DEVELOPMENT AND CHARACTERIZATION OF PRODUCER GAS BURNER

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DEVELOPMENT AND CHARACTERIZATION OF PRODUCER GAS BURNER

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DECLARATION

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

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This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references.

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LIST OF ABBREVIATIONS

GHG	Greenhouse Gas
CO	Carbon Monoxide
CH_4	Methane
H_2	Hydrogen
O_2	Oxygen
O_3	Ozone
N_2O	Nitrous Oxide
N_2	Nitrogen
NOx	Oxide of Nitrogen
PG	Producer Gas
H_2O	Water
CFC	Chlorofluorocarbon
CO_2	Carbon Dioxide
PPM	Particle per Million
ICE	Internal Combustion Engine

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ABSTRAK

Gas Pengeluar (PG) berasal dari proses gasifikasi biomas dari sebatian karbon seperti arang batu dan kayu. Gas ini dapat digunakan sebagai cara alternatif dari pembakaran bahan bakar fosil untuk menghasilkan tenaga. Pembangunan PG burner, dirancang untuk membakar PG mentah dengan cekap. Komposisi karbon monoksida (CO) yang lebih tinggi dalam unsur gas pengeluar, menyukarkan proses pembakaran dan nilai pemanasan juga pada tahap rendah. Pembakaran PG juga mempunyai batasan sejak pelepasan CO dan oksida nitrogen (NOx). Jumlah pelepasan CO dan NOx harus lebih rendah sebanyak mungkin kerana secara tidak langsung mempengaruhi Gas Rumah Kaca (GRK). Ia mungkin tidak mempengaruhi GHG secara langsung kerana komponen utama GHG itu sendiri terdiri daripada wap air (H_2O), karbon dioksida (CO_2), metana (CH_4), ozon (O_3), nitro oksida (N_2O), klorofluorokarbon (CFC). Tetapi pelepasan CO dan NOx mungkin bertindak balas terhadap ozon troposfera yang boleh menyebabkan pencemaran dunia yang lebih teruk. Banyak kajian mendapati bahawa PG dapat seefisien bahan bakar fosil dan pembersih. Kajian dilakukan dan menunjukkan bahawa tahap pelepasan CO dan NOx dapat dikurangkan kerana pembakaran lengkap PG. Terdapat beberapa kaedah dalam meningkatkan pembakaran PG untuk projek penukaran tenaga. Kaedah termasuk, 1) nisbah bahan bakar ke udara, (2) geometri pembakar, (3) sumber biomas untuk PG, (4) dinamika aliran PG dan lain-lain Kajian ini akan memfokuskan pada geometri pembakar untuk hasil yang baik dalam tahap pelepasan CO dan NOx yang rendah. Ada tiga faktor yang akan digunakan untuk menjalankan eksperimen tersebut adalah (1) diameter luar pembakar, (2) diameter nisbah pemegang bahan bakar, dan (3) panjang nisbah pemegang bahan bakar. Kesan faktor ini dikaji melalui simulasi berangka. Eksperimen dan simulasi berangka akan mencirikan pembakar gas pengeluar apabila gas dibakar dalam

beberapa kaedah sebagai peningkatan prestasi pembakaran. Secara keseluruhan, geometri optimum dijumpai di antara faktor-faktor dari eksperimen ini.

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ABSTRACT

Producer Gas (PG) is derived from the biomass gasification process of carbon compounds such as coal and wood. This gas can be used as an alternative way from the burning of fossil fuel to generate power. The development of a PG burner, designed to burn the raw PG efficiently. Higher carbon monoxide (CO) composition in the PG element makes the combustion process and the heating value low. The burning of PG also has limitations since there were emissions of CO and oxide of nitrogen (NOx). The number of CO and NOx emissions should be lower than possible since it indirectly affects Greenhouse Gas (GHG). It may not directly be affecting GHG since the main component of GHG itself are made up of water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), ozone (O3), nitrous oxide (N_2O), chlorofluorocarbon (CFC). However, the emission of CO and NOx may react to the tropospheric ozone that can lead to a worse world of pollution. Many studies were found out that PG could be as efficient as fossil fuel and cleaner. The studies carried out that emission levels of CO and NOx can be reduced due to the complete combustion of PG. There were few methods in improving the burning of PG for the energy conversion project. The method including, 1) the ratio fuel to air, (2) geometry of the burner, (3) Biomass sources for PG, (4) Flow dynamic of PG, etc. This study will focus on the geometry of the burner to have a good result in a low emission level of CO and NOx. There are three factors to be used to run the experiment, which are (1) the outer diameter of the burner, (2) the ratio diameter of the fuel holder, and (3) the ratio length of the fuel

holder. The effect of these factors was studied through numerical simulation. The experiment and numerical simulation will characterize the PG burner when the gas is burned in several methods as improved combustion performance. Overall, the optimum geometry is found out among the factors from this experiment.

CHAPTER 1

INTRODUCTION

1.1 Overview

The standard fuel used in burning and combustion is a fossil fuel. Fossil fuel is non-renewable energy, and it is preserved beneath the ground for a million years before it can be used today. It is widely used around the globe and affecting GHG. The burning of fossil fuel, creating a by-product which CO_2 and contributing to global warming. Global warming is an important issue since the earth faces many effects from global warmings, such as ice melting at the north and south poles, respectively, seawater rise, etc.

Nowadays, energy is become the main issue in the world population due to the modernization of technology and economic development. The demand for this thing is riser day-to-day. Somehow, the problems regarding this issue rise since the depletion of explored reserved oil and the emission created by consuming fossil fuel. The consumption of fossil fuel will never end, and it is true to the emission of CO and NOx that will keep increase. Together with the engineer, researchers and scientists have come out for many technologies to overcome the problem. For example, the invention of the electric car that uses a Battery to move around without using a single drop of fossil fuel to operate. The same goes for the power generator, which is solar energy, hydro energy, wind energy and even sea wave energy used to overcome the fossil fuel as the primary fuel in a power generator. Alternatively, biomass is found and can replace the consumption of fossil fuels in daily life.

