RAPID PREMIXING FUEL-WATER-AIR INJECTOR IN BURNER COMBUSTION

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ABSTRACT

The alternative fuel is attract good attention from worldwide especially for renewable and prevention energy such as biodiesel. Biodiesel is one of the hydrocarbon fuels and it has potential for external combustion. This research used biodiesel Crude Palm Oil (CPO) as fuels in which have been blend with diesel. Biodiesel Crude Palm Oil base (CPO) is free from sulfur and produced by esterification and trans-esterification reaction of vegetable oil with low molecular weight alcohol, such as ethanol or methanol. Rapid mixing injector uses for external combustion especially open burner system. Therefore, the objectives of this research are to investigate the effects of mixture formation between biodiesel and water on using rapid mixing injector and to analyze the influence of mixture formation on flame propagation and combustion characteristics together with the effect of water content on the gas emissions are analyzed. The disadvantages of CPO are high toxic emissions such as NO_X and CO while it can cause the reduction on performance of burner system. However, high toxic emission can be solved by using a new concept injector with fuel-water-air premixing. The additional water in combustion process can be reduced the NO_X emissions. The results of this research focuses on the mixture formation of spray, flame and exhaust gas emissions. CPO biodiesel has longer spray length and bigger spray area than diesel, but the spray angle is smaller than diesel. Based on flame image, it shows that the flame color between pure fuels and fuel-water mix fuel is totally difference compare to each other. Water mix with fuel has the brightness color and shorter flame than fuels. The exhausts gaseous tested are CO, CO_2, HC and NO_X. In this research, water premix of percentage up to 15vol% and blending biodiesel ratio was varied from 5vol% - 15vol%. The result shows that increasing of water content will affected decrement of CO, CO_2 and HC emissions but increasing the NO_X emissions.

ABSTRAK

Bahan api alternatif dapat menarik perhatian dari seluruh dunia terutamanya untuk pembaharuan tenaga seperti biodiesel. Biodiesel adalah salah satu bahan api hidrokarbon dan mempunyai potensi untuk pembakaran luar. Kajian yang menggunakan biodiesel daripada minyak sawit mentah (CPO) sebagai bahan api di mana diesel sebagai bahan pencampuran. Biodiesel minyak sawit mentah (CPO) adalah bebas daripada sulfur dan dihasilkan daripada pengesteran dan trans- pengesteran hasil reaksi minyak sayur-sayuran dengan berat molekul alkohol yang rendah, seperti etanol atau metanol. Penyuntik pencampuran pesat digunakan untuk sistem pembakaran luar terutamanya pada sistem pembakaran terbuka. Oleh itu , objektif kajian ini adalah untuk mengkaji kesan pembentukan campuran antara biodiesel dan air dengan menggunakan penyuntik pencampuran pesat dan bertujuan untuk menganalisis kesan pembentukan campuran pada perambatan api dan ciri-ciri pembakaran sekaligus menganalisis kesan kandungan air pada pelepasan gas. Antara kelemahan CPO adalah dapat mengurangkan prestasi sistem pembakaran dan juga pelepasan toksik yang tinggi seperti NO_X dan CO. Walaubagaimanapun, pelepasan toksik yang tinggi dapat dikurangkan dengan menggunakan konsep penyuntik pencampuran bahan api – air –udara. Percampuran air dapat menggurangkan NO_X. Hasil kajian ini adalah hanya tertumpu kepada campuran semburan bahan api, pembentukan api dan pelepasan toksik. Berdasarkan keputusan semburan, CPO menghasilkan bentuk semburan yang panjang, besar dan sudut lebih kecil berbanding diesel. Percampuran bahan api dan air akan menghasilkan nyalaan warna api yang lebih terang dan nyalaan api yang pendek. Pelepasan toksik dapat dikurangkan dengan meningkatkan kandungan air. Gas-gas pelepasan yang diuji ialah

CO, CO_2, HC dan NO_X. Di dalam kajian ini, pracampuran air ialah sehingga 15% isipadu, manakala julat nisbah percampuran biodiesel pula ialah daripada 5% hingga 15% isipadu. Hasil daripada kajian ini menunjukkan bahawa, gas NO_X berkadar langsung dengan peningkatan kandungan air, tetapi sebaliknya untuk gas CO, CO_2 dan HC.

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LIST OF SYMBOLS AND ABBREVIATIONS

NO_x	-	Nitrogen Oxides
CO	-	Carbon Monoxide
PM	-	Particulate Matter
CP05	-	Crude Palm Oil 5% Biodiesel
CP010	-	Crude Palm Oil 10% Biodiesel
CP015	-	Crude Palm Oil 15% Biodiesel
W0	-	0% Water Content in Diesel
W5	-	5% Water Content in Diesel
W10	-	10% Water Content in Diesel
W15	-	15% Water Content in Diesel
HC	-	Hydrocarbon
CO_2	-	Carbon Dioxide
C	-	Carbon
H_2	-	Hydrogen
O_2	-	Oxygen
H_2O	-	Water
N_2	-	Nitrogen
SOF	-	Soluble Organic Fraction
SOLID	-	Solid Carbon
GO	-	Gas Oil
Q_a	-	Atomizing Air Flow Rate
Q_t	-	Total Air Flow Rate
GOW50	-	50% Water Content in Gas Oil
AFR	-	Air-Fuel Ratio
A/F_{stoic}	-	Stoichiometric Air-Fuel Ratio
cc	-	Cubic centimeter
P	-	Pressure
v	-	Velocity

A	-	Area
ρ	-	Density
Q_2	-	Secondary Air
Φ	-	Equivalent Ratio
MW_f	-	Diesel Molecular Weight
MW_w	-	Water Molecular Weight
MW_a	-	Air Molecular Weight
$\dot{m}$	-	Mass Flow Rate
A/F_{exp}	-	Experimental Air-Fuel Ratio
DSLR	-	Digital Single-Lens Reflex

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CHAPTER 1

INTRODUCTION

1.1 Research Background

In the future, the growth of population and economic require more energy and natural resources. Increasing in environmental issues and the cost of fossil fuel has resulted in research on alternative fuel such as biodiesel. Biodiesel as the renewable resource continue to be of interest research in order to achieve a sustainable energy economy thus reducing dependence on fossil fuels. Moreover, worldwide demand on the biodiesel as an alternative fuel is also increasing due to the world energy sources crisis.

Advantage of biodiesel is an environmentally friendly fuel, which one of the clean and renewable energy resources. The fuel is usually made from animal fat or vegetable oil revenue trans-esterification reaction. The oxygen content in biodiesel is 11% to 15%, which results in increasing the combustion process and reducing the emission from diesel engines [1].

Emission is a main issue in the observation of external combustion characteristics. In combustion process could emitted into the atmosphere, Nitrogen oxide (NO_x) reacts with water and other compounds to form various acidic compounds, fine particles, and ozone. These pollutants can remain in the air for days or even years. Effects of NO_x are decrease in lung function, resulting in difficulty breathing, shortness of breath, and other symptoms.

