DEVELOPMENT OF A MESO-SCALE COMBUSTOR FOR LIQUID FUEL COMBUSTION

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DECLARATION

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LIST OF ABBREVIATIONS

ɳ	Efficiency
PIM	Porous Inert Media
NOX	Nitrogen Oxide
CO	Carbon Monoxide
AFR	Air-Fuel Ratio
ṁ	Mass Flow Rate
ø	Fuel-air Equivalence Ratio
LPM	Litre per minute
P	Density

ABSTRAK

Sebuah pembakar berskala meso dengan pembakaran bahan api cecair yang diletakkan media berliang telah rekabentuk dan dibina. Sistem pembakaran ini dapat menghasilkan kepadatan tenaga dan tenaga tertentu yang lebih tinggi berbanding teknologi batteri litium. Dengan bantuan media berliang yang mampu meningkatkan kecekapan dalam pembakaran di mana ianya mempunyai kawasan permukaan yang luas yang membolehkannya menjana tenaga terma yang tinggi. Selain itu, dengan dua sisi arus udara yang dibekalkan, pembakaran berpusar akan dapat mengurangkan kehilangan haba pembakaran ke persekitaran. Secara amnya, projek ini meilbatkan rekabentuk dan pembinaan sebuah pembakar pusaran yang digunakan dalam pembakaran kerosin dan petrol. Prestasi pembakar pusaran ini diterangkan dengan mengenal pasti suhu di permukaan media berliang dan di sekitarnya sambil memerhatikan aliran nyalaan api semasa proses pembakaran berlaku. Pembakar pusaran ini dicipta dengan menggunakan keluli. Kadar aliran bahan api berbeza mengikut jumlah petrol yang ditambah ke dalam bahan api minyak tanah. Manakala, kadar aliran udara bagi setiap sampel campuran bahan api ialah dari 30 ke 60 liter/minit di mana akan menghasilkan nisbah kesetaraan untuk proses pembakaran setiap sampel bahan api di antara 1.3 hingga 0.6. Di samping itu, proses pembakaran untuk bahan api sepenuhnya minyak tanah disimulasi menggunakan perisian ANSYS Fluent. Penemuan utama menunjukkan bahawa suhu tertinggi yang dihasilkan dengan perbezaan kecil antara suhu permukaan dan gas produk oleh pembakaran adalah pada nisbah kesetaraan berkisar antara 0.9 hingga 0.7 untuk semua sampel bahan api. Tambahan pula, suhu tertinggi yang dicatatkan pada permukaan pembakaran adalah sekitar 609 ° C dengan minyak tanah sepenuhnya sebagai bahan api pada nisbah kesetaraan 0.77. Di samping itu, kadar aliran bahan bakar meningkat apabila kandungan petrol di dalam campurannya bersama minyak tanah meningkat. Ianya bertujuan untuk menstabilkan proses pembakaran. Kesimpulannya, nisbah kesetaraan optimum ialah dari 0.7 hingga 0.9 kerana ia menghasilkan pembakaran yang stabil dengan hasil suhu tertinggi dan jurang perbezaan suhu yang sedikit sepanjang jarak suhu permukaan. Oleh itu, pembakaran yang lebih ringan atau kadar aliran udara melebihan stoikiometri menghasilan pembakaran yang optimum berbanding pembakaran yang kaya dengan bahan api.

ABSTRACT

A meso-scale combustion chamber with liquid fuel combustion and central alumina porous inert media is fabricated which generates higher energy density (per unit volume) or specific energy (per unit mass) compared to lithium battery technology. Porous inert media is known to improve the combustion efficiency with it large surface area of combustion that can generate high thermal energy**.** With tangential air inlet, a swirl combustion is formed as it can reduce the heat loss of the combustion to the surrounding. The primary aim of this project is to design and develop a swirl combustor which can be used to operate on gasoline and kerosene fuels. The performance aspects of the combustor is discussed in terms of the measured surface and product gas temperature while observing the flame flow during the combustion process. The combustor is fabricated using mild steel as the combustor. Fuel flow rate is adjusted by varying the amount of gasoline added to the kerosene fuel. The air flow rate is varied from 30 to 60 LPM and the temperature measured was between the fuel-air equivalence ratios of 1.3 to 0.6. Besides, the combustion process from 100% kerosene fuel is also simulated using ANSYS Fluent software. The main findings shows that the highest temperature produced with small difference between the surface and gas products temperature by the combustion is at fuel-air equivalence ratio range from 0.9 to 0.7 for all samples of fuel. Plus, the highest temperature recorded at the surface of combustion is around 609°C with 100%y kerosene as the fuel at fuel-air equivalence ratio of 0.77. The swirling flame produces minimal heat loss to the surrounding. Also, as the gasoline content increased in the mixture with kerosene fuel, the fuel flow rate used for the combustion to stabilize also increase. To conclude, the optimal fuel-air equivalence ratio from 0.7 to 0.9 as it produced most stabilize combustion with highest temperature produce and small difference of temperature through the distance of surface temperature. Thus, lean combustion will produced the optimum combustion rather than rich combustion.

CHAPTER I

INTRODUCTION

1.1 Introduction

A lot of researches have been done in meso-scale power generation. Meso-scale power generation fueled by liquid fuel is capable of generating higher energy density (per unit volume) or specific energy (per unit mass) compared to battery technology. Small-scale or meso-scale heat engines are capable of producing power in the range of 10-100 W. The stored energy density of hydrocarbons fuels such as liquid heptane can be as high as 45 MJ/kg higher than the lithium-Ion battery that can store energy density of about 0.6 MJ/kg. In additon, specific power generated from combustion is much higher than surface mediated electrochemical reactions. The combustion-based micro power is competitive with lithium batteries as it has larger energy densities even the overall efficiency is a low as 10% [3]. From Table 1-1, it shows the comparison of specific energy of liquid fuels range from 4.0 to 10.9 MJ/kg by assuming 20% of conversion energy [4].

Table 1-1 Specific energies of power

Source	**Specific Energy (MJ/kg)**
Methane ($\eta = 0.20$)	10.9
Methanol ($\eta = 0.20$)	4.0
JP-8 ($\eta = 0.20$)	9.2
Lithium ion battery	0.45

Although there are no universal definition for meso-scale combustor, in this study, it refers to system design with scale ranging of few millimeters to a meter. It is opposite for micro-scale combustor which scale less than few millimeters. Due to the potential application of meso-scale combustor, it has received a huge attention. The low-cost meso-scale combustor can provide high thermal efficiency and longevity for targeted applications. However, for a small scale combustor, there are many challenges. The effects of the large surface-to-volume ratio of small scale combustor, the thermal, and chemical quenching effects of the wall are significant. High percentage of the generated thermal power lost at the surface. Then, heat loss will be effected in reducing the temperature, thermal efficiency and chemical reactions that will cause incomplete combustion or quench the reactions in the wall region.

