Development and performance characteristics of a swirl combustor operating on VCO-blended fuels

By:

MUHAMMED AQEL BIN YUSRI

(Matric No.: 125037)

Supervisor:

Mr. Khairil Faizi Mustafa

May 2018

This dissertation is submitted to

Universiti Sains Malaysia

As partial fulfillment of the requirement to graduate with honors degree in BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)

School of Mechanical Engineering

Engineering Campus

Universiti Sains Malaysia

DECLARATION

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

Signed..(Candidate)

Date..

Statement 1

This journal paper is the result of my own investigation, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

Signed..(Candidate)

Date..

Statement 2

I hereby give consent for my journal paper, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available outside organizations.

Signed..(Candidate)

Date..

AKNOWLEDGEMENT

My first and sincere appreciation goes to my supervisor lecturer, Mr. Khairil Faizi Mustafa, for all I have learned from him and for his useful advices, motivation and continuous support through all stages of this thesis. His positivity an encouragement has always inspired me to do better. Not to forget his suggestion and knowledge in this research has also help me in getting the idea on how to elaborate more on my thesis. Without his guidance and persistent help this thesis writing would not have been possible.

In addition. A sincere appreciation is delivered to Dr. Abdus and Dr. Ikhwan for their guidance on thesis writing and all the briefings and seminar organised in helping in completing the final year project.

Getting though this thesis writing required more than academic support. My gratitude goes to my course mates and other friends for their inputs, supports and friendships. Not forgetting my beloved parent for the constant moral support throughout this project.

I have no valuable words to express my thanks, but my heart is still full of favours received from every person.

Title of thesis: **Development and performance characteristics of a swirl combustor operating on VCO-blended fuels**

Date of submission (Academic year): **23/5/18 (Academic year: 2017/2018)**

Candidate (Matrix no.): **Muhammed Aqel bin Yusri (125037)**

Supervisor: **Mr. Khairil Faizi Mustafa**

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATION

LIST OF ABBREVIATIONS

Symbol	Description
CAD	Computer-Aided Design
VCO	Vegetable cooking oil
KVCO	Weight percentage of kerosene and VCO
(A/F) actual	Actual air-fuel ratio
(A/F) stoic	Stoichiometric air-fuel ratio
Ø	Air equivalence ratio
$\dot{V}$	Volume flow rate (lpm or m^3/s)
$\dot{m}$	Mass flow rate (kg/s)
ρ	Density (kg/m^3)

ABSTRAK

Pembakar pusaran telah diketahui untuk meningkatkan pembakaran dengan membekalkan lebih banyak udara pada pembakaran supaya kadar pembakaran akan meningkat. Walau bagaimanapun, terdapat banyak jenis bahan api yang boleh digunakan dalam pembakaran. Dalam kerja ini, pelbagai nisbah campuran bahan api antara minyak masak sayuran (VCO) dan kerosin yang digunakan dalam pembakar pusaran telah dikaji untuk menentukan prestasi bahan bakar dan pembakar dengan mendapatkan bacaan suhu semasa pembakaran.

Pembakar pusaran yang mudah terdiri dari dua salur masuk udara yang bertentangan antara satu sama lain dan berkedudukan tangen ke arah ruang kebakaran dimodelkan dalam CAD untuk dianalisis dalam perisian simulasi, ANSYS dan ujian secara eksperimen dengan menggunakan nisbah yang berbeza antara campuran bahan api VCO dan kerosin dan nisbah kesetaraan udara-bahan bakar. Profil halaju dan pengagihan suhu di dalam ruang pembakaran kemudian dianalisis dan dibincangkan. Simulasi dari ANSYS menggunakan parameter yang sama dengan eksperimen yang kemudiannya membandingkan hasil dengan kedua-dua kaedah tersebut.

Keputusan dari analisis eksperimen menunjukkan bahawa pembakar pusaran dapat meningkatkan prestasi pembakaran pada campuran lebihan udara dengan suhu tertinggi yang direkodkan ialah sekitar 0.73 hingga 0.81 nisbah kesetaraan udara pada lebihan udara. Campuran lebihan bahan bakar pada pembakaran juga diuji dan dibuktikan bahawa ianya mempunyai suhu yang lebih rendah daripada campuran lebihan udara. Dari analisis simulasi, ia menunjukkan bahawa nisbah kesetaraan udara 0.6 masih dapat menghasilkan suhu setinggi kesetaraan udara 0.73 hingga 0.81. Walau bagaimanapun, suhu yang lebih rendah masih direkodkan pada campuran lebihan bahan bakar pada pembakaran yang memberi nilai yang sama dengan analisis eksperimen.

ABSTRACT

Swirl combustor have been known to enhance a combustion by supplying more air on the combustion so that the combustion rate will increase. However, there are many type of fuels that can be used in combustion. In this work, multiple ratio of mixture of fuels between vegetable cooking oil (VCO) and kerosene that being used in the swirl combustor has been study to determine the performance of the fuels and the combustor by obtaining the temperature reading during combustion.

A simple swirl combustor of two air inlet which are opposite to each other and tangential to the combustion chamber are modelled in CAD to be analyse in simulation software, ANSYS and being test experimentally by implying different ratio between the mixture of VCO and kerosene fuel and the fuel-air equivalence ratio. The velocity profile and temperature distribution in the combustion chamber is then analysed and discussed. The simulation from ANSYS were using the same parameter as the experimental one which were then being compare the result with these two methods.

Result from experimental analysis shows that the swirl combustor able to increase the performance of the combustion at lean mixture with highest temperature recorded is at around 0.73 to 0.81 air equivalence ratio which is at lean mixture. Rich mixture of the combustion were also tested and proved that is has lower temperature than the lean mixture. However, going lower on air equivalence ratio until about 0.6 will cause a significance drop in temperature. From the simulation analysis, it shows that air equivalence ratio of 0.6 still could produce temperature as high as air equivalence of 0.73 to 0.81. However, lower temperature were still recorded on lean mixture of the combustion which is the same as the experimental analysis.

Chapter 1 : INTRODUCTION

1.1 Research Background

Swirl combustor is a combustor that feed air inside the circular shaped combustor tangentially towards the combustor to produce swirling effect on the combustion. The idea of the swirling effect is to enhance the combustion by supplying more air than it should need towards the combustion without interrupting the combustion or maintain the stability of the combustion inside the combustor. By enhancing the combustion, the efficiency of the combustion increase without the need of increase the size of the combustor or changing the design of the combustor [1]. This method is easier, cheaper to implement and maintain in a longer run.