However, this fuel, released toxic emissions such as Nitrogen oxides (NO_X) and Carbon monoxide (CO). NO_X are known to be immediately dangerous to human health and environment. Besides that, NO_X reacted with other pollutants to form toxic chemical as well as contribute to the formation of acid rain. CO is highly toxic to human body even at lower levels.

Rapid premixing in the combustion process was use to reduce the gas emission especially NO_X and flame temperature. The premixing also influenced on flame propagation phenomena. Furthermore, the gas emission also can be reduce by controlling the spray characteristic such as spray penetration and spray angle to compare fuel diesel and biodiesel Crude Palm Oil (CPO).

1.2 Research Problem Statement

Controlling the exhaust emissions is an urgent task to meet future emission legislation. The gas emission can be reduced by two methods. First is by improving an injector with fractals and the other one is by using a biodiesel-water mixture as an alternative fuel. Mixing of water with fuel in the combustion process is a low cost and effective way.

Fractal grid is one of the methods using in the rapid mixing. Fractal grid is a new turbulence generator is used to generate turbulent for improvement of mixture formation between fuel-water-air and performance of combustion. The premixing fuel biodiesel-water-air mixture has been studied previously by manipulating different water content of premixing biodiesel and equivalence ratio [1]. However, the amount of data is still not enough to describe in detail about the combustion characteristics of this premix fuel by using the fractal grid.

This study is focused on the observation of the real images of the spray and flame characteristics for different equivalence ratio of water content and premix fuel. The spray characteristic such as spray angle penetration length is essential data in order to predict the combustion process of the mixture. The combustion characteristics are observed and analyzed the effect of the water content on the gas emission.

1.3 Objectives

i. To investigate the effect of biodiesel and water on mixture formation using rapid mixing injector.
ii. To analyze the influence of mixture formation on flame propagation and combustion characteristics.
iii. To investigate the effect of water content on combustion and emissions.

1.4 Scope of the Study

i. Premix injector is used to mixed between fuel, air, and water.
ii. Fractal grid is inserted in the premix injector for the purpose of controlling combustion.
iii. In this research, different types of blends biodiesel fuel are used from the crude palm oil (CPO) such as CPO5 (5vol%), CPO10 (10vol%) and CPO15 (15vol%).
iv. Different nozzle characteristics of injector which were 45° and 50° are used in burner system.
v. Pressure of 0.25 bar is used to generate the mixture formation with equivalence ratio between 0.6 to 1.4.
vi. Water premixing up to 15% and the ratio of the biodiesel between 5% to 15% are set for this experiment.
vii. The emissions will be focused on Carbon monoxide (CO), carbon dioxide (CO_2), and hydrocarbons (HC) also been studied.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This study aimed to investigate the effect of biodiesel fuel especially from crude palm oil to open burner. In this research, it involves in the development injector for burner system. Premix injector mix the air, fuel and water in combustion process [1].

As the increases of the pollution problem, the demand for technologies to meet different lifestyle requirements increase as well. Consequently, Lean premixed combustion of gaseous fuel is currently one of the most important technologies to achieve low pollutant emission at high efficiencies in the power generation. Reduction of NO_X emissions is a direct outcome of the lower combustion temperatures when burning a lean mixture and complete combustion prevent the creation of unburned hydrocarbons (HC) and carbon monoxide (CO) [2]. However, turbulent premixed flames are studied in various configurations such as burner-stabilized, wire-stabilized flame outward propagating spherical flame and flames stabilized in opposed jet flows. In most cases the fuel mixture flows through a burner and turbulence is generated by the shear flow or by the use of grids upstream of the flame stabilized location.

2.2 Biodiesel

Biodiesel as an alternative fuel for diesel engines is become an increasingly important due to diminishing petroleum reserves and the environmental consequences of exhaust gases from petroleum-fuelled engines. Edible vegetable oils such as canola, soybean, and corn have been used for biodiesel production and are proven diesel substitutes. However, a major obstacle in the commercialization of biodiesel production from edible vegetable oils is their high production cost, which due to the demand for human consumption. Reducing the cost of the feedstock is necessary for biodiesel's long- term commercial viability. One of the ways to reduce the cost of this fuel were use less expensive feedstock including palm oil that are non-edible and require low harvesting costs.

Table 2.1: Physical and chemical properties of B100 [3]

Test Properties	**B100**
Carbon (%mass)	77.10
Hydrogen (%mass)	11.81
Oxygen (%mass)	10.97
Cetane Number (ASTM D613)	51.5
Kinematic Viscosity	4.2691

Biodiesel has a major advantage over petroleum diesel, since the biodiesel derived from renewable sources is clean burning fuel that does not contribute to the increase of carbon dioxide, being environmentally friendly. Biodiesel is an oxygenate, sulphur free and biodegradable fuel, and its content of oxygen helps improve its combustion efficiency. Therefore, fewer greenhouse gases such as carbon dioxide are released into the atmosphere. Biodiesel has positive performance attributes such as increased cetane, high fuel lubricity, and high oxygen content [4]. Since, biodiesel is more lubricating than diesel fuel, it increases engine life and it can be used to replace sulphur, a lubricating agent, that when burned, produces sulphur oxide; the primary component in acid rain. As shown in Table 2.1 stated that the viscosity of biodiesel is evidently higher than that of diesel fuel. The density of the biodiesel is approximately 6.1% higher than that of diesel fuel. The lower heating value is approximately 10.2% lower than that of diesel fuel. Therefore, it is necessary to increase the fuel amount to be injected into the combustion chamber to produce the same amount of power [3].

2.2.1 Biodiesel Properties

The most important difference between the composition of diesel fuel and biodiesel is the oxygen content in the fuel. Biodiesel contains between 10-12% oxygen content in which it has a high density compared to diesel [6]. According to a study, other than oxygen, there are other physical properties that are available on biodiesel fuel [5]. Among biodiesel does not contain sulfur, high cetane number, low heating value, good lubricity, having a high level of viscosity, having the high flash point and no toxic.

In addition, apart from the physical properties listed above, there are several other physical properties that distinguish between biodiesel, petroleum diesel and palm oil [5]. Among other differences, as listed in Table 2.2.

Table 2.2: Physical properties of petroleum diesel, biodiesel blends and palm oil [5]

Types of fuel	Density (kg/m^3)	Surface tension (N/m)	Dynamic Viscosity (kg/ms)
Petroleum diesel	828.7	0.03	0.0032
B5	832.2	0.0305	0.0038
B10	836.1	0.0305	0.0042
B15	838.9	0.0305	0.0046
B20	842.0	0.0305	0.0050
Palm Oil	901.2	0.0345	0.0352

2.2.2 Crude Palm Oil (CPO)

In Malaysia, the development of biodiesel is increase in particularly for Crude palm oil (CPO). CPO is readily available, safe to store and handle, and most importantly, totally renewable. Its negligible sulphur content compared with diesel reduces the possibility of acid rain caused by sulphur dioxide emissions [7].

