studies have shown that the appropriate proportions of diesel-vegetable oil can be used in diesel engines. However, the blends are rarely used in the industrial fuel burner.

Hence, good knowledge of the properties of the blend composition is a must in order to utilize diesel-vegetable oil blends as fuel in the industrial fuel burner. At the same time, it is necessary to study the combustion characteristics of diesel-vegetable oil blend to ensure that the burner is working at its desired state.

1.3 Objectives and Scope of Study

The main objectives of this study are;

a) To study the characteristics of blended diesel-vegetable oil at different volume ratio.
b) To investigate the combustion characteristics of diesel-vegetable oil blended at different volume ratio.
c) To compare the combustion characteristics using both diesel fuel and diesel-vegetable oil blended

In this study, three main properties of six diesel-vegetable oil blends at 0%. 20%, 40%, 60%, 80% and 100% volume ratios were analyzed -- kinematic viscosity, density and calorific value. In the next section, the combustion characteristics of diesel-vegetable oil blends were observed in term of its length, stability, color and shape. Lastly, combustion characteristics of diesel and diesel-vegetable oil blends were compared.

CHAPTER 2

LITERATURE REVIEW

2.1 Characteristics of Diesel Fuel

Diesel fuel is a mixture of hydrocarbons obtained by distillation of crude oil [4]. The important properties which are used to characterize diesel fuel include cetane number (or cetane index), fuel volatility, density, viscosity, cold behavior, and sulfur content. Diesel fuel specifications differ for various fuel grades and in different countries. Table 1 shows the typical value of kinematic viscosity, density and calorific value of diesel fuel [3].

Table 1: Properties of Diesel Fuel

Properties	Typical Value
Kinematic Viscosity	> 2.7 cs
Density	0.80 g/ml – 0.86 g/ml
Calorific Value	10,170 kcal/kg

One major problem with diesel fuel is its high emission of Particulate Matter (PM) and Nitrogen Oxides (NO_x). Research and development are on-going with respect to analysis and reduction of emissions. Generally, the approaches to reduce the emissions are including improvement of the engine, after-treatment of the combustion exhaust gases, deep desulfurization and deep dearomatization, and lastly reformulated diesel fuels into oxygenated diesel fuels or biodiesel [3].

Biodiesel refers to a diesel-equivalent, processed fuel derived from biological sources. It is alkyl esters made from the transesterification of both vegetable oils and/or animal fats. Generally, biodiesel is more expensive to purchase than petroleum diesel [5].

2.2 Characteristics of Vegetable Oils

Vegetable oil comes in various shapes and sizes, with varying properties. The advantages of using vegetable oil as diesel fuel, other than its renewability, are the minimal sulfur and aromatic contents, the higher flash point, and the higher biodegradability and non-toxicity.

However, several drawbacks exist; include very high viscosity, the higher pour point, the lower cetane number, the lower calorific value and the lower volatility [5]. Table 2 shows the three main properties of various types of vegetable oils [10], [11]. As compared with diesel, kinematic viscosity and density of vegetable oils are higher. Meanwhile, calorific value of vegetable oil is lower than diesel.

Table 2: Properties of Various Types of Vegetable Oils

Properties	**Rapeseed oil**	**Palm oil**	**Corn oil**
Kinematic viscosity (cs)	38	45	32.53
Density (g/ml)	0.9 – 0.93	0.8996	0.9046
Calorific value (kcal/kg)	8361	8925	8973

The high viscosity of vegetable oils (highly saturated 16 to 18 carbon fatty acids) may lead to degradation of the equipment. Nevertheless, use of oils that have short-chain unsaturated fatty acids could solve the problem. However, these oils are only can be found in rare plants such as Cuphea. Few studies have been done to genetically modify plants such as soybeans to produce shorter chain fatty acids. The modifications are promising, but not considered as economically feasible yet [10].

2.3 Diesel-Vegetable Oil Blends

There are lots of literatures and researches showing good success with this simple blending approach [12]. The researches were started back in mid-nineties. For example, the earliest research in 1991 indicated the possibility and efficacy of oil-diesel blends [13].

In a report by Franco and Nguyen, lowering the viscosity of vegetable oil can be simply achieved by either increasing the temperature of the oil or by blending it with diesel fuel, or both. They studied properties of diesel fuel and vegetable oil mixtures at different compositions as a function of temperature to determine a viscosity–temperature–composition relationship for use in design and optimization of heating and fuel injection systems used in diesel engines [8]. The viscosity of the olive oil-diesel blends is shown in Figure 1, while density of soybean oil-diesel blends is shown in Figure 2.

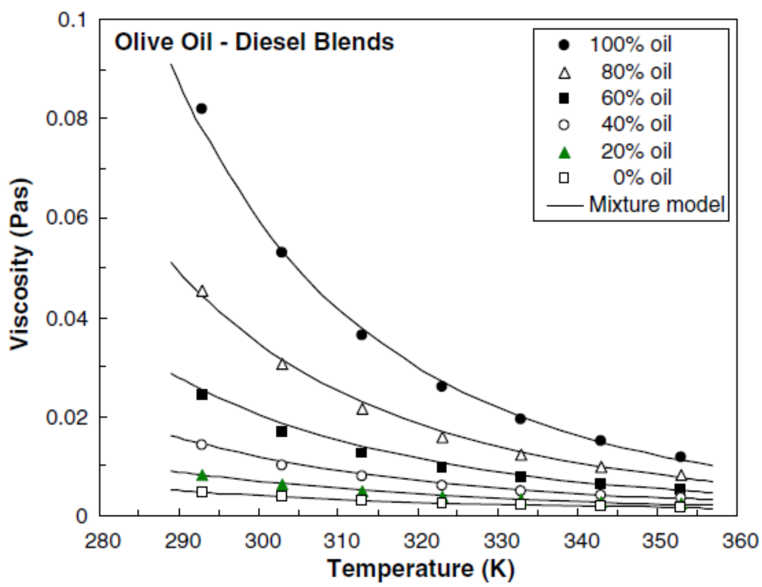


Figure 1: Viscosity vs Temperature for Olive Oil-Diesel Blends

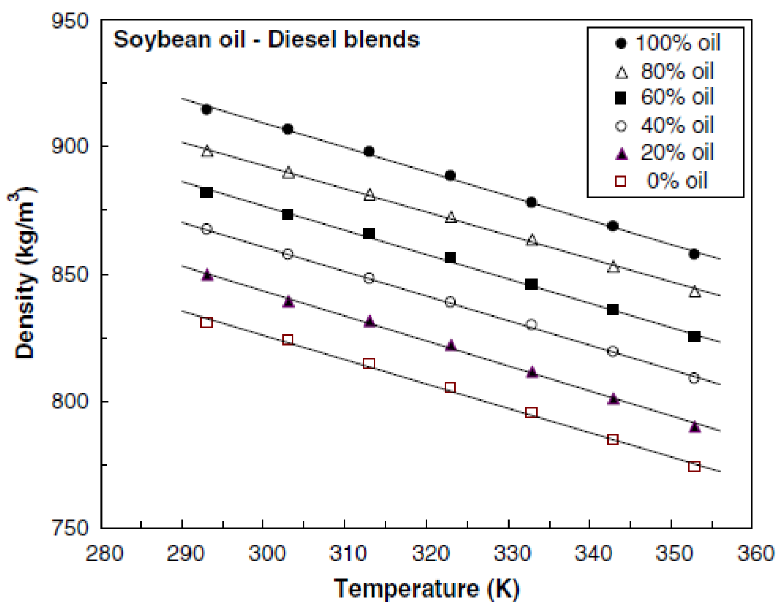


Figure 2: Density-temperature data for soybean oil-diesel blends

Meanwhile in 2011, Misra and Murthy conducted a research on performance, emission and combustion evaluation of soapnut oil-diesel blends in a compression ignition engine. Table 3 shows the properties of the soapnut oil-diesel blends [14]. Denotation SN indicated the ratio of soapnut oil in the blend.

Table 3: Properties of Soapnut Oil-Diesel Blends

Property	**SN10**	**SN20**	**SN30**	**SN40**	**SN100**	**DIESEL**
Density (kg/M^3)	851	862	871	882	904	835
Calorific value (MJ/kg)	43.212	42.958	41.594	40.594	38.207	44.615
Kinematic viscosity (@40^{o}C)	4.92	6.15	7.52	8.95	46.42	2.83

From Table 3, it is shown that, as the ratio of soapnut oil in the blends increased, the kinematic viscosity increased, as well as the density. On the other hand, the calorific value of the blends decreased as the ratio of soapnut oil in the blends increased. Next, impact of these blends onto engine operation and engine performance parameters such as fuel consumption, brake thermal efficiency, and exhaust emissions were analyzed. It is found that the allowed ratio of soapnut oil in the blend is 10%.

Also in 2011, Hassan *et al* carried out an experiment on the effects of producer gas-diesel and vegetable oil blends on the performance and exhaust emissions of a supercharged dual-fuel single-cylinder diesel engine. The vegetable oil was blended with diesel fuel at different volume ratios. The engine performances were reduced and the emission characteristics were increased as the ratio of the vegetable oil in the blends increased [15].

Another study was done by Fontaras *et al* to identify the impact of straight vegetable oil-diesel blends on vehicle emissions. It was found that vegetable oil presence does not affect engine exhaust in the same way as biodiesel. The vegetable oil presence in the fuel appeared to suppress the formation of nucleation mode particles. Straight rapeseed oil increased carbonyl compound emissions over all cycles tested and resulted in higher acroleine/acetone presence in the carbonyl compound composition [16].

2.5 Combustion Characteristics

Combustion is a chemical reaction between a combustible material and oxygen that produces heat [17]. In burner, combustion of fuel must be efficient and complete in order to get the most of energy generated with the least pollutant [18]. The flame produced must have certain geometric shape and dimensions that suit the working space of a furnace. Otherwise, failure to optimize these parameters is bound to lower the furnace efficiency, shorten the service life of refractories, pollute the environment and cause other undesirable effects [2]. Meanwhile, damage burners may cause serious operating problems such as explosion, low plant efficiency, high maintenance cost and high emission of pollutant.

Ideal flame is gained when the flame is blue and burns fairly close to the tip of the burner. Ideal flame happened when there is stoichiometric reaction between fuel and air. Meanwhile, non-ideal flame, known as lazy flame, is yellow and ripples. Non-ideal flame is related to inadequate air in the reaction. Figure 3 shows the example of ideal and non-ideal flame from the burner.

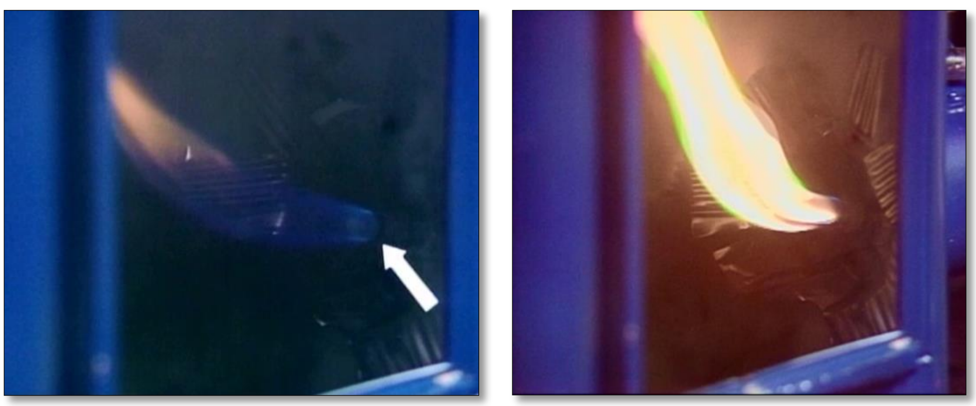


Figure 3: Ideal Flame (left), Non-Ideal Flame (right)

However, too much excess air may lead to low heat transfer efficiency of the burner. Typical actual combustion process of 1 pound of diesel (Fuel#2) in the burner is carried out with 21.54 pounds of air, rather than 14.36 pounds of air (theoretical) [19]. Figure 4 shows the typical actual combustion conditions for #2 fuels.

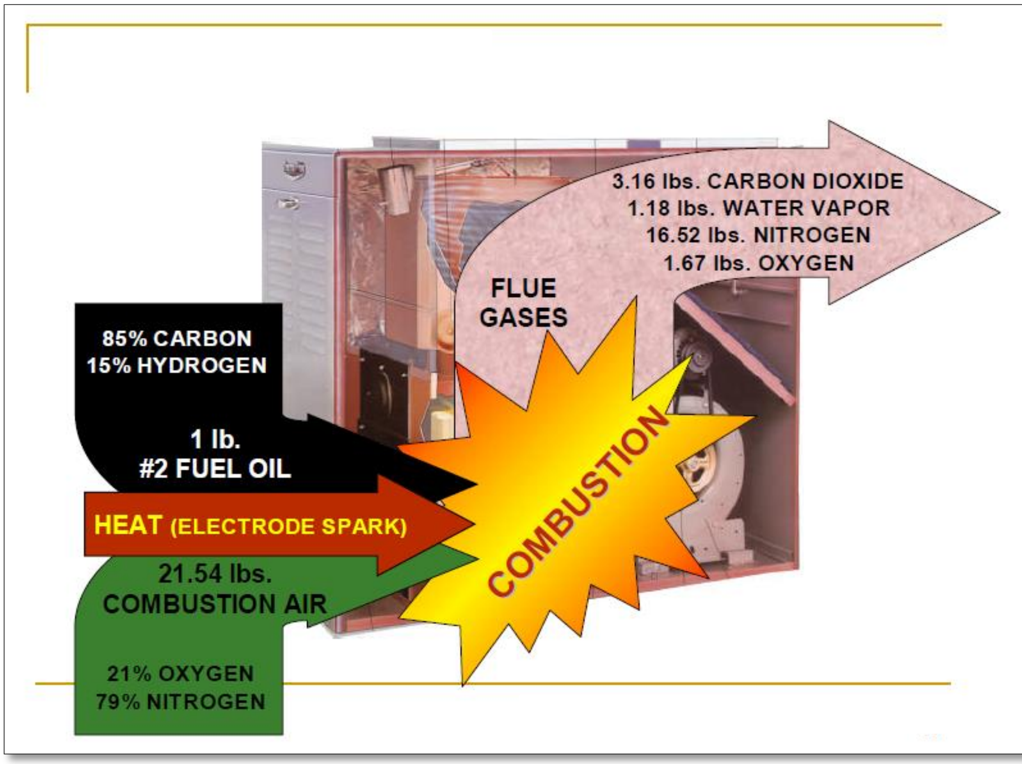


Figure 4: Typical Actual Combustion Condition for #2 Fuels

The flame of a fuel burner is similar to a diffusion flame. Fuel is injected in the form of droplets whose diameter is in general fairly large (about one hundred microns). It is injected into the center of the burner and the air jet enters via an annular peripheral channel. In general, to attach the flame without requiring an obstacle, the air jet is rotated (or swirled), thus produces a recirculation zone near to the fuel-oil injector [17].