Biomass gasification is deriving the primary element from carbon compounds such as wood, dry leaves and organic substance.[1]The process converts the carbon compound into combustible gas, producer gas or synthesis gas without firing any combustion to the carbon compound. This method is called renewable energy since the carbon compound used in the process is from the plant and animal in the ecosystem life. Biomass is called clean energy since the organic substance used in this process is in the carbon cycle. The tree has a photosynthesis process, which reduces the CO_2 in the atmosphere and produces carbon after being burnt.[2]. The net of carbon emissions is zero since the organic compound is neutralized by storing and releasing it together.

The energy demanded around the globe made the higher energy consumption and thus reduced the fossil fuel reserve and affected the GHG. Biomass material is also used to fulfil world demands. Since biomass energy is eco-friendly energy, it benefited the world and renewable energy. Biomass energy also produces an inefficiency of the system, such as burning of biomass to heat steam for the textile industry. The efficiency low due robust burning of biomass compound and lead to an inefficient system. Thus, biomass will consume and using higher work of burning to generate the inefficient system

PG derived by gasification process of biomass. PG is cheap compare to other fossil fuels and natural gas. Instead of the cheaper production, PG having a low calorific value made it more difficult to burn it with the air in a burner. The high degree of dilution with inert gas (N_2 and CO_2) exposed it to the long residence time to oxidizing completely [3].

Many studies have been conducted, including the development of PG bio-fuel as fuel to run an engine. The PG in this study must be lower in tar content since the

PG is dirty and relatively have higher tar content. Having a higher amount of tar content result in a limitation of PG flexibility to the technology. It has to be cleaner or lower amounts of tar content to fit or obey the technology. Few studies also covered how the other method that can improve the burning of PG to the optimum while having lower emission of CO and NOx. The present study focused on determining the optimum geometry to burn PG using the air staging process or continuous air staging.

Finally, PG is an alternative way to the non-renewable energy problem, facing depletion across time. It also provides sustainable renewable energy because PG is related to biomass, which is also related to the leftover from human activities that can benefit the world. Increasing the concerned society and globally towards this green energy will save the Earth for a better future.

1.2 Project Background

PG is derived from the biomass gasification process of carbon compounds such as coal and wood. This gas has been used as an alternative way from the burning of fossil fuels to generate power. The development of a PG burner, designed to burn the raw PG efficiently. Higher CO composition in PG element, complex combustion process, and heating value is also low. That burner will burn PG with a specific method to increase the efficiency of combustion. The few methods including the swirl flow in the burner, preheated fuel before combustion and continuous air staging. The experiment and numerical simulation will characterize the PG burner when the gas is burned in several methods to improve combustion performance.

The development of combustor for PG, giving a better performance in combustion and done. PG comprises combustible gas CO, H_2, and CH_4 and other non-combustible gas [2]. The low flame stability depends on gas composition. Therefore, the high percentage of CO and hydrogen can support better stability of flame during combustion. On the other hand, the combustion is taking a long time residence to burn because the mixing of the fuel and air was not ideal yet for burning efficiently. The burner will use the concept continuous air staging process

Continuous air staging is the process where air combustion and fuel is non-premixed. The process is to distribute the air to the flow of the fuel in the inner tube. The air passes from the outer inner tube through the small holes at the inner tube that support the combustion of the fuel. The holes are arranged in circular and linear around the inner tube. The airflow through the hold is serving to distribute to the fuel to have complete combustion. The combustion air and the fuel are mixed in the inner tube and burned in the combustion chamber or burner.

1.3 Problem Statement

PG is a biomass gasifier product consisting of CH_4, H_2, N_2, O_2, CO, and CO_2. Only certain elements in PG are mainly combustible, which are CO, H_2, and CH_4, respectively. The rest remains as incombustible for CO_2 and N_2. There also have a small percentage of O_2 in PG. The low heating value in PG is a disadvantage in the combustion process. Proper mixing of air to fuel ratio need to implement in the process. The lower heating value of PG results in the combustion of PG that cannot be made in the conventional burner of fossil fuel.[2] Combustion of PG will lead to the emission of CO and NOx. It will result in higher pollution emissions if the PG heating value is higher.[3] Utilizing PG efficiently, higher mixing quality of PG and air is required for the combustion process.[4] However, not many researchers that carried out the solution using the air staging method in utilizing PG. Therefore, numerical calculation and simulation of burning PG using the air staging method were carried out in this study.

1.4 Objectives of the Project

- To design and fabricate a new burner of producer gas for having a better performance in combustion.

- To optimize the chamber geometry for the efficient combustion of low-grade producer gas using ANSYS-FLUENT CFD simulation and characterize the performance of the combustion in terms of temperature, CO and NOx emissions

1.5 Scope of Work

The main scope of this project is to focus on the effect of a few factor on geometry which is 1) Outer diameter of the burner, (2) Inner tube diameter ratio to the outer diameter of the burner and (3) Inner tube length ratio to the length of the burner. The factor is a focus to create or identify the optimum geometry based on those factors. It focuses on analyzed emission amount at the burner outlet as the temperature result varies to the geometry in a single run. The composition of PG was studied to apply in this numerical simulation. The process involving 1) designing, (2) fabrication, (3) experiment and (4) simulation. However, the experiment process was cancelled due to the pandemic crisis, Movement Control Order (MCO) after the fabrication work is up to 95% to finish. The simulation data were recorded and compared between the geometries.

1.6 Outline of the reports

This thesis is divided into four main chapters; the first chapter discusses the current situation facing non-renewable energy, the potential of biomass as an alternative to replacing fossil fuel in the future, and PG's benefit. This chapter also contains the project's aim, the scope of the project and the outline of the project report.

In chapter 2, the literature review based on PG, which are including 1) the method of producing PG efficiently, (2) the composition element of the PG, (3) air staging process and the benefit of using it, (4) alternative method to utilize the PG efficiently by another study, and (5) the limitation of PG towards design and performance.