CPO can be made into a biodiesel through the process of transesterification of triglycerides with methanol. The product of this process is known as palm oil methyl ester (POME), or palm oil diesel. Studies conducted on POME [7–9] have shown promising results compared with diesel, in terms of both engine performance and emission. However, POME is more expensive than CPO, due to the chemical and mechanical processing involved. The interest in CPO as a diesel substitute stems from its simple production process, which makes it less expensive than POME.

CPO is a type of the vegetable oils that process into biodiesel by using transesterification with methanol and the biodiesel produced is called palm oil diesel. One major disadvantage of CPO is their high viscosity which causes clogging of injectors. The methods that can reduce the viscosity is heating process which mixing with lighter oil [9]. From the Fig.2.1 show that the viscosity of biodiesel decrease when the temperature is increased.

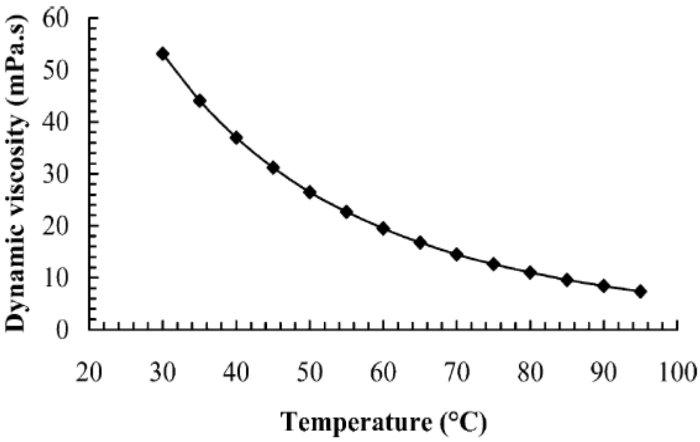


Figure 2.1: The effect of temperature against the dynamic viscosity of pure CPO [10]

The other method to decrease the viscosity of the biodiesel was used blending process because the blending process brings some benefits such as [11]:

a. Can be easily done at any places;

b. Special instruments and chemical processes are unnecessary;

c. The fuel after blend are able to use in the engines that without extensive transformation and modification

2.2.3 Advantages of biodiesel

In this section, there are includes:

i. Availability and renewability
ii. Lower emission
iii. Biodegradability

2.2.3.1 Availability and renewability

Biodiesel is the only alternative fuel with the property that low-concentration bio fuel petroleum fuel blends will run well in unmodified conventional engines. It can be stored anywhere petroleum diesel fuel is stored. Biodiesel can be made from domestically produced, renewable oilseed crops such as soybean, rapeseed and sunflower. The risks of handling, transporting and storing biodiesel are much lower than those associated with petroleum diesel. Biodiesel is safe to handle and transport because it is as biodegradable as sugar and has a high flash point compared to petroleum diesel fuel. Biodiesel can be used alone or mixed in any ratio with petroleum diesel fuel. The most common blend is a mix of 20% biodiesel with 80% petroleum diesel, or B20 in recent scientific investigations; however, for future commercial applications in Europe the current regulation foresees a maximum of 5.75% biodiesel [12].

2.2.3.2 Lower emission

Biodiesel mainly emits carbon monoxide, carbon dioxide, and oxides of nitrogen, sulphur oxides and smoke. Combustion of biodiesel alone provides over a 90% reduction in total unburned hydrocarbons (HC) and a 75–90% reduction in polycyclic aromatic hydrocarbons (PAHs). Biodiesel further provides significant reductions in particulates and carbon monoxide over petroleum diesel fuel. Biodiesel provides a slight increase or decrease in nitrogen oxides depending on engine family and testing procedures. Currently, global warming caused by CO_2 is the main climatic problem in the world. Therefore, environmental protection is important for the future of the world. Because biodiesel is made from renewable sources, it presents a convenient way to provide fuel while protecting the environment from unwanted emissions. Biodiesel is an ecological and non-hazardous fuel with low emission values, and therefore it is environmentally useful. Using bio-diesel as an alternative fuel is a way to minimize global air pollution and in particular reduce the emission levels of potential or probable carcinogens. The emission of unburned hydrocarbons, carbon dioxide, carbon monoxide, sulphates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons and particulate matter from biodiesel; the net emission of CO_2 was considerably lower than that of diesel oil [13].

2.2.3.3 Biodegradability

The biodegradability of biodiesel has been proposed as a solution to the waste problem. Biodegradable fuels such as biodiesel have an expanding range of potential applications and are environmentally friendly. Therefore, there is growing interest in degradable diesel fuels that degrade more rapidly than conventional petroleum fuels. Biodiesel is non-toxic and degrades about four times faster than petroleum diesel. Its oxygen content improves the biodegradation process, leading to an increased level of quick biodegradation [14].

2.3 Injection system

The use of fuel injectors on a diesel burner system is an effective measure to control fuel on the combustion process. An experiment on a new injector system in which the fuel injectors for biodiesel mixture, air and water addition was done. The injector system is compared with the existing one. This injector used rapid internal mixture method where fuel, air and water will be mixed before the combustion process takes place. The other way to explain is when addition of water to combustion field, a process called micro-explosion that will occur when the high temperature break up the water structure, induce fuel atomization and reduces the emission [2]. Figure 2.2

shows rapid internal mixture method injector system which the system is releasing many toxic substances such as CO and flame temperature.

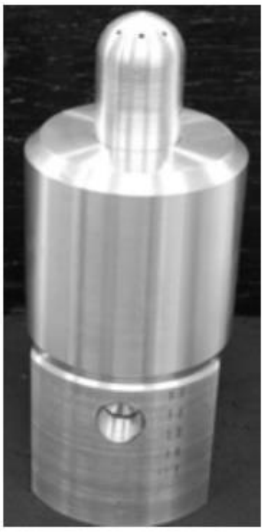


Figure 2.2: Fuel-water-air Internally Rapid Mixing injector system

2.3.1 Fractal Grid

This research has use a fractal grid together to the injector system. Fractal grid is a new turbulence generator used to generate turbulent premixed flames. Conceptually, different fractal grids with regular square grid because it creates turbulence on length scales simultaneously, rather than to a single mechanism that generates turbulent fluctuations are different for the two types of grid. Figure 2.3 shows separated part of rapid mixing injector system, where the flow field generated turbulence intensity continues to increase with distance downstream. In general, high turbulence can be produced in a specific location on the downstream grid. Minimum pressure drop is also to achieve the velocity fluctuations in the intensity of the turbulence peak locations [11].

