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Study of Novel Swirler Design on the Performances of Non-Premixed Combustion

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Abstract: Combustion industries in recent decades has a problem to reduce the emissions with a good performance of combustion. This research aims to reduce emissions and to increase velocity and temperature by using non-premixed combustion. Axial swirler and radial swirler are combined in one design with each swirler having 8 blades. Swirl angle for radial swirler is 35 ° and inclination angle for axial swirler is 15 °. The swirler is designed using Solidworks and transferred into an ANSYS fluent for the simulation and to get the results. The fuel used is LPG gas and turbulence parameters for this study is a standard k-epsilon model. 3 lines have been created on the simulation to get the result at different stages. The result proved that the combination swirler can reduce the CO and CO_2 emission and also able to improve the velocity. The temperature result for axial swirler is better than combination swirler. As a recommendation, the axial part in the combination swirler needs to increase their inclination angle to increase the temperature.

Keywords: Swirler, Non-Premixed Combustion, Emissions, Velocity, Mixing Process

1. Introduction

Swirl flows have been extensively researched for so many decades due to their wider acceptance in all sorts of practical systems, including gas turbine combustion. Numerous experiments in swirl fluxes have been carried out, increasing from very basic isothermal flows to those produced in very complex swirl combustor geometries. Many examples of the uses of swirling jets to control combustion can be found in the literature. Other studies focused on the effects of hurling, stabilization, blowout, and pollutant emissions on the characteristics of lifted flames [1]. The use of lean premixed combustion has been preferred by gas turbine manufacturers over non-premixed combustion to achieve low emissions. While the use of lean pre-premixed combustion is attractive to reduce pollution, it may penalize the complicated system, acoustic instability, and increase size and weight [2]. Swirling can be used in non-premixed combustion to reduce nitrogen oxide emissions. The inflammation temperature decreases

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under the swirl effect. A swirling intensity needs to be identified to achieve a compromise between reducing pollutant emissions and preventing the flame- burning distance. This investigation aims to assess the impact of swirl flow on the burner performance. A new concept of the domestic gas burner with swirling flames is proposed. The results obtained in this work will help us to understand what parameters are dominant in thermal efficiency and emissions pollution, the researchers say. The findings are considerable significance in providing design or working mechanisms and real applications for the manufacturing of the swirl burner that usually used in the industries.

Very high swirl intensity contributes to flashback in premature phase, higher temperatures and failure of the injector. Likewise, the high strength of the swirling allows flames and non-premixed flames to become unstable through combustion [3]. Combustion efficiency and pollutant emissions which, in the design of this non-premixed combustion, are highly influenced by turbulence [4]. Global environmental problems such as greenhouse warming, acid rain, and the hole in the ozone layer have become serious problems all over the world. Therefore, to increase the thermal efficiency and to reduce the emission, this present research will try to solve the problem with non-premixed combustion method [5]. The aims of this study are to determine the parameter of the swirler that can affect the performance of the swirl burner using non-premixed combustion and to investigate the effect of swirl design to improve the temperature, efficiency, mixing process, and reduce the emissions of CO_2 and CO using non-premixed combustion. This study will use the air inlet and fuel inlet with 0.100 kg/s and 0.003 kg/s respectively with the temperature below that 800 °. Each swirler have 8 blades and the radial vane angle is 35 °. The axial swirler inclination angle is 15 °.

2. Methodology

The methodology includes a swirler design, simulation model, setup and procedure, set of parameters, concepts or ideas with a more details description. Every step to complete the project must be followed to ensure that projects do not have any problem.

2.1 Swirler model

In the design to combine the axial swirler and radial swirler has been developed by using Solidworks. The radial swirler is the outer part of this design which is it will be the air inlet for this study. It has been designed with a swirl angle at 35 °. The inner swirler which is axial swirler is designed with 15 ° inclination angle. The diameter for the fuel inlet is 30 mm and the air inlet at the radial swirler is about 120 mm. Meanwhile, the diameter at the inner part is 60 mm.