Several concepts are proposed to achieve stable combustion and to overcome the challenges. Swiss-roll design proposed by Weinberg, Rowe, Min, & Ronney, (2002) to recycle the product gas energy [5]. This concept, the recirculation energy from products reactants can overcome the problem of heat loss in the meso-scale combustion systems. It is a spiral design that preheats the reactants. The heat flows from outside of the combustion process towards the center of the combustion. Catalytic combustion in the Swiss-roll design greatly increased the reaction rates especially at low reactants flow rates [6]. Besides, liquid fuels concept is also introduced by Sirignano, Pham, & Dunn-Rankin, (2002). With liquid fuel, it helps to reduce the heat loss and improve fuel vaporization as the liquid fuel flow directly on the combustor wall [7]. Asides from that, with the help of porous inert media (PIM), heat recirculation can be improved. The stabilization of the combustion is possible just downstream of the PIM or inside the PIM. Greater preheating before combustion can be achieved as Conduction through the solid portion of the PIM yields higher heat transfer to the reactants. PIM is heated by radiation heat transfer from the reaction zone in surface combustion mode while in interior combustion mode will increase the PIM heating since both radiation and convection heat transfer contribute to the heating downstream of the reaction zone.

A meso-scale combustion concept utilizing a flow-blurring injector to produce fine fuel droplets of kerosene fuel will be explored both by experiment and simulation using ANSYS Fluent. The use of counter-flow heat exchanger to the reactants and a porous inert medium to homogenize reactants and the flame stabilizing will be investigated. The combustion performance will be evaluated from surface temperature and product gas temperature

As kerosene is used as the fuel, which is also known as paraffin, it is a thin, clear to pale yellow color liquid that formed from hydrocarbons from the fractional distillation of petroleum between 150°C to 275°C. It is odorless liquid at room temperature but gives off a strong smoke odor when burned. The density is around 0.78 g/cm^3 to 0.81 g/cm^3 that typically contains between 10 to 16 carbon atoms per molecule. In water, it is immiscible but miscible in petroleum. Kerosene's flash point is between 37°C to 65°C and at 220°C, is it auto-ignition temperature. Lower heating value of kerosene is 43.1 MJ/kg while 46.2 MJ/kg is it higher heating value [8].

Porous inert media (PIM) has unique characteristics that improve combustion from conventional combustion. It is more efficient heat transfer from burned gases to unburned mixtures. It gives rise to high radiant output, low emission of NOx and CO, high flame speed, high power density and modulation and also the conduction and radiation modes of heat transfer is significant. As the surface area within the porous matrix is increased, the convective heat transfer is improved. The combustion efficiency is improved as there is a better homogenization of temperature across porous matrix and the presence of significant amount of radiation helps to preheat the incoming air-fuel mixture upstream. In combustion zone, the pore size is large [9]. So, with the addition of porous media in the reaction zone, it increase the combustion surface area exponentially their by generating high thermal energy. As shown in Figure 1-1**,** the porous media type used for the study is alumina porous media. It has thermal conductivity about 38.5 W/mK, which is good to the combustion compared to stainless steel which has lower thermal conductivity. Besides, alumina resists strong acid and alkali attack at elevated temperatures and have high strength and stiffness.

Figure 1-1 Alumina Porous Inert Media

To calculate air-fuel ratio, the mass flow rate in kg/s of air is divided by mass flow rate of fuel. The equation is as follow:

$$AFR\ actual = \frac{\dot{m}\ air}{\dot{m}\ fuel}$$

While, from the calculated AFR_{actual}, the fuel-air equivalence ratio, ø, can be found by dividing $AFR_{stoichiometry}$ with AFR_{actual}.

$$ø = \frac{\text{AFR stoichiometry}}{\text{AFR actual}}$$

As the value of fuel-air equivalence ratio is one (ø=1), it means the combustion process is at stoichiometry. The value of mass air flow is sufficient with the fuel supply. As the fuel-air equivalence ratio less than one (ø<1), the air intake is excess to the combustion process or it can be called as lean combustion. While, when the fuel-air equivalence ratio is more than one (ø>1), the combustion is in rich condition of combustion, more fuel ratio than air inlet.

1.2 Objectives

1- Designing and developing a swirl combustor for liquid fuel combustion by fabricating hollow mild steel into combustor chamber with central alumina porous media.
2- To examine the surface and product temperature during the combustion process with various sample of fuel.
3- To study the fuel and flame flow for the whole combustion process of various sample of fuel.

1.3 Problem Statement

Among the topics that have been discussed, the main objective for the meso-scale combustor is to generate power as it can generate more power compared to the lithium batteries. But, the main problem for the current meso-scale combustor is high surface heat loss due to the large surface area-to-volume ratio, uniformity of fuel and flame flow and the emission of the carbon monoxide (CO) and Nitrogen Oxide (NOx).

1.4 Scope of Work

In order to achieve this project's objective, the following scope of work need to be done. The scope of work is as follow:

1- Study the design of the combustor
2- Simulate the heat flow in the combustor
3- Fabricate the meso-scale combustor

Doing experiment of the combustor and study the heat flow, surface and product temperature.

CHAPTER II

LITERATURE REVIEW

Gan, Chen, Tong, Zhang, & Zhang (2018) design a meso-scale combustor with liquid ethanol is electrosprayed at a flow rate of 3.50 ml/h. From the experiment, they observed a stable flame in a disc shape near the mesh of the combustor with fuel-air equivalence ratio (ø) range from 0.9 to 1.7 [10]. The flame temperature is around 1134-1287 K with combustion efficiencies from 51.2% to 92.4% and heat loss of 29.2% to 43.6 %. Besides, the thermal efficiencies from their finding range from 22.0% to 48.8%. Figure 2-1 is their experimental setup.