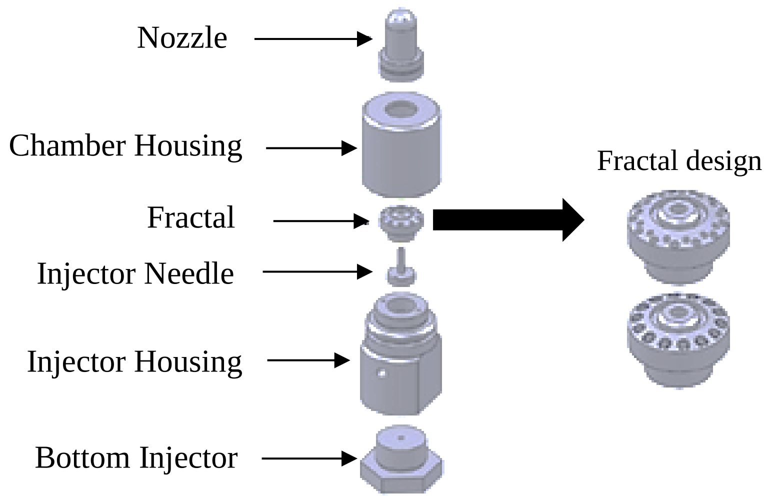


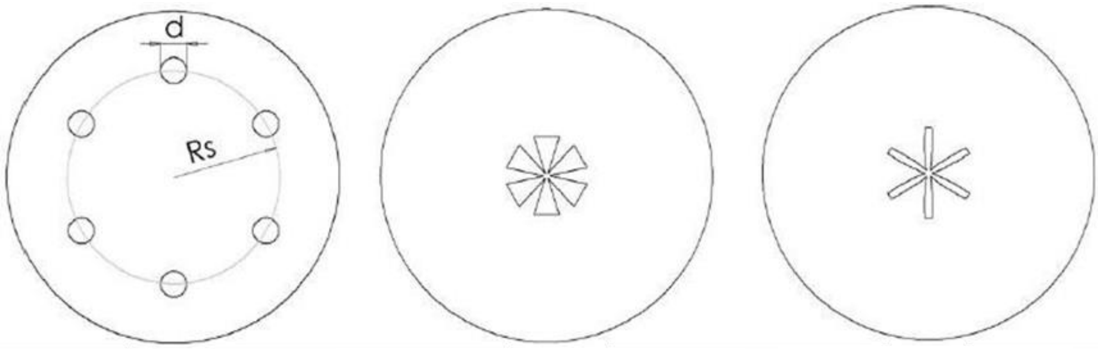
Figure 2.3: Separated part of Rapid Mixing injector system

A flow field is generated where the turbulence intensity keeps increasing with downstream distance by using fractal grid. At a particular location downstream of the grid, high turbulence intensities can be generated. In addition, this location depends on the grid design. Besides, in order to achieve a given level of velocity fluctuations at the peak turbulence intensity location, the pressure drop is minimum. By using the fractal grid, intense turbulence can be generated at a given downstream distance and as consequence, turbulent fluctuations and the turbulent flame speed are high. Besides, the characteristics of the turbulent flow field to a certain stage can be designed to achieve desired values for examples, velocity fluctuations and length scales [11].

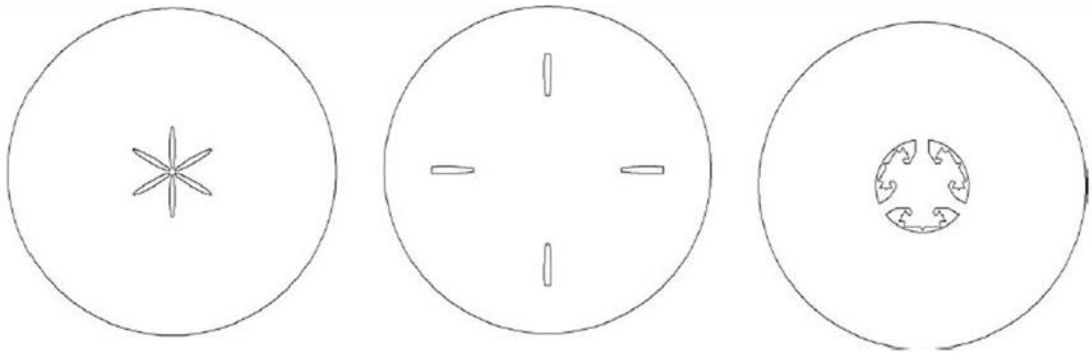
2.3.1.1 Blockage ratio

The definition of blockage ratio is the area blocked by the grid ratio to the whole area of the channel square or circle section before it become turbulent or laminar flow. It is shown that, from the experiment investigation on a turbulence generation system with high blockage ratio that compares two families of turbulent generator (multi circular jet plate and non-circular jet plate), multi circular jet is shown at

Fig. 2.4 have high turbulent level at same blockage ratio, flow rate and preserving radial uniformity [15]. Small increase in blockage ratio lead to the significant increase in turbulence intensity, which is proportional to the square root of the pressure drop. Thus, the maximum turbulent intensity that plays important role in premixed flame combustion could be determined, by measuring the blockage ratio [16]. For turbulence generation in a system, non-circular geometry is considered as a good candidate compared to the circular geometry because of the maximum turbulence intensity of non-circular geometry is much higher than circular geometry, in the same blockage ratio [17].



(a) Multi jet plate type round (MCJ)
(b) Non-circular jet plates (MCJ)
(c) Center-jet



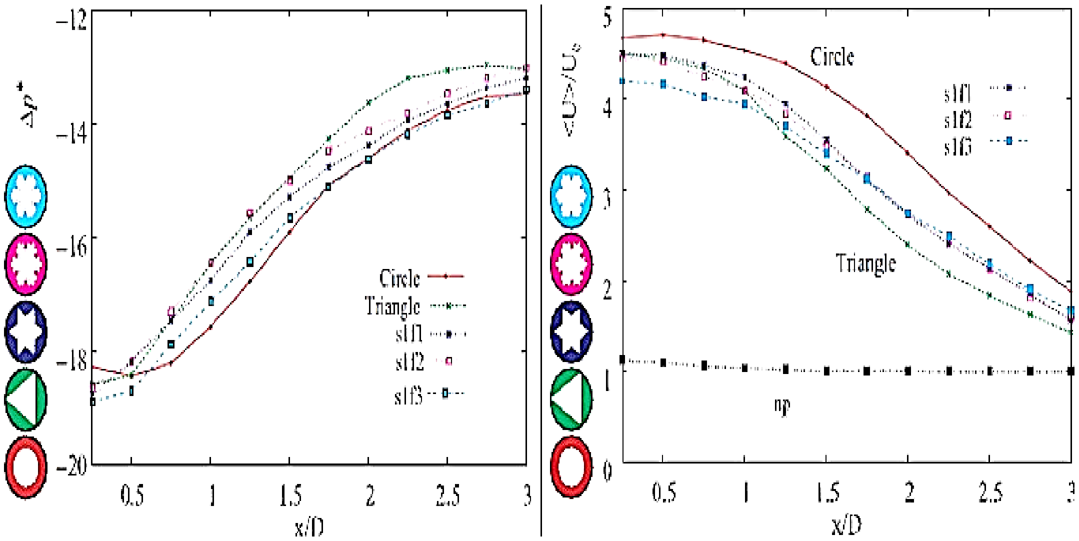
(c) Wake center
(c) Multi-jet
(c) Wake

Figure 2.4: Turbulent level at same blockage ratio [12].

