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Optimization Study on Bias Angle of a Swirl Burner with Tangential Inlet Air

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Abstract

In this paper numerical simulation and experimental study was carried out for a tangential inlet air swirl burner which is used for high heat value biomass gas. Study on the different inlet angle effects on Combustion by numerical method. The results of the study show that the 30 degree is the best. The intake angle burner 30 degrees were tested to verify the accuracy of simulation results. Through the comparative analysis of the trajectory and the velocity of the air, the method and the conclusion of the simulation study are reliable.

Keywords*: Numerical simulation; swirl burner; biomass gas; inlet angle*

1. Introduction

For biomass energy, a kind of high efficiency application is to gasification. Due to the gasification medium and gasification process are different, the composition of biomass gas fluctuates greatly, so the difference of the corresponding calorific value is huge [1-2]. In recent years, with the further development of biomass gas production process, the calorific value of the biomass gas is gradually increased [3]. For calorific value, different kinds of gas need different burner. With the development of biomass gas in high calorific value, a burner must be developed to adapt to it.

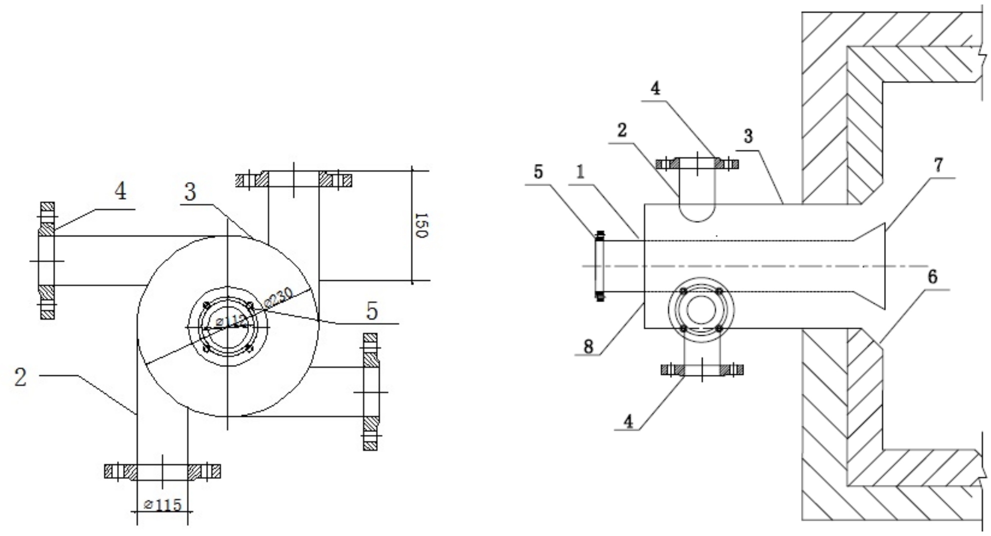
According to the experience of the use of high calorific value gas such as natural gas, Swirl combustion is an appropriate way [4]. Due to the airflow rotating, oxygen and fuel gas mixed strongly, a negative pressure zone will be generated within airflow, which makes the combustion more sufficient. That is to say, it is crucial for the burner, that the airflow rotating characteristics and the size, location of negative pressure zone [5-8].

At present the study of swirl burner are mainly concentrated in the field of natural gas or coke oven gas [9-12]. At the same time, swirl combustion mode applied to the biomass gas rarely reported. This has important implications for the experimental and simulation studies on the combustion characteristics of biomass gas in swirl combustion mode.

2. Research Objects, Methods and Techniques

2.1. Research Object and Method

In this paper, a new type of swirl burner is developed which has four pipe tangential inlet air (see Figure 1). The burner body comprises a gas pipe and an air pipe which surrounds it, four air tubes from tangential to intervention. The specific parameters are shown in Table 1 [13]:



1 Gas pipes, 2 Inlet duct, 3 Cyclone air duct, 4Inlet air duct flange
5 Gas pipe flange,6 Air expander,7 Gas expander,8 Internal and external tube connecting plate

Figure1. New Type of Four Pipe Tangential Inlet Air Swirl Burner

Table 1. Design Parameters of Burner for 2 Tons of Heating Boiler

Burner rated heat load	Gas pipe diameter（m）	Air pipe diameter（m）	Swirl tube diameter（m）	Gas wind speed（m/s）	Air duct wind speed（m/s）
1.4MW	0.112	0.115	0.23	10.1	10.8

The low calorific value of biomass gas in this paper is 14.5 ~ 16.0MJ/Nm^3, which can be obtained by distillation method [13]. Gas composition can be found in Table 2.