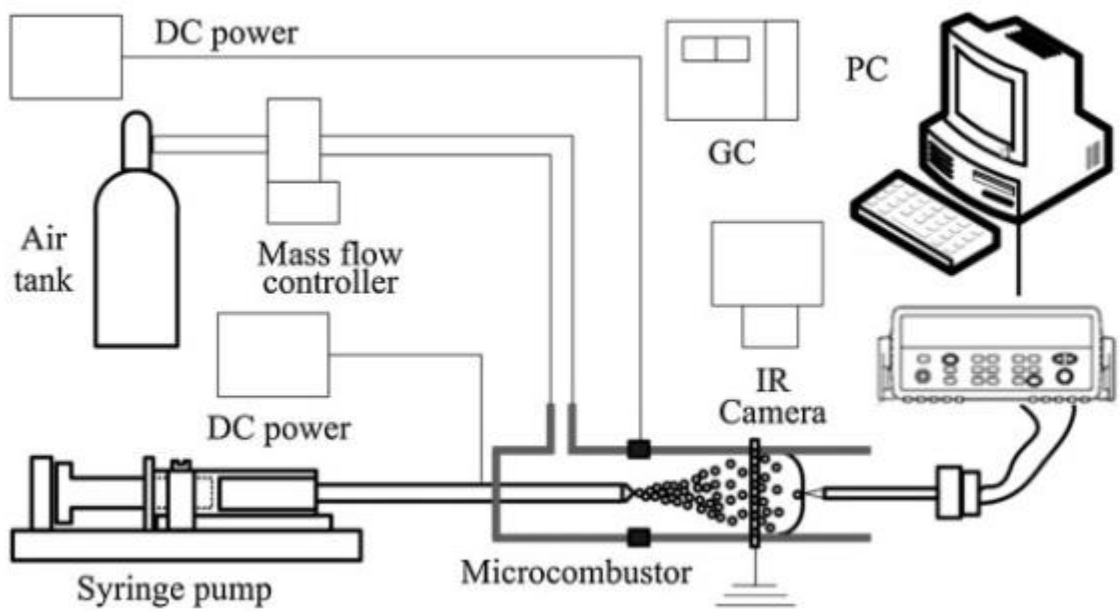

Figure 2-1 Schematic diagram of the combustor chamber

The liquid fuel is dispersed to accelerate its evaporation process by using the electrospray technique. As the combustor outlet is not facing upwards and the air inlet is not swirl, the heat loss is considered.

From another finding by Benard, Moureau, Lartigue, & D'Angelo, (2017) with design of asymmetric swirl flow cuboid meso-scale combustor with methane as the fuel, they concluded that the presence of central recirculation zone is capable of stablizing the flame at the center [11]. But, their combustor is non-optimize chamber, both in heat and shape insulation. The heat release is quite high for about 53 W but the heat loss is also high at 30 W which make about 23 W exits the domain. That makes the combustion efficiency of around 60%. With a very small scale of combustor as in Figure 2-2, the effects of quenching, stretching and limited residence time, high pollutant emissions have been found in exhaust gases such as unburnt CH_4 and CO. They also tested with hydrogen enrichment to the fuel mixture that showed different behaviors in performance. With small amount of hydrogen added, it enhanced the fuel conversion and better performance of the combustor with lower pollutant emissions but high amount of hydrogen addition will results in increasing the wall heat losses and dramatically change the flame topology due to the flame quenching that leads to incomplete combustion and pollutant formation. From the design, it is suggested to make the outlet facing upwards with bigger diameter and add another air inlet at the opposite side and direction of inlet to make better swirl of combustion, thus, reducing the heat loss of the combustion.

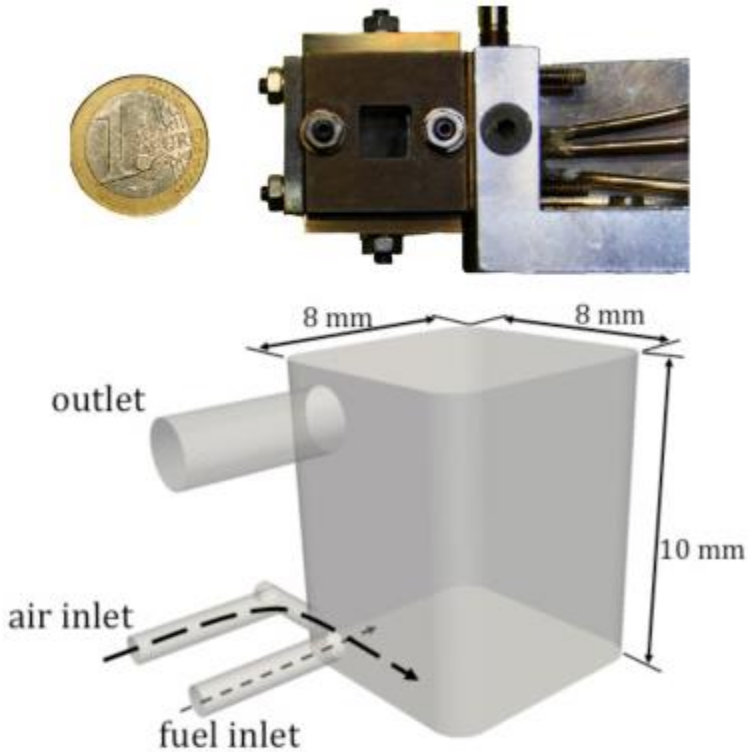

Figure 2-2 Experimental combustor and schematic of the computed fluid

Next, from Shirsat & Gupta, (2011), they use methanol and kerosene as the fuels, by utilizing steam or oxygen as an oxidizer for the meso-scale combustor as shown in Figure 2-3. For the decomposition products of hydrogen peroxide, the steam oxygen is surrogate and the combustor development is towards meso-scale bi-propellant propulsion. With the unique design incorporating heat recirculation, the extinction behavior and thermal performances are examined. Both methanol and kerosene show stable combustion with thermal efficiency of nearly 90% [12].

