Transactions of the TSME (2022) Vol. 10, No. 2
Journal of Research and Applications in Mechanical Engineering
ISSN: 2229-2152 (Print); 2697-424x (Online)
Paper No. JRAME-22-10-010
DOI: 10.14456/jrame.2022.10

Research Article

INVESTIGATION OF NATURAL GAS FLAME TEMPERATURE INFLUENCED SPIRAL PORT ON AXIAL BURNER

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Received 20 June 2022
Revised 2 September 2022
Accepted 7 September 2022

ABSTRACT:
This research focuses on the design of the inverse diffusion flame burner (IDF) that affected the natural gas flame temperature by studying numerical model. In order to enhance the flame temperature by the simulation study, the obtained simulation results were compared to the previous experimental study with less than a 10% difference. In this research, there are four types of the air and fuel ports, which consist of inner and outer spiral air ports, inner spiral fuel ports, and combinations ports, for the study of the flame temperature, flame characteristics and, flow characteristics of air and fuel. The obtained results showed that the outer spiral air port with the inner spiral fuel port designed affected the best mixing between air and fuel and the highest flame temperature (1,362.37 °C). Therefore, this study could enhance the natural gas flame temperature to higher than previous research burner by outer spiral air port and inner spiral fuel ports IDF axial burner.

Keywords: *IDF Axial burner, Non-premixed combustion, Synthetic natural gas, Flame temperature, Spiral port*

1. INTRODUCTION

The energy industries are one of the industries that are very necessary for the economy of Thailand, especially power plants. One of the main fuels used in the power plant is natural gas. Because Thailand can produce natural gas in the country and helps to reduce to import of fuel from other countries. Besides natural gas has a high safety because it has a lighter weight than the air when has a leakage the natural gas will float above the air which makes no serious danger when used. The famous non-premixed burner in industrial plants has 2 types hereinafter, Normal Diffusion Flame (NDF) and Inverse Diffusion Flame (IDF). From the study found that the IDF burner has better combustion than NDF burner, as observed by the blue flame (Premixed flame) generated during the combustion of the IDF burner are more than NDF burner. Besides that, the non-premixed burner has more safety than the premixed burner. Because air and fuel do not mix together before combustion that prevents the flashback of flame which is one of the reasons of explode. [1]

In order to improve the non-premixed burner, therefore we were compiling the techniques about improvement the combustion result of burner from the researches i.e., the study of flow characteristic of fuel jet (co-flowing and submerge) and flame characteristic on CAP burner that has different amount of jet of fuel and Re of air found that when has more jets of fuel and higher Re of air that make the higher flame temperature and reduce the size of flame neck [2], The study of recessed backstep burner and recessed coaxial burner found that the flame of the recessed coaxial burner, which reduces the height of the air port to create the space for the increased mixing time of fuel and

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air, has a shorter length, higher flame temperature, less emission, and more flammability limit than the Recessed backstep burner [3], the study of the sizing of the diameter of the IDF axial burner found that when the burner has a small diameter, the air flow speed will increase that has a good effect to the mixing of air and fuel, the flame temperature and the emission, the last one, the study of the effect of the air flow along the combustion chamber in the can type burner by numerical method. The result showed when the air has more circular time in the combustion chamber that make a higher flame temperature [4]. As the recent research, there was many studies to improve the efficiency of the IDF axial burner. The effect of burner design on flame characteristics, flow characteristics and the flame temperature has been studied. However, the maximum flame temperature of the previous IDF axial burner was not close to the adiabatic flame temperature of natural gas which was about 1900 °C. The highest maximum flame temperature burner is the spiral case, which has a spiral at the end of the fuel port, but the local extinction was occurring on the flame that signs of non-steady flame [5, 6].

As the above reasons, it is interested to study and improve the efficiency of IDF axial burner for improvement of flame temperature. The design of burner affected to the fuel and air flow for improving the maximum flame temperature. Thus, the techniques of threading within the burner are interesting for improvement of combustion characteristics. Consequently, this research focus on developing the spiral technique in the IDF axial burner to enhance the maximum flame temperature and combustion characteristics

2. METHODOLOGY

2.1 Natural gas

Natural gas is a naturally occurring gas that contains hydrocarbon compounds with methane as the main component (89% CH_4 and 11% CO_2 by volume). Natural gas has a high heating value between 36-46 MJ/m^3, and it is easy to combust and the lowest air pollution [7].

2.2 Non-premixed axial burner

Non-premixed axial burner is a burner that has air and fuel flow along with the burner without mixing together. Air and fuel will be mixed at the burner tip before combustion. As this reason, the burner could prevent the flame flash back and more safety.

2.3 Key factors of combustion

The combustion depends on three factors which consists of time, temperature, and turbulence.