2.3.1.2 Fractal pattern

Fractal pattern is a variable that important to measure the turbulent burning velocity, pressure drop and turbulent system. By using different pattern in experiment, pressure drop increases by escalation the distance. Blockage ratio of 33.6% are used and the experiment were conducted to compare pressure drop and velocity on the centerline normalized by inlet velocity by using different patterns such as circle, triangle and pentagon with same blockage ratio [18].

From Fig. 2.5, circle pattern shows the lower pressure drop compare to the other pattern as shown in figure (a). Meanwhile, in figure (b), velocity on the centerline normalized by inlet velocity for circle pattern is higher compare to the other pattern such as triangle and others fractal orifice plate [17].



(a) (b)

Figure 2.5: Comparison between different fractal patterns (pressure drop and turbulence intensity) [17]

2.3.1.3 Turbulence intensity

Turbulent intensity often referred to as turbulence level. For fractal generated turbulent case, the level classified as medium turbulent case (no complex device) usually in between 1% to 5% turbulent intensity. The location maximum turbulence intensity determined by the blockage ratio (the ratio between the area occupied by the grid and the duct area). By using similar blockage ratio, the fractal grids have higher turbulence intensity compared to the regular grids [17].

Figure 2.6 shows the turbulence intensity for the fractal grids (FG1, FG2 and FG3) are higher than the regular grid. By using fractal grid, the turbulence intensities can be about three times larger than those generated by classical grid, after comparing both fractal and without fractal grid [19].

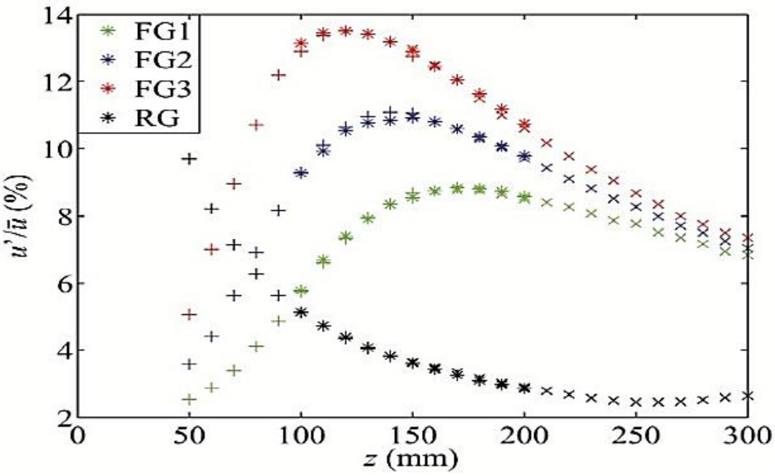


Figure 2.6: Comparison of turbulent intensity varied by different fractal grid and a regular grid [19]

Turbulence generated by fractal grid (fractal grid turbulence) were also experimentally investigated in a wind tunnel. The experiments were performed with a total of 21 fractal grids and the homogeneity and isotropy of this fractal grid turbulence were investigated. The results showed that, by using fractal grids, turbulence intensities higher than using regular grid [20].

2.3.1.4 Velocity profile

Beside downstream evolution of the turbulent intensity, nozzle exit velocity profile is another difference between regular and fractal grid. Figure 2.7 shows the velocity profiles across burner at the exit plane for both fractal and regular grid. This figure also show the velocity across the burner at the exit plane for both fractal and regular grids. The profiles show that the flow is symmetric for both cases and in regular square grid, the flow is also uniform. Contrary, the fractal grid imposes a velocity distribution across the burner with higher velocities at the centerline. In case of fractal grid, it should be noted that the velocity near the duct wall is lower, thus integrating the full velocity profile (including these boundary layer) gives the same area-averaged velocity for both grids. In the case of fractal grid, the limited number of fractal iterations is probably the reason of inhomogeneity of this grid [11].

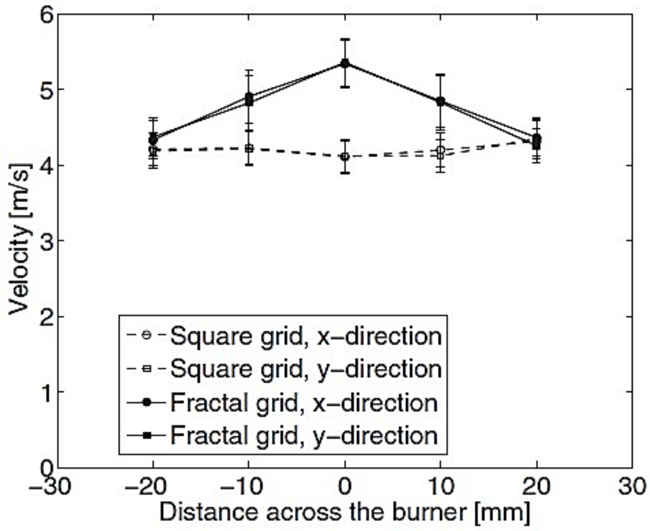


Figure 2.7: The velocity profile for fractal and regular grid [11]

2.4 Equivalence ratio

Equivalence ratio (Φ) is an informative paranormal uses normally uses to show the composition of quality where the oxidize fuel is rich, lean or stoichiometry. The equivalence ratio for this research was 0.6 up to 1.4, which occur in the mixing. Fuel air equivalence ratio is defined as:

$$\phi = \frac{(A/F)_{stoich}}{(A/F)_{exp}} = \frac{(F/A)}{(F/A)_{stoic}}$$

From the second equation are able to be determined where the fuel is rich ($\Phi > 1$), lean ($\Phi < 1$), and stoichiometric ($\Phi = 1$) [16].

The variation of flame speed with mixture strength roughly follows that of flame temperature. In almost all cases, the maximum value occurs at an equivalence ratio of between 1.05 and 1.10. Notable exceptions to this general rule are hydrogen and carbon monoxide [15].