Table 2. Biomass Dry Distillation Gas Composition

composition	H_2	CH_4	CO	C_mH_n	N_2 O_2 CO_2
Volume％	23～28	26～36	8～12	1.4～4.2	30～35

Deflection angle is the angle between the axial direction of the air inlet pipe and the gas pipe. The deflection angle has direct influence on the swirl intensity and the size of the negative pressure zone in the furnace. Therefore, reasonable deflection angle is very important.

The size of the inlet angle is directly influenced by the swirl combustion intensity. And then cause the size of the recirculation zone in the furnace corresponding to the burner. Therefore, the proper choice of the inlet deflection angle is helpful to the optimization of the recirculation region.

In this paper, we will carry out research on the burner of three kinds of angles, which are 30 degrees, 45 degrees and 60 degrees. Analysis the flow characteristics and pressure distribution in the furnace to find the optimal inlet angle.

2.2. Technical Roadmap

The technical roadmap is shown in Figure 1 below.

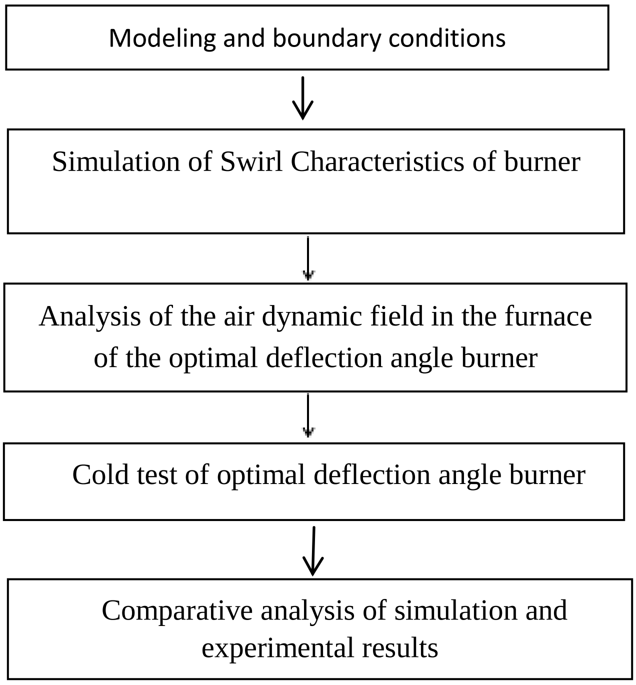


Figure 2. Technical Route

3. Numerical Simulation of Biomass Swirl Burner

3.1. Model Establishment and Boundary Conditions Setting

In order to make the numerical simulation more accurate, commercial software is used to establish the model. Air entry mode of the swirl burner is tangential wind from four tubes. Compared to the guide vane swirl burner or volute inlet swirl burner, this burner has the advantage of simple structure, regular shape. At the same time in order to simplify the calculation model, the shape of the furnace is assumed to be cylindrical. So structured mesh is adopted in the burner model, and obtained grid is shown in Figure 3.

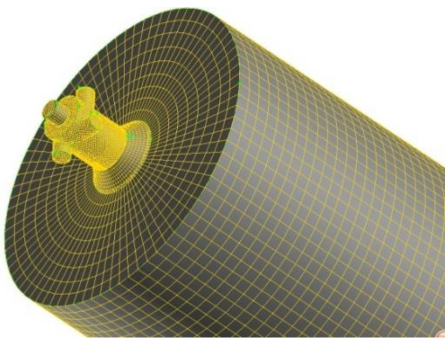


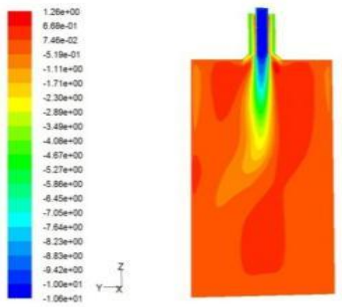
Figure 2. Grid Division of the Swirl Burner

Velocity inlet condition is used in the inlet boundary. The gas pipeline entrance is 15m/s, and air duct entrance is 10m/s. free outlet condition is used in the outlet boundary, and non-slip condition is used in the wall boundary. Gas turbulence model is realizable k-ε .