Time should be enough to be mixed and fuel burned out.
Temperature should be high enough for ongoing combustion.
Turbulence should be enough to mix well between fuel and air.

2.4 Equivalence ratio

The equivalence ratio, as shown in Eq. (1), is a ratio of air to fuel in the theory of combustion and the actual combustion. In actual combustion, the air volume flow rate can be higher than or less than the theory. If the air volume flow rate is less than theory, it is called "Lean Mixture" but if the air volume is more than theory, it is called "Rich Mixture".

$$\Phi = \frac{(\frac{A}{F})_{stioc}}{(\frac{A}{F})_{actual}} = \frac{(\frac{F}{A})_{actual}}{(\frac{F}{A})_{stioc}} \tag{1}$$

2.5 Reynolds number

The Reynolds number (Re) is the ratio of inertia force and viscosity force. Considered as an indicator of the flow characteristics of a fluid. The critical Reynolds number is divided into 2 types of fluid flow characteristics. If the Reynolds number is less than the critical Reynolds number the flow of fluid is "Laminar flow" but if the Reynolds number is more than the critical Reynolds number the flow of fluid is "Turbulence flow". The Reynolds number can be calculated by Eq. (2).

$$Re = {}^{\rho v D}/_{\mu} \tag{2}$$

2.6 Adiabatic flame temperature

The adiabatic flame temperature is the theory flame temperature. It can occur when the combustion reaction has a perfect volume of air and fuel, in theory, the exhaust gas from the combustion does not lose any heat from the system and does not have the heat transfer to the atmosphere. Therefore, the adiabatic flame temperature can call "The possible maximum flame temperature of the fuel". And the adiabatic flame temperature can be calculated by Eq. (3).

$$h_k^m = n(\underbrace{\int_{T_0}^{T} C_{pk}^m dT}_{sensible} + \underbrace{\Delta h_{f,k}^{o,m}}_{chenical}) \quad (3)$$

2.7 Flow rate

Flow rate is the relation between the cross-sectional area of the pipe and the average magnitude of the flow velocity. And the flow rate can be calculated by Eq. (4) [8].

$$Q = Av \quad (4)$$

But for burner designs of this research are use the spiral technique that creates the thread at the end up of the burner. So, a few textures of the burner are replaced by a thread. Therefore, all of the designs can assume the spiral does not have any effect on the flow velocity. It only has an effect to the flow direction.

3. SIMULATION STUDY

This research is studying flame temperature and flame characteristics of synthetic natural gas combustion on the IDF axial burner for improving the combustion efficiency of non-premixed natural gas combustion by using Ansys Fluent 2021 R1 for simulation. The results will analyze the flame temperature and flame characteristic by comparing it with the IDF spiral burner in previous research.

3.1 Burner design

Design the 3D parts of the burner by using the SolidWorks2020 that can adjust the characteristic or sizing of the burner parts with the fastness and preciseness. The simulation used only the upper parts of the burner to reduce the computer resources and time for the simulation used. From Fig. 1 is show the model for use in simulation. The inner port is the air port and the outer port is the fuel port. In this research was designed 5 types of air ports and fuel ports were as following in Fig. 2.

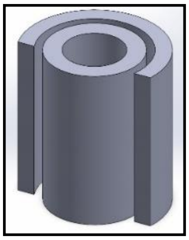


Fig. 1. Example of burner simulation model

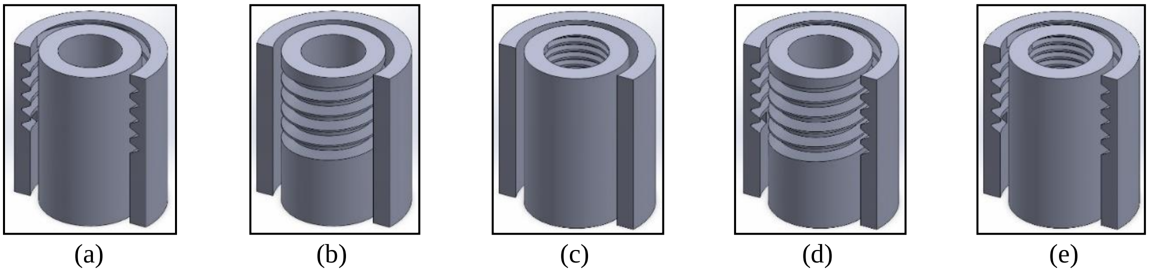


Fig. 2. Burner model for calculation; (a) Inner spiral fuel port; (b) Outer spiral air port; (c) Inner spiral air port; (d) Inner spiral fuel port and Outer spiral air port; (e) Inner spiral fuel port and Inner spiral air port

3.2 Simulation calculation

3.2.1 Conditions of calculation

This research is to improve the flame temperature by comparison with the experimental result from the IDF spiral burner [5] and simulation result. Firstly, The simulation results are compared with the experimental result at the obtained flame temperature of 1310.11°C for burner model validation.