2.4.1 Stoichiometric

This research uses stoichiometric to determine the air fuel ratio for spray injector. The stoichiometric quantity of oxidizer is amount needed to completely burn a quantity of fuel. The stoichiometric oxidizer - (or air-) fuel ratio (mass) is determined by writing simple atom balances, assuming that the fuel reacts to form an ideal set of products. Stoichiometric combustion is complete combustion and no O_2 in product. All equation in this section were use d in this research. Hydrocarbon fuel especially diesel given by C_xH_y, the stoichiometric relation can be expressed [21] as

$$C_x H_y + a\,(O_2 + 3.76N_2) \rightarrow xCO_2 + \left(\frac{y}{2}\right) H_2O + (3.76\,a)N_2 \qquad \textbf{(2.1)}$$

Where $\quad a = x + {}^{y}/_{4}$

Assume the simplified composition for air is 21 percent O_2 and 79 percent N_2 (by volume), i.e., for each mole of O_2 in air, and 3.76 moles of N_2.

The stoichiometric air-fuel-ratio can be found as

$$(A/F)_{stoich} = \left(\frac{m_{air}}{m_{fuel}}\right)_{stoich} = \frac{4.76a}{1}\frac{MW_{air}}{MW_{fuel}}$$

Where, $MW_{air} = \text{molecular weight of the air}$

$MW_{fuel} = \text{molecular weight of the fuel}$

For Biodiesel fuel assuming a general chemical formula $C_xH_{2y}O_{2z}$. The chemical equation for stoichiometric combustion can found as follows [28] :

$$C_x H_{2y} O_{2z} + a\,(O_2 + 3.76N_2) \rightarrow xCO_2 + yH_2O + (3.76\,a)N_2 \qquad \textbf{(2.2)}$$

Where $\quad a = x + \frac{y}{2} - z$

The stoichiometric air-fuel ratio for biodiesel is:

$$(A/F)_{stoich,bio} = \frac{a[32 + 3.76\,(28)]}{12x + 2y + 32z} = 34.32\left(\frac{2x + y - 2z}{6x + y + 16z}\right)$$

2.5 Spray Characteristic

Spray quality play an important role in controlling the emission released during combustion process. A better spray quality which indicates the droplets of spray, spray penetration, spray angle, breakup length will reduce the hazardous emission, and thus the study of spray characteristic is necessary before combustion process occur. Water emulsification process can reduce the emissions, other than that, another method to lower the level of soot emission is reduce the droplet size of the fuel-water-air mixing, nevertheless there are some parameters else will give effect on the spray characteristic such as nozzle geometry and injection pressure.

Spray atomization can be enhanced if the diameter holes of the nozzle is smaller, which is will produce more homogeneous mixture during spray formation [22]. In addition, the increment of injection pressure can promote the combustion efficiency which the heat release found that was highest [23]. The reason behind of this is because the high injection pressure will produce fine droplets and this improves the fuel and air atomization, hence the soot and HC emission is decreases [23-24]. Soot emission was influenced by droplet size of the spray, where the largest size of droplets will emit more soot than the finer ones. This due to the fine droplets can evaporate and burn in high rates, hence it reduce the soot concentration [25].

Figure 2.10 shows the difference of soot emission with vary droplets size and equivalence ratio. With the increment of the equivalent ratio, the soot emission also increases, however, the figure show that soot emission on fine droplets is much lower than the large droplets, and thus it proved that fine droplets have significant effects on soot reduction [24].

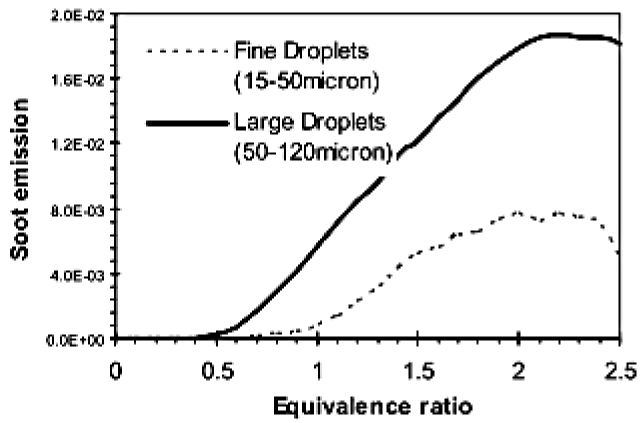


Figure 2.8: Effect of equivalent ratio and droplets size on soot emission [23]

The typical spray pattern as shown in Figure 2.9 of the swirl injector is like cone shaped [26]. The spray angle and breakup length and penetration of the spray are influenced by the injection pressure and viscosity of the mixtures.

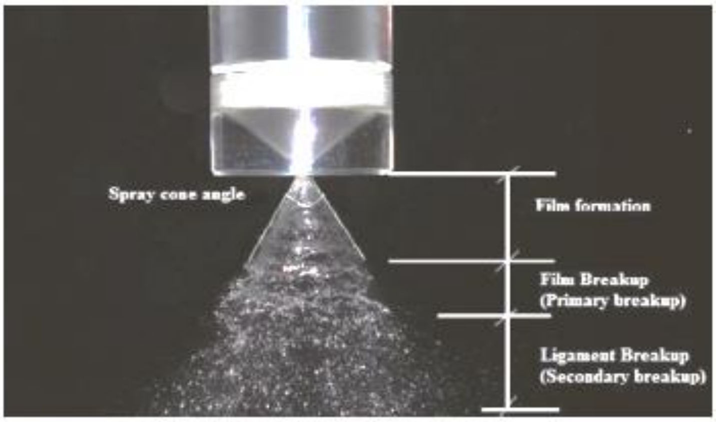


Figure 2.9: Spray pattern [20]

From the result of the researchers, the high injection pressure will give small breakup length and wide spray angle [23, 27, 28]. The combustion chamber of the burner system can reduced its size and performs better combustion due to the advantages of shorter breakup length. When the injection pressure increase, the resultant axial velocity component also increase. Therefore causing higher possibility of the liquid film to disintegrate faster, hence breakup length will be decreased [23, 28].

Figure 2.10 shows the effect of injection pressure on the breakup length and spray angle. From the graph, it clearly show that as the injection pressure increase, the break up length were decreases, then the spray angle increasing as the injection pressure increase [23].

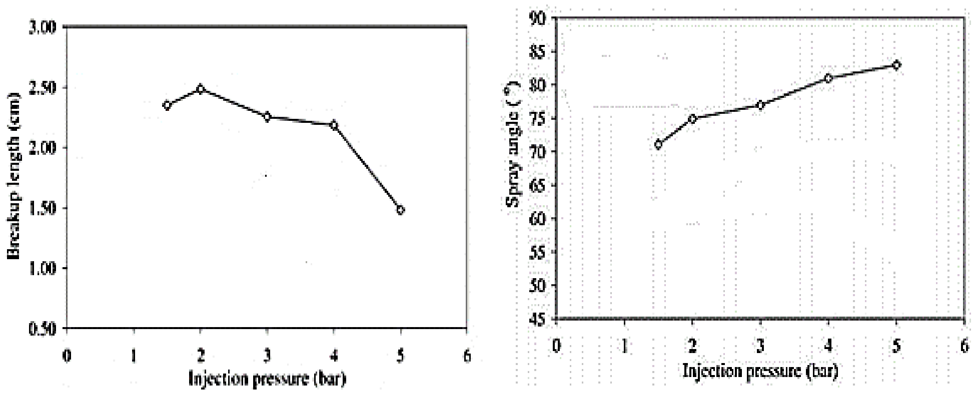


Figure 2.10: Effect of injection pressure on breakup length and spray angle [29]

Apart from this, water emulsion will tends to increase the viscosity, thus it will give effect on the spray characteristic like spray angle and penetration length. Viscosity increases would make the ligaments of the spray difficult to break up, the surface tension on the fuel becomes more resistant to shear and break up [27][30]. On the other hand, the spray angle of a high viscosity fuel is usually smaller than low viscosity fuel [31].