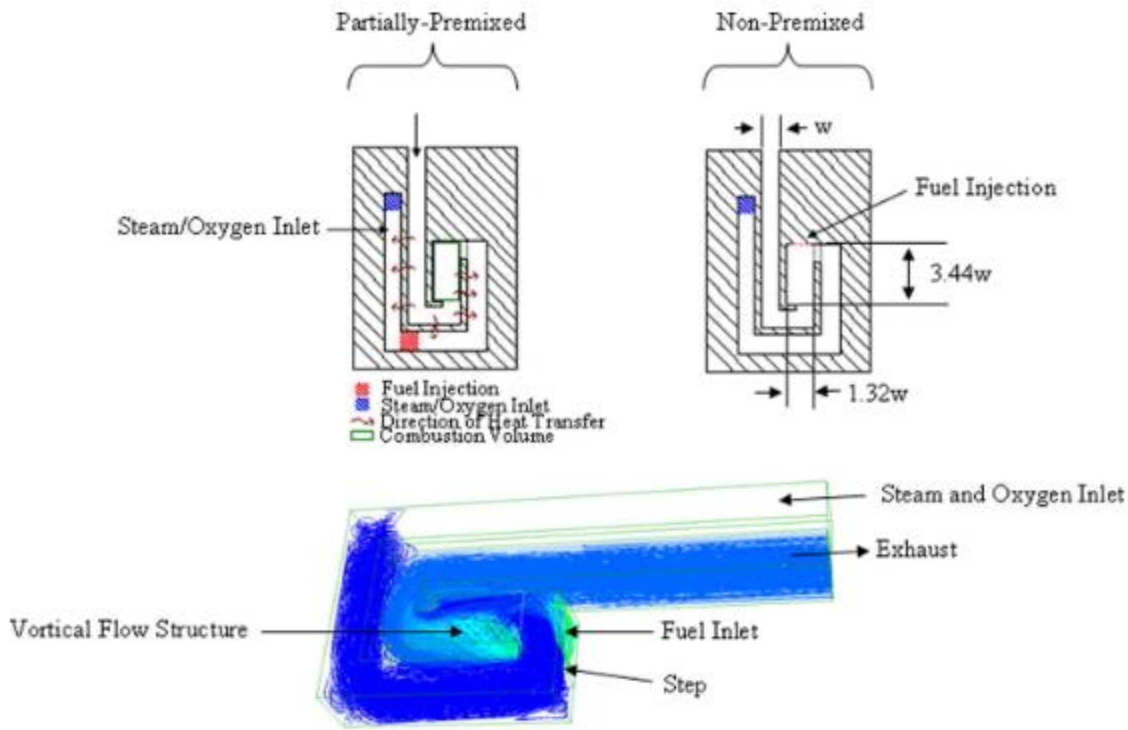

Figure 2-3 Combustor schematics highlighting the fuel injection locations

Then, from the study from Li, Chao, & Dunn-Rankin, (2008) of "Concept and combustion characteristics of the high-luminescence flame for thermophotovoltaic systems", they did the same combustion performance on meso-scale combustor chamber but at a smaller size of combustor which is about 14mm of inner diameter of the combustor. The main difference from their project and this project is the fuel used and the surface area to volume ratio. The surface area to volume ratio can affect the rate of the fuel diffusion, thus also affect the combustion performance [1]. As the surface area to volume ratio is increased, the rate of diffusion will be decreased. So, their combustor has smaller scale of combustor that makes their diffusion rate is lower and the flame behavior and temperature distribution are hard to investigate. That is why, in this project, the scale is increased with no emitter tube as to observed the flame behavior and determine the temperature distribution along the combustor chamber. Plus, they use stainless steel and bronze as the porous media. Stainless steel has lower thermal conductivity (16.2 W/m K) than bronze (~385 W/m K). For this study, alumina is use as the porous media. Alumina thermal conductivity is about 38.5 W/m K which is lower that the bronze but higher than the stainless steel. The higher the thermal conductivity, the faster the temperature to reach equilibrium condition. Thus, as for this project, alumina will make reach faster temperature equilibrium than stainless steel porous media.

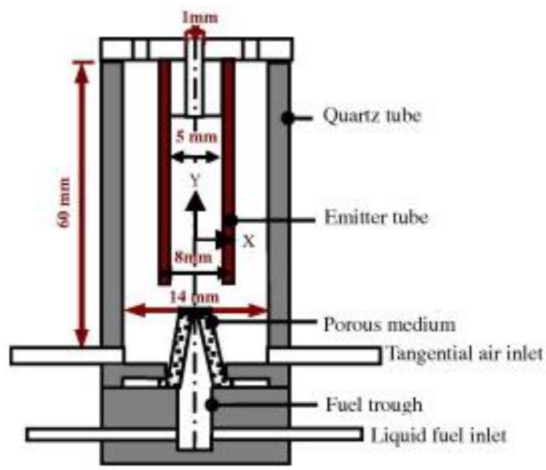

Figure 2-4 The meso-scale design from [1]

Besides, from a novel meso-scale combustion system for operation with liquid fuels by Sadasivuni & Agrawal (2009), they used the same fuel which is kerosene. Nearly, 94% of the heat released was retained by the products, thus, less than 6% of the heat released was lost to the ambient [2]**.** As compared to our project, it is using the same fuel which is kerosene, so the effect is of the fuel is expected the same. The main different is the meso-scale combustor design which is quite different. For the study, the design will be as the same as figure 1 but, the scale of the design will be larger and the position of the fuel inlet. With larger scale of the combustor, the flame behavior can be observed directly but there will some effect of heat loss due to the surface area to volume ratio. While there are using a series of electro-chemical gas analyzer, they stated that neither soot nor cooking problem was observed during and after the experiment. The absence of soot in the flame suggests lean pre-vaporized, premixed combustion [2]. The device to measure the temperature is the same which is using thermocouple.

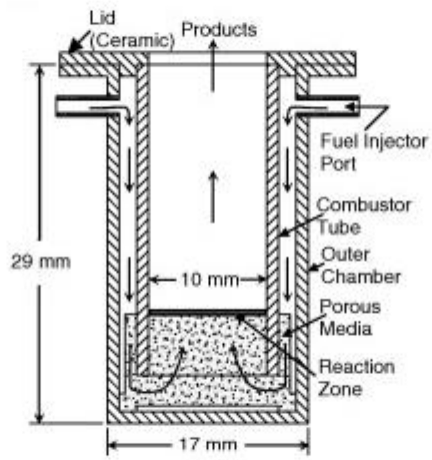

Figure 2-5 Sadasivuni & Agrawal, (2009) Combustor's design

CHAPTER III

RESEARCH METHODOLOGY

3.1 Fabrication

Hollow mild steel with a height of 300 mm, 160 mm internal diameter and 150 mm external diameter will be the combustion chamber for the experiment. Three holes with the size of 5 mm were drilled at height measured from the surface of the porous media (70 mm), in middle of the combustor (170 mm), and at the top of the combustor (270 mm) as shown in Figure 3-1**.** These holes is for the placement of thermocouple for the temperature reading.

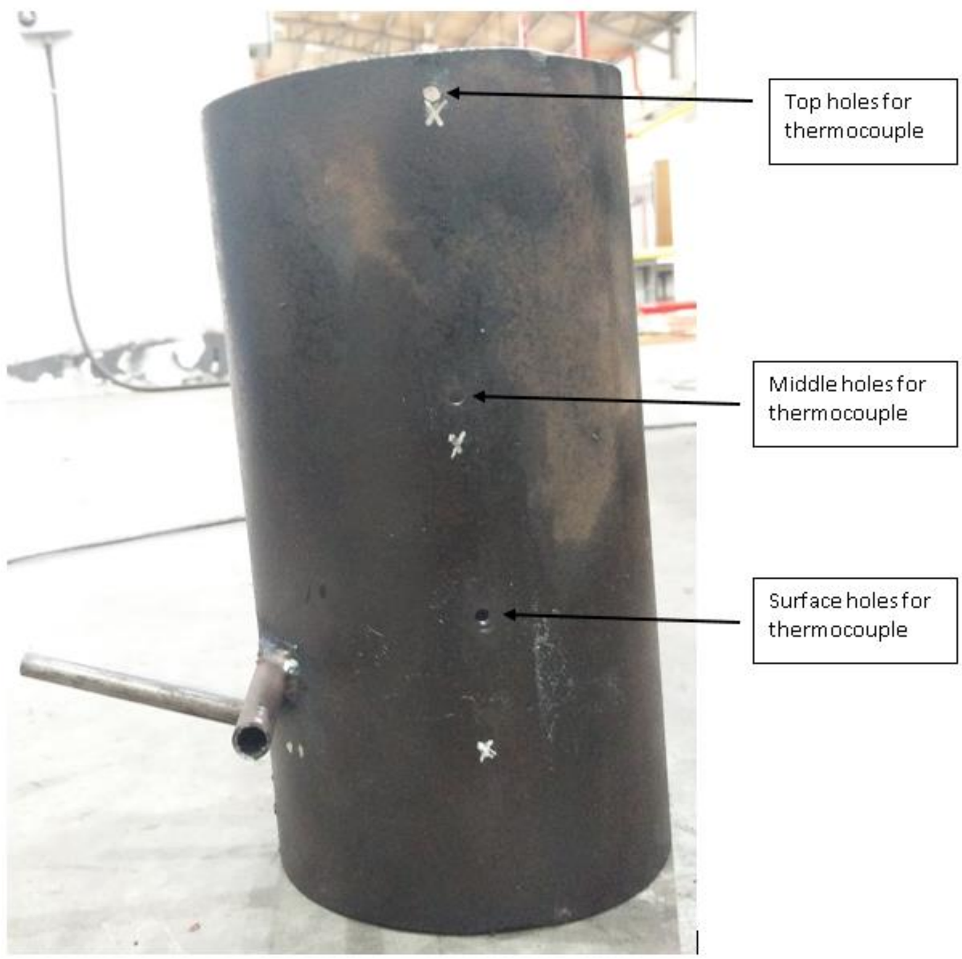

Figure 3-1 Various distance for the thermocouples.