The VCO-kerosene fuels blend becomes quite common in combustion system because of the high temperature that can be achieved by the combustor despite of their small in size compare to other normal combustor. Other than this heptane was also used as a fuels in this system [1], [2]. However researcher trying to study more on the VCO-kerosene fuels blend since this type of blend is more eco-friendly [3]. But, there were very limited information about the use of VCO-kerosene fuels blend with variety of ratio in the swirl combustor for any combustion system that will give information on the performance of the fuels based on the achievable temperature based on the mixture ratio and the controlled air fuel rate.

Therefore, the main objective of the present paper is to study on the performance of the swirl combustor by using different ratio of fuels blend between VCO and kerosene to obtain data about the achievable temperature with this configuration. The VCO is very important in this combustion because the VCO could reduce the detrimental effects on the environment [3]. The availability of the swirl combustor in the market also quite low. Hence, the present paper will also include on the design, dimension and simulation on performance of the swirl combustor for other further research purpose.

1.2 Problem Statement

The use of VCO in combustion is not widely researched. However, the use of VCO in combustion system is getting more common due to the detrimental effects on the environment. Previous works on this low volatility and high viscosity fuels were limited. The ratio used in the fuels blend between VCO and kerosene was not in wide range. This could led to lack of information about temperature could achieve by using different type of ratio. The usage of swirl combustor also not common in these day makes the combustor is hard to find in the market for easier research purpose.

1.3 Objective

- To design and develop a swirl burner suitable for VCO-kerosene fuel blends with optimum size and dimension of swirl combustor that can be used to carry the experiment and can be used for other further research purpose.

- To study more about VCO-kerosene fuels blend in swirl combustor with different ratio configuration between those two fuels by controlling different parameters such as air supply rate and fuel supply rate to obtain temperature reading at desired position that can achieved by the fuels blend.

1.4 Scope of Research

The main focus of this work is to perform an experiment on fabricated swirl combustor to obtain temperature reading on various fuel blends ratio between vegetable cooking oil and kerosene and by controlling the air and fuel rate ratio on the combustion. However, the design of the swirl combustor must first undergo designing process on SolidWorks and will be simulate by using ANSYS Fluent before proceeding with fabrication to ensure the design meet the desired specification of the final design of the combustor.

After that, the combustor will be fabricated based on the design and the fuel blends will be prepared. The experiment will then be conducted and three temperature reading point will be generated by thermocouple. The result will then be analysed and finalize.

Chapter 2 : LITERATURE REVIEW

Performance of a swirl combustor by using any type of fuels such as VCO-kerosene is a main concern. Many studies and research has been dedicated to obtain the performance of the fuels blend for the use of combustion system that was influenced by various parameter. Experimental techniques is mostly used to analyse the performance of the combustor to different parameter. An in-depth study of the literature published in this area is necessary to understand the approaches used to address the reliability concerns.

2.1 Swirl Combustor

The basic idea of a swirl combustor is basically a combustion chamber that supply air tangentially towards the swirl combustor. This will creates swirling effect of air inside the combustor. The swirling effect of air will then makes the fire becomes swirl inside the combustor [4]. The swirl combustor is design in cylinder shape in order to force the air to move circularly inside the combustor. The purpose of the swirl combustor is to increase the air supply rate so that the combustion rate will also be increase. Hence, the performance and efficiency of the combustor will be increase [1].

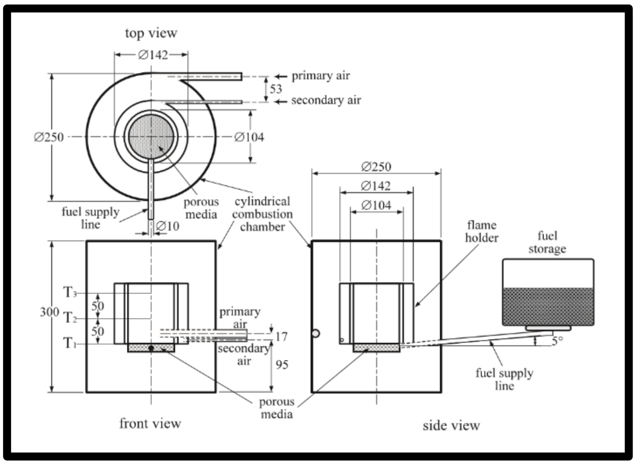

Figure 2.1: Example of swirl combustor. Adapted from "Comparative assessment of a porous burner using vegetable cooking oil-kerosene fuel blends for thermoelectric and thermophotovoltaic power generation" by K.F. Mustafa et al., 2016, Fuel, 180, 137–147.

2.2 Fuels blend

There were many type of fuels blend used for combustion to enhance the performance and efficiency of the combustion. But the combustion performance and efficiency depends on what the purpose of the combustion and the target of the combustion. For example, a combustion that need a very high temperature and a combustion that need lowest cost might have different type of fuels and setup. From the prior paper, the VCO-kerosene fuels blend were used in the swirl combustor to measure the performance and the efficiency of the combustion and the swirl combustor [1]. VCO was used in the combustion is mainly because the VCO combustion could decrease the detrimental effect on the environment [3].

Various ratio of the fuels blend were used in order to study the effect of different ratio in the blend, such as, 9010 KVCO (90% Kerosene with 10% VCO), 7525 KVCO (75% Kerosene with 25% VCO) and 5050 KVCO (50% Kerosene with 20% VCO) [5].

2.3 Air-fuel Equivalence Ratio

For combustion, it is always related to the air-fuel equivalence ratio in order to measure the performance of the combustion. The air-fuel equivalence ratio is basically the ratio between the supply rate of air into the combustion and the air that is needed for the combustion, which called air-fuel ratio stoichiometric. The air-fuel ratio always represent in terms of mass flow rate of air supplied per 1kg of fuel supplied. The air-fuel equivalence ratio is the ratio between the actual air-fuel ratio and the air-fuel ratio stoichiometric. For the air-fuel ratio stoichiometric, it can be calculated using several different method such as moles of element in the fuel that involve Carbon, Hydrogen and Oxygen [3] or using ultimate analysis that based on weight percentage of Carbon, Hydrogen, Nitrogen, Sulphur and Oxygen.

The air-fuel equivalence ratio shows that the combustion either are lean combustion or rich combustion. For lean combustion, which also mean weak combustion or excess air combustion, the value of air-equivalence is less than 1. Meanwhile, for rich combustion, which also mean less air supplied, the value of air-equivalence is more than 1. If the air-fuel equivalence ratio has the value of exactly 1, it means that the combustion is at stoichiometric combustion.

For the air-fuel equivalence ratio, it is referred that lean combustion will has lower performance in terms of temperature compare to rich combustion. However, lean combustion is known to have lower emission rate compare to rich combustion [6]. Swirl combustor is designed to be able to increase the performance in terms of temperature in a combustion while increasing the air supplied so that the combustion is at lean combustion.