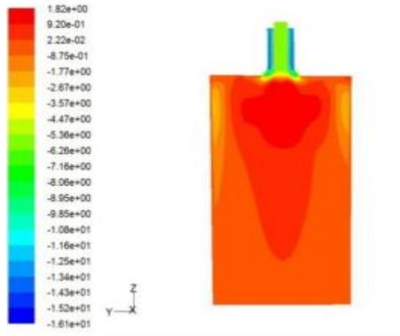
Table 1. Velocity Distribution under Different Inlet Angle

Angle size	Axial velocity (m/s)	Tangential velocity (m/s)
15 degrees	3.9	14.5
30 degrees	7.5	13
45 degrees	10.6	10.6

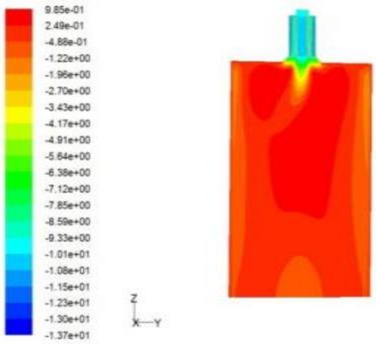
3.2. Analysis of Simulation Results



The 15 Degree Angle of Inlet



The 30 Degree Angle of Inlet



The 45 Degree Angle of Inlet

Figure 3. Axial Velocity Distribution Under

Figure 3 is an axial velocity contour of the furnace longitudinal section under different inlet tangential angles. The jet expansion range increases with the increasing of the inlet deflection angle, which is due to the increase of swirl intensity causing the enhancement of the fluid centrifugal force. On the other hand, tangential velocity of jet decays faster, increasing the negative pressure gradient. The result is more fluid reverse flow, the diameter of the recirculation zone increases and the length becomes longer.

When the air deflection angle is 15-degree, the axial velocity of the gas is 3.9m/s which are significantly less than the inlet velocity of the gas. Swirling flow in the combustion chamber is relatively strong, but due to the differences of axial speeds, swirl gas cannot be fully entraining fuel gas and a good swirl flow field cannot be formed. When the air deflection angle is 30-degree, the axial velocity of the gas adds up to 7.5m/s. There is no difference between air axial velocity and gas axial velocity. At the same time, the rotating air flow has a large radial velocity at the outlet, which can form a larger jet expansion angle and enhance the disturbance of the air flow. It can be seen that the velocity distribution of recirculation zone is uniform, and the area distribution is large. When the air deflection angle is 45-degree, the axial velocity adds up to 10.6m/s, tangential velocity decrease to 10.6m/s. In this case, the area of the recirculation zone is decreased, and the velocity is uneven. The reason is that the decrease of the air rotational strength leads to its entrainment capacity insufficient.

3.3. Aerodynamic Field Simulation under the Optimal Inlet Deflection Angle

As noted above, gas flow in the burner and the furnace has achieved very good results under 30 degree intake deflection angle. In order to obtain the aerodynamic characteristics of the optimal intake side angle, a further simulation of the operating point is carried out, through which velocity contour and vector distribution diagram of the burner exit, the particle trajectory and the velocity distribution of the longitudinal section of the furnace are analyzed.

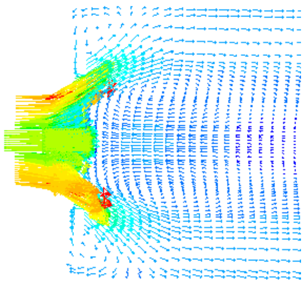


Figure 4. Velocity Vector Diagram in Furnace

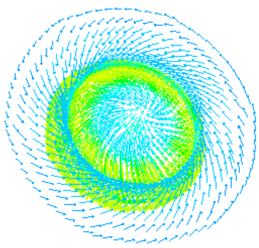


Figure 5. Burner Exit Velocity Chart

It can be seen from Figure 4 and Figure 5 that primary air flow drives the central wind forming the recirculation zone, which distributes in the vicinity of the burner exit, at both sides of the central air flow and the front section. Because of the edge of the back movement in the center circumfluence, high temperature flue gas is sucked to allow the purpose of stable combustion [14].

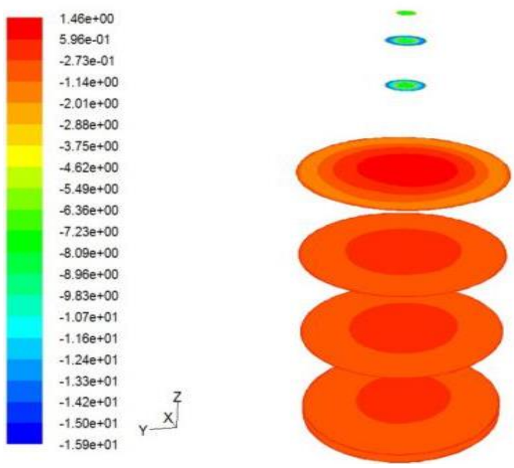


Figure 6. Axial Velocity Distribution along the Furnace

Figure 6 show that the inlet deflection angle is 30 degrees. Distance from the nozzle is -0.5m, 0m, 0.5m, 1m, 1.5m, 2m, and 2.5m. As can be seen from the picture, due to the rotation of the air, the direct gas is gradually being rolled out, showing the swirl speed.