Conventional swirler is also designed to compare the results to be obtained. Axial swirler is designed with a diameter at the air inlet is 60 mm and a diameter at the fuel inlet is 30 mm. the combustion chamber for these two designs is the same. The length of this combustion chamber is 800 mm and its diameter is 320 mm. The design for the combination of radial swirler and axials swirler is shown in Figure 1(a) and Figure 1(b). Figure 2(a) and Figure 2(b) shows the design for the axials swirler.

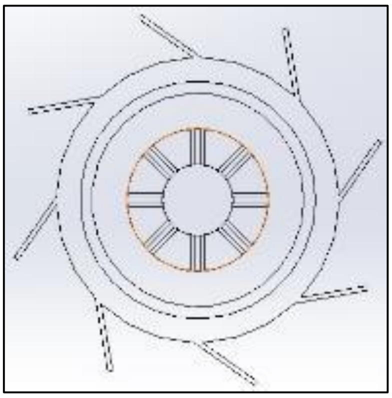

Figure 1(a): Front view of combine swirler

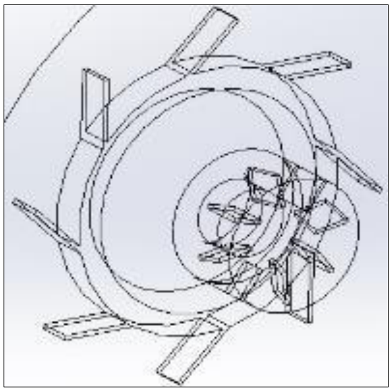

Figure 1(b): Isometric view of combine swirler

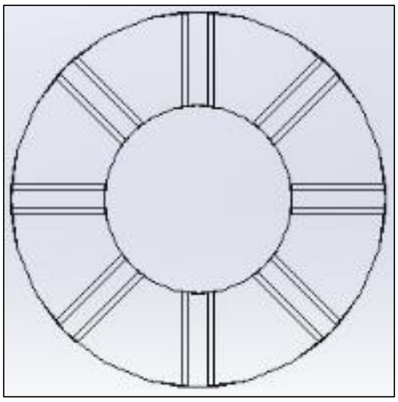

Figure 2(a): Front view of axial swirler

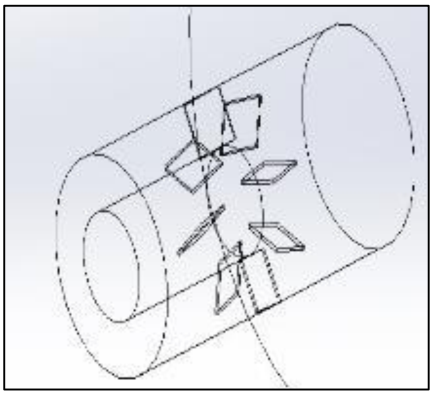

Figure 2(b): Isometric view of axial swirler

2.2 Equations

The commercial software, Ansys Fluent, is used to solve the conservation equations of mass, momentum, and scalar quantities. According to the [6], the general forms of averaged governing equations in the gas phase are expressed as:

For conservation of mass:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u_1)}{\partial x_i}=\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u_x)}{\partial x}+\frac{\partial(p u_y)}{\partial y}+\frac{\partial(\rho u_z)}{\partial z}=0 \qquad Eq.1$$

For conservation of momentum:

$$\frac{\partial(p u_i)}{\partial t}+\frac{\partial(\rho u_j u_j)}{\partial x_j}=\frac{\partial \tau_{jj}}{\partial x_j}-\frac{\partial p}{\partial x_1}+\rho g_i \qquad Eq.2$$

For conservation of scalars:

$$\frac{\partial(\rho \phi)}{\partial t}+\frac{\partial(\rho u_j \phi)}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\Gamma \frac{\partial \phi}{\partial x_j}\right)+q_\phi \qquad Eq.3$$