Such burners are commonly used in furnaces or boilers, and a consideration of flame length is an essential factor in the design. Flame length is an approximate indicator of frontal fire intensity. Flame lengths of lower intensity fires will pulsate at a higher frequency with a small variation in flame length. Meanwhile, high intensity fire will pulsate at a lower frequency with greater variation in flame lengths [20]. According to Alexander & Cruz as well, flame intensity can be calculated as follows;

$$I_B = 259.833 * L^{2.174} \qquad (1)$$

where I_B is flame intensity (kW/m) and L is flame length (m).

Flame length can be measured through distance between the tip of the flame and the ground (or surface of the remaining fuel) midway in the zone of active flaming. However, the flame tip is a very unsteady reference hence typically average length over a reasonable time period is taken into account [21]. Figure 5 illustrates how the measurement of flame length is taken.

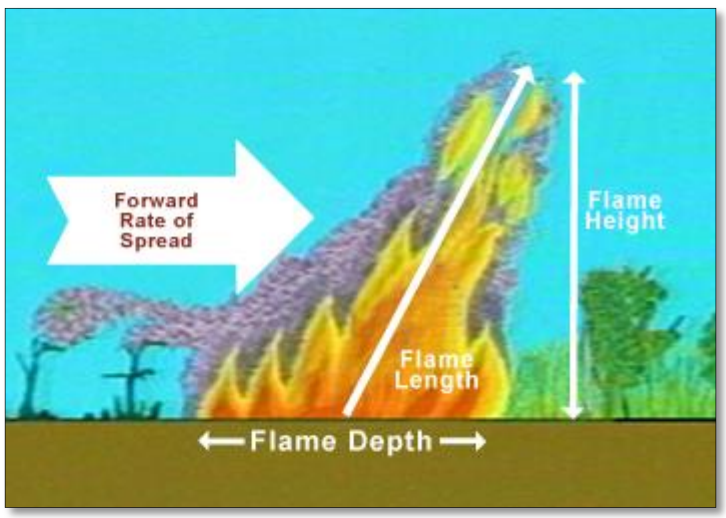


Figure 5: Measurement of Flame Length, Flame Height and Flame Depth

Another primary combustion characteristic is flame stability. Stable combustion is the basis for obtaining the desired rate of heat release. It is therefore necessary to maintain flame stability throughout the combustion process.

Basically, flames can be divided into three regimes [22];

a) Yellow tipping -- When the airflow to the burner is prevented, the flame will have a yellow tip and may produce smoke. When the airflow is increased, the yellow tip will disappear and replaced by a blue non-luminous flame.
b) Lift off -- When the airflow to burner is gradually increased with a constant flow, given sufficient gas flow, the yellow tipping will disappear and blue flame will be established. Further increase in airflow will result in the lifting of the flame around the surface of the burner. At this moment, the velocity of mixture leaving the burner approaches the mixture flame speed. If airflow is further increased, the flow velocity will exceed the flame speed and the flame will lift off and extinguished.
c) Light back --With a low burner loading, when the airflow is increased, after observing yellow tipping and blue flame, flame will move down the tube to inlet part which means that the flame speed exceeds the flow velocity.

Flame stabilization can be related to the competition between the velocity of chemical reactions and the turbulent diffusion rate of species and energy. A flame is said to be stable when there is a balance between the reactants velocity and the laminar burning velocity. When an imbalance between both velocities occurs, instability phenomena such as blowout and flashback appear. (Blow out is refers to the situation where the flame becomes detached from the location where it is anchored and is physically “blown out” of the combustor. On the other hand, if the flame attains a stable lifted position prior to the extinction limits, it is often called blowoff [23]).

Both the blowout and blowoff limits depend on the mixture composition and the temperature and pressure conditions [24]. Blowout is a concern in low emission combustors that often operate very near the blowout limits [25]. Flashback occurs when the flame propagates upstream of the region where it supposed to be anchored and into premixing passages that are not designed for high temperature. Although flashback flames may remain stable, the flashback region is marked as a different region from that delimitating the conventional stable flames.

All factors causing flame extinction or flash-back are to be avoided. Some types of flame holders enhance flame stability. Hence, it is an important parameter for basic combustor design.

CHAPTER 3

METHODOLOGY

3.1 Project Activities

Project activities involved were the literature review, experiments and thesis preparation. Figure 6 shows the flow of activities in the study.

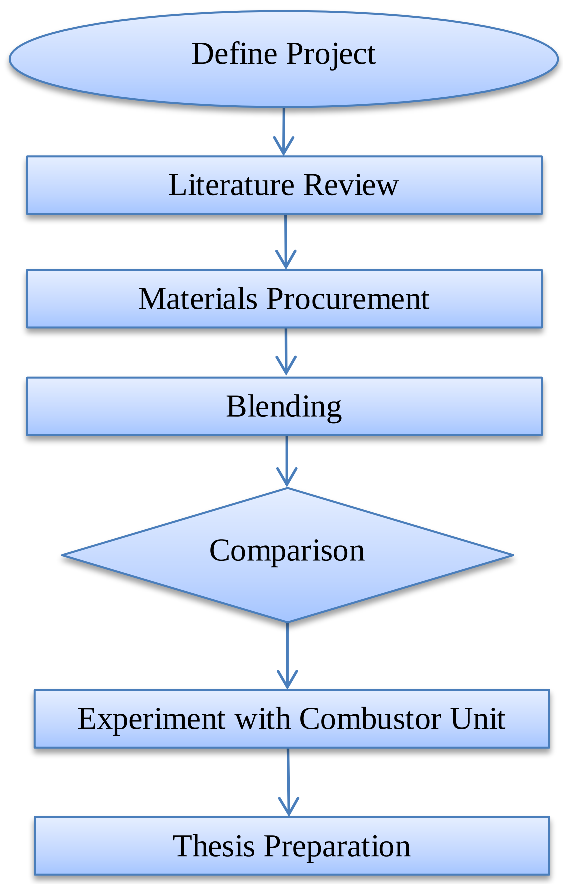


Figure 6: Flow Chart of the Activities

3.2 Part 1: Blending Diesel with Vegetable Oil

In this study, vegetable oil was blended with diesel at 0%, 20%, 40%, 60%, 80% and 100% volume ratios. Each sample was denoted with "VD". VD denotes the percentage by volume of vegetable oil in the blend. For example, VD60 denotes that 60% of the blend is volume of vegetable oil while the remaining 40% is volume of diesel.

Blending experiments were carried out at room temperature by adding a measured volume of the vegetable oil into the diesel under continuous agitation with stirrer. Diesel-vegetable oil blends were later stored in the container located in the fume chamber.

Table 4 shows the denotation of each blend along with the volume ratio.

Table 4: Volume Ratio of Vegetable-Oil Diesel

Denotation	Vegetable Oil	Diesel
VD0	0%	100%
VD20	20%	80%
VD40	40%	60%
VD60	60%	40%
VD80	80%	20%
VD100	100%	0%

In the next section, three main properties of diesel-vegetable blends were determined - kinematic viscosity, density and calorific value.

3.2.1 Kinematic Viscosity

Many petroleum products, and some non-petroleum materials, are used as lubricants, and the correct operation of the equipment depends upon the appropriate viscosity of the liquid being used. In addition, the viscosity of many petroleum fuels is important for the estimation of optimum storage, handling and operational conditions. Thus, the accurate measurement of viscosity is essential to product specifications.

One of the main reasons for blending vegetable oils is to reduce the viscosity hence improving fuel flow characteristics. Fuels with low viscosity may not provide sufficient lubrication for the precision fit of fuel injection pumps, thus causing leakage or wear. On the other hand, fuels with high viscosity may form larger droplets on injection which can cause poor combustion [10].

In order to measure kinematic viscosity of the blends, ASTM Standard D445-88(9) (Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids) was used. Kinematic viscosity was measured by using Brookfield Digital Viscometer (Model LVDV-I+) as shown in the Figure 7.

Figure 7: Brookfield Digital Viscometer (Model LVDV-I+)

500ml of each sample was taken for measurement. The measurement was done at constant room temperature at various speeds.

3.2.2 Density

The denser the oil, the more energy it has. High density indicated more thermal energy for the same amount of fuel hence better fuel economy [10].

Density of diesel-vegetable oil blends was determined from the equation (2) as follow;

$$\text{Density}, \rho = \frac{\text{Mass, m}}{\text{Volume, V}} \qquad (2)$$

100 ml from each sample was taken and its mass was measured by using weighing machine as shown in Figure 8.

Figure 8: Weighing Machine

3.2.3 Fuel Analysis: Calorific Value

Calorific value determines the amount of heat released per unit mass of fuel from its complete combustion. Although cetane number determines the combustion performance, calorific value and thermodynamic criteria set the maximum possible output of power [3]. This value is essential when considering the thermal efficiency of equipment for producing either power or heat.

Calorific value was measured according to ASTM D240-92 (Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter). Calorific value was determined by burning a weighed sample in an oxygen bomb calorimeter under controlled conditions. The heat of combustion was computed from temperature observations before, during, and after combustion, with proper allowance for thermochemical and heat transfer corrections. Either isothermal or adiabatic calorimeter jackets can be used.

Figure 9 shows the bomb calorimeter that has been used to measure calorific value.

Figure 9: Bomb Calorimeter

3.3 Part 2: Combustion of Diesel-Vegetable Oil Blends

The combustion of diesel-vegetable oil was carried out by using Combustion Unit C491. The unit comes with the burner, combustion chamber, control panel and instruments. Figure 10 shows the setup of the experiment while Figure 11 shows the schematic of the experiment setup.

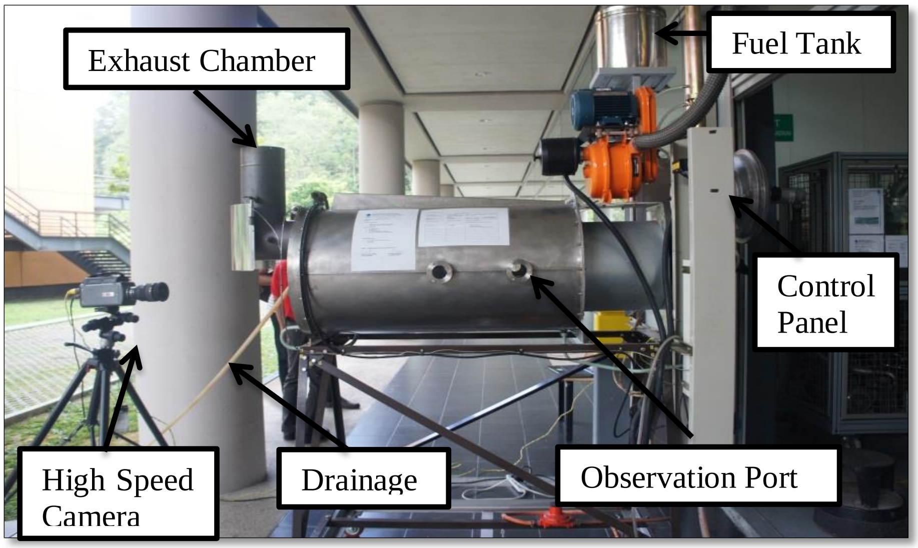


Figure 10: Setup of Combustion Unit C491 and High Speed Camera

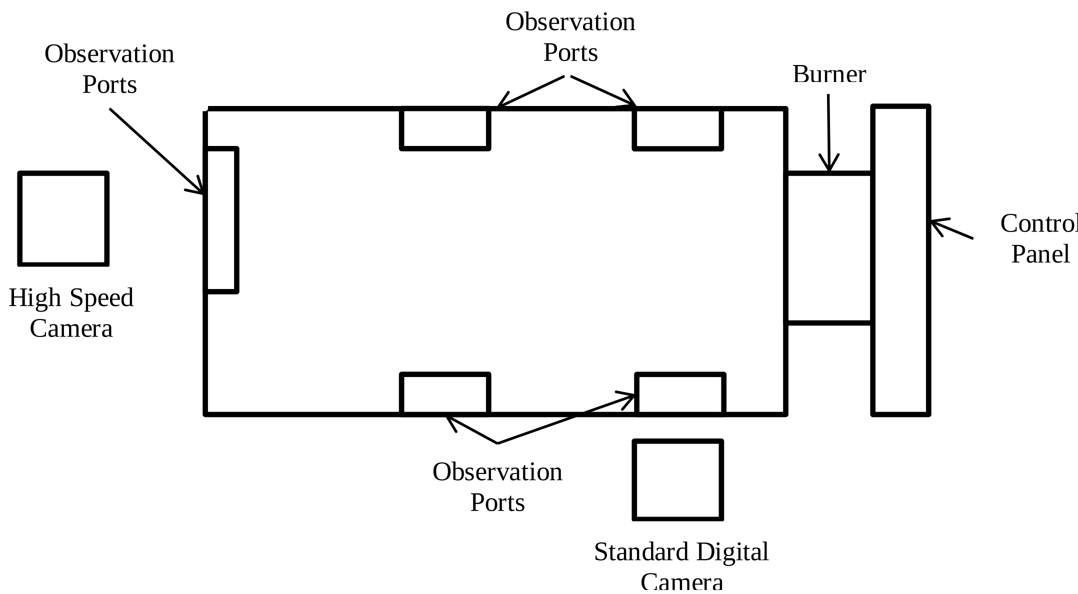


Figure 11: Schematic Setup of Combustion Unit C491 and Camera (Top View)

The C491 unit mounted on a frame that allows easy access to the burner control and the combustion chamber. The package burner started with an air purge, ignited its fuel (oil or gas) and automatically set to a safe firing condition. Combustion air was provided by the integral fan and a sensor was provided to monitor the flame, shutting the fuel valve in the event of flame failure.