2.4 Porous Media

For the combustion to occurs, most fuel required to vaporize in orders for the fuel to burn. Vaporization of fuel occurs when the fuel reach a certain temperature which is called volatile point. For this experiment, the fuel that were used, kerosene and VCO have quite high volatile temperature. For kerosene, it need to reach 38 °C or higher in order to generate flammable vapour.

In this experiment, instead of vaporizer, porous medium were used. A porous medium provides a liquid-film-surface area large enough to produce the necessary fuel vaporization rates and it provides thermal recuperation between the liquid fuel and the flame it supports [2]. The porous medium will also separate the main chamber from the liquid-fuel. Porous medium will generates a film of liquid fuel on the surface of the porous medium. Porous medium creates a large area for the liquid-fuel to vaporize.

2.5 Performance Rating

The performance of the combustor can be measured differently based on what the researcher want from the research. From the prior paper, most of the performance were measured mostly based on the temperature rate, temperature distribution, temperature settling time, NOx emission, CO emission, electrical power output, radiant power, radiant efficiency, electrical efficiency or thermal efficiency [5]. These performance will be varies with different blend ratio, air supply rate and fuel supply rate. Each data will be then analyse towards the conclusion of the research. However for this research, only temperature will be measured towards the end of the experiment.

Chapter 3 : METHODOLOGY

3.1 Designing Process

The design process of the combustion chamber for the project undergo multiple stage design. The design of the combustor in 3D CAD will be developed by referred (Fig. 3.1) to previous study [3]. First, the conceptual design which is very basic idea on how swirl combustor look like. This also help further understanding on the combustor design and to create some new idea on the design. The design consist of porous media holder with main combustor chamber. The combustor chamber was attached with air inlet which is tangential to the combustor chamber to create the swirling effect. Next, multiple design were done to be compared to each other to determine the final design that will be used in the experiment. There are two main design were being evaluate which are combustor chamber with one air inlet (Fig. 3.2) and two air inlet (Fig. 3.3). The two air inlet are both opposite to each other. After a few evaluation had been done, the final design were determined to be the two air inlet design as shown in Fig. 3.3. All the designing process were done by using SolidWorks software.

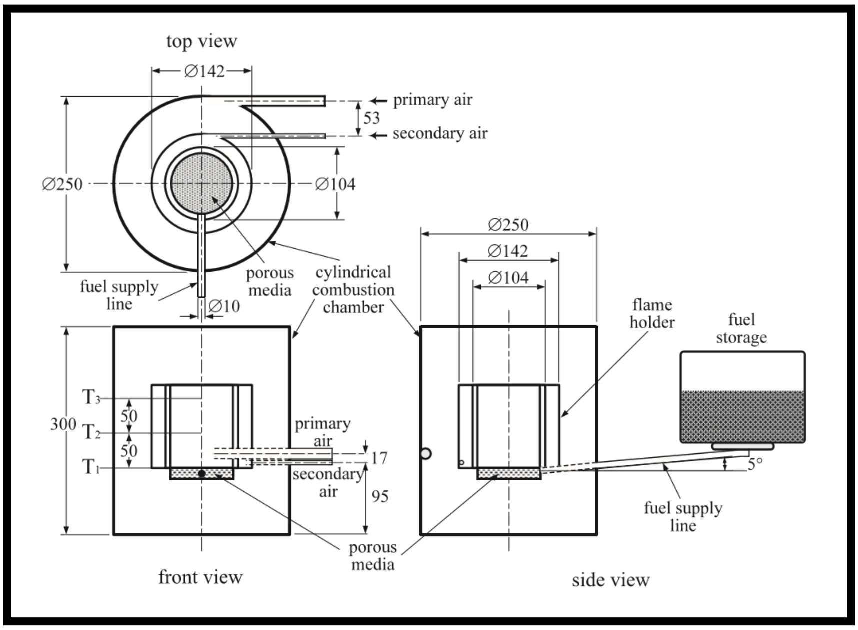

Figure 3.1: Swirl combustor design. Adapted from "Comparative assessment of a porous burner using vegetable cooking oil-kerosene fuel blends for thermoelectric and thermophotovoltaic power generation" by K.F. Mustafa et al., 2016, Fuel, 180, 137–147.