The turbulent quantities are solved by [7] using the standard k-ε model, with the *k* and *ε* equations expressed as:

$$\mu_t = \bar{\rho} C_\mu \frac{k^2}{\varepsilon} \qquad Eq.4$$

Where ε dissipates turbulent kinetic energy, k and ε are represented by the closure of two equations of balance:

$$\frac{\partial}{\partial t}(\bar{\rho}k) + \frac{\partial}{\partial x_i}(\bar{\rho}\tilde{u}_i k) = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] + P_k - \bar{\rho}\varepsilon \qquad Eq.5$$

$$\frac{\partial}{\partial t}(\bar{\rho}\varepsilon) + \frac{\partial}{\partial x_i}(\bar{\rho}\tilde{u}_i \varepsilon) = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right] + C_{\varepsilon 1}\frac{\varepsilon}{k}P_k - C_{\varepsilon 2}\bar{\rho}\frac{\varepsilon^2}{k} \qquad Eq.6$$

The source term Pk is given by:

$$P_k = -\bar{\rho}\mathrm{u}_\mathrm{i}^{\pi}\mathrm{u}_\mathrm{j}'' \frac{\partial \tilde{u}_i}{\partial x_j} \qquad Eq.7$$

2.3 Procedures

The thesis study plans to proceed to the following software-associated steps in chronological order:

1. Design of the combustor and 3D Modeling (Solidworks)

The parameter of the combine swirler is shown in Table 1:

Table 1: Design parameter for combine swirler

Design parameter	Details
Fuel inlet diameter	30 mm
Air outlet diameter	60 mm
Furnace diameter	320 mm
Furnace length	800 mm
Radial swirler vane angle	35°
Axial swirler inclination angle	15°

2. Geometry conversion and adjustments (ANSYS Design Modeler)

This is to change the body part from solid to fluid

3. Mesh Generation (ANSYS AUTODYN)

The meshing sizing parameter is shown in Table 2:

Table 2: Meshing sizing parameter

Sizing Parameter	Setting
Growth rate	Default (1.2)
Max size	Default (9.841 *e*-002 m)
Defeature size	Default (2.460 *e*-004 m)
Curvature min size	0.003 m
Curvature normal angle	Default (18.0°)
Smoothing	medium
Average surface area	1.2328 *e*-002 m^2
Minimum edge length	0.03 m
Bounding box diagonal	0.98416 m

4. CFD Simulation (ANSYS Fluent).

After meshing the model, it provides to simulate by using the Ansys Fluent with some simulation parameter. The solution method parameter to get the result is shown in Table 3:

Table 3: Simulation parameter

No.	Simulation Method Parameter	Setting
1	Pressure Velocity Coupling	SIMPLE
2	Gradient	Least Squares Cell Based
3	Pressure	Second Order Upwind
4	Momentum	Second Order Upwind
5	Turbulent Kinetic Energy	First Order Upwind
6	Turbulent Dissipation Rate	First Order Upwind
7	Energy	Second Order Upwind
8	Mean Mixture Fraction	Second Order Upwind
9	Mixture Fraction Variance	Second Order Upwind

5. Results analysis (ANSYS Results).

The set of parameters need to be followed to get the results, Table 4 shows the set of a variable parameter that used for the combination swirler and axial swirler.

Table 4: Set of variables parameters

Geometry	Details
Air flowrate	0.1 kg/s
Fuel flowrate	0.003 kg/s
Air temperature	350 K
Fuel temperature	300 K
Combustor pressure	2 atm
Model	Standard k-ε model
Near wall treatment	Standard wall functions
Pressure-velocity coupling	SIMPLE
Furnace length	800 mm
Furnace diameter	320 mm
Propane	0.3
Butane	0.7

3. Results and Discussion

In this study, the LPG gas is used as the fuel for the burner. The swirl burner will be able to reduce the emissions and improve the thermal efficiency with using the non-premixed combustion. One of the expected results in this study is the issue of environmental pollution can be reduced by using the swirl burner. Other than that, this product also studies the advantages and disadvantages of the combination between axial swirl burner and radial swirl burner. The effectiveness of a swirl burner on reducing the emission and the thermal efficiency are measured by using the ANSYS (Fluent) simulation. All result has 3 different stages to compare the data. The first stage is close to the swirler. The middle stage of stage 1 and stage 3 is the second stage. Stage 3 is the last stage of the analysis. The first stage is 0.065 m, the second is 0.13 m and the third stage is 0.2 m from the combustion chamber. Results display different graphic types for each stage. Figure 1 shows the line that represents for each stage.

