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by Tria Puspa Sari

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Non-Premixed Combustion Simulation with Variation of Swirl Burner Slope using Turbulence Modeling $K-\epsilon$

R D Issafira^{1,*}, W Wijayanti², L Edahwati¹, W D Lestari¹, W Saputro¹, A K Faizin¹, N Adyono¹, and T P Sari¹

¹ Department of Mechanical Engineering, Faculty of Engineering, University of Pembangunan Nasional Veteran Jawa Timur, 60294, Indonesia

² Department of Mechanical Engineering, Faculty of Engineering, University of Brawijaya Malang, 65145, Indonesia

*Corresponding e-mail: radissa.d.tm@upnjatim.ac.id

Abstract. Combustion is a very complex matter. Therefore, we need to know the phenomenon that occur in combustion apart from the temperature distribution. This research uses quasi-research. The background in using quasi-experimental is because it has advantages in data collection. Moreover, the phenomena that occur in more detailed research by means of a numerical approach could also be observed. This research was conducted with an approach (simulation) of diffusion combustion using methane (CH_4) fuel and air containing 29% oxygen (O_2), 71% nitrogen (N_2) and the addition of swirl in the air ducts. The $K-\epsilon$ turbulence modeling was applied in this simulation. This variation of the fuel velocities are 3 m/s, 5 m/s, 7 m/s, where the air velocity was varied for 3 m/s, 8 m/s, 7m/s. In this simulation, room pressure of 1 atm was applied for the surrounding. The results showed that, the greater the angle of inclination of the swirl burner, the shorter the flame. And on the variation of fuel velocity, we get the result that the higher fuel velocity, increase fire height; however, the temperature of the fire height will decrease.

Keyword: Combustion, Swirl Burner, Simulation, Non-Premixed, $K-\epsilon$ model

1. Introduction

Combustion is a very important aspect of our lives. Almost all areas of our lives require the combustion process. In the future, it is undeniable that the need for energy will increase [1]. The increase in consumption was mostly due to the industrial and transportation sectors. Therefore, we need to develop further research on combustion topic. So that, the availability of fuel in the future can still be sufficient. It was one of the reason combustion is very important in the field of engineering. Many research studies has been done on combustion technology with the aim of improving the work of the combustion process in terms of efficiency and the results of the combustion itself.

There are many factors that affect the combustion process [2]. Thus, to be able to increase efficiency and the combustion process, it is important to understand the phenomena that occur in the combustion. By knowing the phenomena that occur in combustion we can find out what are the factors that influence the combustion process. To improve the combustion process, research was conducted on non-premixed combustion with the addition of a swirl burner, the addition of this swirl burner is intended to form a tangential flow to the oxidizer so that this tangential flow will cause turbulence and produce a turbulent

flow [3,4]. Turbulent flow is used to speed up the process of mixing fuel and air which is more homogeneous, the addition of this swirl combustion will increase the efficiency. In previous studies, simulations of non-premixed combustion have been carried out with the addition of CO₂ [5]. The results of this simulation show that the addition of CO₂ will reduce the temperature of the fire. Combustion is a chemical reaction process between fuel and oxidizer mixed with the addition of activation energy where combustion will produce heat, and that heat will later be converted into the energy we want to do activities.

Thus, the purpose of this study is to determine the phenomena that occur in combustion. So that we know what factors affect combustion and can consider these factors. In addition, this study aimed to determine the flame temperature distribution, air flow velocity distribution, and density distribution during combustion on the addition of swirl especially with the effect of swirl degree inclination.

2. Research Method

This study uses a quasi-research method. Where in the quasi-research method the experiments were conducted with a numerical approach (simulation). This method will analyze the effect of temperature distribution on the installation of swirl, air velocity, and fuel velocity. This simulation uses Ansys Fluent 14.5 software.

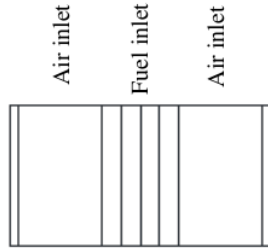


Figure 1. Air and Fuel pipeline

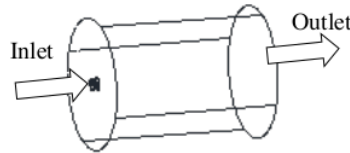


Figure 2. Geometrical Illustration of Burner

In this simulation, a mesh size of 0.01 m is used. This simulation is carried out by simulating in 3 dimensions and then cutting the results in 2 dimensions to make it easier to see the results of the simulation. This simulation uses 0.01m meshing, which is a process of dividing the components to be analyzed into several small elements. The geometry later becomes a node that is used as a numerical calculation. The smaller the elements formed, the larger the equations solved by the program.

Table 1. Simulation Parameter

	Value	Unit
Pressure (<i>P</i>)	1	atm
Surrounding Temperature (<i>T_e</i>)	27	°C
Air Temperature (<i>T_a</i>)	27	°C
Air Velocity (<i>v_a</i>)	3, 5, and 7	m/s
Fuel Velocity (<i>v_f</i>)	3, 5, and 7	m/s
Fuel Composition (CH ₄)	100	%
Oxidator Composition (O ₂)	79	100%
Oxidator Composition (N ₂)	21	100%

The fuel and air channel illustration were shown in Figure 1 below. The fuel used in this study is 100% pure methane (CH_4) and the air content used is 79% N_2 and 21% O_2 . The flow rate of air velocity was varied between 4 m/s, 5 m/s, 7 m/s with constant fuel speed of 5 m/s. Furthermore, the fuel velocity also varied between 3 m/s, 5 m/s, 7 m/s and a constant air velocity of 5 m/s. The turbulent model used in this research is the K- ϵ turbulent model. The detailed geometrical of the burner used in this simulation were shown on the Figure 2. The detailed simulation parameter was shown in table 1. Taking data in this test, we give the plane $x=0; 0.3 < y < 0.3; 0 < z < 0.4$ to make it easier for data retrieval. Then a point every 2 cm was set above the mouth of the jet to see the temperature distribution.

2.1 Research Validation

To find out whether the results of our quasi-experimental simulation are correct, we need to validate the simulation with the existing experimental results. In this study, the comparison of the contour shape of our quasi-experimental temperature distribution with the experimental flame carried out by Arief Kumiawan [6]. Figure 3 below is a visualization image of the diffusion experimental flame and the simulation results of temperature distribution contours.

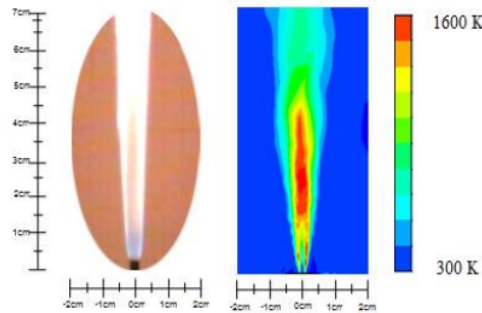


Figure 3. Data Validation of experimental diffusion flame (left) and temperature distribution (right)

It can be seen from the figure the experimental flame visualization and simulation of temperature distribution in non-premixed combustion without swirl with air velocity of 1.60123 m/s and fuel velocity of 0.5784 m/s. Both of the flame have similar widen trend on the flame form. This shows that the simulation we use has the similar result to the real experiment. Thus, the simulation parameter for temperature distribution is validated.

3. Result and Discussion

Figure 4 shows the effect of swirl inclination angle variations to temperature distribution contour at different fuel velocity and constant air velocity. From Figure 4, we can see that the greater the inclination angle of the swirl, the shorter the height of the flame. However, at 10° swirl inclination the flame height is getting higher. This is because at 10° swirl installation, the oxidizing air flow is still laminar. Moreover, at 10° swirl installation the flame is higher than swirl without vanes due to swirl vanes ability to add resistance to the flow.

This is in accordance with the theory of Reynolds equation in equation (1) where the resistance is directly proportional to the velocity. Thus, the air velocity increases with the installation of the swirl vanes on the burner. The overall flame velocity is increasing but the flow is still relatively laminar so, the fire is getting higher. Furthermore, at the installation of swirl above 10° inclination causes higher turbulence intensity, which increases radial velocity and decrease the flame height.

$$Re = \frac{\rho v L}{\mu} \quad (1)$$

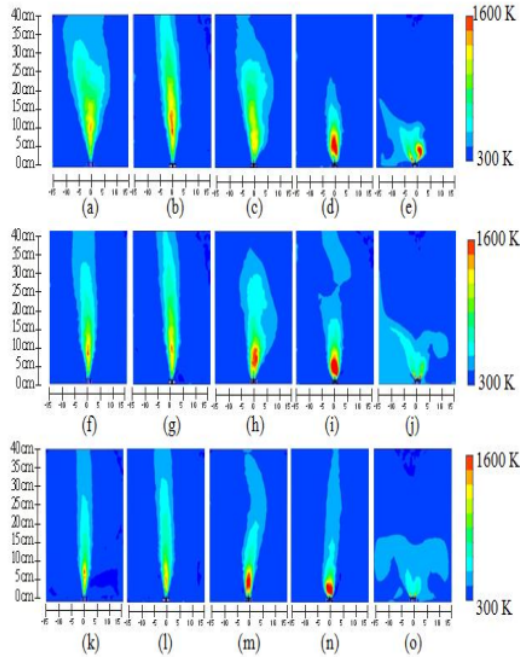


Figure 4. Temperature distribution contour at different fuel velocity in constant air velocity of 5 m/s and varied swirl vane configuration where (a) without swirl $v_f = 3$ m/s (b) swirl $10^\circ v_f = 3$ m/s (c) swirl $30^\circ v_f = 3$ m/s (d) swirl $45^\circ v_f = 3$ m/s (e) swirl $60^\circ v_f = 3$ m/s (f) without swirl $v_f = 5$ m/s (g) swirl $10^\circ v_f = 5$ m/s (h) swirl $30^\circ v_f = 5$ m/s (i) swirl $45^\circ v_f = 5$ m/s (j) swirl $60^\circ v_f = 5$ m/s (k) without swirl $v_f = 7$ m/s (l) swirl $10^\circ v_f = 7$ m/s (m) swirl $30^\circ v_f = 7$ m/s (n) swirl $45^\circ v_f = 7$ m/s (o) swirl $60^\circ v_f = 7$ m/s

Figure 5 shows the temperature distribution as a function of flame height at different swirl vane configuration with the variation of fuel velocity. We can see on figure 5 (a), (b), and (e) for burner without swirl, swirl 10° , swirl 60° , respectively that, the highest temperature is obtained at fuel speed of 5 m/s and decreases at 7 m/s. This is because at a speed of 5 m/s the mixture of fuel and air is still optimal and the air availability supply from the outside is still abundant so that air and fuel can still mix optimally. However, at a speed of 7 m/s, the temperature decreases, because at that speed the mixing is not optimal, and the fuel availability is less.

In the installation of swirl 30° , and swirl 45° , it can be seen that the higher the fuel velocity causes the highest temperature in the temperature distribution to decrease. This is because the burner with the installation of swirl 30° , and swirl 45° have more turbulent air flow, so that the mixture of fuel and air improves and increases the flame temperature [7].

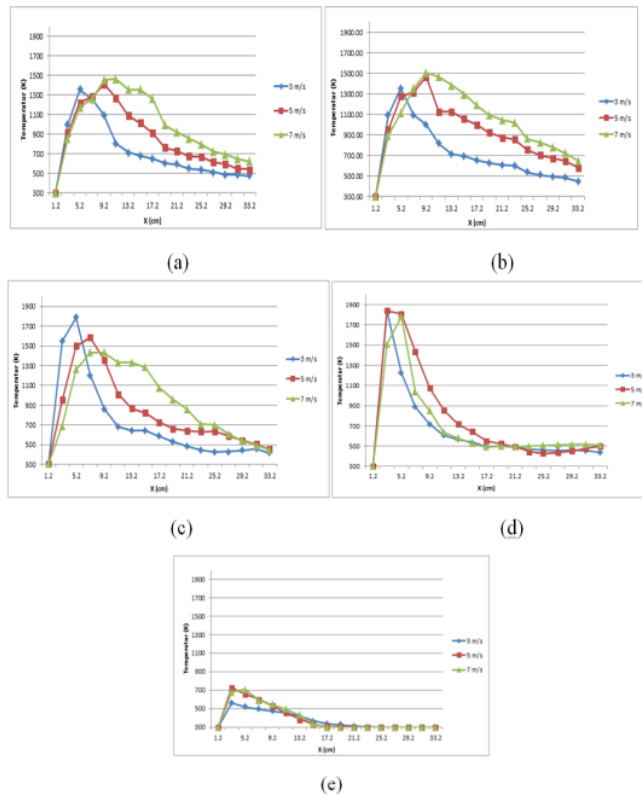


Figure 5. Temperature distribution graphic at different swirl vane configuration (a) without swirl vanes (b) 10° (c) 30° (d) 45° and (e) 60° as a function of flame height at different fuel velocity 3 , 5, and 7 m/s

However, as the velocity of the air increases, the flame height increases. This can be seen in the x-direction distribution that at the point of 3.2 cm, the higher the fuel velocity, the higher the temperature. This shows that the height of the fire is getting higher as well.

4. Conclusion

The conclusion of this study are summarize as follows. The greater the angle of inclination of the swirl vanes, the shorter the flame will be. The flame height increases when the swirl with 10° inclination is installed in the burner, because the flow of the air will be faster, so that the flame height will be higher. But on installation of swirl above 10° the flame starts to shorten. This happens because the intensity of the turbulence is large. Thus, even though the air flow is getting faster, the flow will rotate somewhere. The higher the speed of the fuel, the wider the flame. The higher the fluid velocity, the shorter the flame will be.

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