For air inlet and fuel inlet, hollow tube of mild steel with internal diameter of 12mm and outer diameter of 13mm were chose. For air inlet, the mild steel tube was cut into two pieces with length of 100mm while for fuel inlet the tube was cut with length of 150mm.

Then, at the combustion chamber, two holes of opposite side with size of 13mm were drilled through. Also, the chamber with 15mm of drill size drilled from bottom of the chamber for about 60 mm of length by using the milling machine. After the process is completed, the mild steel tube for the air inlet is weld to the holes that were made as shown in Figure 3-2.

Figure 3-2 Fabrication process for the air and fuel inlet

Next, the porous media's holder was made by cutting hollow mild steel with internal diameter of 12 mm and external diameter of 11 mm for about 50 mm height. A hole with a size of 13mm is drilled at the top of the hollow mild steel. A plate of mild steel is machined to fit the combustion chamber which formed the base for the porous media holder. Then, the mild steel plate was weld with the hollow mild steel. The 150mm mild steel tube was also welded at the hole that was created. A leak test was done to the porous media's holder with water to ensure that there was no leaking from the porous medium holder. The porous media holders are shown in Figure 3-3 and Figure 3-4**.**

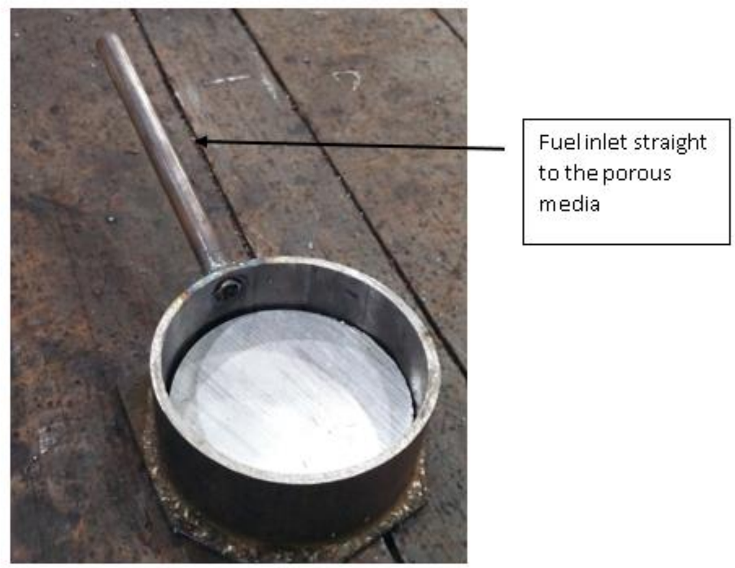

Figure 3-3 Porous media's holder

Figure 3-4 The tube from fuel tank is downwards straight to the porous media

After the fabrication process for the combustion chamber and porous media holder is completed (Figure 3-5), the combustor is shown in Figure 3-6 and Figure 3-7 when the experimental work was carried out.

Figure 3-5 Alumina porous inert media in the porous media's holder

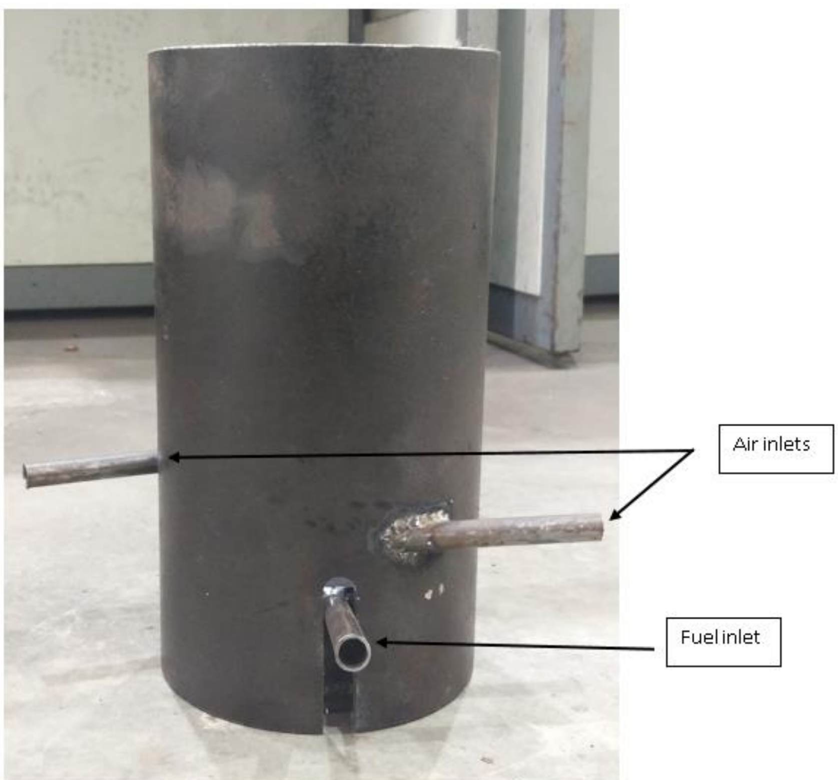

Figure 3-6 Tubes for the air and fuel inlets

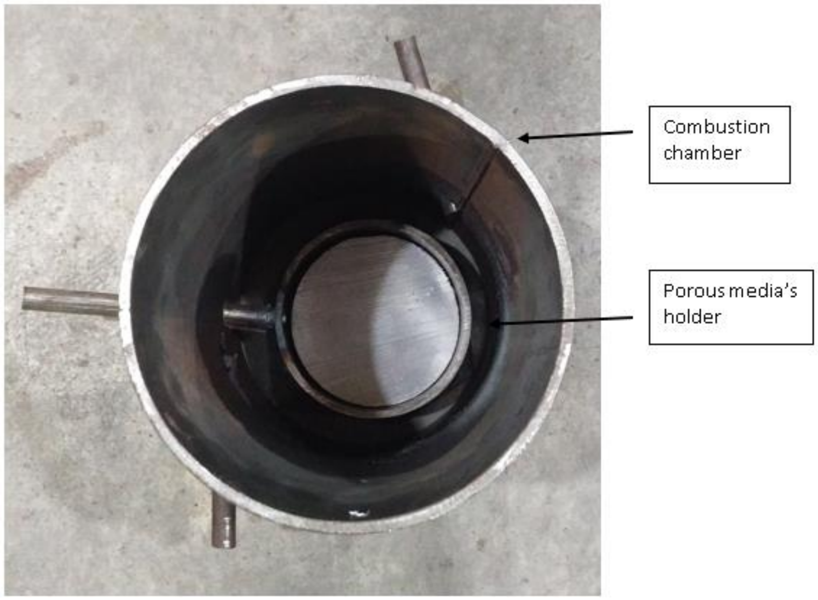

Figure 3-7 Top view of the combustor

3.2 Experimental Setup

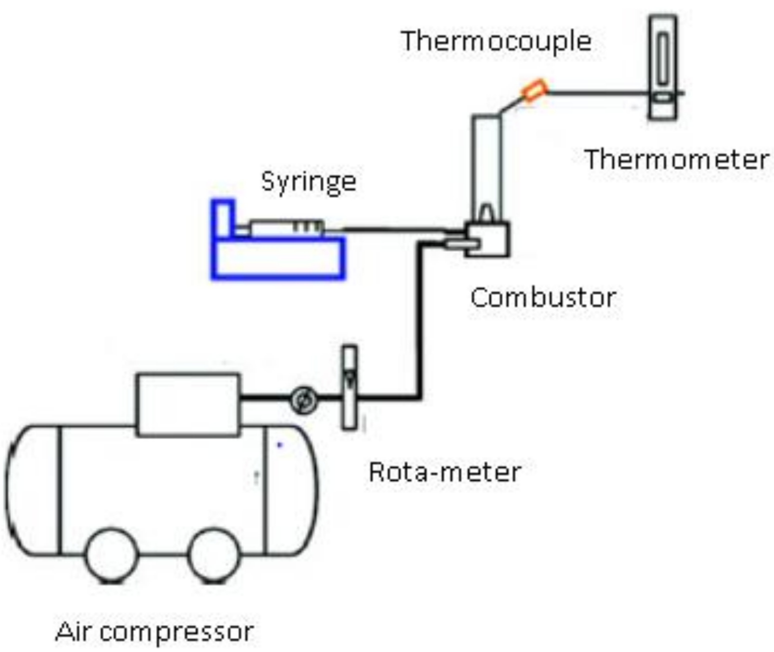

Figure 3-8 Schematic diagram of the project

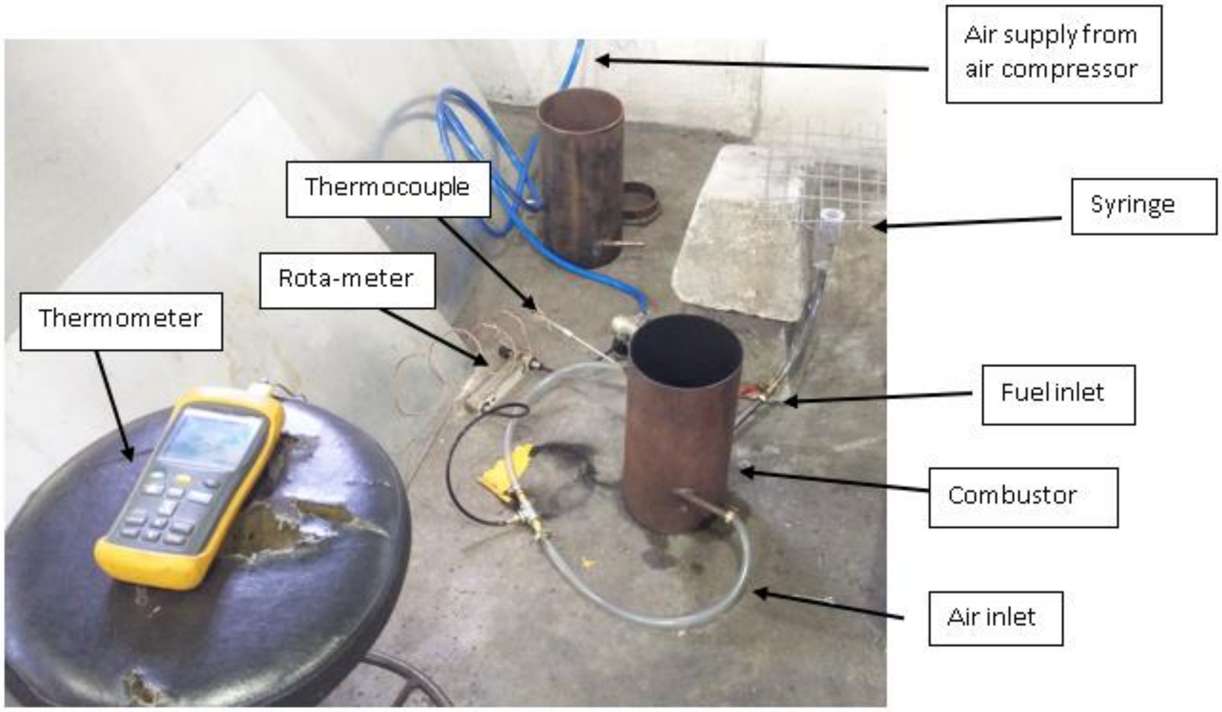

Figure 3-9 Experimental setup for the study

The combustion chamber consists of the main combustion chamber with swirling air inlet ports and base chamber of porous media and fuel inlet port. Kerosene fuel is filled in the syringe and flowed through the fuel inlet into the porous media. Air supply is from air compressor, through the rotameter to control the air flow rate then goes through the air inlets that will make the combustion swirl. Then, the fuel will be ignited and the air flow rate will be adjusted according to the fuel-air equivalence ratio (ø) of kerosene-air like shown in Figure 3-8 and Figure 3-9. Type K thermocouples were placed through the 5mm holes as shown Figure 3-10 and the temperature reading by the thermometer will be recorded for all at the three hole with various air flow rate.

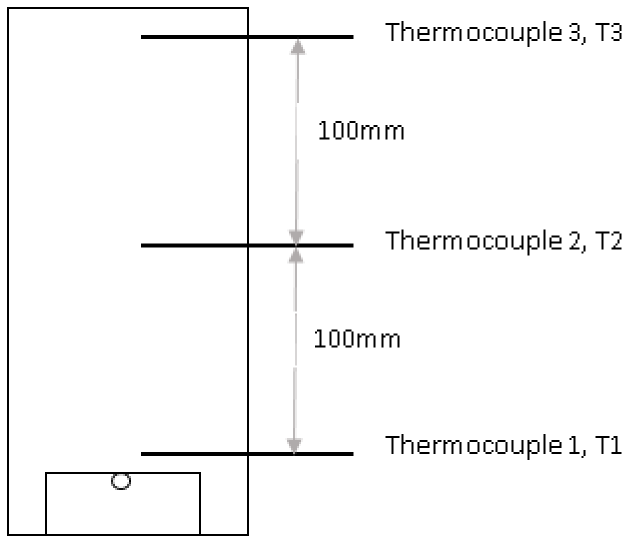

Figure 3-10 Thermocouples placing during the experiment

The experiment was carried out by varying the air flow rate into the combustor and at constant value of the fuel flow rate. The air flow rate was varied between 30, 40, 50 and 60 LPM. As for the fuel flow rate, for 100% kerosene used 0.055 ml/s, 90% kerosene with 10% gasoline used 0.060 ml/s, 80% kerosene with 20% gasoline used 0.065 ml/s and 70% kerosene with 30% gasoline used 0.070 ml/s for every air flow rate. Thus, the fuel-air equivalence ratio obtained for every samples was varied from 1.3 to 0.6.

The swirl combustor was designed to be bigger than any meso-scale combustor as to reduce the surface area-to-volume ratio that will reduce the effect of the heat loss. Also, the tangential air inlet that will produce swirl combustion also can reduce the heat loss from the combustor.

3.3 Simulation

The simulation of the combustion process was carried out using the ANSYS Fluent software. The model of the combustor was created using Solidwork software, and then the model was imported into the ANSYS Fluent software. After that, the model was meshed up which defined the important parts of the model such as the fuel inlet, the air inlet and the outlet for the combustor model as shown in Figure 3-11.

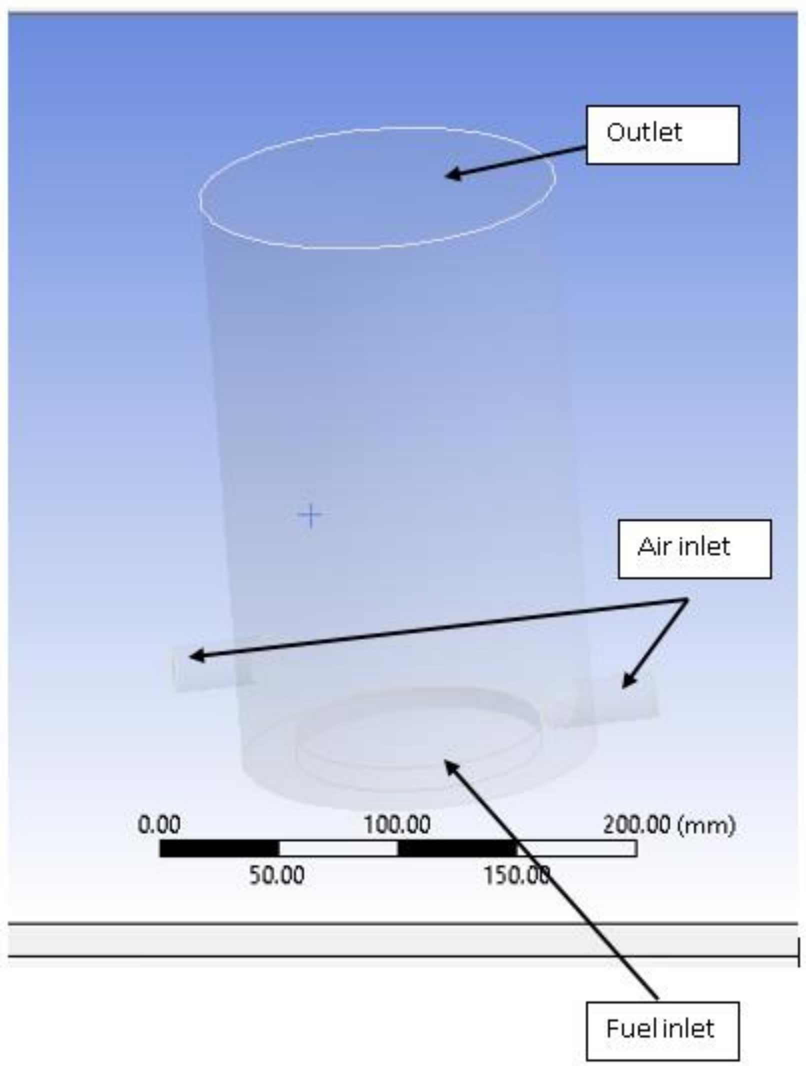

Figure 3-11 The simulation model for the case study

The next step is the setting up of the model to simulate the combustion process. Kerosene fuel was selected with the mass flow rate of fuel to be the same as the experimental setup. Similar approach was used for flow rate of air the inlet.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Experimental Results

To ensure that the combustion occur at steady-state condition, the fuel-air equivalence ratio (ø) of the combustion must be approximately close to 1.0. This means that the combustion occur near the stoichiometry condition. If the fuel-air equivalence ratio was more than 1 ($ø>1$), it means the combustion occur in rich fuel condition, and less air intake into the combustion process. While, when the fuel-air equivalence ratio is less than 1 ($ø<1$), the combustion process is lean. More air intake towards the combustion.

4.1.1 100% Kerosene

Table 4-1 Temperature readings with various air flow rate for 100% kerosene

Air flow rate, $\dot{m}_{air}$ (LPM)	**30**	**40**	**50**	**60**
Temperature 1, T1 (°C) (60mm)	554	575	609	561
Temperature 2, T2 (°C) (160mm)	527	542	546	502.4
Temperature 3, T3 (°C) (260mm)	472	492	497	464

Table 4-2 Fuel Characteristics and experiment setup for 100% kerosene

Density ,ρ (kg/m^3)	Flow rate,ṁ (kg/s)		Air-fuel ratio (AFR)		Equivalence ratio (ø)
	Fuel	**Air**	**Actual**	**Stoichiometry**	
810	4.455E-05	0.00058	13.01908	16.5891	1.274218
		0.00077	17.28395		0.959801
		0.00096	21.54882		0.76984
		0.00116	26.03816		0.637109

Figure 4-1 shows the temperature distribution at temperature 1, T1 (temperature close to the porous media), at temperature 2, T2 (temperature 100 mm height from the porous media) and at temperature 3, T3 (temperature 200 mm height from the porous media) against the value of fuel-air equivalence ratio. Theoretically, the highest value of temperature occur at range of 0.8<ø<1.2, when the value of ø is lower than 0.8, it means the air is too much for the fuel that makes the combustion complete while the excess air will cooled down the flame formed. At T1, T2 and T3, the highest temperature for all the position are at fuel-air equivalence ratio of 0.77, near the value of fuel-air equivalence ratio of 0.8. As the fuel-air equivalence ratio go lower than 0.8 which means more air flow rate and fuel-air equivalence ratio more than 1.2, less air flow rate, the temperature will decrease. Besides, temperature closer to the porous media produces higher flame temperature around 609°C at fuel-air equivalence ratio of 0.77 and the temperature decrease as the distance from porous media increase. This makes the highest temperature can produce from the fuel is at fuel-air equivalence ratio of 0.77.

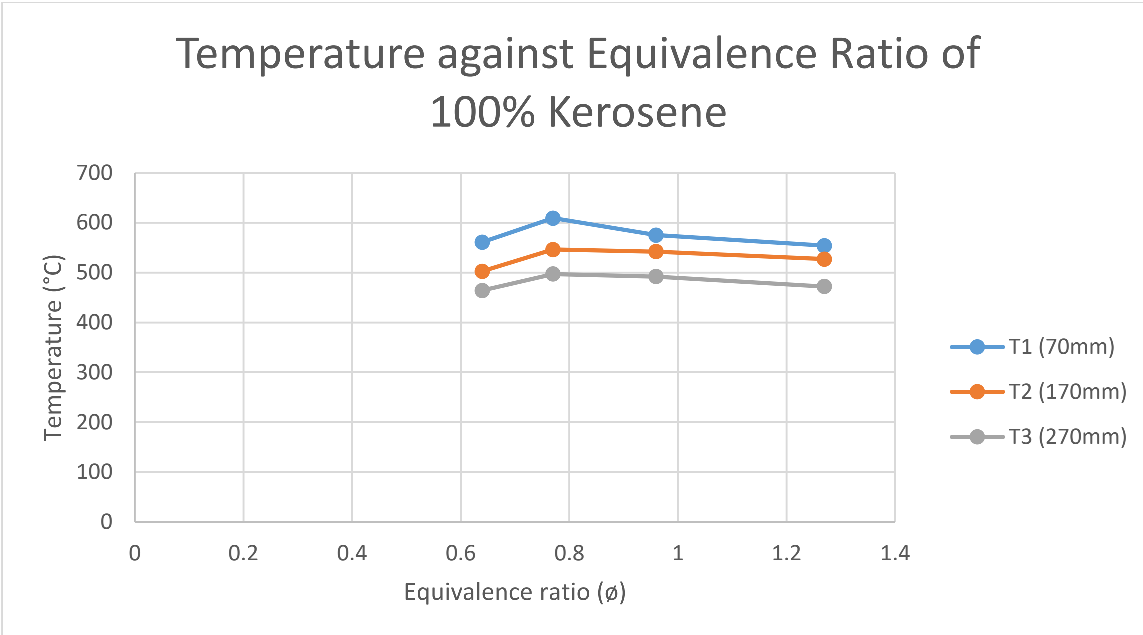

Figure 4-1 Statistical data from the experiment of 100% kerosene fuel

4.1.2 90% Kerosene and 10% Gasoline

Table 4-3 Temperature readings with various air flow rate for 90% kerosene and 10% gasoline

Air flow rate, $\dot{m}_{air}$ (LPM)	**30**	**40**	**50**	**60**
Temperature 1, T1 (°C) (60mm)	638.2	525.4	595	628
Temperature 2, T2 (°C) (160mm)	578.2	540.7	592	594.7
Temperature 3, T3 (°C) (260mm)	462.8	407.8	585	539.6

Table 4-4 Fuel Characteristics and experiment setup for 90% kerosene and 10% gasoline

Density, ρ (kg/m^3)	**Flow rate, $\dot{m}$ (kg/s)**		**Air-fuel ratio (AFR)**		**Equivalence ratio (ø)**
	Fuel	**Air**	**Actual**	**Stoichiometry**	
806.6602	4.83996E-05	0.00058	11.98357	14.4576	1.206452
		0.00077	15.90922		0.908756
		0.00096	19.83487		0.728898
		0.00116	23.96713		0.603226

Results from Figure 4-2 shows some flaws at the results. As the fuel-air equivalence ratio close to 1, the temperature for all the three positions should be higher than fuel-air equivalence ratio value of more than 1.2 and less than 0.8. But, the results shows vice versa. This happen as when gasoline is added into the kerosene oil, the combustion reaction is not stable between the kerosene and gasoline. As the gasoline fuel has higher value of evaporization to the surrounding and lower flash point than kerosene fuel, it thus effect the combustion process. After all, the results still show that the temperature is higher at the porous media for about 638°C at fuel-air equivalence ratio of 1.21 and the temperature decrease as the distance from the porous media increase. At fuel-air equivalence ratio of

0.73, the temperature at any distance from the porous media showed a small change from 595°C at T1 to 585°C at T3. From this data, it can be concluded that at the fuel-air equivalence ratio of 0.73 for 90% of kerosene and 10% of gasoline mixture shows the stable reaction of the combustion with minimum temperature difference through the distance from porous media.

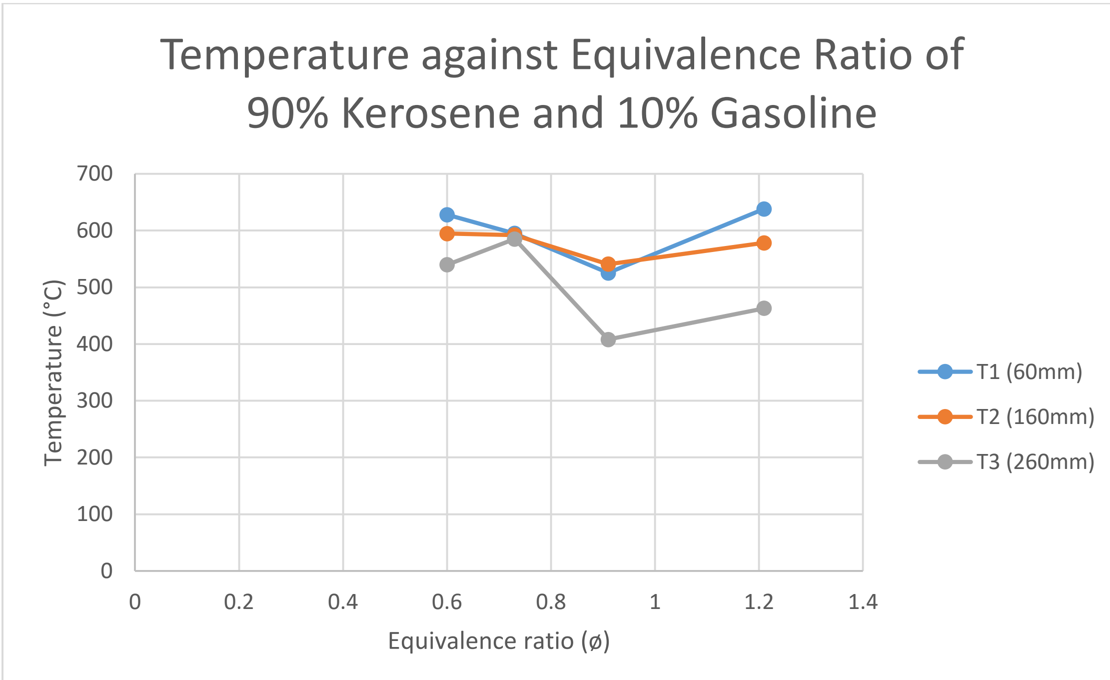

Figure 4-2 Statistical data from the experiment of 90% kerosene with 10% gasoline fuel