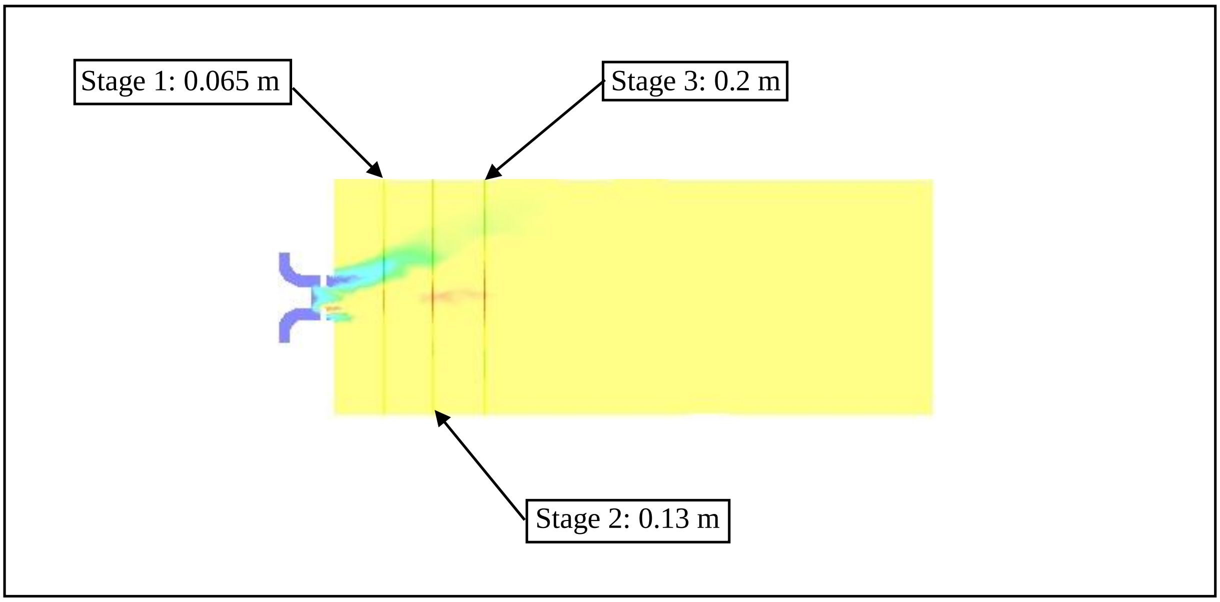

Figure 1: Position for each stage

3.1 Contour of total temperature

The contour result for temperature is shown as Figure 2 and Figure 3. The temperature behind the wall chamber is lower for axial swirler. This is good to prevent damage to the chamber. The temperature at 0.2 m is still high for the axial swirler but the combine swirler temperature is almost yellow. This contour result show that the temperature for combine swirler is low and need to be improve for the future work [8].

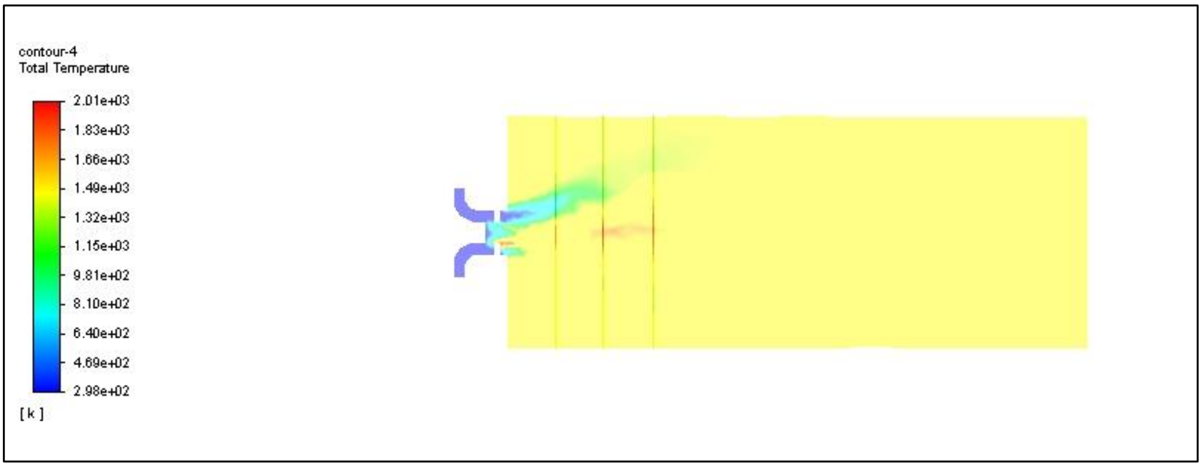

Figure 2: Temperature contour for combine swirler.