In chapter 3, the methodology covered the design process, including design selection and modelling into a computer-aided drawing (CAD). Then the numerical simulation that including the meshing process and solution to the numerical. Then fabrication process takes place simultaneously with the simulation process in Bio-Lab, School of Mechanical Engineering.

In the last chapter, conclusion in terms of higher temperature while considering the number of CO and NOx emissions at the lowest

CHAPTER 2

LITERATURE REVIEW

2.1 Producer gas

PG is a derivative product of biomass gasification. PG can be produced via three methods from biomass which are 1) direct combustion, (2)biological conversion and (3) thermochemical conversion[5]. Since the producer is combustible, it is relevant to been used for thermal application. When it comes to better energy conversion, thermal is one of the best solutions. It is because electric generators nowadays more into the heat captured to generating electrical energy. Show that PG is an alternative way to replace the current fuel such, fossil fuel and coal to be the primary concern in alternative fuel in the industry

Gasification converts solid carbonaceous fuels such as coal, wood, agricultural residues, urban wastes even sewage sludge waste into combustible gas by partial combustion. Among the method of producing PG, thermochemical conversion is called the promising method of producing better quality PG[6]. Since the gasification process also involving the flow of air or steam to the biomass material to react. The moisture content involves and the flow in the gasification process influences the quality of the PG. The higher moisture results in lower biomass consumption since higher energy is required to dry it. The higher its flow will make more biomass material get oxidised and faster the combustion process for airflow. Commonly, the gasification reaction undergoes according to the few methods or ways of the gasifier. As a result, the gasifier is a significant factor that affects the gasification reaction process. There were few common types of gasifiers which are 1) fixed bed gasifiers, (2) fluidized bed gasifiers, and (3) entrained flow gasifiers.[7] The characteristic of different gasifiers shows in **Table 2.1**

Table 2.1 : Characteristic of different gasifier

Gasifier	Characteristics
Fixed bed	- Slight capacity
	- Can operate substantial particles
	- Producer gas has a low heating value
	- Producer gas has a high quality content
	- High gasification agent consumption
	- Ash is removed as slag or dry
Fluidized bed	- Medium capacity
	- Constant thermal distribution
	- High temperature operation
	- Producer gas has a low quality content
	- Suitable for raw material with low level of fusion temperature
	- Ash is removed as slag or dry
Entrained flow	- Huge capacity
	- High temperature operation
	- Unfit for high-ash-content feedstock
	- Requires huge consumption of oxygen
	- Residence times is slightly lower
	- Ash is removed as slag

Based on the study [8], the calorific value of fuel gas or PG produced from air blown gasifier is significantly lower than an oxygen-blown gasifier. The calorific is about (5MJ/m3) and (10-20MJ/m3), respectively. The study shows the importance of oxygen in the gasification process to support the combustion of biomass material to have a high quality of PG.

The by-product from biomass gasification as ash is also useful since it can be used in fertilizer. Overall, biomass can be called clean energy that benefits from the early stage of the process until the last or final product benefits the world. GHG also can be reduced and save the world from natural disasters caused by the main event that is global warming.

2.2 Composition of Producer Gas

PG is a gas mixture containing CH_4, H_2, N_2, O_2, CO, and CO_2. From that, there were few combustible gases, which are CO, H_2, and CH_4. The incombustible gases, including N_2 and CO_2 the presence of a small amount of O_2.

To produce PG, many types of material or biomass compounds feed into the gasifier. Thus, the various type influences the composition of the producer. On average, the main composition of the combustible elements in PG is still the same, but the percentage might vary slightly. Based on a study, [8] the CO and H_2 content significantly higher from the wood pieces that are smallest compared to the other size. The type of gasifier used influences PG composition, such as air gasification as the most economical among the other gasifier types. The air gasification, which results in a low heating value (<6MJm-3) influenced by dilution in N_2[9]. In comparison, steam gasification results in higher H_2 content compared to air gasification. Overall, by comparing these two types of the gasifier, steam gasification much better benefits PG's performance as fuel.

The PG is a product from biomass which agricultural residues, urban wastes even sewage sludge waste. The gasification of biomass also produced PG that contains tar and char, or the other words, is a contaminant. The presence of this contaminant in PG might be a problem to technologies.[2] Tar is in liquid form while char is in solid form. Both are composed of a higher number of hydrocarbon. As might be a problem, it cannot be used directly to the equipment or any combustion that has any small hollow or path. Since the tar present in the PG need to undergo treatment, which is filtration. The tar that not through the filtration process will result in clogged, for example, PG's internal combustion engine. Based on the study, [2] **Figure2.2.1** shows the biomass gasification process flow and production after pyrolysis.

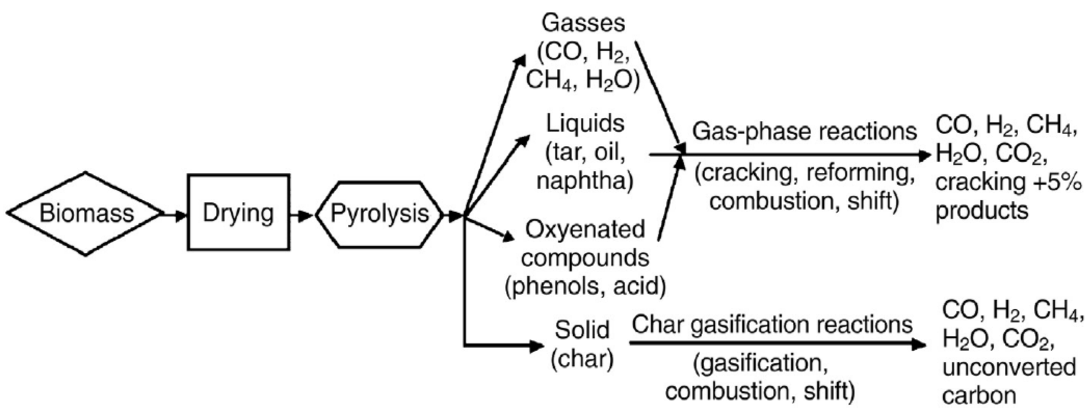

Figure 2.2.1 : The process of gasification and gasification product

2.3 Air staging

Air staging combustion is one of the most efficient combustion methods. This method introduces the support of fuel or air based on what type of staging is used in the system. Based on explaining in [4], the air staging is based on the separated stream used for combustion air entering the respective zone, divided up to 3 zones of combustion. The benefit of using staged combustion is to control the pollution emission from the combustion. In other words, staged combustion can reduce the NOx and CO emission compared to the conventional burner[10].

