Design and optimization of mixing structure of fully premixed surface burner

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Abstract. This paper disassembles a brand of fully premixed surface burners, designs a new type of air-fuel mixing structure through literature survey, and uses Fluent software to simulate the prototype and new type of mixing structure through numerical simulation. The simulation of the mixing was carried out. Through comparative analysis, the relevant structural parameters were changed and the new mixing structure was optimized and verified by numerical simulation. The results show that the new mixing structure proposed in this paper has a better effect on mixing, and some rules affecting the mixing are obtained.

1. Introduction
Surface combustion technology is a new type of combustion technology that has been developed in recent years with high efficiency and low pollution[1]. At present, the environmental protection emission standards of developed provinces (municipalities or districts) are becoming stricter. The fully premixed surface burner can achieve the goal of low NOx combustion, and will be the mainstream of ultra low emission combustion technology for small and medium-sized combustion equipment.

Fuel and air mixing technology is the core technology of a fully premixed surface burner. NOx emissions are directly related to mixing unevenness. As the mixing unevenness increases, the NOx emission increases sharply[2], especially when the mixing unevenness is >5% and the adiabatic flame temperature is higher than 1800K. Only the uniform mixing of fuel and air can achieve the combustion economy, low emission and tempering safety of the burner. Therefore, the mixing technology of fully premixed surface burners is crucial. Fric[3] combined theoretical analysis and experimental research on the fuel/air mixing process in premixed nozzles, and proposed the concept of premixing inhomogeneity, and gave the calculation method. Leong[4] et al. achieve uniform fuel/air mixing by varying the fuel jet angle, position, and fuel/air momentum ratio. Sun Baocheng[5] used numerical simulation to study the gas/air mixing law, and summarized the factors including the turbulence, the fuel/air momentum ratio and other factors used to predict the mixing unevenness of the cylindrical premixing section. Xie Gang [6-7] studied the fuel/air mixing process and pollutant emission performance in the R0110 gas turbine combustor through simulation and experimental methods.
2. Numerical Simulation Study on a Mixture Structure of a Burner

2.1 Meshing and irrelevance verification

According to the survey results, the mixing structure was drawn by ProE software. The model was slightly simplified, the igniter and the fire detection fixture were removed. The fluid domain obtained after the mixed structure model is shown in Fig.1.

![Fig.1 Prototype prototype mixing model](image)

Use ICEM to mesh, in order to ensure the quality of the grid, while reducing the total number of grids, define the global size parameter mapping grid in two sections, and connect the two parts of the grid with interface. Using a tetrahedral unstructured grid, the mesh quality is above 0.3, which can meet the accuracy requirements.

Three grids of 2.50 million, 3.99 million and 4.86 million are taken for calculation. The first section is taken in the flow direction of the blade trailing edge of 100 mm, and another section is placed every 50 mm, and a total of six sections are taken. Spatial Mixing Velocity-unevenness (SMV) of 6 sections is taken out by Fluent calculation result. The curve is shown in Fig. 2. It can be seen from the graph that the results of 2.50 million, 3.99 million and 4.86 million are basically coincident. It can be considered that the grid increase has little effect on the result. In order to save the calculation cost, 2.50 million grids were selected to calculate the prototype model.

![Fig.2 SMV distribution with three grid numbers](image)

2.2 Numerical simulation and result analysis

The numerical calculation uses the standard realizable turbulence model and the methane-air component model. The air and gas inlets are both set as mass flow inlets and the outlet is pressure outlet, as shown in Table 1.

|                  | Fuel        | Air        | Outlet |
|------------------|-------------|------------|--------|
| Volume flow rate | 0.0459375   | 0.65       | -      |
| Temperature/K    | 298         | 298        | 298    |
| Density (kg/m3)  | 0.7831      | 1.1850     | -      |
| Mass flow rate   | 0.03597     | 0.77025    | -      |
| Pressure (Pa)    | 13789       | 2074       | 1600   |

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The formula for calculating the concentration unevenness [8] is as follows:

$$SMD = \frac{\iiint |f - \bar{f}|dA}{Af}$$  \hspace{1cm} (1)

Where A is the cross-sectional area of the selected section.