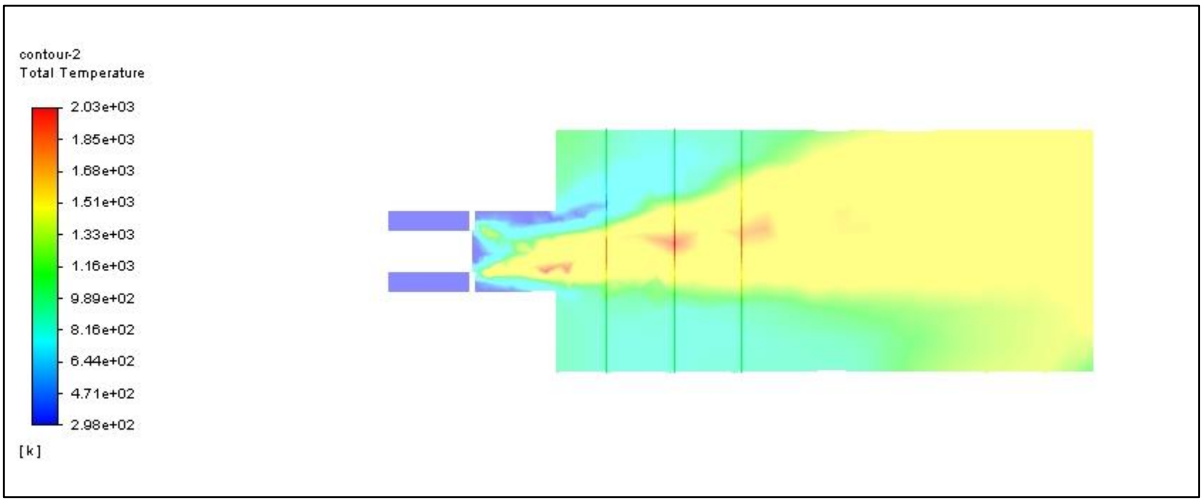

Figure 3: Temperature contour for axial swirler.

3.2 Graph of total temperature

Figure 3 shows that the total temperature for the axial swirler is wider than the combine swirler. The maximum temperature at 0.065 m is for axial swirler is about 1724 K and the combine swirler is at 1650 K. But the minimum temperature on the combine swirler is higher than the axial swirler with 813 K. The mass flow rate and inlet temperature that applied for these two designs is same, but the inlet air diameter is different. The inlet air diameter will affect the temperature in the combustion chamber [9].