Table 1: Variable value comparison of the simulation of IDF spiral burner and real experimental result.

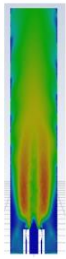
Variable	Experimental	Condition
Φ	1	1
Fuel velocity	13.14 m/s	13.14 m/s
Air velocity	1.59 m/s	1.59 m/s
Maximum flame temperature	1310.11 °C	1206.86 °C
Error	-	8.53 %
Flame characteristic		

Table 1 shows the comparison between the maximum flame temperature at 95mm above the burner tip of the experimental results and the simulation results of the IDF spiral burner in previous research. The designs of the burner in this research make the flow of air and fuel have more turbulence flow by adding the spiral at the inner air port, outer air port, and inner fuel port. In addition, add the left-hand thread for some cases.

The calculation of air and fuel flow rate for having a nearly mass flow rate with the real experiment of the IDF spiral burner. So, at the calculation of the Equivalence ration is 1, the fuel flow rate is 5.49 x 10^{-5} kg/s and air flow rate is 7.038 x 10^{-4} kg/s.

3.2.2 Program setting

In SolidWorks, Saved the burner parts and air boundary parts by saving them as Part.(prt). And then used Assembly mode to meshing the burner parts and air boundary part together (The origin point must be the same point). Next, use Cavity to scoop the air boundary part by the burner part characteristic. Last, save the air boundary part to use in Ansys Fluent 2021R1

In the Simulation was used Ansys Fluent 2021R1. The species model is the non-premixed combustion model. The compositions of syntactic natural gas are Methane (CH_4) and Carbon dioxide (CO_2) at 70:30 % by volume. The viscous model is the Transition SST model. The radiation model is the Discrete Ordinates (DO) model. The inlet of air and fuel are mass-flow inlet at stoichiometry condition. The fuel flow rate is 5.49 x 10^{-5} kg/s and the air flow rate is 7.038 x 10^{-4} kg/s at 300°K. And the outlet is pressure outlet at 1 bar. Selecting the mesh element size for use in the simulation had to do the mesh independent to select the suitable mesh element size as shown in Fig. 3.

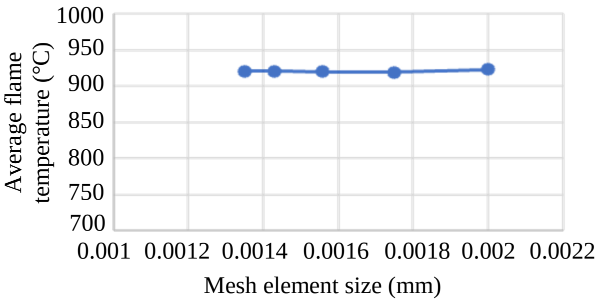


Fig. 3. Comparison between mesh element size and average flame temperature

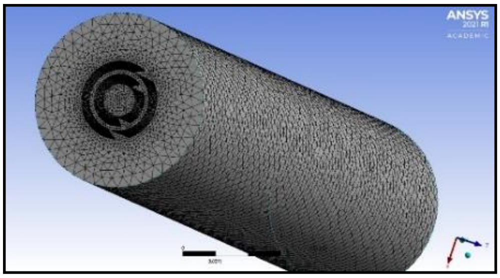


Fig. 4. Mesh element size of the burner model.

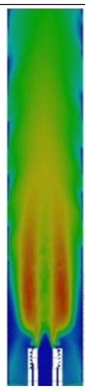
Therefore, the selected mesh element size is 2e^{-3} for simulation, however in the inner zone of the burner, the mesh element size must have more preciseness. The inner zone of the burner position of the inlets and outlet have shown in Fig.5.

Fig. 5. Position of the inlets and the outlet of burner model.