Approximately, the speed unevenness is calculated as follows:

$$SMV = \frac{\iiint |v - \bar{v}|dA}{Av}$$  \hspace{1cm} (2)

The distribution of the six sections CH4 is shown in Figure 3.

![Fig.3 Cloud map of each section CH4 distribution](image)

The uniformity of the distribution of air and CH4 gas increases, indicating that the mixing section promotes the uniform mixing of the gas. However, the gas was not completely mixed, and the CH4 concentration was extremely low near the center. It shows that the prototype has certain defects, there is no gas flowing behind the central gas pipe, resulting in a dead zone with extremely low concentration, which is difficult to mix evenly. The structure needs to be improved.

3. New mixing structure

After analyzing the patent research mixing technology [9-11], the following mixing scheme is proposed and have applied for a patent. As shown in Figure 4, the mixing structure mainly includes a premixing chamber, an internal gas pipe, a ring gas chamber and swirl blades. The inner horizontal tube is longer than the outer horizontal tube, and the inner and outer two sections are connected to form a truncated cone shape. The annular gas chamber divides the air passage into an inner and outer air passage, and the outer air passage is in a venturi structure. Gas injection holes are formed in the inner and outer sides of the annular cavity, and gas is respectively injected into the inner and outer air passages, and the swirling blades are bolted to the end of the annular gas chamber.
4. Numerical Simulation and Optimization of New Mixing Structure

Similar to section 2.1, the model and fluid domain were established. Simultaneously, the model was meshed, and the independence was verified. 3.89 million grids were selected for calculation.

4.1 Effect of the ratio of the number of holes in the gas chamber to the mixing

The gas hole diameter is 3 mm, and the ratio of the inner and outer holes is set to (1:1), (2:3), (1:2), (1:4). Numerical simulation is performed to study the effect of the number of holes in the cavity on the mixing.

![Fig.5 SMD and SMV distribution different internal and external aperture ratios](image)

It can be seen from Fig.5 that the mixing result has the lowest concentration unevenness under the ratio of the inner and outer holes is 1:4. However, from Figure 7, the speed unevenness does not match, and there is no obvious law.

The ratio of the cross-sectional area of the inner and outer air ducts is close to 1:4. Therefore, it can be concluded that after the gas enters the chamber, the flow rate to the gas holes of each inner and outer air passages is approximately the same, so the ratio of the inner and outer gas holes determines the flow ratio. When the cross-sectional area of the air duct is very different, the difference between the two gas concentrations will be large, and there will be a large concentration unevenness. Therefore, the ratio of the inner and outer holes should be consistent with the cross-sectional area of the inner and outer air ducts. The gas flow ratio of the duct is consistent with the cross-sectional area ratio, which is conducive to uniform concentration. The distribution has no obvious relationship with the speed, so the speed uniformity does not conform to this law.

4.2 Effect of gas pore size on mixing

The ratio of the number of holes in the chamber is 1:4 (8:32), and the diameter of gas holes is set to 3mm, 4mm, and 5mm respectively. Numerical simulation is carried out to study the effect of gas pore size on the mixing.
It can be seen from Fig. 6 that in the three cases, the mixing result is the best at 5mm aperture and the SMD is the smallest, but it can be seen that the three results are relatively close, and the difference is not very large. Compared with the prototype burner, the three results are much better. The analysis shows that the size of the gas pore size affects the gas exit velocity, which in turn affects the jet depth, thus affecting the mixing. It can be seen from Fig. 6 that the SMV and SMD distributions have similar consistency, and the three cases are smaller than the results of the prototype.

4.3 Effect of the number of gas holes on the mixing

The ratio of the inner and outer holes of the gas chamber is 1:4, the gas hole diameter is 3mm, and the number of gas holes is 8+32, 12+48, 16+64, respectively. Numerical simulation is carried out to study the effect of the number of holes on the mixing.

It can be seen from Fig. 7 that in the three cases, the mixing result is the best at 16:64, and the SMD is the smallest, but it can be seen that the three results are relatively close, and the difference is not very large. Compared with the prototype burner, the three results are better. The number of gas holes also affects the gas outlet speed, which in turn affects the jet depth, thus affecting the mixing. It can be seen from Fig. 7 that the SMV and SMD distributions have similar consistency.