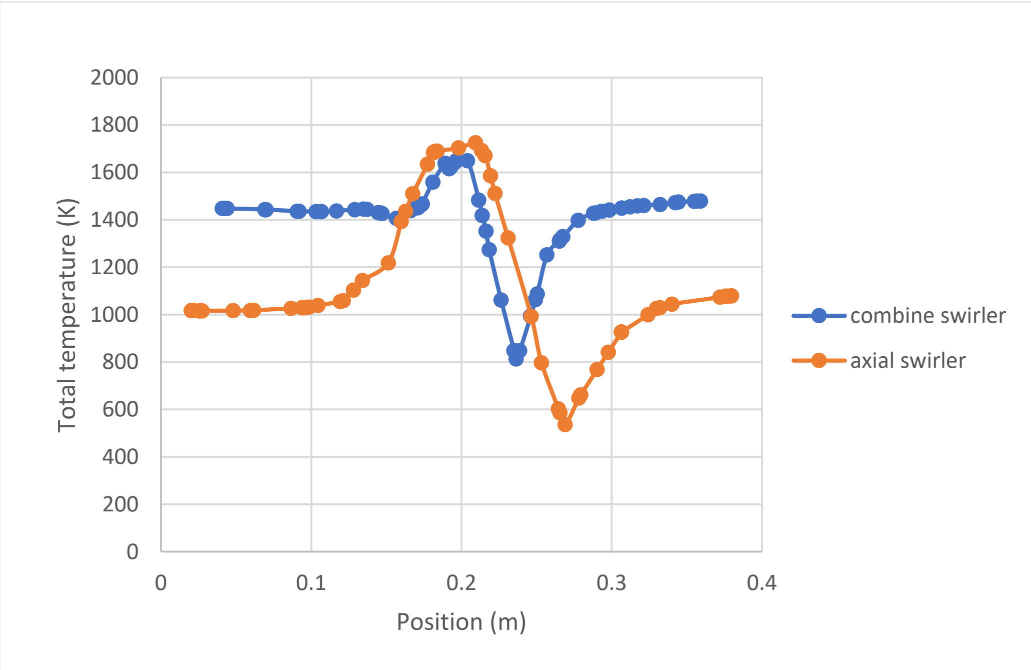

Figure 4: comparison of total temperature for combine swirler and axial swirler at 0.065 m

At 0.13 m, the graph for the axial swirler is still wider than the combine swirler. This is because of the inlet air diameter for the axial swirler is bigger than the combine swirler. The combine swirler has 8 air inlets with a small area which is 0.3 cm^2 for each inlet. The maximum temperature for axial swirler is still higher than combine swirler with 1977 K. Meanwhile, the minimum temperature for combine swirler is still higher than axial swirler which is the temperature is 1157 K. The fuel was also one of the factors that affect the temperature in the combustion [10].

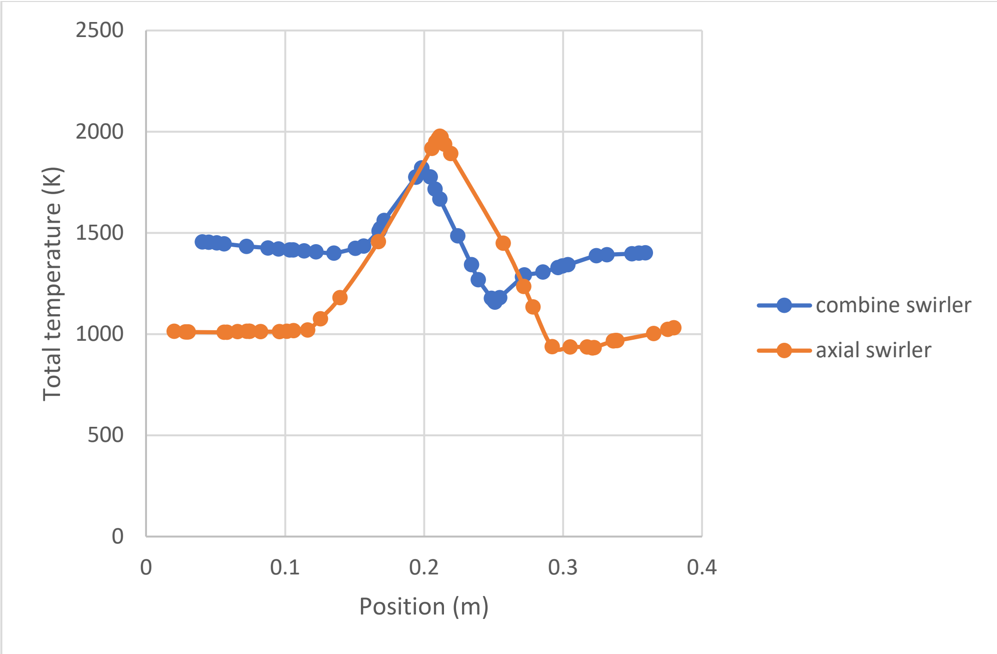

Figure 5: comparison of total temperature for combine swirler and axial swirler at 0.130 m

Figure 5 shows the total temperature for combine swirler and axial swirler at 0.200 m from the swirler. The maximum value for combine swirler graph is still lower than the axial swirler. But the combine swirler graph has become wider than the previous graph at 0.130 m and 0.065 m. It shows that the temperature for the axial swirler is better than combine swirler even the minimum value is higher than axial swirler. The high flame temperature will reduce the combustion time and process of combustion become faster [5].