Gas was fed through pipes to the connections on the frame. Fuel was supplied from portable tanks provisioned with the oil burner. The flame burnt within a stainless steel combustion chamber which was water cooled and of sufficient size to prevent flame impingement under normal conditions. Observation windows on the side of the chamber allowed the flame to be observed.

The combustion product left the combustion chamber through a duct in the end remote from the burner and discharged vertically upward. The combustion unit must be installed in a well-ventilated area, with access to the burner end at least one of the two sides.

Requirement for combustion unit operation and the ignition procedure can be referred to Appendix A and Appendix B respectively. Figure 12 shows the schematic of dual fuel burner.

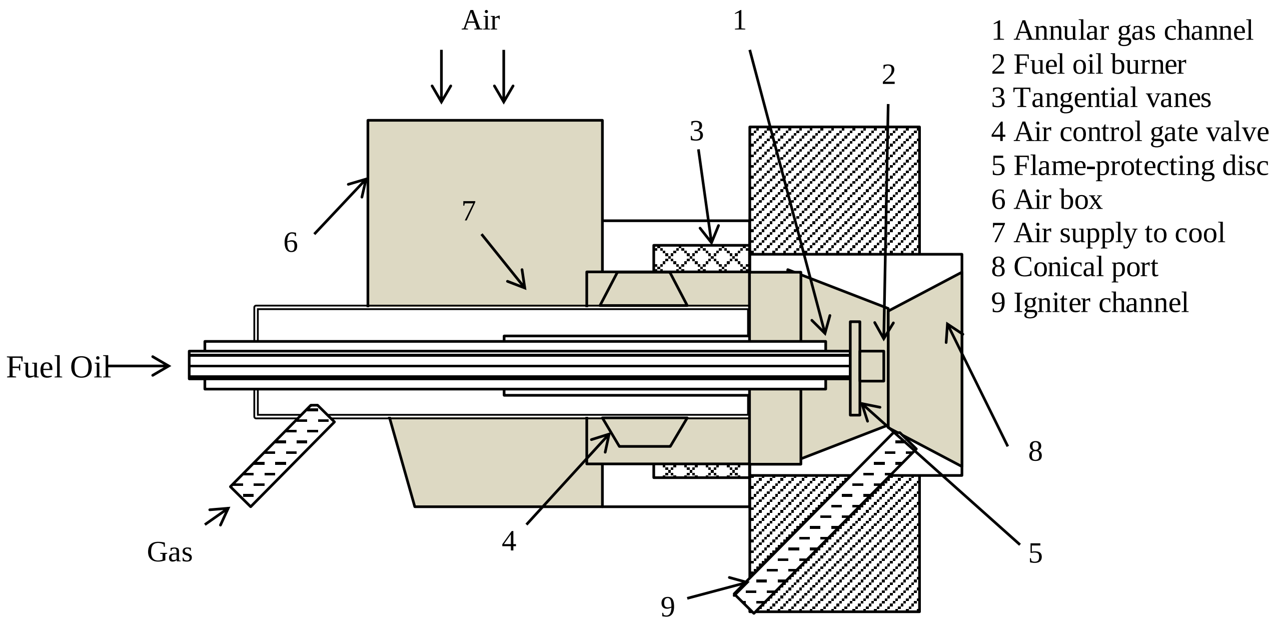


Figure 12: Schematic of Dual Fuel Burner

Meanwhile, Table 5 shows the specification of the Combustion Unit C491.

Table 5: Specification of Combustion Unit C491

Items	**Description**
Burner	Lamborghini Twin 13-E Burner with refractory quarl to burn distillate oils and gases at total heat rates up to approximate 150 kW
Combustion Chamber	Cylindrical stainless steel chamber 500 mm x 1000 mm with water cooled walls. Fitted with 5 pieces of 100 mm diameter observation ports.
Controls	Manual controls for air and cooling water.
Instrumentations	The unit is fitted with necessary sensors for measuring flow rate of air, oil, gas and cooling water, temperature of air, flue gas and cooling water and pressure of gas.

Gas flow rate (5.4 m^3/hr), fuel flow rate (1g/s), air flow rate (25kg/hr) were remained constant throughout all experiments. Combustion process was recorded using High Speed Camera and standard Digital Camera. The following combustion characteristics of diesel-vegetable oil blends were observed and analyzed;

- flame shape,
- length,
- stability, and
- color

CHAPTER 4

RESULT AND DISCUSSION

In this chapter, result from the blending and combustion of diesel-vegetable oil was tabulated and analyzed.

4.1 Part 1: Blending Diesel with Vegetable Oil

Each sample of 500ml diesel-vegetable oil blend was prepared for properties analysis. Table 6 shows volume ratio for each sample.

Table 6: Volume Ratio for Each 500ml Sample

Denotation	Volume of Vegetable Oil (ml)	Volume of Diesel (ml)
VD0	0.0	500.0
VD20	100.0	400.0
VD40	200.0	300.0
VD60	300.0	200.0
VD80	400.0	100.0
VD100	500.0	100.0

Change of color can be seen between the blends. VD0 produced a slightly bright yellow color blend. As the ratio of vegetable oil in the blend increased, the color of the blend become slightly dark yellow. Figure 13 shows the 500ml sample of each diesel-vegetable oil blend.

Figure 13: Samples (VD0 on the right and VD100 on the left)

The following sections show the properties of the fuel of diesel-vegetable oil blends.

4.1.1 Kinematic Viscosity

Kinematic viscosity of each sample was measured by using Brookfield Digital Viscometer (Model LVDV-I+) at various speed. Table 7 shows the kinematic viscosity of each sample at 50 rpm. Meanwhile, kinematic viscosity of diesel-vegetable oil blend at various speeds can be referred to Appendix C.

Table 7: Kinematic Viscosity of Each Sample at 50rpm

Sample	**Kinematic Viscosity (cP)**
VD0	0.53
VD20	0.83
VD40	1.58
VD60	3.75
VD80	6.60
VD100	13.50

From Figure 14, it can be concluded that kinematic viscosity of vegetable oil (VD100) is higher as compared with diesel (VD0). From the graph, it can be seen that kinematic viscosity of the blend increases as the ratio of vegetable oil in the blend increases.

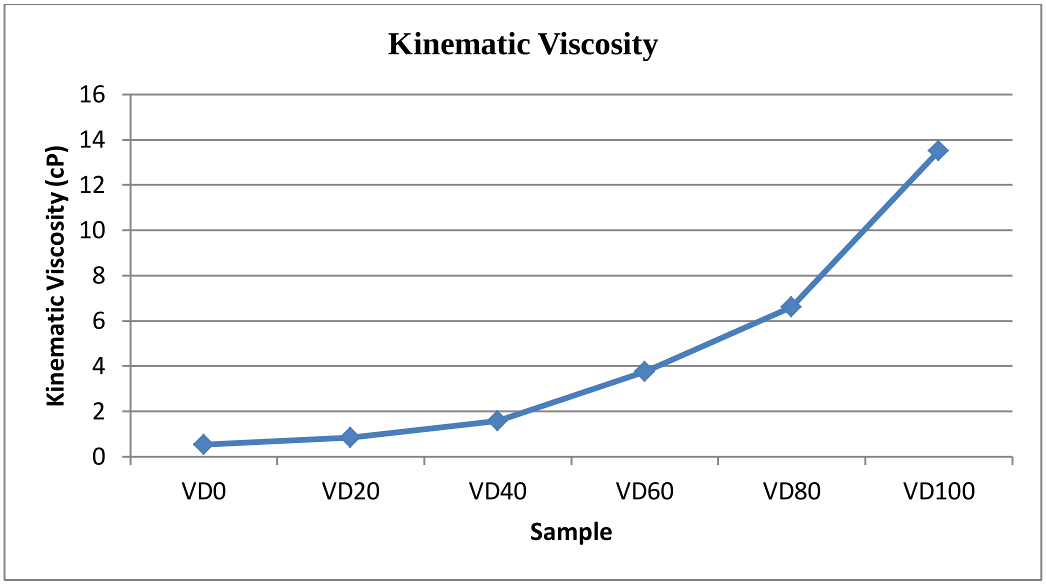


Figure 14: Graph of Kinematic Viscosity against Sample

4.1.2 Density

100ml of the sample was taken and weighed using the weighing machine. Table 8 shows the calculated density of each blend, using Equation (2).

Table 8: Density of Each Sample

Sample	**Volume (ml)**	**Mass (g)**	**Density (g/ml)**	**Density (kg/m^3)**
VD0	100.0	78.5647	0.785647	785.647
VD20	100.0	79.7735	0.797735	797.735
VD40	100.0	81.2743	0.812743	812.743
VD60	100.0	83.3824	0.833824	833.824
VD80	100.0	84.0323	0.840323	840.323
VD100	100.0	86.0364	0.860364	860.364

From Figure 15, it can be concluded that vegetable oil (VD100) has higher density as compared with diesel (VD0). From the graph, it is shown that density of the blend increases as the ratio of vegetable oil in the blend increases.

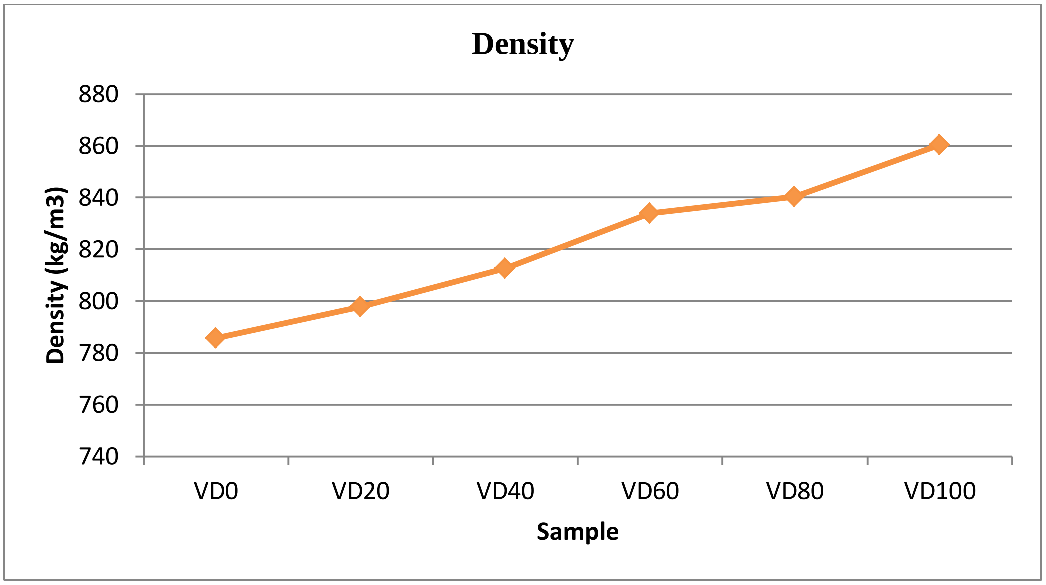


Figure 15: Graph of Density against Sample

4.1.3 Calorific Value

Calorific value of each blend was measured by using bomb calorimeter. Table 9 shows the calorific value of each blend.

Table 9: Calorific Value of Each Sample

Sample	**Calorific Value (J/g)**
VD0	46,206
VD20	44,923
VD40	43,985
VD60	43,572
VD80	42,791
VD100	40,493

From Figure 16, it can be concluded that vegetable oil (VD100) has lower calorific value as compared pure diesel (VD0). It is shown that calorific value of the blend decreases as the volume ratio of vegetable oil in the blend increases.