2.6 Combustion Process

Combustion is an exothermic reaction where it occurs when the fuel reacts with oxygen in air to produce heat, carbon dioxide (CO_2) and water. Combustion consists of two parts, which is complete combustion and incomplete combustion. Complete combustion require sufficient of oxygen supplied in order for all the hydrocarbon of the fuel reacts with the oxygen, that is carbon oxidizes into carbon dioxide and hydrogen oxidizes into water, hence the complete combustion produce heat, carbon dioxide and water only. Incomplete combustion is combustion process which require insufficient amount of oxygen to allow the fuel react completely with the oxygen, therefore the hazard gaseous which is carbon monoxide instead of carbon dioxide is produced and soot. Carbon monoxide and soot have impact to the environment and human health [32].

2.7 Emission Characteristic of Water Emulsified Fuel

The effects on emission of water-emulsified fuel on the diesel has been studied by few researchers, the findings of the researchers are summarize in Table 2.3. Although the operating parameters that have been used by researchers are difference, but the purpose of the study is to determine the main emission characteristic by adding water in fuel.

Table 2.3 Comparison of emission on water-emulsified fuel [33-35]

Researcher's name	Water-Diesel emulsion	Emission characteristic		
		NO_x	PM	CO
Y.Kidoguchi et al.	Water-diesel emulsion 30%, 50%	Decrease	Decrease	Increase
T.Yatsufusa et al.	Water-diesel emulsion 50%	Decrease	Decrease	Increase
K.A. Subramanian	Water-diesel emulsion 28%	Decrease	Decrease	Increase
K.Kannan et al.	Water-diesel emulsion 10%, 20%	Decrease	Decrease	No Data
S.Kee et al.	Water-diesel emulsion 20%, 30%	Decrease	Decrease	No Data

From the Table 2.3, the researchers are all agreed that the NO_x and PM emission can be reduced by introduce water in fuel, while the CO emission are increased from the researchers. Water addition can reduces the temperature of flame that increase at the core region of the flame, hence the NOx formation process will also decreases [1][36]. NO_X concentration reduction is due to the low NO formation rate and short duration of NO formation [36].

PM is divided by two major components, which is solid carbon (SOLID) and soluble organic fraction (SOF). SOLID is the main component in smoke while SOF is the unburned fuel component [1][36]. In fuel combustion, PM reduction is dependent on atomizing air. Increase of atomizing air flow rate will facilitates the fuel atomization and therefore it promotes the combustion, thus suppresses PM emission [1]. Apart of that, the hydro-gaseous reaction is a factor of PM reduction. During combustion process the high temperature of water vapor converted solid carbon in the emission into CO and H_2 by hydro-gaseous reaction.

$$C + H_2O \rightarrow CO + H_2 \qquad (1)$$

Hence, the CO emission is increase is due to the hydro-gaseous reaction which release CO from the solid carbon and water vapor [1, 37]. By using gas oil (GO) and

50% of water content in gas oil (GOW50) as a diesel fuel in the combustion process [37]. The characteristic of the emissions with different atomizing air ratio, Q_a/Q_t and different fuel injection is show in Fig. 2.11. From Fig. 2.11, NOx emission of GOW50 is lower than pure gas oil fuel for every different atomizing air ratio. While the PM concentrations are reduced with increases of atomizing air ratio where it can promote the fuel atomization and enhance fuel combustion. Furthermore SOLID are perfectly suppresses by GOW50 and CO level are increased which it proved the hydro-gaseous reaction in fuel combustion with water.

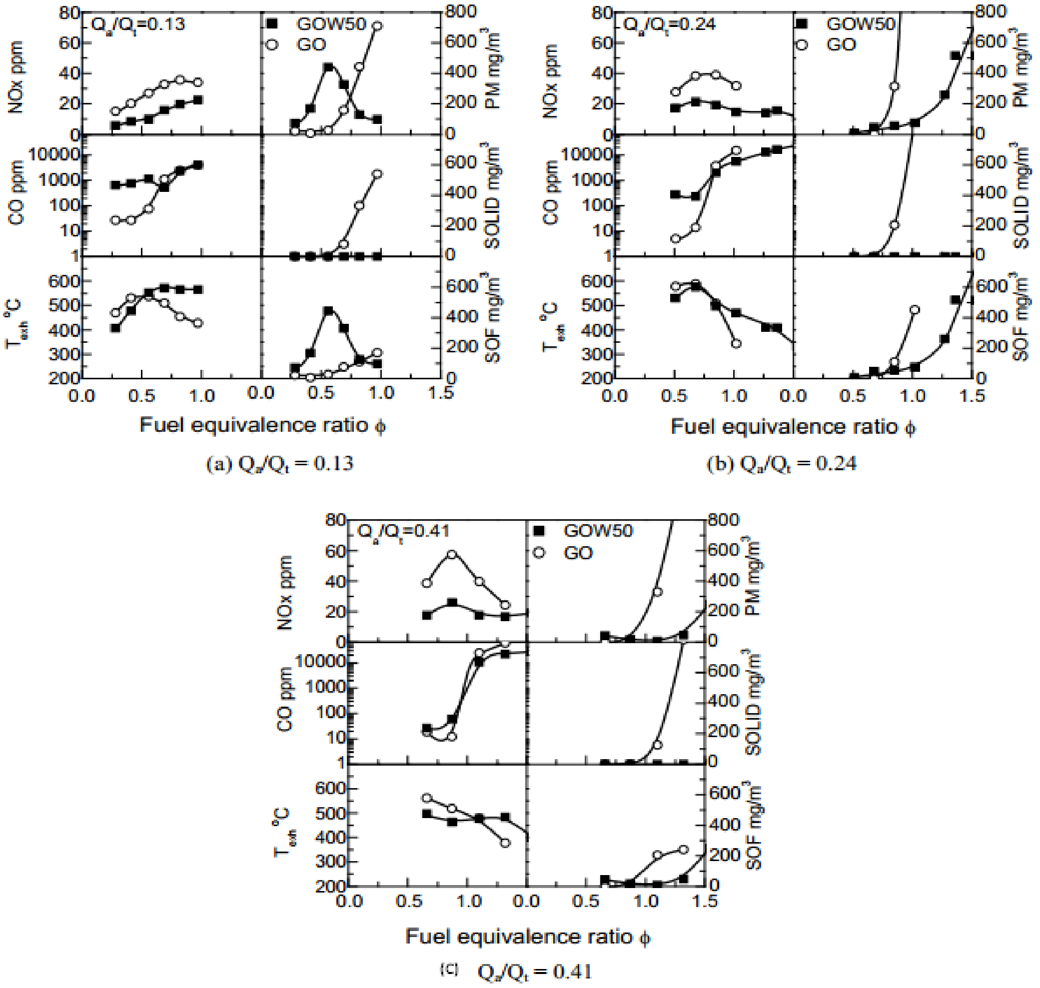


Figure 2.11 Effect of fuel equivalence ratio and atomizing air ratio on emission characteristic (a)Q_a/Q_t=0.13, (b) Q_a/Q_t=0.24, (c) Q_a/Q_t=0.41 [37]