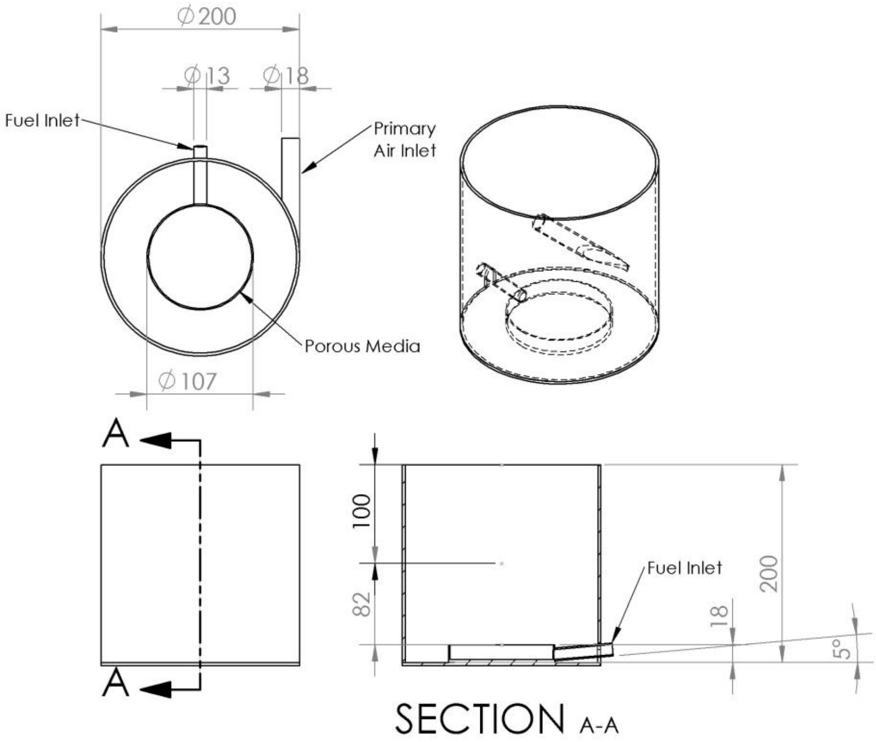

Figure 3.2: 1 air inlet combustor design

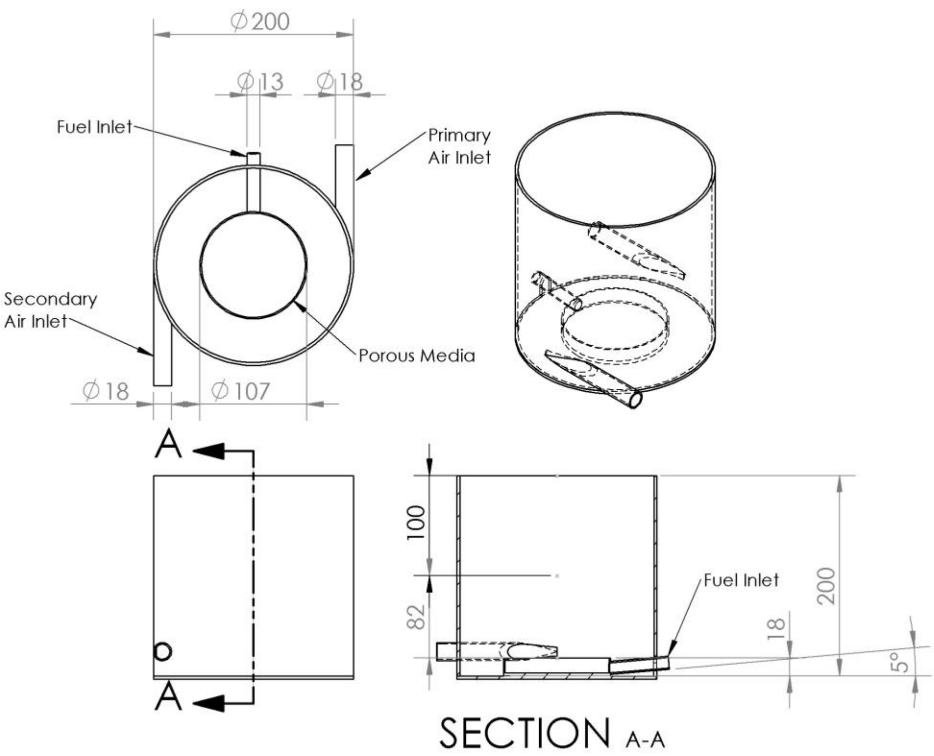

Figure 3.3: 2 air inlet combustor design

3.2 Fuel Blends and Parameter Setting

There are multiple set of fuel blends that will be used for this experiment that seems suitable for this experiment to understand how the ratio between the fuel blends affects the result which is temperature. Fuel that will blend and being used in this experiment are kerosene and vegetable cooking oil. All the type of blends can be referred at Table 3.1. The parameter that will change in this are the air-fuel ratio for the combustion which includes the mass flow rate of air and the mass flow rate of fuel. The air-fuel ratio value will be then represented as air-fuel equivalence ratio which is ratio between air-fuel ratio from stoichiometric and air-fuel ratio that were used. The air-fuel ratio from stoichiometric were taken from calculation from previous research [3] at Table 3.2. The fuel mixture will be prepared by using ultrasonic mixer.

Table 3.1: Type of fuel blends adapted from "Comparative assessment of a porous burner using vegetable cooking oil-kerosene fuel blends for thermoelectric and thermophotovoltaic power generation" by K.F. Mustafa et al., 2016, Fuel, 180, 137–147.

Fuel Blends	Description
100 Kerosene	100% Kerosene mixture
9010 KVCO	90% Kerosene and 10% VCO mixture
7525 KVCO	75% Kerosene and 25% VCO mixture
5050 KVCO	50% Kerosene and 50% VCO mixture

Table 3.2: Air-fuel ratio stoichiometric calculation. Adapted from "Comparative assessment of a porous burner using vegetable cooking oil-kerosene fuel blends for thermoelectric and thermophotovoltaic power generation" by K.F. Mustafa et al., 2016, Fuel, 180, 137

Fuel Blends	Moles			$C_xH_{2y}O_{2z}$			$a = x + \frac{y}{2} - z$	$(A/F)_{stoic} = \frac{a(32 + 3.76 \times 28)}{12x + 2y + 32z}$
	C	H	O	x	y	z	a	(A/F)stoic
100 Kerosene	5.937	24.43	0.199	5.937	12.217	0.0994	11.946314	16.58914567
9010 KVCO	6.215	17.381	0.390	6.215	8.690	0.195	10.365374	14.49003160
7525 KVCO	6.651	18.284	0.028	6.651	9.142	0.014	11.20744	15.61344074
5050 KVCO	5.888	18.075	0.608	5.888	9.038	0.304	10.102723	14.08585125

The aim for this project is to use various set of fuel-air equivalence ratio, Ø which will be determined by adjusting the mass flow rate of fuel and air. The actual mass flow rate of fuel and air will be using to calculate the air-fuel ratio actual (Eq. 3.1). Ø can then be determined by using Eq. 3.2 based on the air-fuel ratio stoichiometric (Table 3.2) of the fuel and the actual air-fuel ratio. The Ø will be used to represent the result on the performance rating of the fuels. The value of Ø will be first obtained by experimental process, then the same value of Ø will be used in the simulation process to compare the result between experimental result and simulation result. Target value of Ø is between 0.4 up to 1.6. The parameter setting will then be tabulated on Table 3.3 as follows.

$$(A/F)_{actual} = \frac{Mass\ flow\ rate\ of\ air\ (kg/s)}{Mass\ flow\ rate\ of\ fuel\ (kg/s)} \tag{3.1}$$

Equation 3.1: Actual air-fuel ratio

$$\emptyset = \frac{(A/F)_{stoic}}{(A/F)_{actual}} \tag{3.2}$$

Equation 3.2: Air-fuel equivalence ratio

Table 3.3: Estimated parameter setting based on desired value of Ø, from 0.4 to 1.6 with constant mass flow rate of fuel.