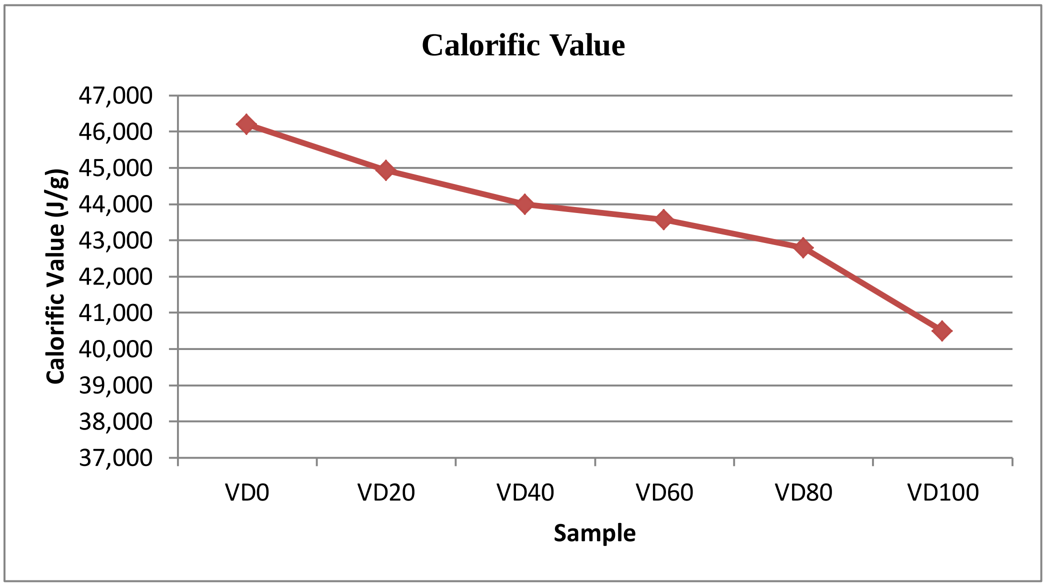


Figure 16: Graph of Calorific Value against Sample

4.1.4 Discussion on Diesel-Vegetable Oil Blends

As mentioned in the previous sections, three properties of the diesel-vegetable oil were analyzed. The analysis shows that, at constant temperature and the same speed, the kinematic viscosity of the diesel-vegetable oil blend increases as the volume ratio of vegetable oil in the blend increases. The increasing volume of vegetable oil in the blend also increases the density of diesel-vegetable oil blend. However, due to low calorific value of vegetable oil, the calorific value of diesel-vegetable oil decreases as the volume ratio of vegetable oil in the blend increases.

The same observations have been reported in previous study by Misra and Murthy.
According to the report, the higher the volume of vegetable oil in the blend;

- the higher the viscosity,
- the higher the density, and
- the lower the calorific value of the blend [14].

One of the main reasons for blending vegetable oils with diesel was to reduce the viscosity hence improving fuel flow characteristics. Fuels with low viscosity may not provide sufficient lubrication for the precision fit of fuel injection pumps, thus causing leakage or wear. Apart from that, fuels with high viscosity may form larger droplets on injection which can cause poor combustion [10]. Diesel and vegetable oil blends reduce the viscosity of vegetable oils [26], thereby avoiding blockage of fuel line, atomization and heavy particulate emissions [27].

In conclusion, the experiment shows that blending vegetable oils can reduce the viscosity. Next, the following section shows the combustion characteristics of diesel-vegetable oil blends in the industrial dual fuel burner.

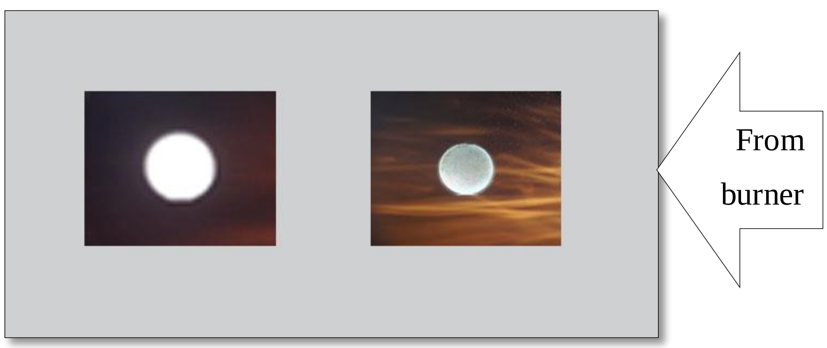
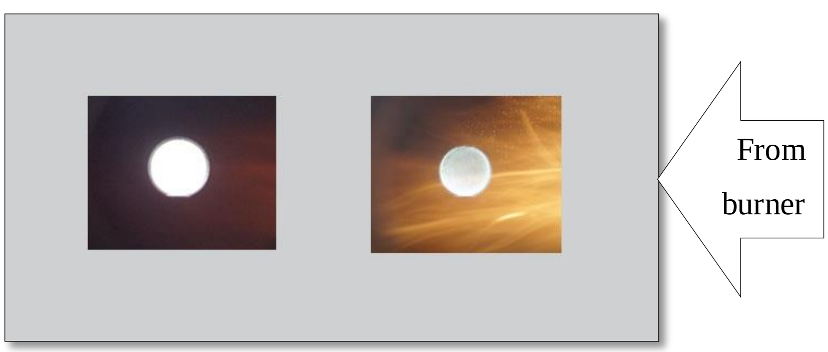
4.2 Part 2: Combustion of Diesel-Vegetable Oil Blends

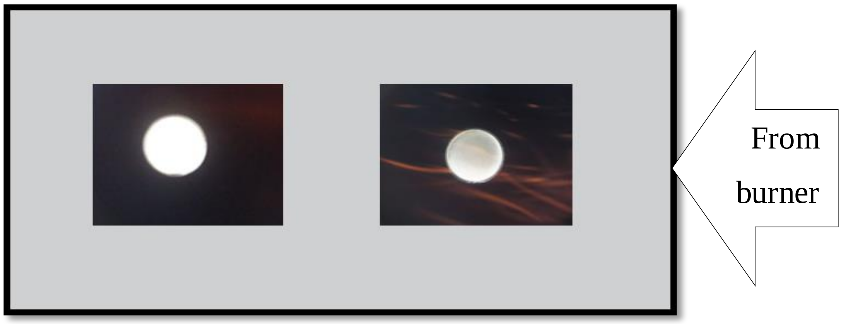
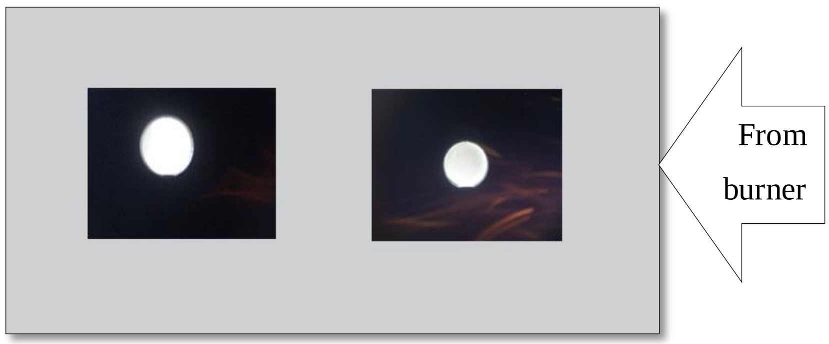
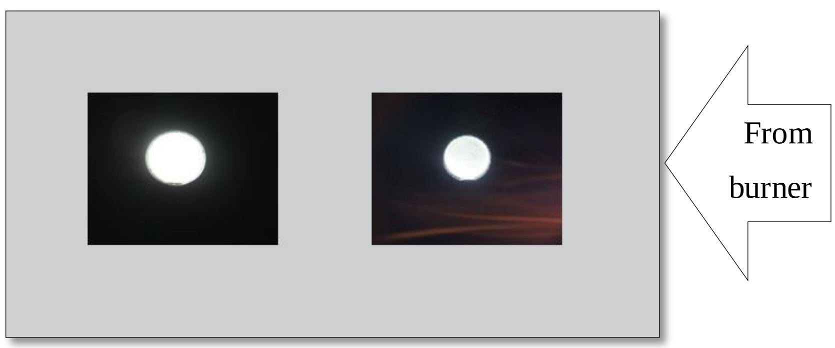
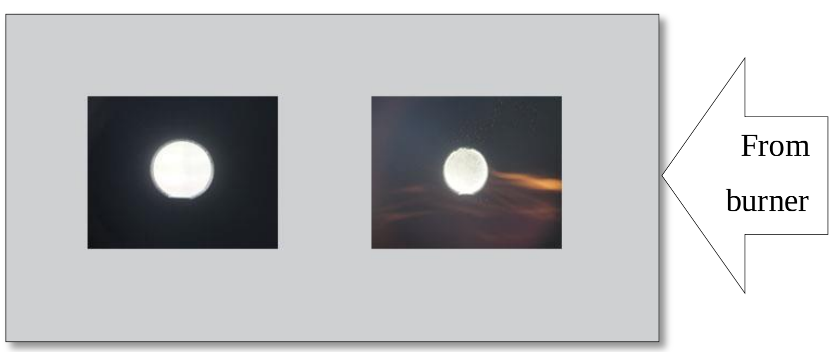
Combustion was done in constant environment; air/fuel ratio, gas flow rate. Diesel-vegetable oil blends were fed into the burner as the temperature rise to 400^oC. The following sections show the result gained from the experiments.

4.2.1 Flame Length

Flame behavior was observed from the side observation glass. Flame length measurements were made with standard video camera. Images were taken and videos were recorded for certain amount of time. The interval of each data taken was 0.02 s. The average flame length was estimated. At the same time, flame intensity was calculated. Data were tabulated in Table 10;

Table 10: Flame Length of Each Sample

Sample	**Flame Length from Observation Chamber**	**Length (m)**	**Intensity (kW/m)**
VD0		0.9270	220.36
VD20		0.9008	207.02

VD40		0.8920	202.66
VD60		0.8678	190.91
VD80		0.8282	172.47
VD100		0.7733	148.58

Flame length was measured through distance between the tip of the flame and the burner. However, the flame tip is a very unsteady reference hence average length over a reasonable time period is taken into account.

Figure 17 shows the relation between flame lengths against diesel-vegetable oil blends. From the graph, it can be concluded that the flame length decreases as the volume ratio of vegetable oil in the blend increases.

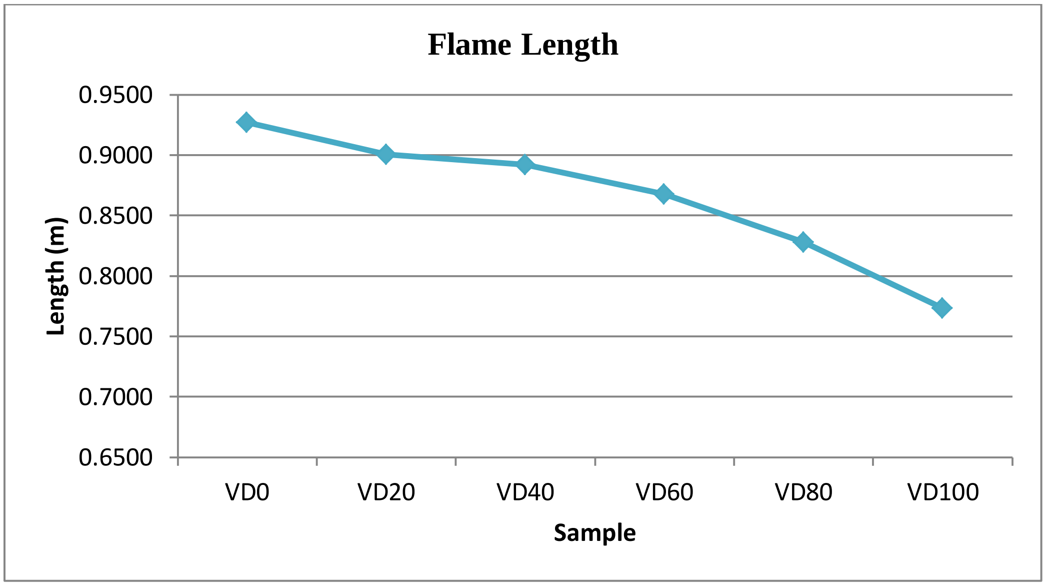


Figure 17: Flame Length of Each Sample

As mentioned in the literature review, a consideration of flame length is an essential factor in the design. Flame length is an approximate indicator of frontal fire intensity. Flame with lower intensity fires will pulsate at a higher frequency with a small variation in flame length. On the other hand, high intensity fire will pulsate at a lower frequency with greater variation in flame lengths [20]. Figure 18 shows the flame intensity of diesel-vegetable oil blends. The graph shows that flame intensity decreases as the volume ratio of vegetable oil in the blend increases.

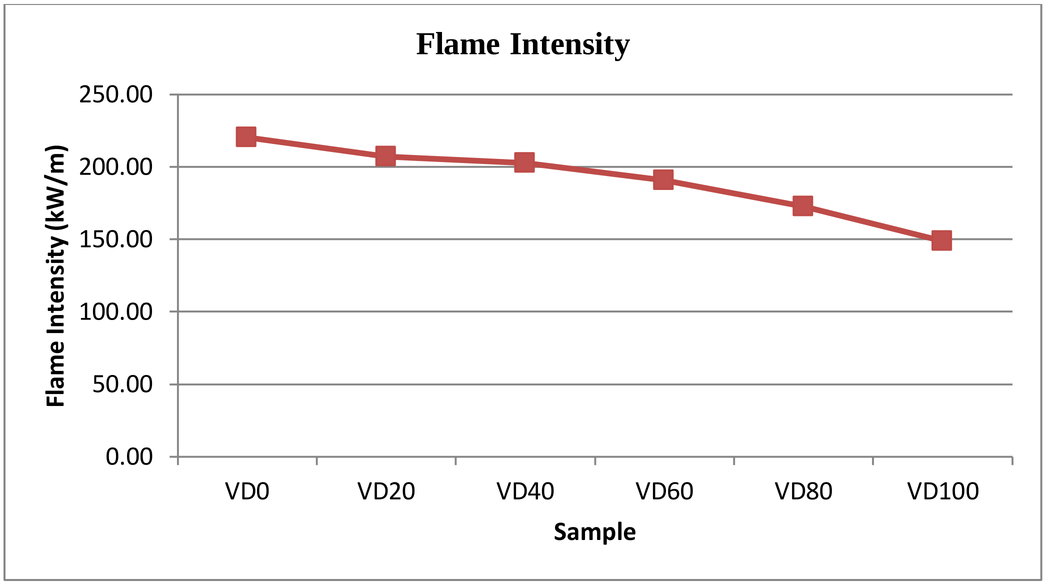


Figure 18: Flame Intensity of Each Blend

Next, the reduction in length between diesel (VD0) and other diesel-vegetable oil blends were calculated. Table 11 shows the total of length reduction as compared with diesel (VD0) and its percentage reduced.