4. Results

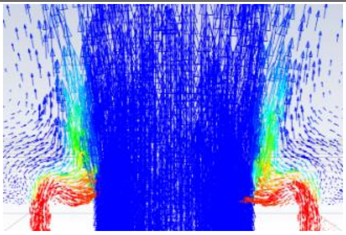
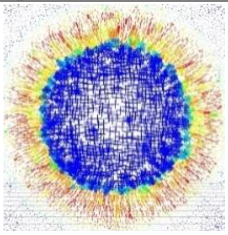
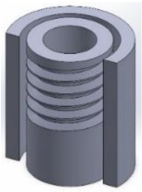
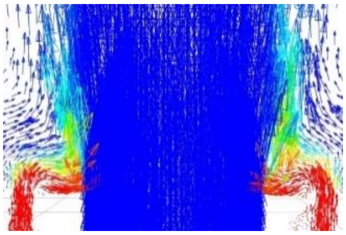
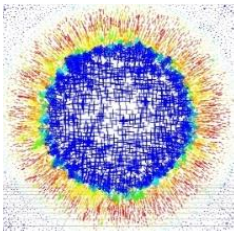
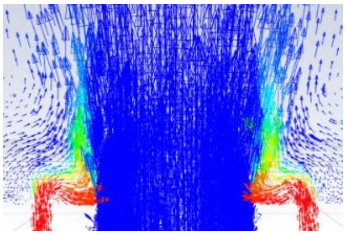
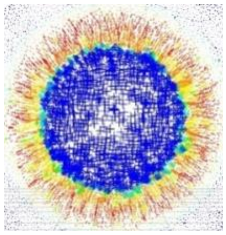
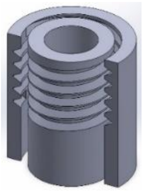
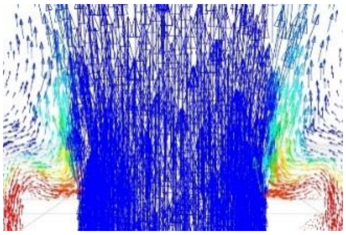
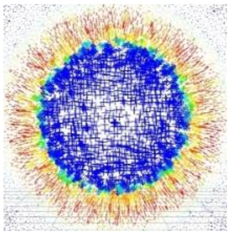
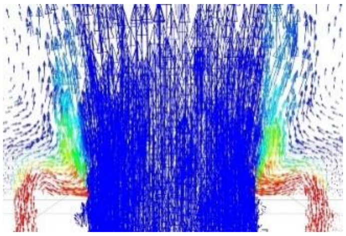
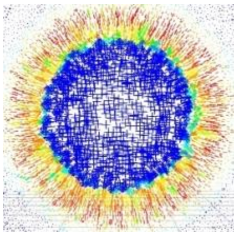
4.1 Flame temperature and flame characteristic

Table 2: The maximum flame temperature and flame characteristics.

Flame Characteristic					
Burner type					
Maximum flame temperature	1309.81 °C	1313.36 °C	1329.20 °C	1362.37 °C	1311.81 °C

4.2 Flow distribution of fuel and air results from simulation

Table 3: Flow distribution of fuel and air

Burner types	Side view	Top view at burner tip
		
		
		
		
		

From Table 2 show the maximum flame temperature results from the simulation, the inner spiral fuel and Outer spiral air port IDF burner affected the 1362.37 °C flame temperature was improved 4.0% of the flame temperature

Flow distribution of air and fuel was shown in Table 3, These results can analyze about mixing of fuel and air by considering the color in the picture (red represented by concentration CH_4 and then gradient down to blue which means concentration of air). These results were very similar and difficult to analyze because the design parameters for each burner type characteristic and the flame temperature results were very close to each other. The two spirals in the fuel port make the fuel port have more roughness that can increase the turbulence in the fuel flow. Because of the high turbulence in the fuel flow, The fuel flow of this case has more diffusion into the air than other burners, were observed due to better mixing of air and fuel. As the result, much of green line was observed owing to well-mixed air and fuel for higher flame temperature.

5. Conclusions

The study of the design of the non-premixed Inverse Diffusion Flame (IDF) axial burner by simulation model with synthesis natural gas (89% CH_4 and 11% CO_2 by volume) for developing the burner in flame temperature and flame characteristic by using the techniques of the air port and fuel port as follows, (a) inner spiral air port, (b) outer spiral air port, (c) inner spiral fuel port, and (d) and (e) combinations. In the case of the inner spiral fuel port with outer spiral air port IDF burner is the best technique for increasing the turbulence of air and fuel flow affected enhancement of the maximum flame temperature to be 1362.37 °C or 4.00 % higher of referenced burner. As all the techniques can be concluded as follows.

(a) Adding more than one spiral in the fuel port can make fuel flow has more turbulence flow that can improve the flame temperature.
(b) The combination of the inner fuel port and inner air port was hardly less effect on the flame temperature
(c) The inner spiral air port technique had more effect on the flame temperature than the inner spiral fuel port technique because in the normal case the air gave the higher turbulence flow technique. Thus, more turbulence influenced for mixture mixing and higher the flame temperature.

Nomenclature

A/F	ratio of air to fuel
Φ	equivalence ratio
Re	Reynolds number
ρ	density, kg/m^3
v	flow velocity, m/s
D	diameter, m
μ	dynamic viscosity, Pa.s
Q	flow rate, m^3/s
A	Cross section area, m^2
h	enthalpy, J
T	temperature, °k

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