The concept was burning the fuel in the primary zone with the rich condition of the fuel. The staged air or secondary combustion air will mix right after the primary zone and lean combustion regime. The excellent mixing of the combustion air in a lean combustion regime can avoid thermal NOx formation. Other studies [11] explained the same theory in detail, where air staging creates a fuel-rich zone in the combustion zone by entering the combustion air into the burner. The study also explains that air staging performed the NOx reduction by two mechanisms. There was 1) oxygen deprivation due to a lesser combustion air mixing with the fuel in the combustion zone. Then the conversion of fuel-N to NOx is inhibited. The result is reducing fuel-NOx. The next is 2) the introduced air staging into combustion zone will let the primary combustion flame cooler, result in less thermal-NOx.

However, the trade-off between NOx and CO emission needs to be mentioned as the high degree of air staging could also increase CO emissions. It might be because of not being optimized for secondary air and primary air in the burner. Such factors may affect the emission of CO while reducing the NOx by air staging, 1) design of burner including size and shape of the burner, and (2) the mixing rate of primary combustion product with the secondary air. There was an example used in the study [12] on the geometry used in air staging combustion in **Figure 2.3.1**

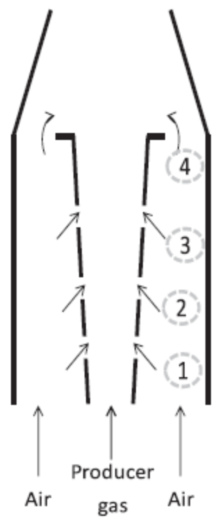

Figure 2.3.1 : Schematic of the burner used for producer gas combustion

2.4 Other methods in improving Producer Gas Combustion

Producer gas is low heating value gas fuel. To have the same amount of power as natural gas in energy production, about seven times of volume or the flow rate of PG to reach the performance of natural gas is required. Abundance study revealed the alternative way or method in improving producer gas performance as fuel in combustion.

The swirl flow is applied to enhance the internal gas circulation. The process or method is done by place the inlet that tangentially order to the circumference of the tank. The tangential inlet can increase the mixing rate between a fuel (producer gas) to the air. The better mixing also resulted in a proper burning of fuel, completely burnt with oxygen. The perfect burn of both elements with the result perfect stability of flame.[13]

The low flame stability depends on gas composition.[2] Therefore, the high percentage of carbon monoxide and hydrogen can support better stability of flame during combustion. On the other hand, the combustion is taking a long time residence to burn because the mixing of the fuel and air was not ideal yet for burning efficiently. The combustor will use the concept of swirl flow for both air and fuel, respectively

The burner of producer gas can be efficient as it burns the producer gas entirely with oxygen. However, the producer gas burned time delay can be reduced by preheating the fuel and combustion air before entering the combustion chamber.[1] The different temperatures of inlet reactants resulted in a different result of burn time delay as the preheating reactant will support the performance of the producer gas burner in combustion.

Utilizing the flameless combustion also is the better way to higher the performance of PG. To reach flameless combustion, the air and the fuel need to have a good circulation where high internal gas recirculation is required and the key to better flameless combustion.[3] Flameless combustion, higher internal gas recirculation is required. Therefore, increasing the number of burners could meet the criteria. It same as the air staging concept, where it helps utilize the PG into complete combustion. As a result of a higher number of the burner, CO emission can be lower. Reducing the diameter of the burner can affect internal gas recirculation. The smaller the burner, the higher recirculation of the internal gas. Therefore, the premixed concept applied to have flameless combustion.

2.5 Limitation of Producer Gas

PG combustion does result in CO and NOx emission. However, in production, the producer gas also has byproducts such NOx, SO2 and Tar. The limitation of producer gas is the presence of Tar as a byproduct in the production of PG. The tar is not a problem if used in direct combustion. But it does have a limitation when using in ICE.[14] Based on the study, it cannot run directly into ICE. Since ICE is sensitive to Tar and other contaminants. The improper fed of PG will lead to the lower performance or high-cost maintenance of equipment

Lower heating value is the other limitation and disadvantage of PG. The nitrogen component in PG is unchanged and make the PG itself dilute.[8]As a result, PG has a low heating value (<6 MJ m-3)[9]. The low heating value of PG usually produces a low-intensity of thermal field. The thermal field is the key to flame temperature. As a result, the flame temperature is lower due to the low intensity of the thermal field.

CHAPTER 3

METHODOLOGY

3.1 Overview

Information and previous research papers related to this project can be obtained from the internet via ResearchGate and ScienceDirect with access to Universiti Sains Malaysia, Hamzah Sendut Library. Study the behaviour and composition of PG. The example from previous research gives an overview of how to perform the project. To design, fabricate, and run the numerical simulation using CFD software, ANSYS-CFD-Simulation prepared by the School of Mechanical Engineering. In this project, more focus is on the CO and NOx emission from the geometry of the PG burner to obtain the optimum geometry based on the recent focus issue.

The design selection was made based on the focus method of burning PG, which is air staging. The design process is done by using Solidwork with the geometry is ready to be used in ANSYS-CFD-Simulation. In other words, the design in Solidwork is the fluid flow geometry inside the burner. To have an optimum result or optimum geometry of burner, few modifications or different dimensions of burner drawn to compare CO and NOx emission results. Fabrication was also done to run the experiment to compare with the simulation result and the experimental result. Due to Movement Control Order in the nation, the experiment was postponed.

The simulation result is the key to the experiment. Since the result indicates the project's objective, which is the emission of CO and NOx and the temperature of the outlet burner. From the simulation, the contour throughout the burner is obtained, and the behaviour of combustion propagates through the burner.

3.2 Designing the Burner

This project is focused more on air staging combustion or burning. Characteristic air staging process, the design should meet the process of it. The designing process is challenging since we need to understand the behaviour of the PG as well. The characteristic of PG mostly is dirt, which contains tar. Tar is a form of contamination that will disturb the system through the small path. For example, in **Figure 3.2.1**. The flow is passing through such a narrow path, called a nozzle. The disadvantage of the design is that Tar will clog the nozzle as it will be deposited as the PG keeps flow during the combustion process. The detailed view of the nozzle is shown in **Figure 3.2.2**.

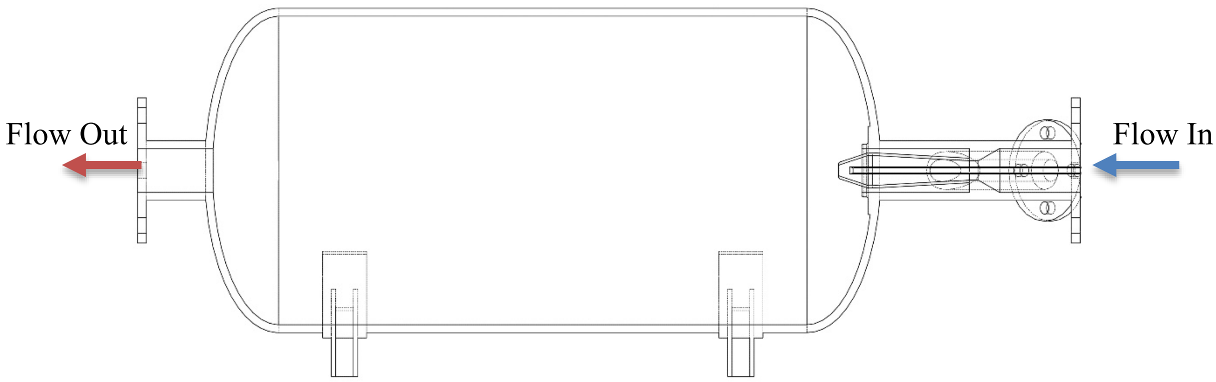

Figure 3.2.1 : Design 1 of Air Staging

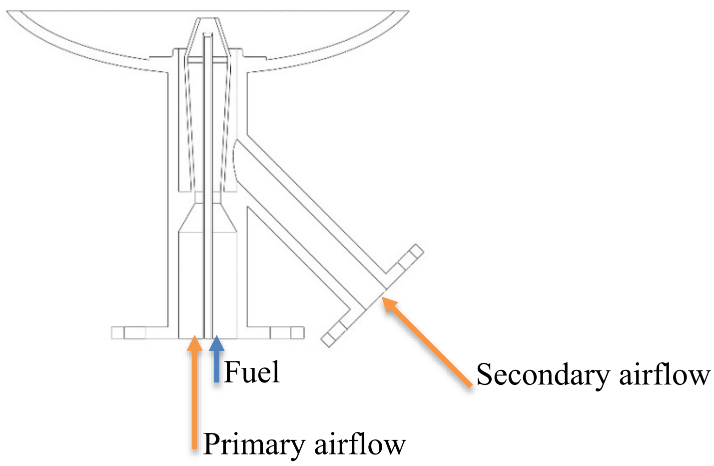

Figure 3.2.2 : Detail view of nozzle on design 1

The fuel flow is crucial since it drives the main component of combustion. Explain in the study [15] that maintenance needs to be done to clean the dirt of tar deposited at the tip of the nozzle if the clogged problem occurs. The following design also faces the same problem since the distributor inside the burner use is small, which is not convenient for PG as fuel to work on it. Design 2 is shown in **Figure 3.2.3**. This design was also not selected since the concept of air staging is not clear. It is because the air and fuel undergoes premixed before combustion or enter the combustion chamber through the distributor

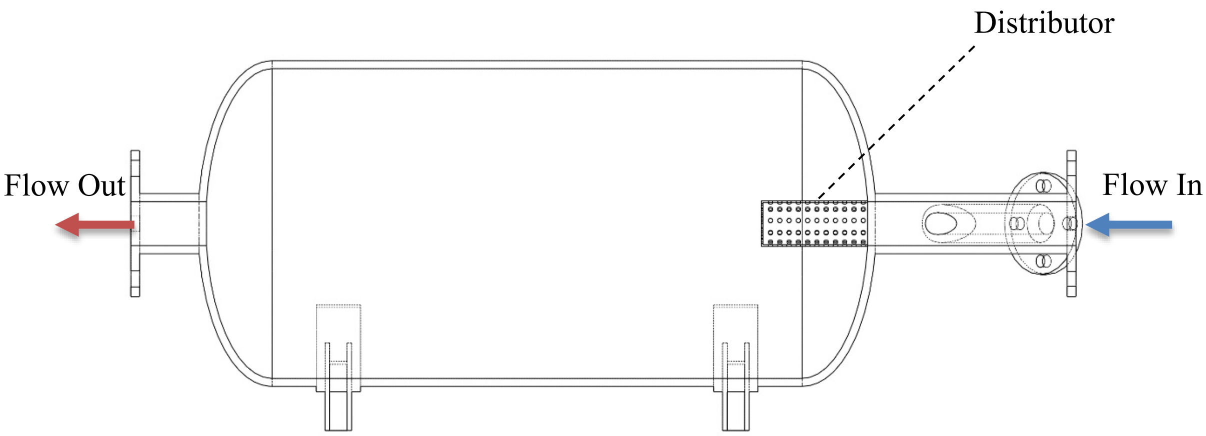

Figure 3.2.3 : Design 2 of Air Staging

After modification, the final design was selected, which the flow of PG supported with the air staging through a hole. The hole with a diameter of 25.4mm, which is equivalent to 1 inch. The hole is arranged in circular along the inner tube in the final design of air staging. The design was selected because the geometry is simple that follow the air-staging concept. In other words, the air feed into the fuel stream or fuel flow by level. The final design also is the open-end burner **Figure 3.2.4** show the final design for the air staging project. **Figure 3.2.5** clearly shows the fuel and air combustion flow path in the 3-D burner drawing. The air combustion will mix with the fuel through the holes in the inner tube, as the fuel flow is already in the primary combustion zone. The design was selected as it compromised the better solution for NOx and Co emission. It is because the air is distributed evenly with fuel in the combustor. Therefore, the hot spot area is avoided and reduces residence time between the combustor's nitrogen gas and hot gas.

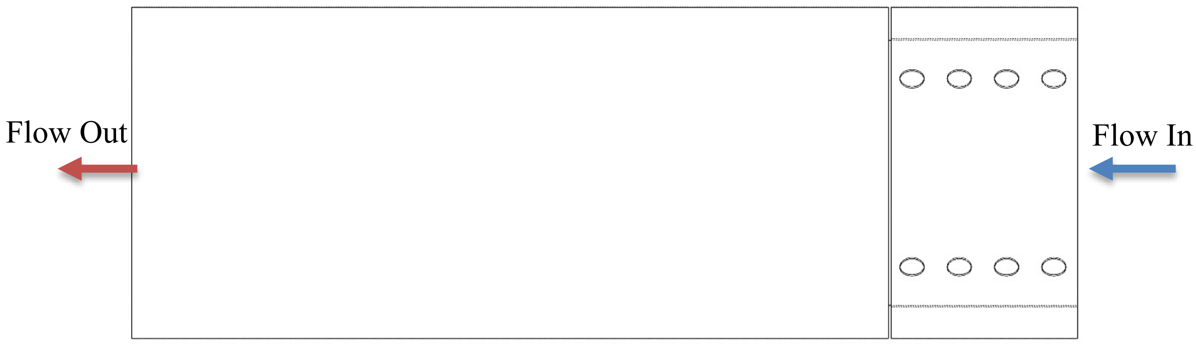

Figure 3.2.4 : Final design of Air staging

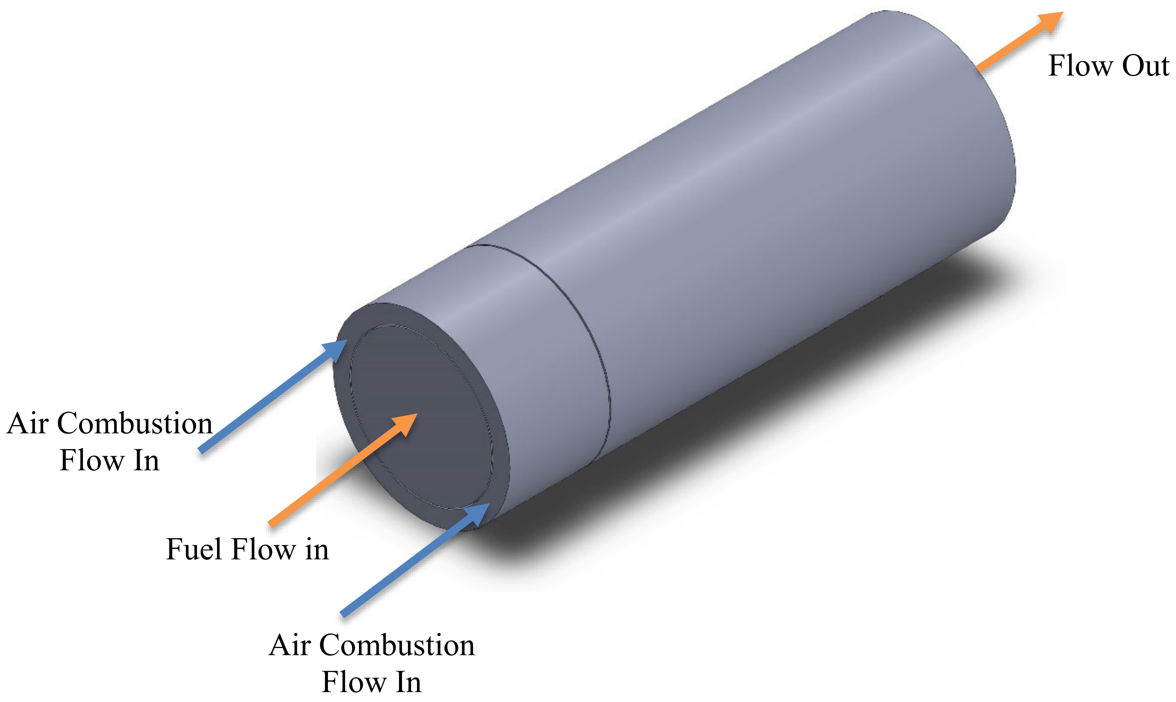

Figure 3.2.5 : Design of the burner in domain

3.3 Fabrication

The fabrication process is done to compare the simulation result with the experiment result. In this project, two designs were running simultaneously. The first design is run by a master student covering the swirl inlet for PG, and this design covers air staging. The purpose of doing this is to determine the best design to reduce CO and NOx emissions. The scratch-built from ready part material such as a Pipe of 5-inch diameter for 500mm in length, hollow bar, and pipe for the early stage in the fabrication process. After preparing all this material, the welding process continued, making the burner properly shape the burner. Figure 6 show the scratch that finishes the welding process.

After finish, the burner shell, moving on to finish, the swirled blade for swirling effect on air inlet into the burner. The nozzle of fuel flow is located in the middle of the burner, attached with a swirled blade around it. It is placed at the tip of the burner inlet. To make the swirled blade in position, it was welding to the wall of the burner. Next, for fuel flow and airflow, link of pipe attached to the fuel inlet and air inlet, which will connect to the Volumetric Flowmeter for airflow and fuel flow. For assembly activities, the fabrication needs to been stopped due to Movement Control Order across the nation. The experiment was also postponed and yet to finish. Figure 7 shows the model already in 85% of progress to finish before the assembly process is done.

Figure 3.3.1 : Scratch after the welding process

Figure 3.3.2 : Burner fabrication at 85% progress

3.4 Simulation

3.4.1 The parameter for design

Table 3.1 shows the design parameter, which the design varies through few manipulated variables to record the response towards the variable. The manipulated variable for this project are 1) the outer diameter of the burner, (2) the diameter ratio of the inner tube or flame holder to the diameter of the burner and (3) the length ratio of the inner tube or flame holder to the total length of the burner. The responses from this project are the amount of CO emission and NOx emission.

Table 3.1 : Design of Experiment setup

No. of Design	Outer Diameter	Diameter Ratio	Length Ratio
1	150	0.4	0.2
2	350	0.4	0.2
3	150	0.8	0.2
4	350	0.8	0.2
5	150	0.4	0.5
6	350	0.4	0.5
7	150	0.8	0.5
8	350	0.8	0.5

Table 3.2 show the composition of PG used in this experiment based on the study[16]. It comprises combustible gases (H_2, CO, and CH_4), incombustible gases (N_2 and CO_2) and very little oxygen. Which also, this composition of PG has a lower heating value LHV of 3.99MJ/m3

Table 3.2 : Composition of Producer Gas

Species and concentration (Vol %)					
CH_4	H_2	CO	N_2	CO_2	O_2
0.3	5.0	29.2	62.5	2.1	0.9

For all design, air to fuel mixture ratio was set at it which 0.85. The mass flow rate for the air and fuel are 0.00256kg/s and 0.003 kg/s, respectively.

3.4.2 Meshing

For the meshing process, the fluid domain is used for the whole combustion volume, and it is meshed by 5mm of element size tetrahedral grid type of mesh. The 5mm was chosen to minimize the number of elements since the geometry of the fluid domain is not the complex geometry for fluent simulation.

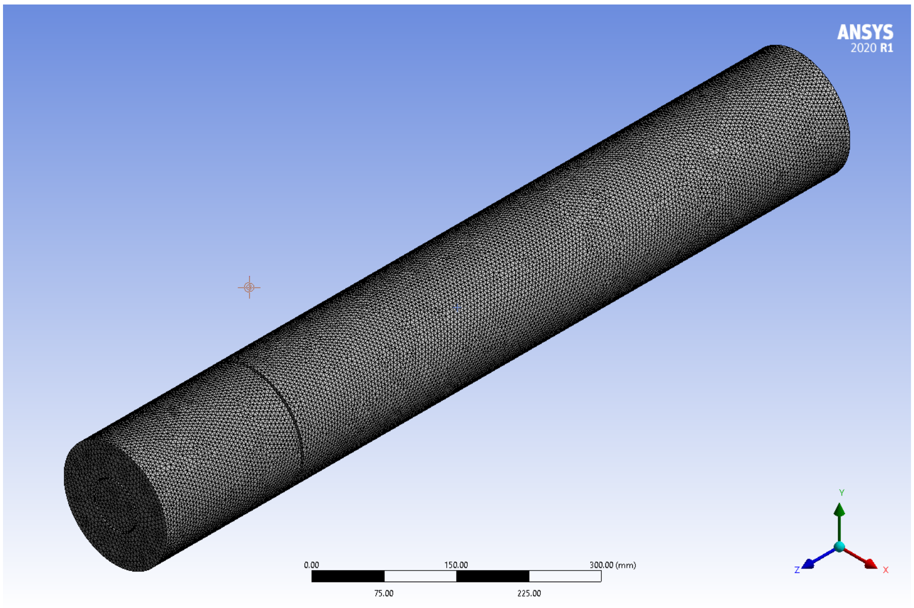

Figure 3.4.1 : Meshing of the design

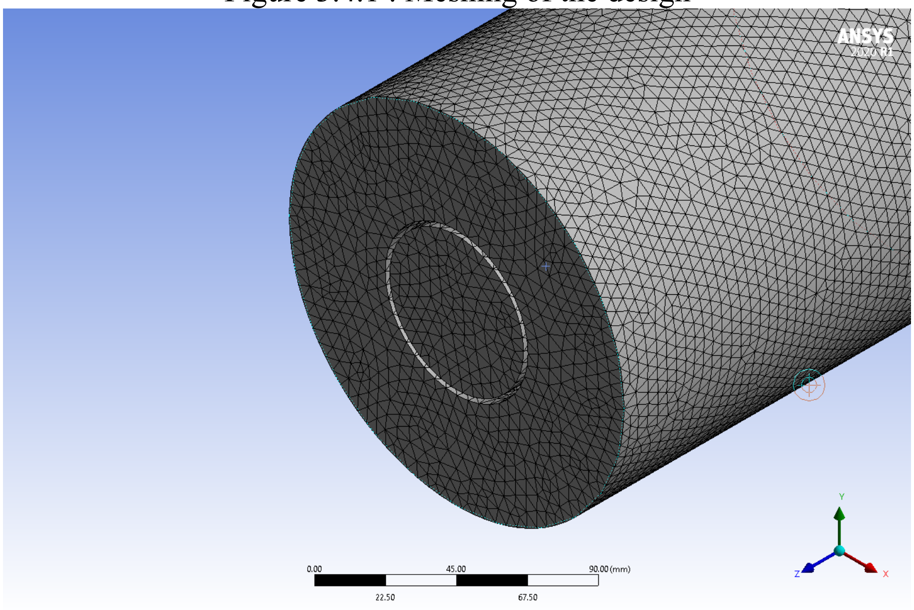

Figure 3.4.2 : Detail view of tetrahedral grid meshing on Inlet

3.4.3 Initial Setup

The modelling process was performed using a steady-state pressured-based solver with the active energy equation. The K-epsilon (k-ε) turbulence model with default setting selected. Non-premixed combustion model used for setting the combustion of PG and air since both enter the reaction zone or combustion chamber from the different and distinct stream. Boundary species were also updated based on the composition and percentage of content in PG. The boundary set up shown in Figure 10. The number assigned to the species is according to the respective percentage, which in total refers to 100%. PDF table is calculated (mean data for density, temperature and specific heat)

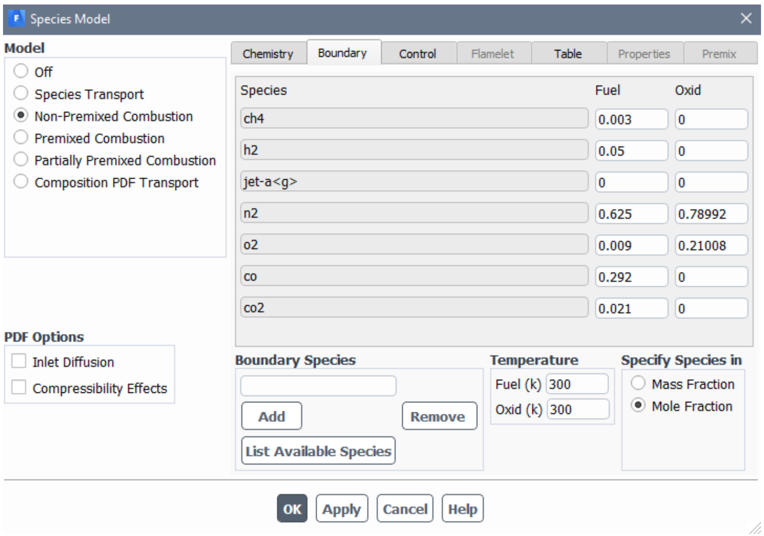

Figure 3.4.3 : Boundary species for non-premixed combustion setup

NOx Model is active to calculate the NOx production in the postprocessor. By activating the model. NOx number will be determined, and the result shown after the calculation is done.

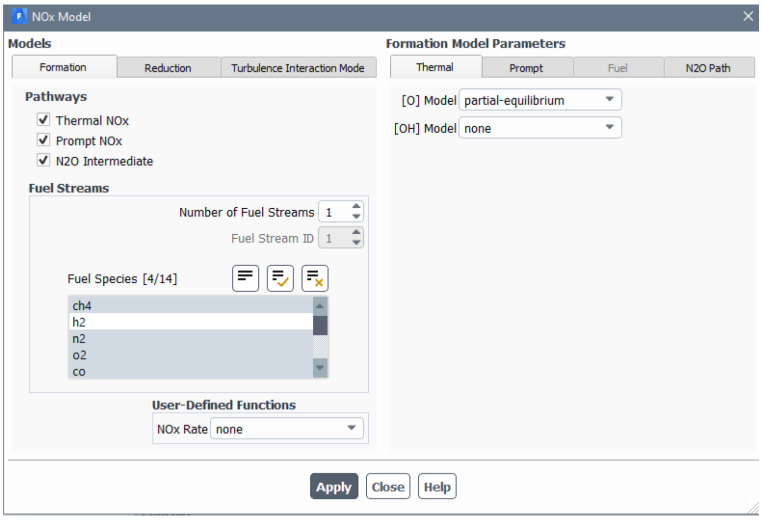

Figure 3.4.4 : NOx model setup

3.4.4 Boundary condition

Inlet boundary for both fuel and air is set up using mass-flow inlet condition. Where the volume of air and fuel flow is calculated based on mass flow rate. The mass flow rate for the air and fuel are 0.00256kg/s and 0.003kg/s. For the air inlet, the temperature is set to 350K temperature since it assumed the air come out the blower heated up a little due to the compressed by the blower. For the producer, gas is set to 300K temperature, which is about room temperature. For Fuel at the inlet, an additional setup is for Mean Mixture Fraction is set up as one since we need the concentration of all species at the inlet without any mixture present for fuel inlet. Two atm of pressure is set up for initial gauge pressure to make the initial pressure at the inlet of fuel for two atm.

For pressure velocity coupling, the SIMPLE algorithm was applied with the Second-Order Upwind spatial discretization setting. Standard initialization was used with a declared initial value for temperature and mean mixture fraction, 2500K temperature. Lastly, 500 iterations were used for calculation. The finished calculation will result in the contour of temperature at the outlet, amount of CO emission and amount of NOx emission. The data will be the table in Excel for results and discussion

CHAPTER 4

RESULT AND DISCUSSION

4.1 Overview

The result was obtained from the simulation using ANSYS-FLUENT simulation. The result is not supported by the experimental work and experiment result since the experiment stopped until the fabrication process. The fabrication process was finished, but the experiment work not continue since the MCO across the nation started again. Therefore, this project will explain the result obtained from the CFD simulation and the combustion chamber geometry optimisation. The main investigated parameters were:

1. The outer diameter of the combustion chamber.
2. Diameter ratio between outer diameter and inner tube diameter for air staging.
3. Length ratio between the total chamber length to the length of the inner tube.

4.2 Effect of chamber diameter on combustion

The diameter of the burner is significant in designing the burner since the diameter will govern the effect of air-fuel mixing at the first stage. To increase the probability of complete combustion, early and good air-fuel mixing is needed. The smaller the diameter, the higher the mixing quality inside the air distributing tube since air is forced through the tube at earlier stages. Higher air-fuel mixing quality inside the distributor tube will start the flame propagation earlier at the first stage. It will increase the residence time for combustion to complete at the second stage of the chamber. The result revealed that temperature increase when decreasing the diameter of the burner