Table 11: Length Reduction of Each Blend Compared with Diesel (VD0)

Sample	**Length Reduction (m)**	**Length Reduction (%)**
VD0	0.0000	0.00
VD20	0.0262	2.83
VD40	0.0350	3.78
VD60	0.0592	6.39
VD80	0.0988	10.66
VD100	0.1537	16.58

From Figure 19, about only 2.83% of the flame length was reduced when the diesel-vegetable oil blend was made of 20% vegetable oil (VD20). The percentage of flame length reduction increases further as the volume ratio of vegetable oil in the blend increases. Last but not least, the combustion of 100% vegetable oil (VD100) produced flame length that 16.58% shorter than of 0% vegetable oil (VD0).

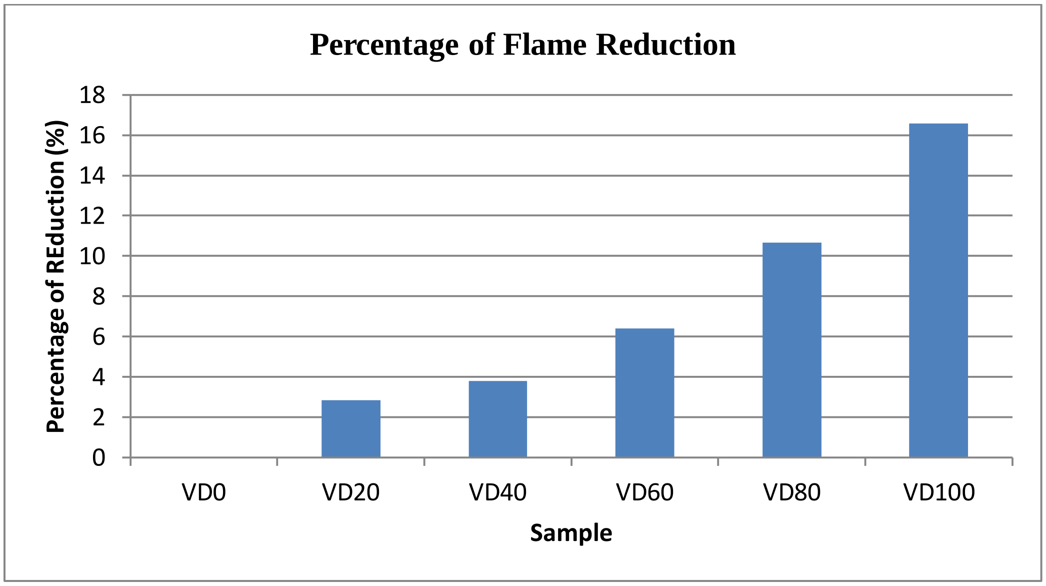


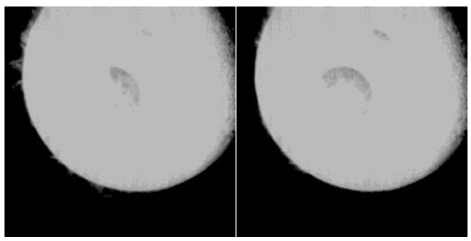
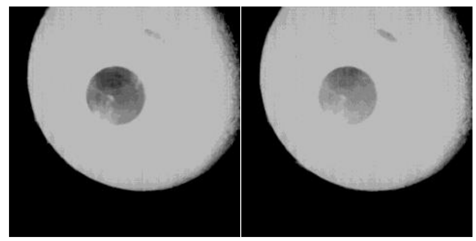
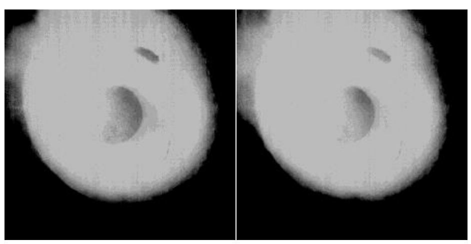
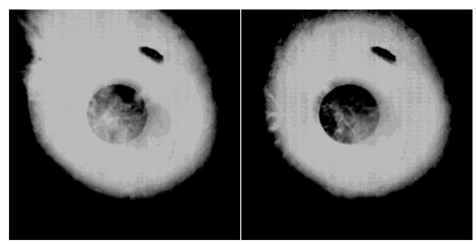
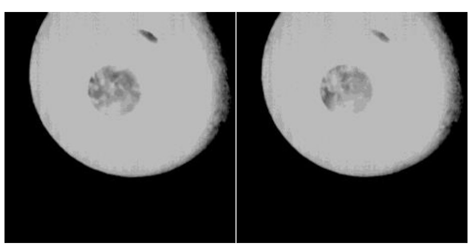
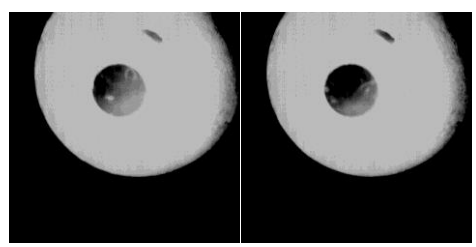
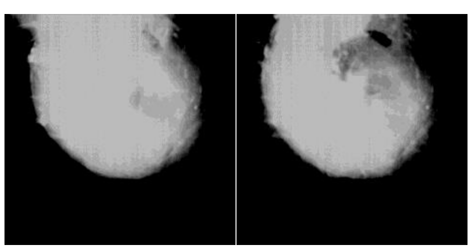
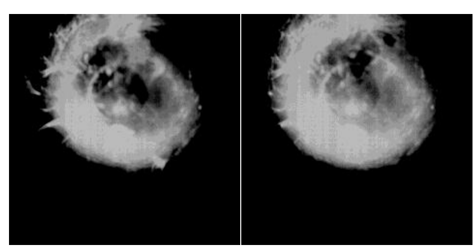
Figure 19: Percentage of Flame Length Reduction

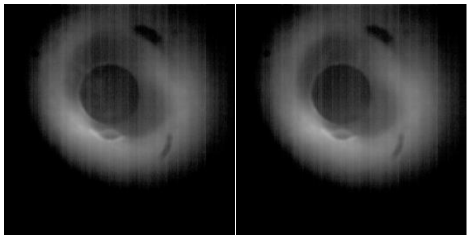
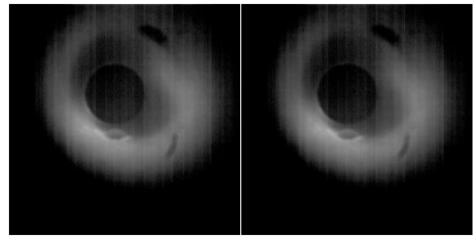
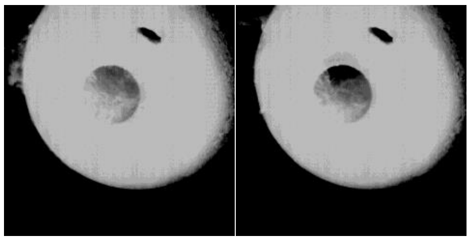
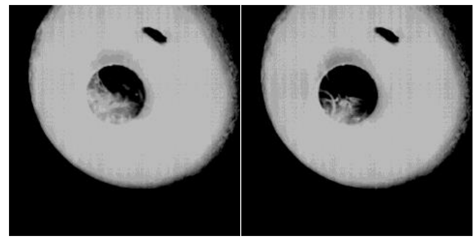
This is mainly due to high density and high kinematic viscosity of vegetable oil. Density and kinematic viscosity of diesel-vegetable oil blend increase as the volume ratio of vegetable oil in the blend increases. As mentioned in the literature, fuels with high viscosity may form larger droplets on injection which can cause poor combustion [10].

4.2.2 Flame Stability

Flame stability was observed from the front observation glass. The combustion was recorded by using High Speed Camera (black and white image) at interval of 0.02 s per frame, for certain amount of time. Table 12 shows some images of blowout and blowoff of the combustion. 100 frames of the combustion behavior can be referred to Appendix D till Appendix I.

Table 12: Blowout and Blowoff of Combustion of Each Sample

Sample	**Blowout**	**Blowoff**
VD0		
VD20		
VD40		
VD60		

VD80		
VD100		

Through the data, flame stability was analyzed and time taken to blow-off was estimated. Table 13 shows the estimated time to blow off for each sample.

Table 13: Average Time to Blowoff for Each Sample

Sample	**Average Time to Blowoff (s)**
VD0	0.1875
VD20	0.1220
VD40	0.1178
VD60	0.1075
VD80	0.0733
VD100	0.0560

From Figure 20, it can be concluded that flame stability decreases as the volume ratio of diesel-vegetable oil blend increases. Blowoff is more frequent in the combustion of vegetable oil (VD100).

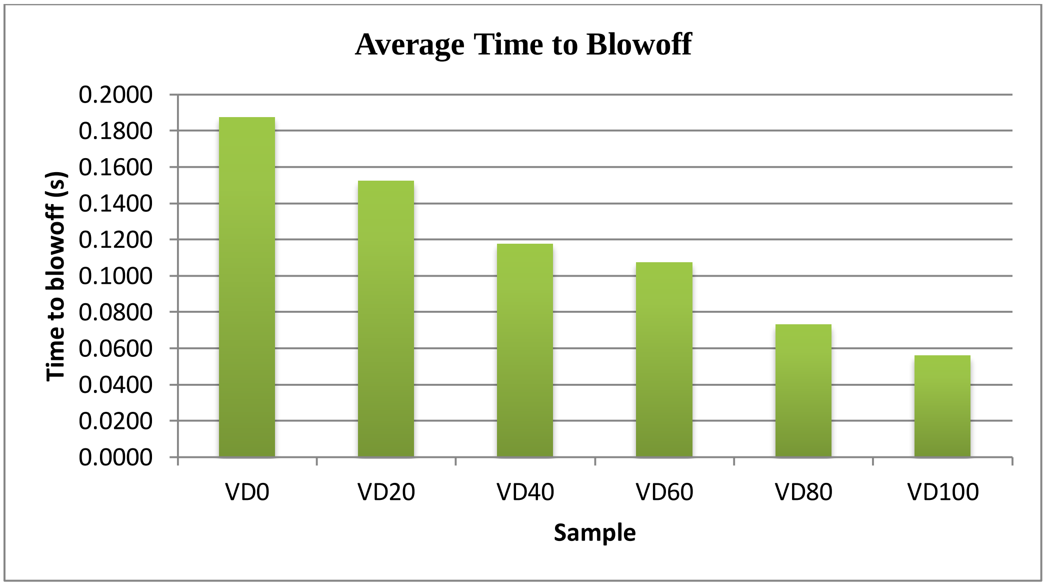


Figure 20: Time Taken to Blow-Off for Each Sample

Table 14 shows time difference to blowoff of each blend as compared with diesel (VD0).

Table 14: Time Difference for Each Blend Compared with Diesel (VD0)

Sample	**Time Difference (s)**	**Percentage of Time Difference (%)**
VD0	0.0000	0.00
VD20	0.0350	18.67
VD40	0.0697	37.19
VD60	0.0800	42.67
VD80	0.1142	60.89
VD100	0.1315	70.13

As shown in Figure 21, combustion of VD20 produced about 18.67% lower in time to blowoff as compared with combustion of VD0. The time difference in blowoff increases as the volume ratio of vegetable oil in the blend increases. In other words, flame stability decreases as the volume ratio of vegetable oil in the blend increases. Flame extinction occurs more frequent in the combustion of vegetable oil (VD100). All factors causing flame extinction or flash-back are to be avoided.

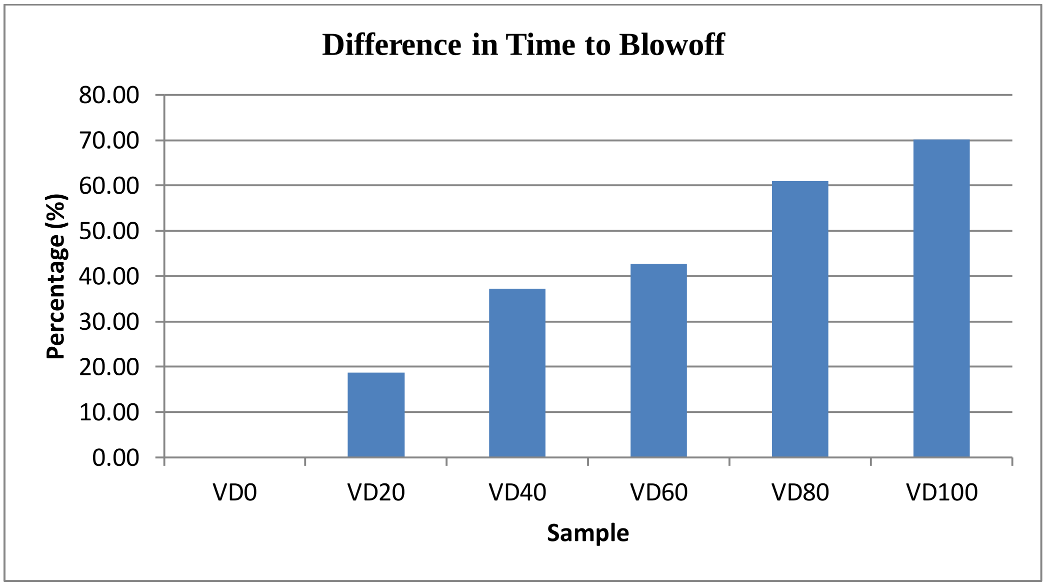


Figure 21: Reduction in Time to Blowoff

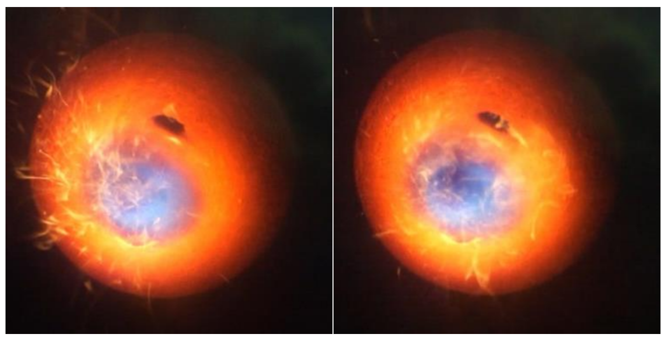
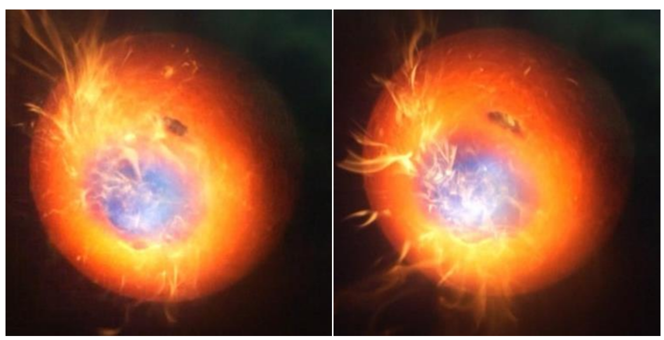
The frequent flame extinction is mainly due to high viscosity of the vegetable oil. Poor atomization of high viscous fuel cause the combustion reaction front may thicken hence the flame does not blow out, unlike the combustion of diesel (VD0).