CHAPTER 3

METHODOLOGY

3.1 Introduction of methodology

In this chapter, a description of the methodology is present in short briefing production of blended biodiesel, design of premix injector, schematic diagram of the project and image analysis. Theory of stoichiometric combustion was studied to commence a modeling of spray. The following are brief methods of spray modeling:

The flow processes are outline in Fig. 3.2: Research flow chart. The experimental works are mainly preparation on the apparatus which ensuring the premix injector are function well.

3.2 Research flow chart

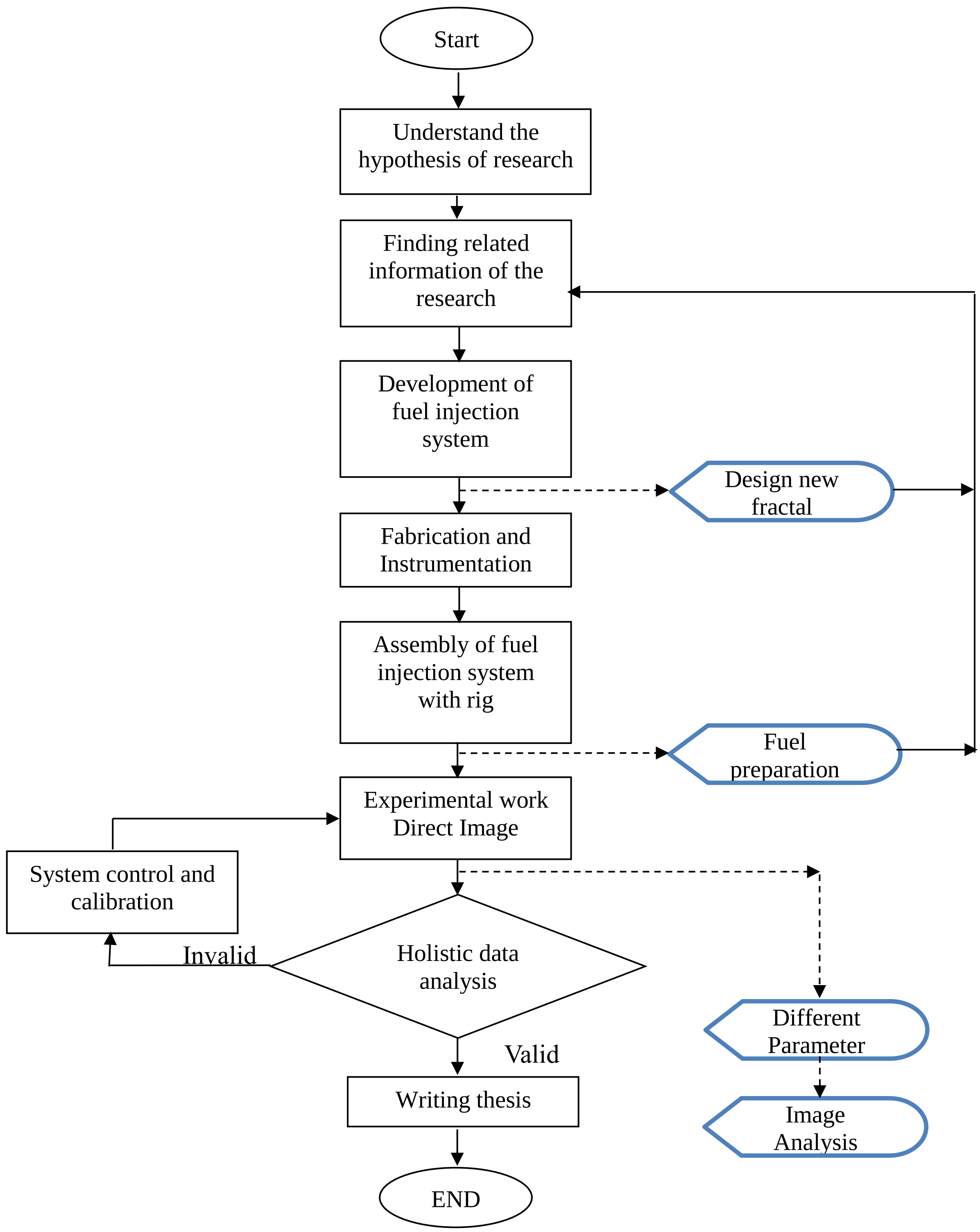


Figure 3.1: Research flow chart.

3.3 Development of injection system

Figure 3.2 shows the fractal design. In order to improve the mixing of premix injector, fractal concept designed with considering method such as blockage ratio, fractal pattern and turbulence intensity, which was discussed in Chapter 2.

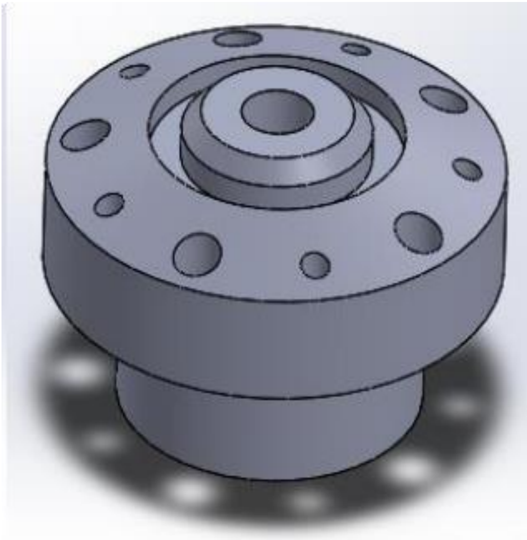


Figure 3.2: Fractal design

3.4 Blending process of biodiesel

The fuel used in the experiment is biodiesel. Blending process shall be done by using blending machine to obtain the biodiesel. Figure 3.4 shows the schematic of blending process and blending machine. The blending machine has a limitation for blending in which maximum blending of 10 liters. Figure 3.3 below is the procedure of blending biodiesel CPO5.