2 air inlet	(A/F)stoic	Ø = (A/F)stoic/ (A/F)actual	(A/F)actual	ṁ fuel (kg/s)	ṁ air (kg/s)	ṁ air each inlet (kg/s)
100 kerosene	16.5891457	0.4	41.4728642	0.000025	0.001036822	0.000518411
		0.6	27.6485761		0.000691214	0.000345607
		0.8	20.7364321		0.000518411	0.000259205
		0.9	18.4323841		0.00046081	0.000230405
		1	16.5891457		0.000414729	0.000207364
		1.1	15.0810415		0.000377026	0.000188513
		1.2	13.8242881		0.000345607	0.000172804
		1.4	11.8493898		0.000296235	0.000148117
		1.6	10.368216		0.000259205	0.000129603
9010 KVCO	14.4900316	0.4	36.225079	0.000025	0.000905627	0.000452813
		0.6	24.1500527		0.000603751	0.000301876
		0.8	18.1125395		0.000452813	0.000226407
		0.9	16.1000351		0.000402501	0.00020125
		1	14.4900316		0.000362251	0.000181125
		1.1	13.172756		0.000329319	0.000164659
		1.2	12.0750263		0.000301876	0.000150938
		1.4	10.3500226		0.000258751	0.000129375
		1.6	9.05626975		0.000226407	0.000113203
7525 KVCO	15.6134407	0.4	39.0336019	0.000025	0.00097584	0.00048792
		0.6	26.0224012		0.00065056	0.00032528
		0.8	19.5168009		0.00048792	0.00024396
		0.9	17.3482675		0.000433707	0.000216853
		1	15.6134407		0.000390336	0.000195168
		1.1	14.194037		0.000354851	0.000177425
		1.2	13.0112006		0.00032528	0.00016264
		1.4	11.1524577		0.000278811	0.000139406
		1.6	9.75840047		0.00024396	0.00012198
5050 KVCO	14.0858512	0.4	35.2146281	0.000025	0.000880366	0.000440183
		0.6	23.4764187		0.00058691	0.000293455
		0.8	17.6073141		0.000440183	0.000220091
		0.9	15.6509458		0.000391274	0.000195637
		1	14.0858512		0.000352146	0.000176073
		1.1	12.8053193		0.000320133	0.000160066
		1.2	11.7382094		0.000293455	0.000146728
		1.4	10.0613223		0.000251533	0.000125767
		1.6	8.80365703		0.000220091	0.000110046

3.3 Simulation Modelling

Before the fuel blends were used on the experiment on the fabricated swirl combustor, the design will first be simulate by using ANSYS Fluent 16.0 to get overview of the experiment and the result. The simulation also helps to obtain the flow pattern inside the combustor before the experiment. This simulation also helps to differentiate between the 2 air inlet configurations with the 1 air inlet configuration which were used to determine the final design that will be used for the experimental process. For the simulation, the design for the combustor were slightly change to satisfy the simulation condition which is slightly different from the final design. However, geometry wise, it represent the same geometry with the final design. Only the final design were further used in the simulation to compare the result of the simulation and the experimental result. The design of the combustor for the simulation process is shown as Fig. 3.4.

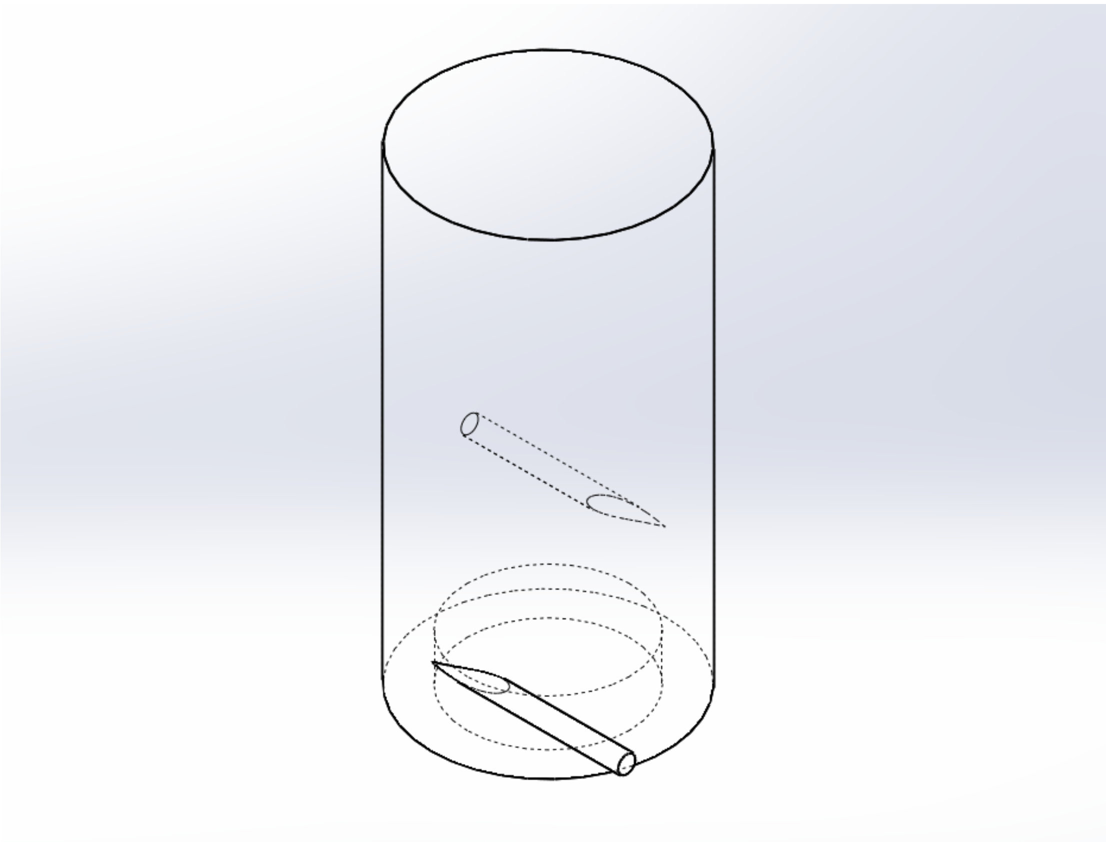

Figure 3.4: Combustor design for simulation process

For the simulation process, several changes need to be done in order to simulate what the real situation are on the simulation process.

First, the design geometry were imported from SolidWorks into ANSYS Fluent. Then, the body of the geometry were changed from solid to fluid (Appendix A1). This step is necessary in order to be able to analyse the behaviour of the fluid movement inside the body which means there is no particle outside of the body that would be considered in the simulation.

Second, the mesh sizing. For simplicity, only few things changes on this part (Appendix A2). The meshing will be generated based on those setting. Meshing will determine the accuracy of the solution. Fine mesh will prevent a sudden change in the solution since the solution is basically were divided into a smaller scale of the mesh size. However, a too detailed mesh will result a longer time for the simulation to complete since each mesh will be individually calculate its own solution.

Next on fluent modelling, one of few things need to be change (Appendix A3) is turning on the Energy Equation. The energy equation is use to solves total enthalpy if non-adiabatic non-premixed combustion is use. K-epsilon (2-equation) includes two extra transport equations to represent the turbulent properties of the flow. This allows a two equation model to account for history effects like convection and diffusion of turbulent energy. The first transported variable is turbulent kinetic energy. The second transported variable in this case is the turbulent dissipation.

Lastly, non-premixed combustion was used in this simulation (Appendix A4) in order to simulate the type of fuels that were used in the combustion. The fuel mixture were represent based on the mass percentage of the element inside the fuel mixture which were obtained by using ultimate analysis on the fuel mixture. The element that were included were Carbon, Hydrogen, Oxygen, Sulphur and Nitrogen.