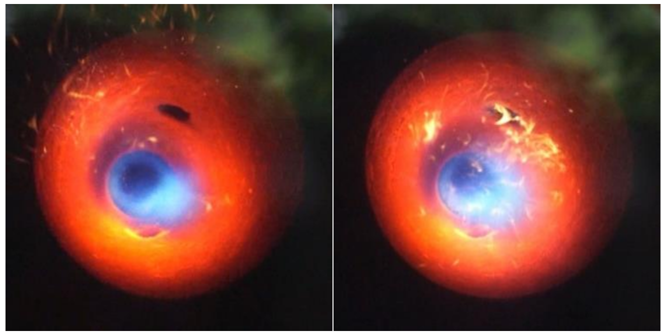
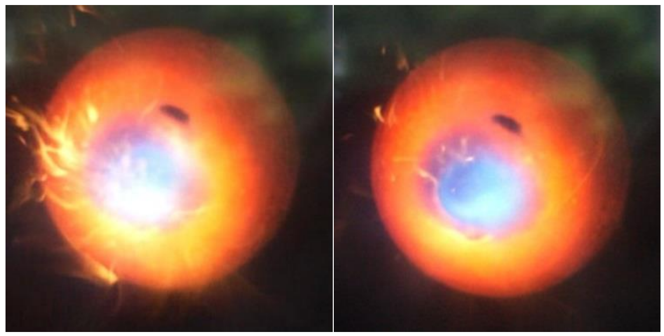
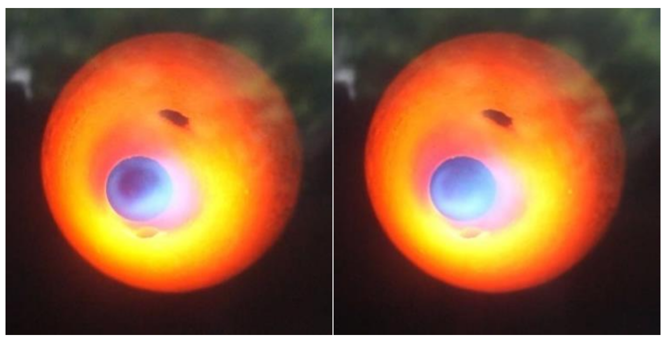
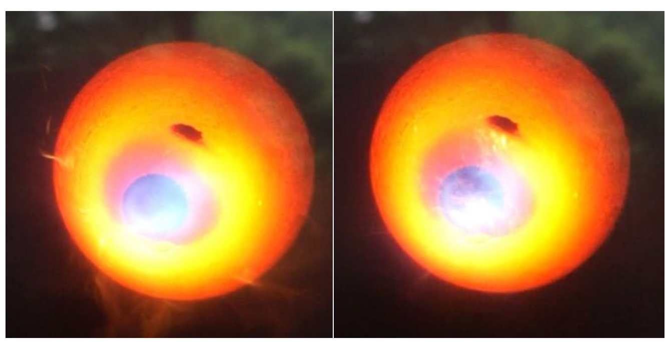
4.2.3 Flame Color and Shape

Flame color and shape was observed from the observation glass. The combustion was recorded by using High Speed Camera at interval of 0.02 s per frame, for certain amount of time. Table 15 shows some images of flame color.

From Table 15, it can be seen that combustion of diesel gave blue luminous flame with yellow tip. Meanwhile, combustion of vegetable oil gave blue luminous flame with yellow tip, but slightly more yellowish as compared with combustion of diesel.

Table 15: Flame Color of Each Sample

Sample	Flame Color
VD0	
VD20	

VD40	
VD60	
VD80	
VD100	

On the other hand, flame shape that can be seen from the observation glass is estimated as shown in Figure 22;

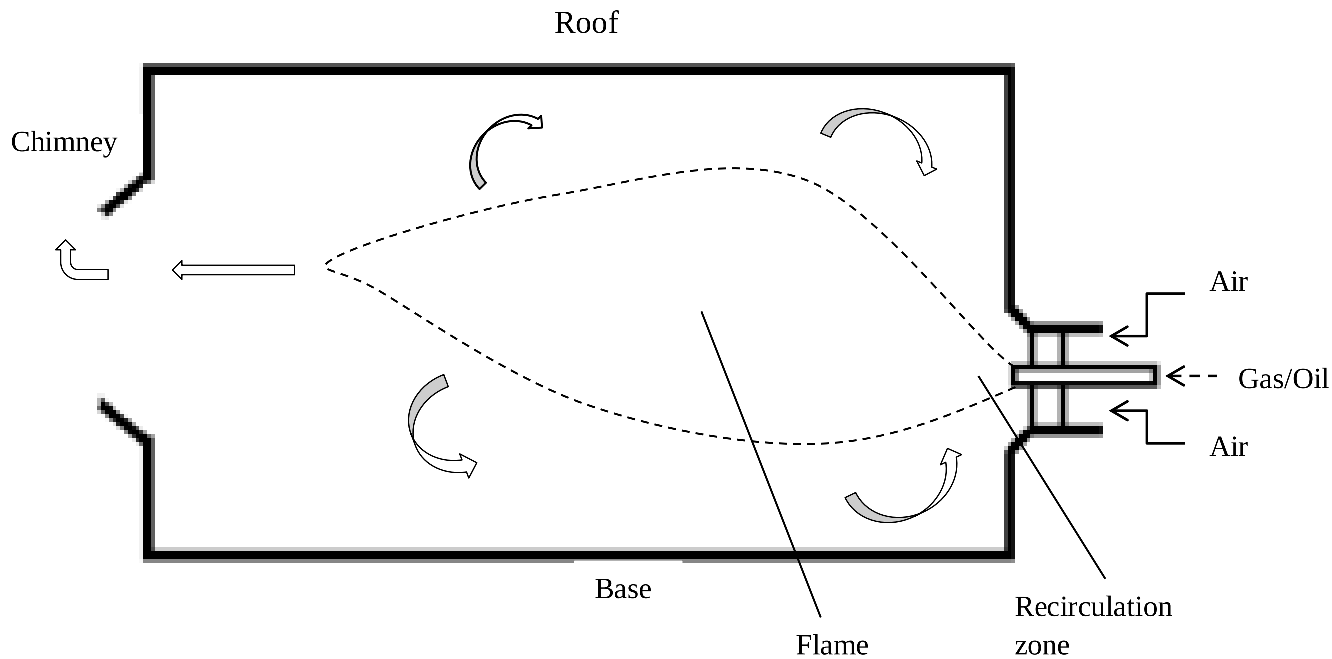


Figure 22: Sketch on Flame Shape in Furnace

From observation, flame shape for combustion of each diesel-vegetable oil blend was almost similar, except for the flame length. However, due to limited observation area, flame shape cannot be observed properly.

4.2.4 Discussion on Combustion Characteristics

As mentioned in the literature, the flame produced by the burner must have certain geometric shape and dimensions that suit the hearth or working space of a furnace. Failure to optimize these parameters is bound to lower the furnace efficiency, shorten the service life of refractories, pollute the environment and cause other undesirable effects [2].

From the experiments, flame length produced from combustion of diesel-vegetable oil decreases as the volume ratio of vegetable oil increases. VD0 produced flame length of 0.9270m; flame length reduced about 2.83% in VD20, 3.78% in VD40, 6.39% in VD60, 10.66% in VD80 and 16.58% in VD100.

Meanwhile, flame stability also decreases as the volume ratio of vegetable oil increases. VD0 took about 0.1875 s to blowoff; flame stability reduced about 18.67% in VD20, 37.19% in VD40, 42.67% in VD60, 60.89% in VD80 and 70.13% in VD100.

From the data, it can be concluded that diesel-vegetable oil can be used in industrial fuel burner. However, the optimum ratio of vegetable oil in the blend allowed to get similar combustion as diesel is 20%. Diesel-vegetable oil blend at 20% vegetable oil and 80% diesel has viscosity at $22^{o}C$ (@ 50rpm) is 0.83cP. Hence, the viscosity of fuel higher than 0.83cP is not recommended to be used in industrial fuel burner.

4.3 Study Limitations

Uncertainty in Determining Flame Length and Flame Shape

The video images from standard camera were used to qualitatively examine the flame length and flame shape. About 1000 frames were recorded in order to analyze the flame length and flame shape. Determining those combustion characteristics by video imaging relies strongly upon the sooting of the flame and the framing rate of the video. In addition, the camera was not synchronized with the fuel injection cycle, thus the individual images were sampled at different stages.

General fluctuations in the flame length due to the nature of the flames were another barrier in this study. Apart from that, the observation glass of the combustor unit is relatively small to the size of the flame. Hence, only partial of the flames can be observed.

Possible Mixing of Sample in between Changing Fuel in the Tank

In each experiment, about one liter of diesel-vegetable oil blend was poured into fuel tank located on top of the combustor unit. After the experiment, the unused blend was drained out and new sample of diesel-vegetable oil blend was poured in. The standard procedure stated that the fuel must be kept flowing in order to avoid air in the fuel tube. Hence, previous sample was remained in the tube because it cannot be drained out when the tank is empty. The combustor unit was allowed to burn the remaining sample until the new sample enters the tube. This was done by observing the color change of sample. As a result, starting time for combustion of each blend may not be the same.

Excess Air Effects on Heat Transfer

Combustion must be carried out with some excess combustion air above its theoretical requirement in order to achieve complete combustion with no unburned oil remaining. However, the increasing of excess air can lower heat transfer efficiency by absorbing additional heat, diluting combustion gases and increasing the volume of flue gas.

CHAPTER 5

CONCLUSION

In recent years, many researches have been done to determine the suitability of vegetable oil and its derivatives as fuel or additives to the diesel. Researches showed that vegetable oils alone are not considered acceptable fuels for large-scale or long term use. A major problem with vegetable oils is the high viscosity, which causes poor fuel atomization and inefficient mixing with air in combustion chambers.

One of the popular methods to handle the problem is by blending vegetable oil with diesel. Diesel-vegetable oil blend uses less energy to produce and is more environmental-friendly compared to petroleum-based fuels. Besides, the advantages of bypassing the conversion process to biodiesel substantially reducing the cost of fuel.

The first objective of the study was to study the characteristics of blended diesel-vegetable oil at different volume ratio. The experiments showed that kinematic viscosity reduced as the volume ratio of diesel in the blend increases. Same goes with the fuel density. However, calorific value of diesel-vegetable oil blend decreases as the volume ratio of vegetable oil in the blend increases.

Next, the combustion characteristics of diesel-vegetable oil blends at different volume ratio were investigated. The experiments showed that flame length and flame stability decreases as the volume ratio of vegetable oil in the blend increases. This is mainly due to high viscosity and high density of vegetable oil.

Last but not least, the combustion characteristics using both diesel fuel and diesel-vegetable oil blends were compared. It is found that the combustion characteristics were almost similar in combustion of 20% of vegetable oil, 80% diesel. This blend has about 0.83cP kinematic viscosity. Hence, it is concluded that vegetable oil can be used as alternative to diesel in the combustion using industrial fuel burner.

CHAPTER 6

RECOMMENDATION FOR FUTURE STUDIES

6.1 Study on Emission from Combustion of Diesel-Vegetable Oil Blends

Combustion of fuel produces carbon dioxide, oxides of nitrogen, sulphur oxides and carbon monoxide. Amount of these products are different for each fuel. Study on this matter is important in order to identify the optimum ratio of diesel-vegetable oil that can be used in industrial fuel burner without exceeding the emission standard.

6.2 Fuel Consumption of Diesel-Vegetable Oil Blends

Given that the fuel properties of the diesel-vegetable oil blends are different from each other, fuel consumption of the burning of the blends may be differed as well. Effect of the blending on fuel consumption of industrial fuel burner can be studied to identify whether it is economically viable or not.

6.3 Usage of Natural Gas instead of Liquefied Petroleum Gas (LPG)

As compared with LPG, the use of natural gas will reduce the emission of carbon dioxide, sulphur dioxide and oxides of nitrogen [1]. The emissions of natural gas against LPG are shown in Table 16.