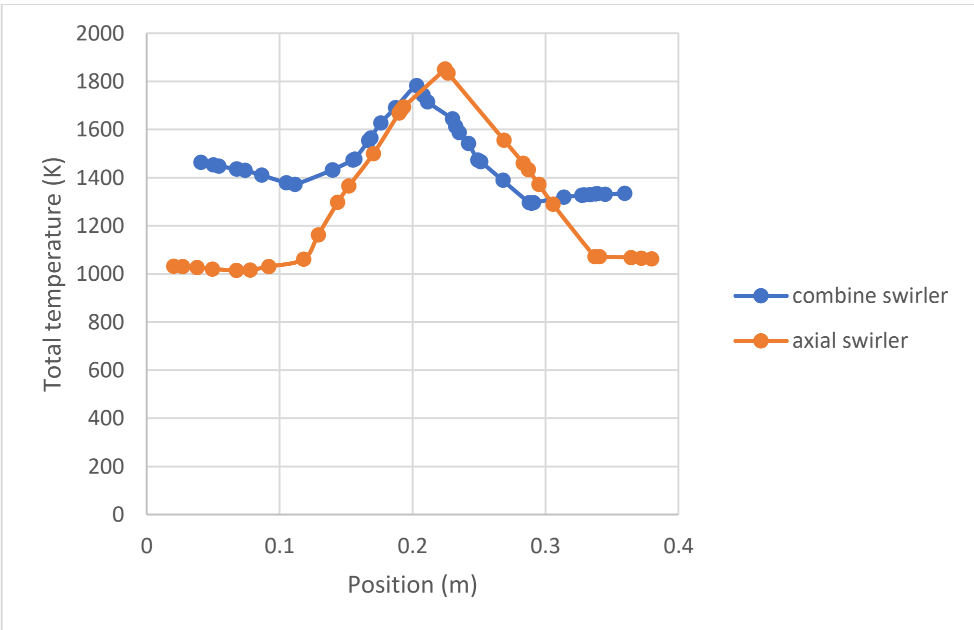

Figure 6: Comparison of total temperature for combine swirler and axial swirler at 0.200 m

3.3 Discussions

Based on the result from the contour and the graph, we simulated the non-premixed combustion for combine swirler and axial swirler. The result for the combine swirler graph and an axial graph is compared. It can be seen that the plot graph results are very well matching with the contour result. The velocity graph shows that the velocity magnitude for the combine swirler is very high. However, the emission for CO and CO_2 lower than the axial swirler. This graph has proved that the combine swirler can reduce the emission even the velocity for the swirler is high. Other than that, when the velocity is high, it will also improve the mixing process at a high level.

Then, the temperature of the combine swirler in Figure 6 shows that the temperature is lower than the axial swirler. It can be seen, the total temperatures in stages 1 and 2 are not much different. But when the temperature is at a distance of 0.200 m that is at stage 3, the temperature becomes the same as in the second stage. This in turn made the combustion process slower compared to the axial swirler. While the axial swirler is at a relatively good temperature to speed up the combustion process but the emissions released are quite high. Combine swirler is good at reducing emissions but cannot produce high enough temperatures.

4. Conclusion

As a conclusion, first achieved objective by simulating the two design to know the velocity, temperature and emission results but one of the objectives is not achieved which is to improve the flame temperature. The swirl velocity at high levels can reduce CO and CO_2 emissions for this design. However, the temperature for the combination of the radial and axial swirler is lower than the temperature in the axial swirler design. The objective to increase the temperature by reducing CO and CO_2 emissions is not successful but only emissions were successfully decreased. This may be due to the design of the swirler or the type of fuel used in this study [2][10].

Recommendation of this study is the temperature can be raised by changing the inclination angle on the axial swirler section at 30 °. In a previous study, an axial swirler with 8 blades at an inclination angle of 30 ° got a higher temperature than an axial swirler with 6 blades and 10 blades [5]. To reduce the emissions and increase the temperature, the axial swirler section to need to change at the 30 degrees inclination angle.

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