4.4 Effect of the number of gas holes on the mixing

The ratio of the inner and outer holes of the gas chamber is 1:4 (8:32), the gas hole diameter is 3 mm, and the length of blades is taken as 98 mm, 70 mm, 45 mm and 0 mm (no blade) respectively.
Fig. 8 SMD and SMV distribution with different blade lengths

It can be seen from Fig. 8 that the swirling blade has a certain promoting effect on the gas mixing. The SMD becomes larger as the length of the blade decreases. The SMV has the same tendency as SMD. From this, it can be concluded that the blade has a significant effect on promoting the mixing, especially for the velocity uniformity, and the gas will generate a swirling flow through the swirling blade, thereby improving the uniformity of the gas concentration and the uniformity of the velocity.

5. Conclusion
In this paper, the numerical simulation method is used to simulate the mixing structure and the new mixing structure of a certain type of burner, and the number of inner and outer holes, the size of the gas hole, the number of gas holes and the swirling flow of the new mixing structure are changed. The effect of the blade length on the mixing is compared with a mixing structure of a burner. Some conclusions are as follows:

a. There is a certain defect in the mixing structure of a certain type of burner. There is no gas flowing through the central duct and the blade, and there is a dead zone of the airflow, resulting in a dead zone with extremely low concentration in the vicinity of the central axis of the blade, even a long distance from the center. The CH4 concentration is very low and it is difficult to mix evenly.

b. The ratio of the inner and outer gas holes determines the flow ratio, so the ratio of the inner and outer holes should be cut with the inner and outer air passages. The gas flow ratio of the inner and outer air ducts is consistent with the cross-sectional area ratio, which is conducive to uniform concentration.

c. The size of the gas pore size affects the gas exit velocity, which in turn affects the jet depth, thereby affecting the mixing.

d. The number of gas holes also affects the gas exit velocity, which in turn affects the jet depth. However, when the jet depth can be reached, the number of gas holes is large, and the holes are denser, which is more favorable for mixing.

e. The blade has a significant effect on promoting the mixing, especially for the speed uniformity. The gas will generate a swirling flow through the swirling blade, which improves the gas concentration uniformity and speed uniformity.

References

[1] Tang, H.P., Xi, Z.P. (2006) Development Status of Surface Burners for Metal Porous Materials. J. Rare metal materials and engineering. S2: 423-427.

[2] Shao, W.W., Zhao, Y., Liu, Y. (2015) Study on Gas Fuel/Air Blending Uniformity of Gas Turbine Combustion Chamber Premixed Burner. J. Proceedings of The Chinese Society for Electrical Engineering. 37.

[3] Fric, T.F. (1993) Effects of fuel-air unmixedness on NOxemissions. J. Journal of Propulsion and Power., 9(5): 708-713
[4] Leong, M.Y., Samuelsen, G.S., Holdeman, J.D. (1999) Mixing of jetair with a fuel-rich, reacting crossflow. J. Journal of Propulsion and Power, 15(5): 617-622.

[5] Sun, B.C. (2007) Numerical study on gas turbine fuel/air mixing. D. Beijing: Tsinghua University.

[6] Feng, C., Kuang, H.Y., Xie, G., etc. (2011) Analysis of fuel/air premixing uniformity of dry low NOx gas turbine combustor. J. Proceedings of The Chinese Society for Electrical Engineering. 31(17): 9-19.

[7] Xie, G., Kuang, H.Y., Li, Y.H., etc. (2010) Study on Pollution Emission Performance of R0110 Heavy Duty Gas Turbine Combustor. J. Proceedings of The Chinese Society for Electrical Engineering. 30(20): 51-57.

[8] Zhao, Y. (2016) Study on Gas-filling and Combustion Characteristics of Natural Gas Lean Premixed Burners. D. Institute of Engineering Thermophysics, Chinese Academy of Sciences.

[9] Zhao, R.X., Wang, Y.Q. (2015) Gas-grading combustion ultra-low NOx burner: CN202483751U. P.

[10] Jiang, Y.K., Yang, J., Guo, Y. (2012) Venturi tubular gas mixer: CN202483751U. P.

[11] Qiu, P.H., Gu, X.L., Liu, L. High-speed injection combustion device adapted to multiple fuels: CN105509049A. P.