Table 16: Combustion Quality of Natural Gas

Combustion Quality	**Natural Gas**	**Liquefied Petroleum Gas**
Carbon Dioxide	0.05136 kg/MJ	0.06882 kg/MJ
Sulphur Dioxide	0.73 mg/MJ	140 mg/MJ
Oxides of Nitrogen	40 – 125 mg/MJ	70 – 160 mg/MJ

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Appendix A

Requirement for C491 Operation

a) Air

A medium pressure air blower is available to produce a maximum of 160kg/hr which is regulated to a constant pressure of 250mm water gauge.

b) Water Supply

Cooling water is required with a minimum flow rate 30L/min. The connection at the lower end of the flow meter on the left hand control panel is of the compression type suitable for an inlet pipe of 25mm outside diameter. A 3 m length of suitable 25 mm inside diameter flexible hose is supplied.

c) Power Supply

A blower fan is supplied to operate on 230V/50Hz with direct on line starters. The electrical ignition and flame failure systems are operated from the same power source.

d) Fuel (Diesel-vegetable oil blends)

Fuel is stored in tank located on top of the combustion unit. It is fed to the burner through suitable piping and valves.

e) Liquefied Petroleum Gas (LPG) Supply

Gas from an LPG cylinder is fed to the burner through suitable piping and valves. Gas required for the combustion is 5.4 m^3/hr.

f) Drainage

Drainage is provided for cooling water from the combustion chamber.

Appendix B

Ignition Procedure for C491

1. Turn on the gas at the supply only. Check that gas pressure at the manometer is between 125 and 500 water gauge by depressing the green pressure check button to control panel. Using a suitable screwdriver, rotating the internal adjuster to increase the pressure.
2. Turn on the main water supply. Slowly open the water control valve to the chamber and adjust the flow to 1800 kg/h. Maintain this flow until the outlet is seem to be running fuel.
3. Reduce the water flow to 1600 kg/h.
4. Switch on the mains electricity supply and the master switch at the unit.
5. Open the air control to position 1 and switch on the air fan. Wait for the motor to reach normal operating speed.
6. Open the air control to a flow at least 170 kg/h and run for at least 1 minutes at this setting to purge the chamber.
7. Reduce the air flow to 25 kg/h.
8. Set the cut out on the final water temperature meter to 80°C
9. Press the "press to reset" button. Switch on the set switch and check that the red light on the water outlet temperature gauge is illuminated.
10. After 5 second delays the reset switch red indicating light on the control panel illurninates to indicate that the flame failure system is operational.
11. Press and hold the ignition switch.
12. At the same time quickly open the gas fuel control valve.
13. When the flame is established release the ignition switch and allow the system to stabilize.
14. Diesel-vegetable oil is fed when the temperature reached 400^{o}C.
15. Stable running conditions are indicated by steady cooling water and exhaust gas temperatures and also a steady exhaust note.

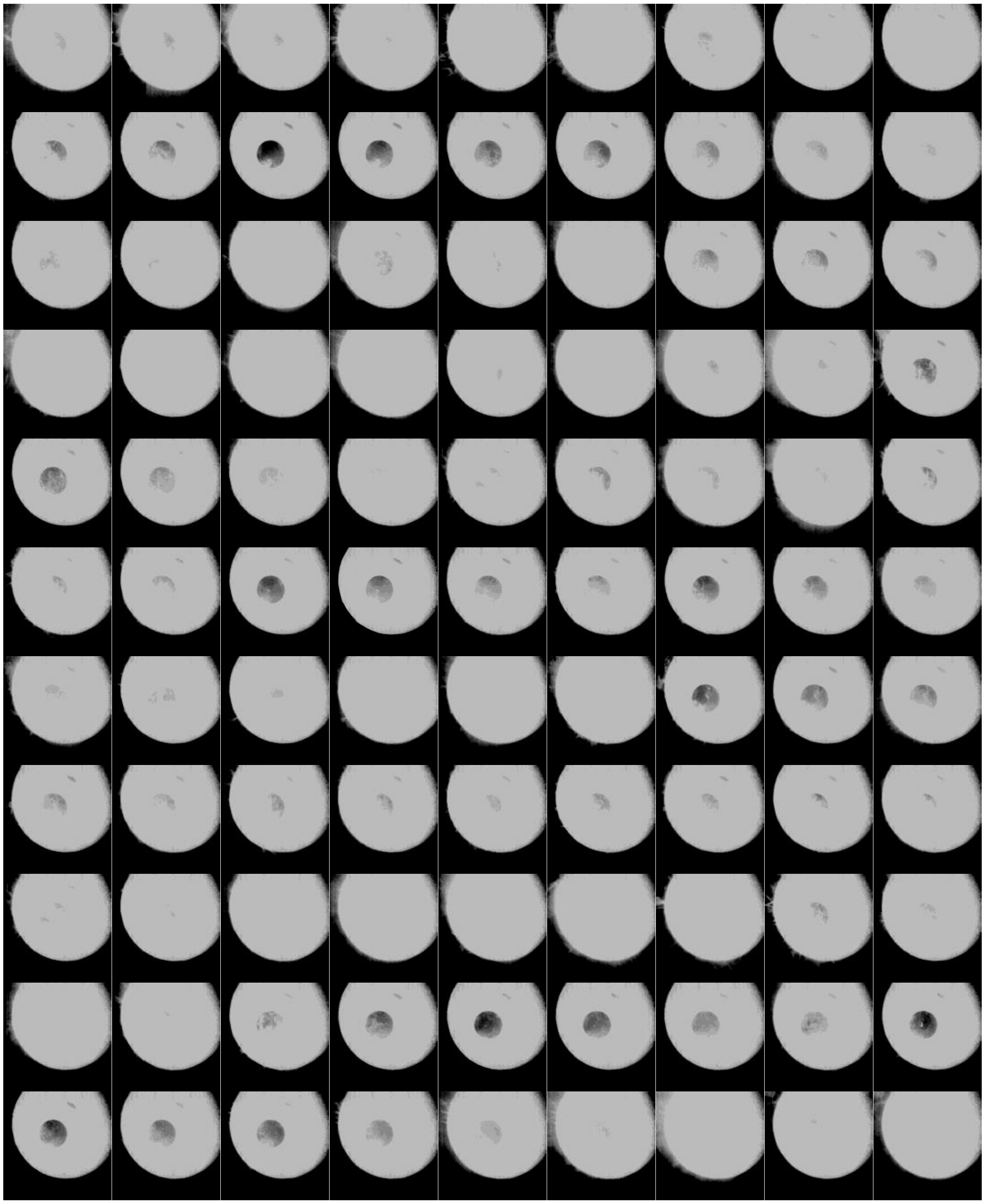
Appendix C

Kinematic Viscosity of Diesel-Vegetable Oil Blends

Speed (rpm)	Kinematic Viscosity (cP)					
	VD0	VD20	VD40	VD60	VD80	VD100
0.3	-	-	-	59.40	62.50	81.30
0.6	-	-	-	15.60	21.90	43.80
1.5	-	-	-	-	-	22.50
3.0	7.19	8.13	15.63	16.90	22.80	25.00
6.0	0.47	-	-	5.94	9.84	15.80
12.0	-	0.39	0.63	3.75	6.80	13.60
30.0	0.22	0.69	1.63	4.53	6.72	14.80
60.0	0.75	1.13	1.80	3.86	6.64	13.90
0.0	-	-	-	-	-	-
0.5	-	-	-	-	-	45.00
1.0	-	-	-	-	1.88	30.0
2.0	-	-	-	4.69	9.84	15.50
2.5	-	-	-	6.75	9.38	15.80
4.0	-	-	-	3.75	6.80	15.50
5.0	-	-	-	4.69	7.88	16.50
10.0	-	-	-	3.75	6.00	13.10
20.0	0.14	0.75	1.27	3.84	6.70	14.00
50.0	0.53	0.83	1.58	3.75	6.60	13.50
100.0	1.16	1.65	2.40	4.17	6.61	-