3.4 Fabrication Process

Based on the final design of the combustor design, it then proceed to fabrication of the swirl combustion. However, due to limited supplies available at School of Mechanical store, some changes on the design were changed from the original plan. The dimension of the final design were included (Fig. 3.5) while the simulation model were also followed by the new design. Fortunately, the original aim of the project still could be achieved without changing anything. The fabrication process includes multiple of machining process which includes, cutting, milling, drilling and welding process. Complete fabrication were shown as main chamber (Fig. 3.6), porous media holder (Fig. 3.7) and whole set of the swirl combustor chamber (Fig. 3.8).

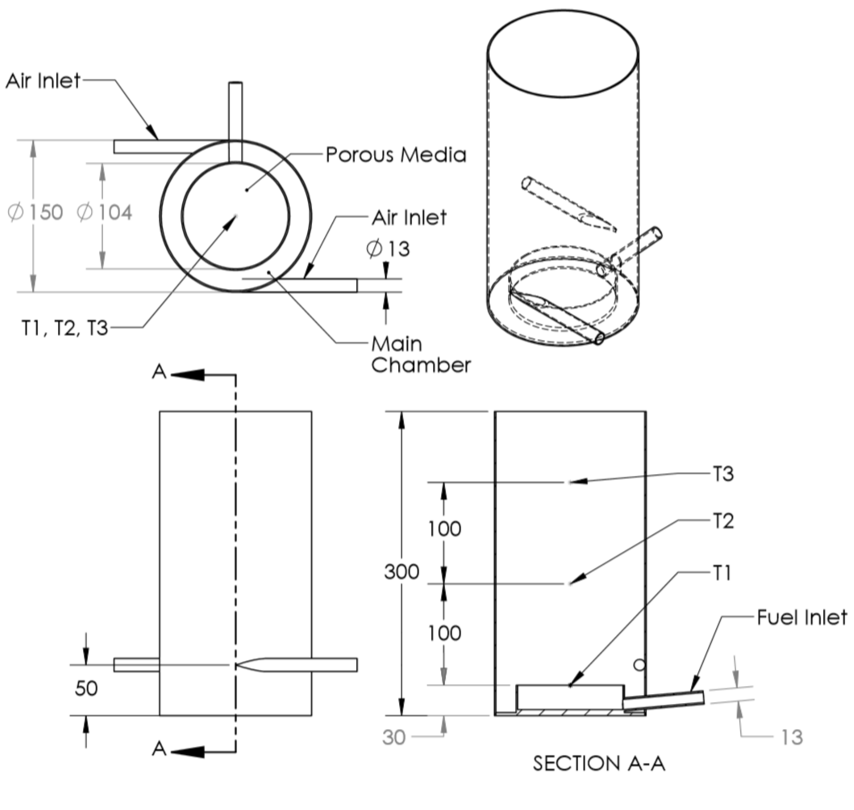

Figure 3.5: Dimension for the swirl combustion chamber

Figure 3.6: Main chamber

Figure 3.7: Porous media holder

Figure 3.8: Swirl combustor chamber set

3.5 Experimental Setup

After the simulation process, the combustor design will undergo fabrication process for the experimental result. At the combustor, there will be three temperature reading that will be taken for the result analysis. Those there temperature where located inside the combustor which are labelled as T1, T2 and T3 that are located as shown in Fig. 3.9. Only two air inlet combustor were being used in the experiment as it was selected to be the final design. Those three temperature reading were used to obtain the temperature distribution along the height of the combustor with respect to fuel blends ratio and the air fuel ratio. There are 3 thermocouple, air compressor and weighing scale for the fuel inlet. Those 2 air inlet were connected to the aim compressor with valve and flow meter in the middle to determine the air flow rate and to control it. For the fuel, it is also connected with valve with tank and weighing scale to measure mass flow rate of fuel over time. The fuel and air flow rate were controlled to obtain the desired air-fuel ratio and fuel-air equivalence ratio. Thermocouple were used in order to measure the temperature inside the combustor.

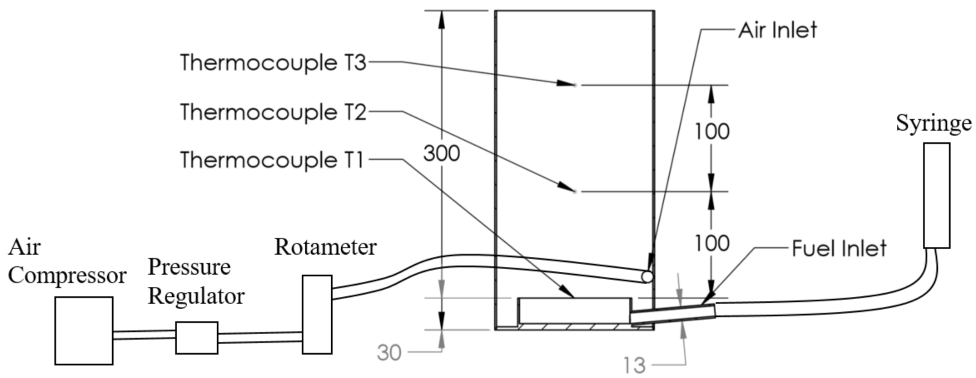

Figure 3.9: Experimental setup

Figure 3.10: Pressure gauge

Figure 3.11: Rotameter for air flow rate

Figure 3.12: Splitting air inlet into both inlet

Figure 3.13: Syringe for volume of fuel used

Figure 3.14: Valve controlling fuel flow

Figure 3.15: Porous media

Figure 3.16: Thermocouple position

Figure 3.17: Thermocouple

3.6 Fuel blends preparation

For this experiment, two type of fuel were used as a mixture for the fuel for the combustion. The two type of fuel were kerosene and vegetable cooking oil. These two fuel were prepared based on desired mixture of 9010 KVCO (90% Kerosene 10% VCO), 7525 KVCO (75% Kerosene 25% VCO) and 5050 KVCO (50% Kerosene 50% VCO). All these three mixture were mixed based on the weight percentage which means for instance, for 9010 KVCO, 90% weight of the mixture was kerosene while 10% of the mixture weight was VCO. Each mixture were prepared about 200ml - 250ml for each mixture for the experiment.

3.6.1 Fuel physical properties

Simple experiment were conducted to measure one of the fuel physical properties which is the density of the fuel. In order to calculate the air-fuel ratio of the combustion, the mass flow rate of the fuel and air is needed. Since this experiment were using syringe to measure the usage of the fuel in combustion, which measure the volume of the fuel that will give the volume flow rate of the fuel instead of mass flow rate, it is needed to convert the volume flow rate to mass flow rate of fuel. In order to change volume flow rate to mass flow rate, the density of each fuel mixture were needed. To get the density, a measuring cylinder were used with the electronic balance. A measuring cylinder was put on top of the electronic balance and the weight was set to zero. Then, each mixture was poured into the measuring cylinder. The volume of the fuel was measured on the measuring cylinder and the mass of the fuel was measured on the electronic scale. Finally, the density was calculated based on the volume and mass of the fuel (Eq. 3.3).

$$Density\ of\ fuel\ \left(\frac{kg}{m^3}\right) = \frac{Mass\ of\ fuel\ (kg)}{Volume\ of\ fuel\ (m^3)} \tag{3.3}$$

Equation 3.3: Density of fuel

Chapter 4 : RESULT AND DISCUSSION

4.1 Fuel Physical Properties

Density of the mixture of the fuel

Table 4.1: Properties of fuel

Type of fuel	**Density, ρ (kg/m^3)**
100 Kerosene	800.00
9010 KVCO	809.9174
7525 KVCO	818.1818
5050 KVCO	845.679
100 VCO	910.00

The density of each mixture, 9010 KVCO, 7525 KVCO and 5050 KVCO were increase respectively. The density of kerosene is quite low compare to the VCO. Since the percentage of kerosene is high in most of the mixture, the mixture density are most likely to be more affected by the density of kerosene.

4.2 Experimental Analysis

4.2.1 Flame Propagation

From Fig. 4.1, it shows few example of the flame propagation during the experiment. From the result, the flame can be clearly seen to be swirling inside the combustion chamber. These events happens due to the 2 air inlet were located tangentially towards the combustion chamber. Based on the result, the objective of this experiment to design a swirl combustor was achieved. The flame was also balance on the wall of the combustion chamber since the 2 air inlet were located opposite to each other. The length of the chamber was also at about the right length since the flame of the combustion was full up until the top of the chamber.

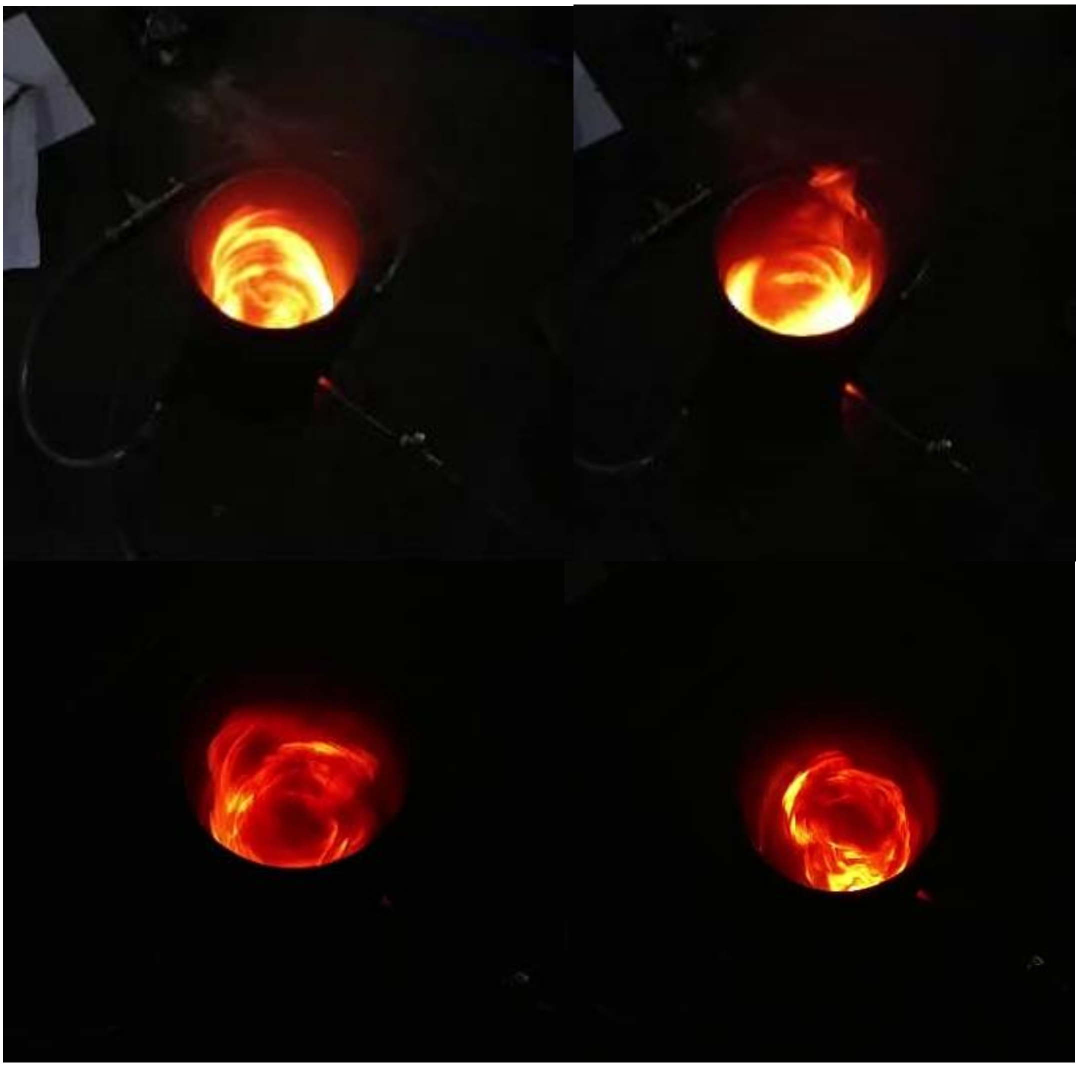
Figure 4.1: Examples of flame propagation on the swirl combustor

4.2.2 Temperature Reading

Table 4.2: Temperature data tabulation for each type of fuel for experimental analysis

Fuel	Set	$\dot{V}$ (lpm)	$\dot{m}$ fuel (kg/s)	A/F Stoic	Ø = (A/F)stoic/ (A/F)actual	T1	T2	T3
9010 KVCO	1	30	5.00E-05	14.4900	1.24914	447.3	482.7	433.5
	2	40	5.02E-05	14.4900	0.94467	495.2	485.2	470.4
	3	50	4.99E-05	14.4900	0.75318	520.7	495	473.5
	4	60	5.03E-05	14.4900	0.62832	490.6	476.2	414.3
7525 KVCO	1	30	5.01E-05	15.6134	1.34599	463.2	460.8	402.7
	2	40	5.00E-05	15.6134	1.01386	476.3	463.8	438.4
	3	50	5.02E-05	15.6134	0.8132	558.3	473	422.6
	4	60	4.98E-05	15.6134	0.67299	505.3	430.6	372.3
5050 KVCO	1	30	4.99E-05	14.0859	1.2143	554.1	536.2	506
	2	40	5.01E-05	14.0859	0.91467	597.3	590.4	539.6
	3	50	5.00E-05	14.0859	0.73364	610.3	575.6	486.3
	4	60	5.03E-05	14.0859	0.60715	510.2	445.7	377.3

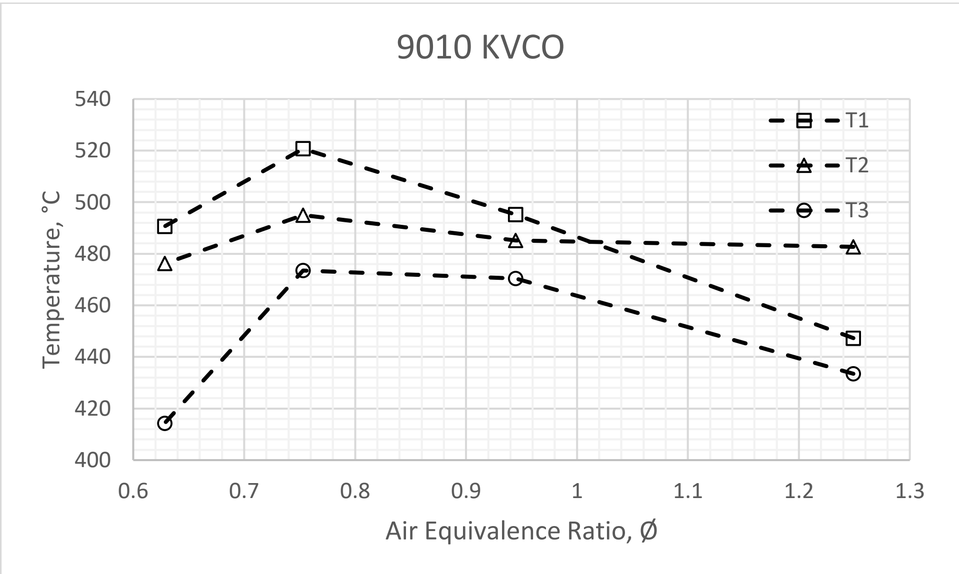

Figure 4.2: Temperature against air equivalence ratio for 9010 KVCO for experimental analysis

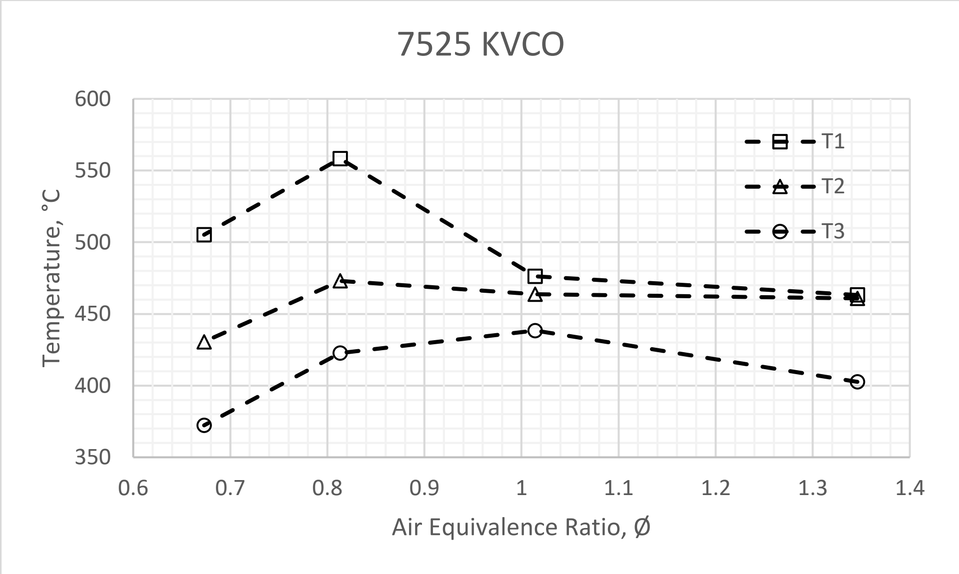

Figure 4.3: Temperature against air equivalence ratio for 7525 KVCO for experimental analysis

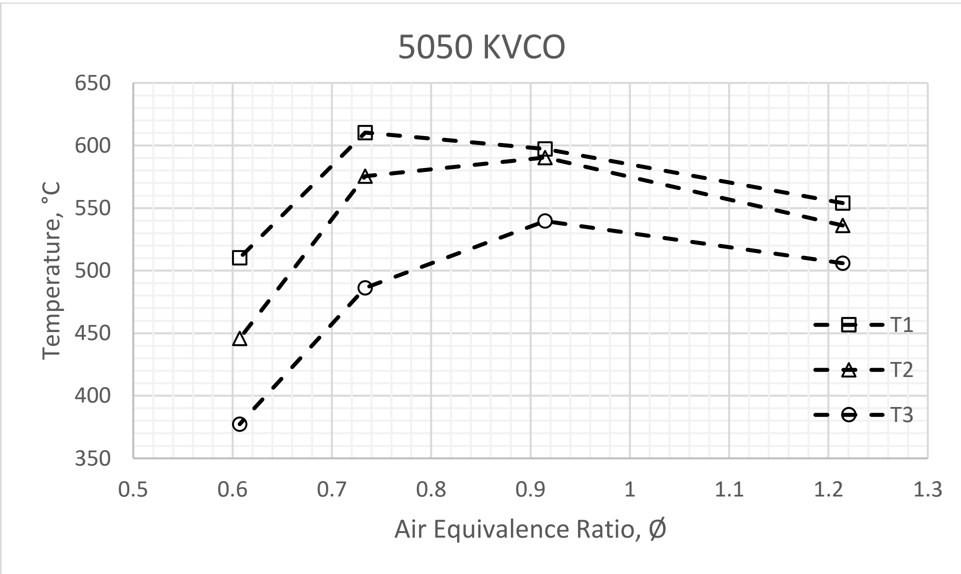

Figure 4.4: Temperature against air equivalence ratio for 5050 KVCO for experimental analysis

For the experimental analysis, three type of fuel were carried out during the experiment which are 9010 KVCO, 7525 KVCO and 5050 KVCO. Four different volume flow rate of air were used during the experiment to create different air-fuel equivalence ratio for each mixture. The volume flow rate or air were set as it will give both lean and rich mixture of the fuel. The air-fuel equivalence ratio obtained were