The central recirculation zone in the 0.2m is beginning to appear, reaching to the maximum area around 0.4m, and then decaying along the direction of the furnace.

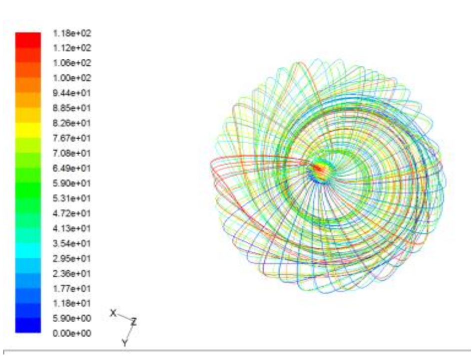


Figure 7. Gas Pipe Velocity Chart

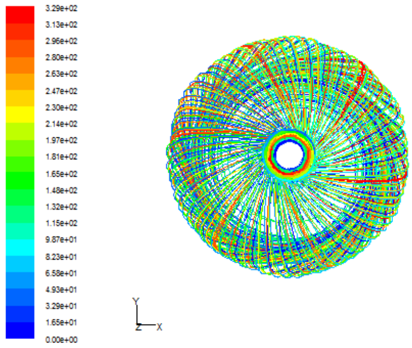


Figure 8. Air Tube Velocity Chart

Figure 7 and Figure 8 show the trajectory of the gas pipe and the air pipe along the center of the furnace. Comparing of results indicates that the air pipe is wrapped in the gas pipe to rotate forward in the furnace. The gas flow in the burner is very good in the furnace. There is no impact on the wall of the furnace. The air flow of the burner is of good full degree in the furnace, there is no phenomenon of hitting the wall of the furnace. Thus it can be seen the gas is driven by the rotating air to fill up the furnace. This rotary way makes the biomass gas in the furnace have sufficient residence time, which favors to the full combustion of biomass gas.

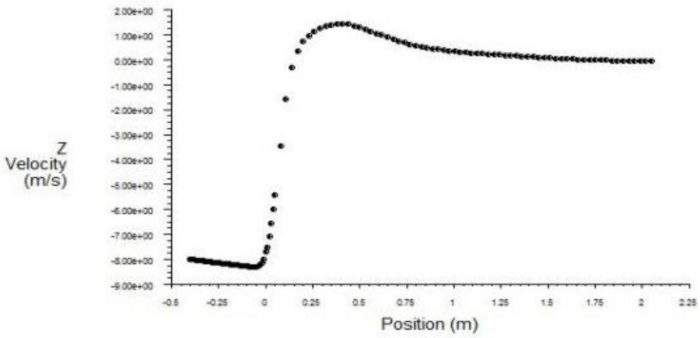


Figure 9. Axial Velocity Distribution

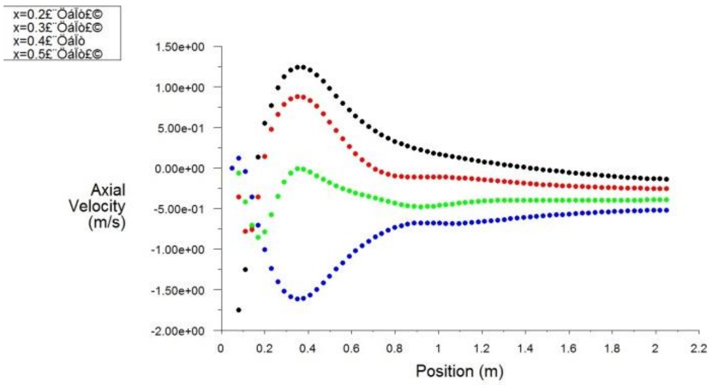


Figure 10. The Axial Velocity Distribution along the X Direction

The axial velocity distribution of Figure 9 and figure 10 show that there is a trend of the same velocity distribution along the axial direction of the burner in x=0.2m section, x=0.3m section and x=0.4m section, which is decrease first and increase later and then close to 0.

This trend is not appeared in the X=0.5 section. It indicates that there is no recirculation zone at the interface of the boiler. The ultimate cross section of the recirculation zone is located in the x=0.4m section.

On the other hand, it can be seen that the whole recirculation zone in the boiler starts from the burner exit, along the axial direction at Z=0.4m, the recirculation zone reaches the maximum value. Thereafter, the axial direction of the boiler is gradually reduced.

4. Cold Test of Optimal Deflection Angle Burner

In order to verify the accuracy of the numerical simulation, the corresponding experiment platform was set up for the optimum deflection angle burner and the cold test was carried out.

4.1. Apparatus and Methods

Cold test device is composed of three parts, the gas system, the air system and the burner. As shown in Figure 4. The gas system is composed of three parts, the blower and the regulating valve flow meter. The air distribution system consists of gas tank, control valve, flow meter and a pipeline of four parts. The burner consists of two parts, the burner body and the combustion chamber. The velocity of the burner exit is measured by a hot bulb. To improve the accuracy, use a combination of observation and measurement methods and watch using the Ribbon watch burner flow. In order to gain burning flow field, set different axial and radial measuring points.

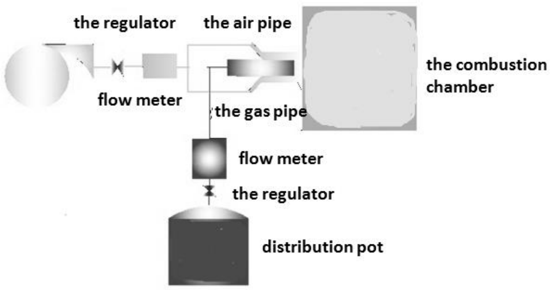


Figure 11. Biomass Gas-fired Swirl Burner Cold Test-Bed

4.2. The Process of Test

Make the air flow meter size to the required working conditions through the regulation of the valve. Open with distribution pot control valve, then make the air flow meter size to the required working conditions through the regulation of the valve. Test the speed of different position in the furnace under different conditions.

4.3. Comparison of Experimental Results and Simulation Results

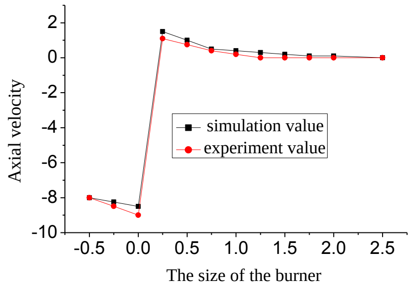


Figure 5. Axial Velocity Distribution of the Central Axis of the Burner

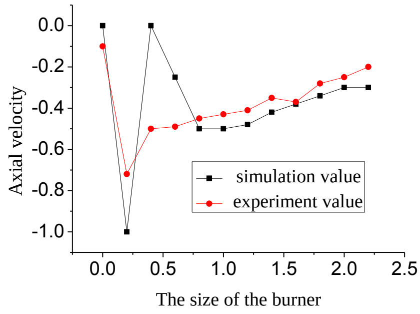


Figure 6. Axial Velocity Distribution of Radial Distance X=0.4m

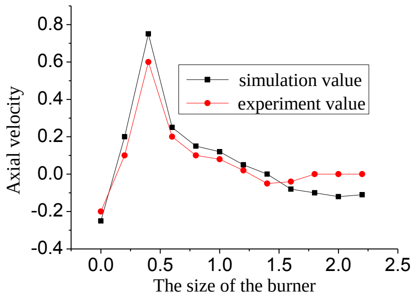


Figure 7. Axial Velocity Distribution of Radial Distance X=0.3m

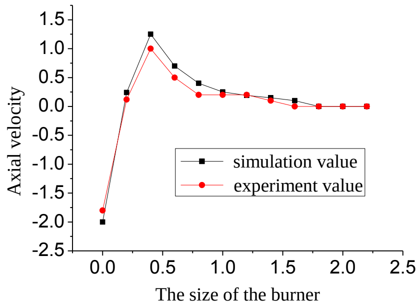


Figure 8. Axial Velocity Distribution of Radial Distance X=0.2m

In contrast to the experimental and simulation results, the two are consistent in the trend of speed change. For the axial velocity in the furnace, the experimental results are much lower than the simulated values. This is mainly because the existence of the viscous force of the actual gas causes the loss of speed along the axial direction. In addition, the processing technology of the burner is the main reason for the difference.

5. Conclusion

(1) The negative pressure zone in the combustion chamber is gradually increased with the increase of the intake angle, from the negative pressure zone size and swirl intensity, 30 degrees is the best. Further increase in angle will lead to airflow disturbance in the pressure zone.

(2) At 30 degrees from the intake angle, the negative pressure zone starts from Z=0.2m, and the maximum value is reached at Z=0.4m, then the recirculation zone is gradually reduced along the axial direction.

(3) From the comparison of experiment and simulation results, the simulation process is credible.

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