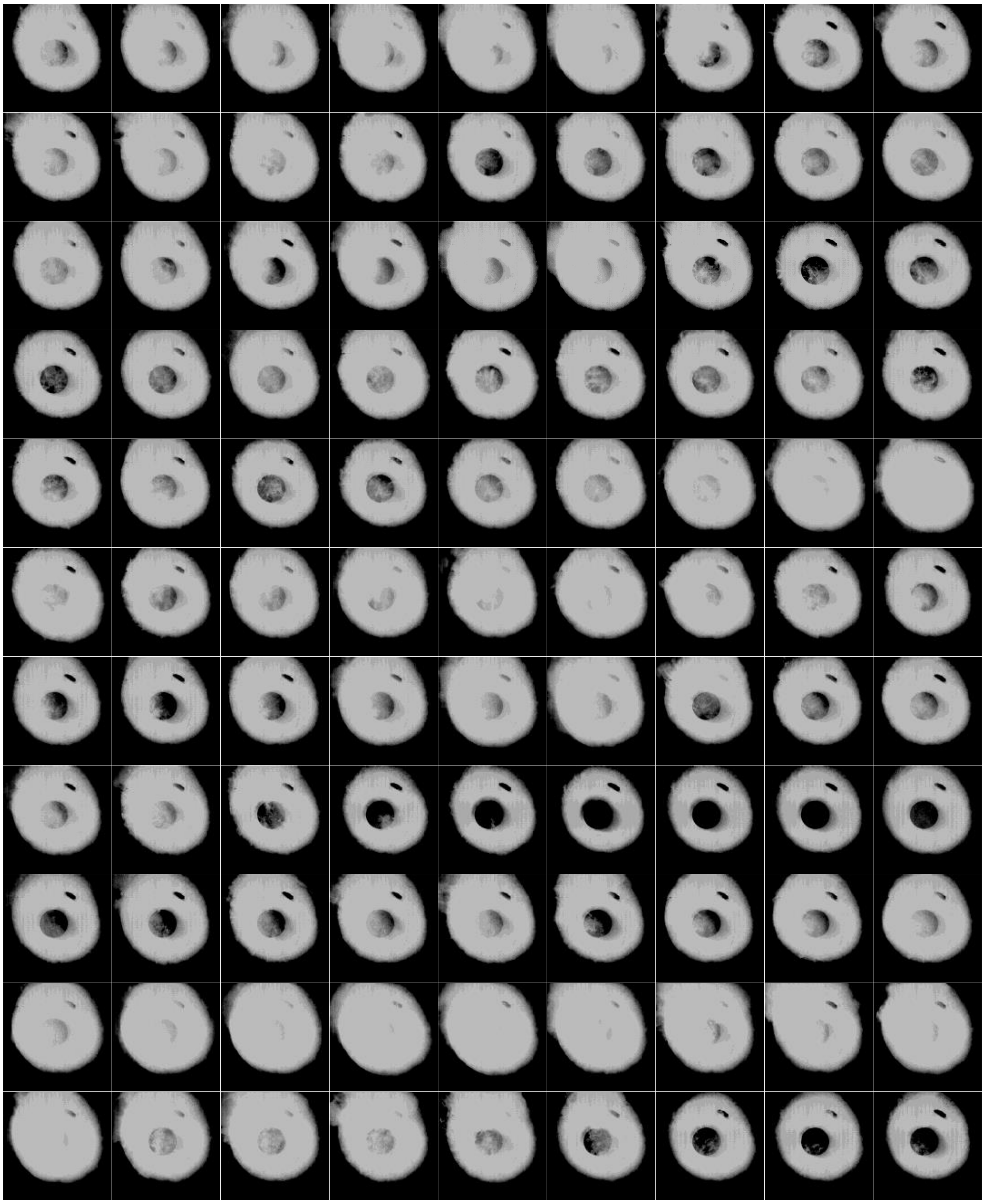
Appendix D

Combustion of VD0 through High Speed Camera



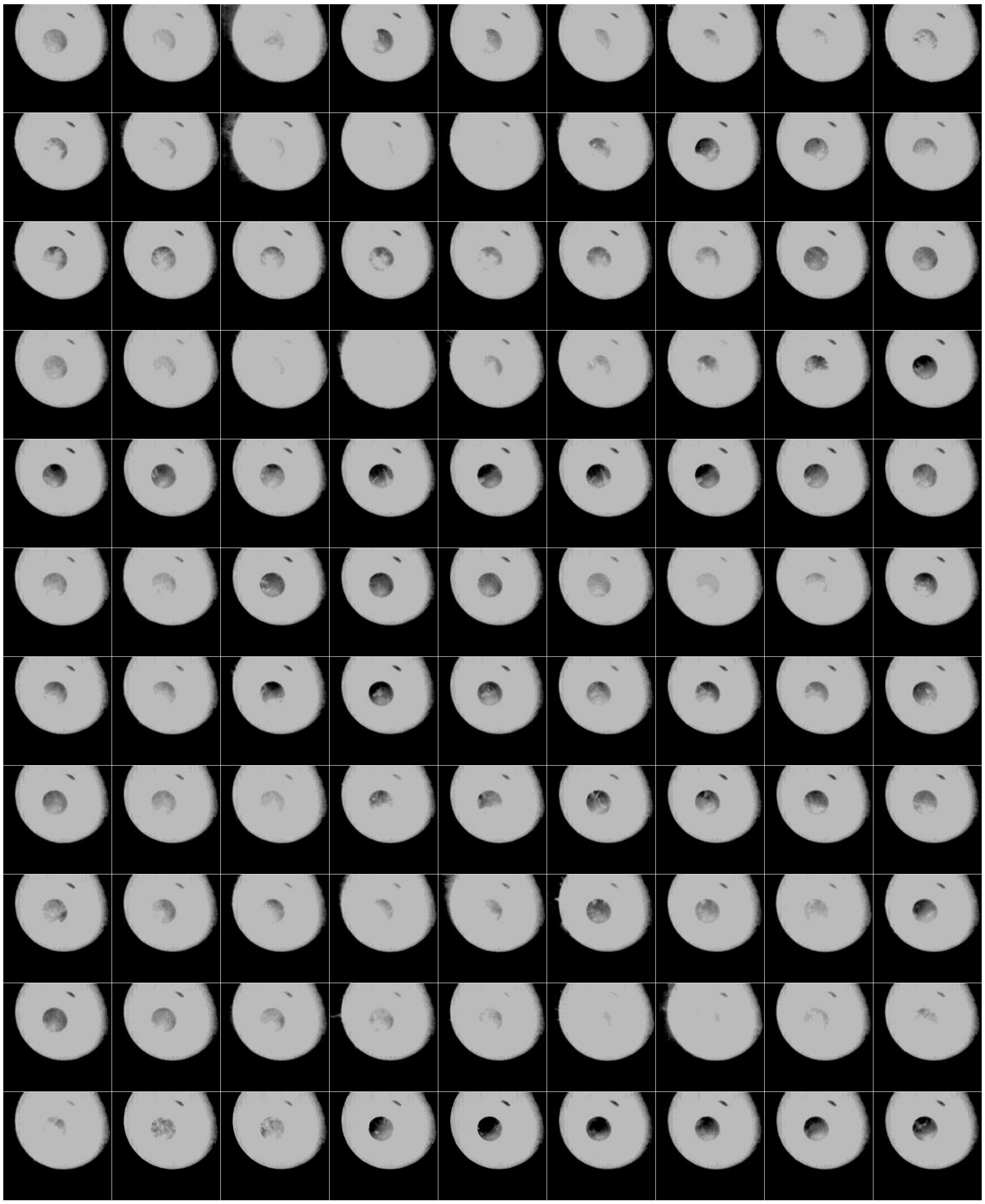
Appendix E

Combustion of VD20 through High Speed Camera



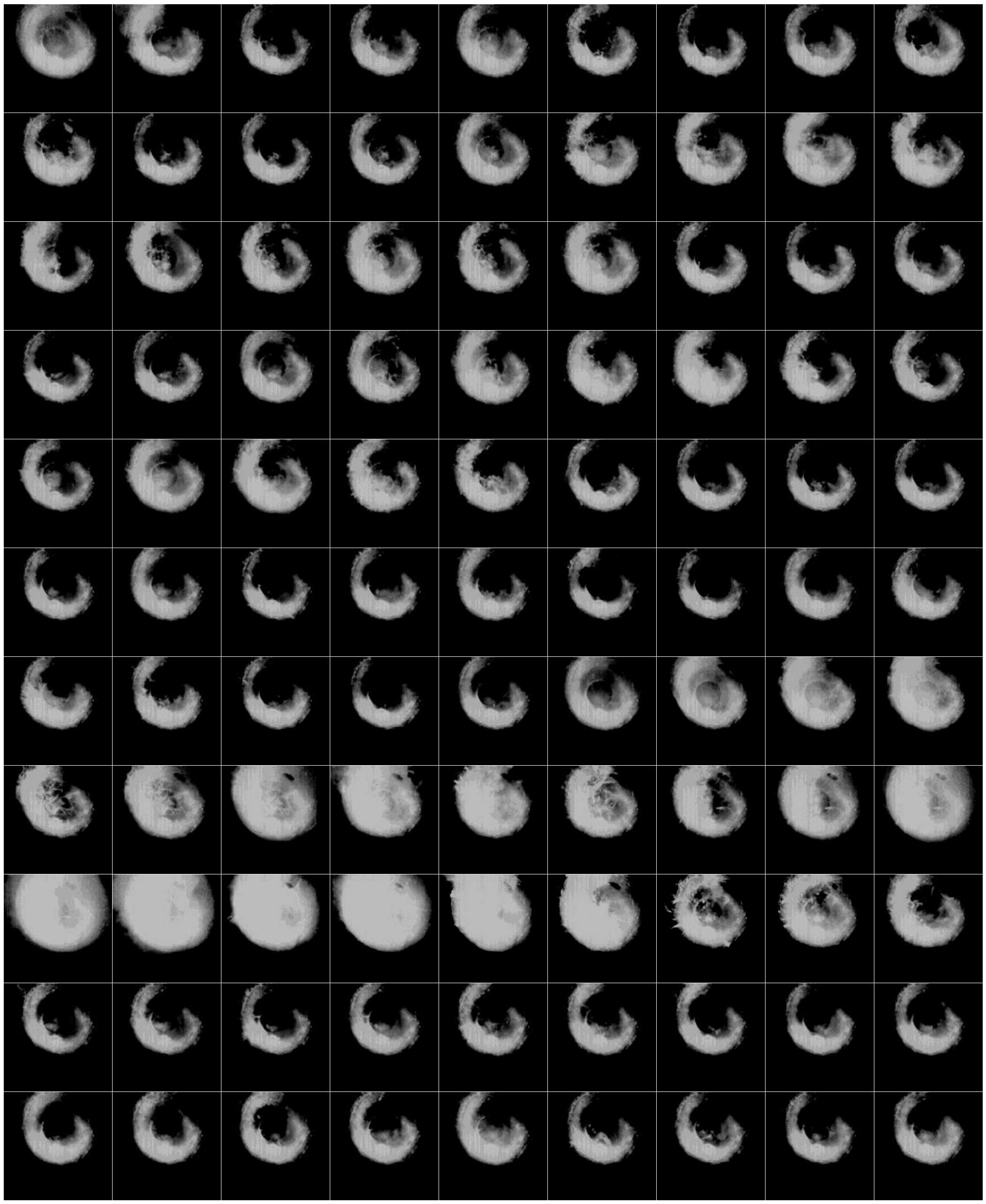
Appendix F

Combustion of VD40 through High Speed Camera



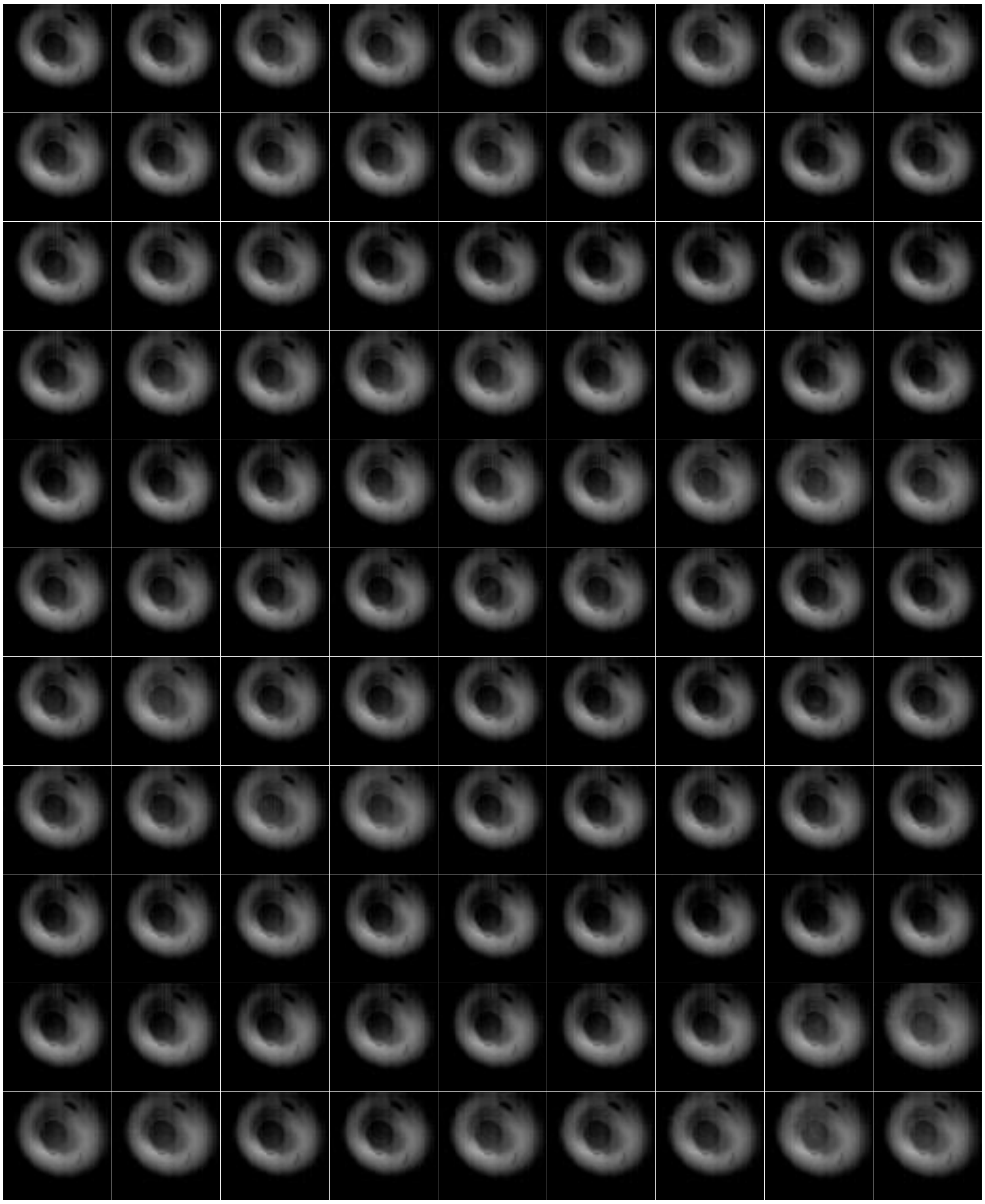
Appendix G

Combustion of VD60 through High Speed Camera



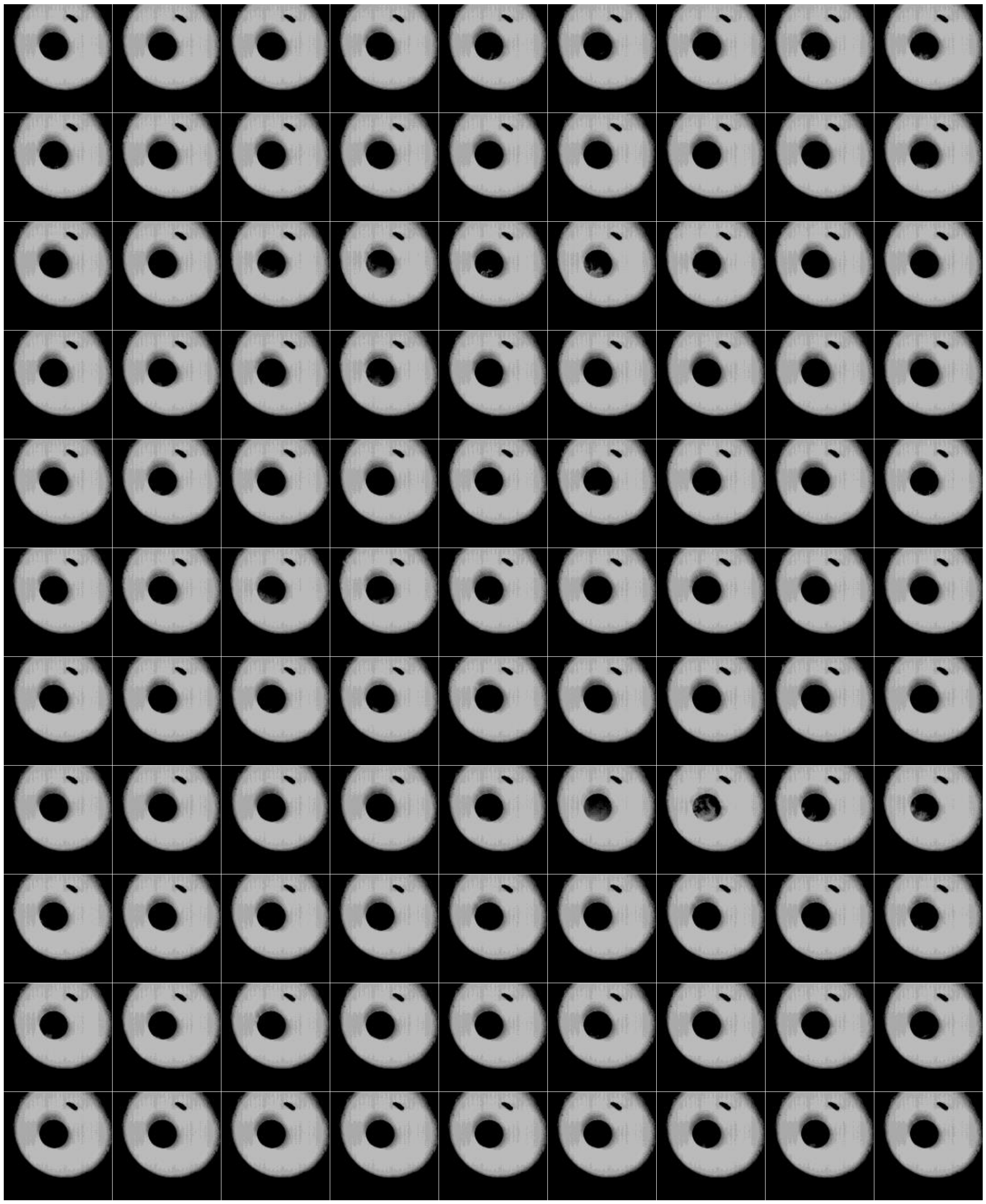
Appendix H

Combustion of VD80 through High Speed Camera



Appendix I

Combustion of VD100 through High Speed Camera



Appendix J

ASTM D 445 – 97 Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids

Appendix K

ASTM D 240 – 92 Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter