Structural Optimization of Ring Type Oxygen Injector for Waste Incineration Research

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Abstract: Waste incineration is one of the most effective means to achieve harmless, reduction and resource recovery. As environmental problems become more and more prominent, increasingly stringent environmental standards will greatly limit the development of conventional waste incineration technology, therefore, the development of a new clean and efficient waste incineration technology will be the inevitable development trend of the waste incineration industry. Based on the computational fluid dynamics (CFD) technology, the structural optimization of the ring oxygen injector used in the oxygen-enriched incineration technology of the waste grate incinerator is investigated. The results show that the oxygen injection ring diameter is 0.7071D, the air duct length is 1.4D, and the oxygen injection ring outer hole is 0.28d and inner hole is 0.4d.

1. Introduction

Oxyfuel incineration is the use of oxygen-rich air with a higher oxygen content than air for combustion, which is an energy-saving and environmentally friendly yet efficient incineration technology[1-5] . The combustion of oxygen-enriched incineration can be divided into oxygen premixed and oxygen non-premixed. Oxygen premixing is more widely used in oxyfuel combustion in order to make the flow field reasonably organized and to ensure the stability of combustion. Oxygen premixing means that the oxygen is first mixed evenly with the air/flue gas in the duct and then passed into the furnace to mix with the combustible material for combustion. The oxygen injector is the device that mixes the oxygen with the air/fume.

The uniformity of oxygen and air/fume premixing also has a great impact on combustion, so the oxygen injector must ensure that oxygen and air/fume are mixed quickly and uniformly, avoiding the danger in the pipeline due to insufficient mixing of oxygen and air/fume and unstable combustion due to uneven mixing[6-10] .

In this paper, a ring type oxygen injector is given, and the numerical simulation technology is combined with the optimization study of the ring type oxygen injector ring diameter, air pipe length and oxygen injector ring internal and external spray hole diameter to determine a kind of oxygen injector that can meet the safety, rapid mixing uniformity, structural simplicity, operability and intelligent control to meet the actual needs of engineering.

2. Study Object

In this paper, the structure of the ring type oxygen injector designed according to the theory of fluid dynamics is shown in Figure 1:

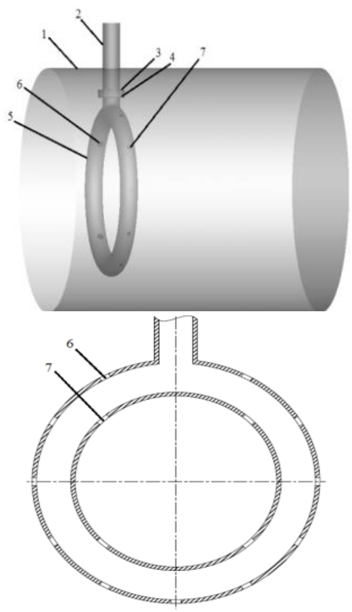

Fig.1 The structure of the ring oxygen injector

Where: air or flue gas pipe 1, oxygen DC pipe 2, first flange 3, second flange 4, oxygen injection ring pipe 5, oxygen injection ring inner spray hole 6, oxygen injection ring outer spray hole 7.

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The oxygen injection ring tube 5 is in the form of a ring, and the oxygen inlet end is installed in the direction of the extension of the ring diameter of the oxygen injection ring tube 5, and the oxygen inlet end is in the form of a tube, and a second flange 4 is installed on the port of the oxygen inlet end, and the oxygen injection ring tube has a plurality of oxygen injection ring inner spray holes 6 on the inner wall of the ring, and a plurality of oxygen injection ring outer spray holes 7 on the outer wall of the ring. One port of the oxygen DC tube 2 is located inside the air or flue gas pipe and a first flange 3 is installed at the port, and the other end is connected to an external oxygen source. The size of the oxygen direct current tube is the same as the oxygen inlet end of the oxygen injection ring tube 5, and the first flange 3 and the second flange 4 are of the same type, when the oxygen inlet end of the oxygen injection ring tube is connected to the oxygen direct current tube 2 through the second flange 4 and the first flange 3, on the one hand, the oxygen inlet end of the oxygen injection ring tube 5 and the oxygen direct current tube 3 are coaxial, on the other hand, the length of the oxygen inlet end and the length of the oxygen direct current tube are matched to ensure that the oxygen inlet end of the oxygen injection ring tube 5 and the oxygen direct current tube 3 are coaxial. On the other hand, by matching the length of the oxygen inlet end and the length of the oxygen DC tube to ensure that the centerline of the ring of the oxygen injection ring tube 5 coincides with the centerline of the air or flue gas pipe, to create conditions for the mixing of oxygen and flue gas or air. The normal vectors at the center of all the holes of the inner oxygen injection ring 6 and the outer oxygen injection ring 7 intersect with the centerline of the air or flue gas pipe. When outside oxygen enters the oxygen injection ring tube 5 through the oxygen DC tube 2, it can be ejected through the oxygen injection ring inner spray hole 6 and outer spray hole 7 in a direction perpendicular to the inner wall of the air or flue gas pipe, i.e., along the radius of the air or flue gas pipe.

3. Research content

This research on the structural optimization design of oxygen injector focuses on the key part parameters of oxygen injector, with emphasis on controllability. For the local structure optimization design of the ring oxygen injector is mainly based on the original design of the oxygen injector to optimize the diameter of the oxygen injection ring (ring outer diameter), the length of the air pipe, and the internal and external apertures of the ring. The oxygen injection ring diameter and air pipe length were analyzed by taking the air pipe diameter D as the base and using different multiples to compare one by one; the inner and outer ring apertures were analyzed by taking the oxygen pipe diameter d as the base and taking different multiples to analyze one by one. The coefficient of variation C.V is quoted in the analysis of the study results. it is defined as the ratio of standard deviation to mean, i.e., C.V = (SD/MN) × 100%. The optimal results were obtained by comparing the coefficients of variation of velocity (V), temperature (T) and oxygen concentration (C) for different operating conditions.

4. Analysis of research results

4.1. Effect of oxygen injection ring diameter

The size of the oxygen injection ring diameter (ring outer diameter) has a serious impact on the diffusion of oxygen in the air duct. In order to get the best oxygen injection ring diameter, five different working conditions are given below for numerical calculation. The average turbulent kinetic energy distribution and the coefficient of variation of velocity, temperature and concentration for the five operating conditions are shown in Fig. 2 and Fig. 3.

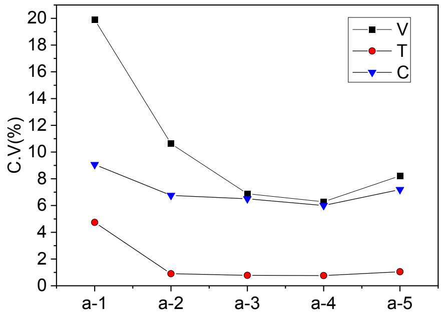

Fig.2 Variation coefficient distribution under different conditions

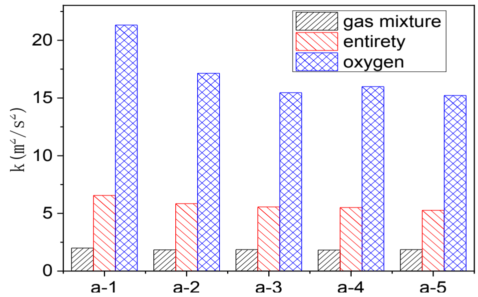

Fig.3 The average turbulent kinetic energy distribution under different conditions

As shown in Fig. 2, the coefficients of variation of velocity, temperature and concentration all tend to decrease and then increase with the increase of oxygen injection ring diameter. The coefficients of variation of temperature distribution are much lower than those of velocity and concentration under the same conditions, which indicates that the temperature of the oxygen and air mixes with large temperature difference and reaches uniformity quickly through strong convective heat exchange. The coefficient of variation of the velocity distribution between working condition a-1 and working condition a-2 is most obviously affected by the diameter of the oxygen injection ring, combined with the analysis of Figure 3, it can be seen that in working condition a-1 to a-2, the oxygen export turbulence intensity changes most drastically, the local disturbance is serious, oxygen can not quickly and better diffuse around the air pipe, so that the oxygen and air at the oxygen injector outlet does not get a good mixture and still maintain a large speed difference. In addition, the gradient of temperature and concentration coefficient of variation can also be proved. The coefficient of variation of the temperature distribution does not change significantly after the diameter of the oxygen injection ring reaches 0.6D. The coefficients of variation of velocity, temperature and concentration reach their minimum values at working condition a-4, i.e. D4=0.7071D, indicating the best mixing effect. At this time, oxygen and air are mixed most uniformly under the same conditions.

4.2. Effect of air duct length

The length of the oxygen injector air pipe has an absolute effect on the residence time of oxygen and air in the oxygen injector, which is also the mixing time of oxygen and air. In order to standardize the measurement of the mixing effect of the oxygen injector, it is hereby stipulated that the coefficient of variation C.V of the speed, temperature and molar concentration of oxygen in the exit section of the mixed gas is less than or equal to 10%. After the previous optimization of the oxygen injection ring diameter, the best oxygen injection ring diameter is selected as 0.7071D, as a premise, the following is the numerical simulation analysis of the five working conditions of different air pipe length, set the air pipe length as L, air pipe diameter as D, then: working condition b-1: L1 = 1.1D; working condition b-2: L2 = 1.2D; working condition b-3: L3 = 1.3D; working condition b -The distribution of the coefficient of variation of velocity, temperature and concentration at the outlet section of the pipe for the five working conditions is shown in Fig. 4.

As can be seen from Figure 4, the coefficients of variation of velocity distribution, temperature distribution, and oxygen concentration distribution of the oxygen injector air duct outlet section under five different operating conditions all decrease with the increase of the length of the oxygen injector air duct. The coefficient of variation of velocity distribution has the largest variation gradient, followed by concentration distribution and the smallest temperature distribution. It is obvious that the coefficient of variation of the temperature distribution is much lower than 10% and therefore need not be considered, while the coefficients of variation of the velocity and concentration distributions are different. The coefficient of variation of the velocity distribution is 15.37% at b-1 and decreases to 10.1% at b-3, but it is still higher than 10% and only below 10% at b-4, which is acceptable. The coefficient of variation of oxygen molar concentration changes more slowly, 11.23% in b-1 working condition, and has been reduced to 9.73% in b-3 working condition to reach qualification. Combined with the above analysis, it can be seen that the coefficient of variation of velocity distribution, temperature distribution and oxygen molar concentration distribution of the outlet section of the oxygen injector air duct under b-4 working condition are qualified, so L4=1.4D can meet the needs.

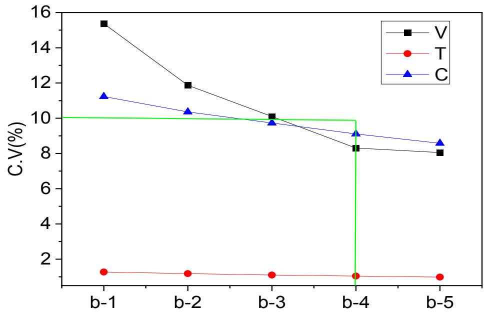

Fig.4 Variation coefficient distribution under different conditions

4.3. Influence of the aperture size of the spray hole inside and outside the oxygen injection ring

The oxygen injection ring in the oxygen injector designed in this paper includes inner and outer spray holes. The size of the inner and outer spray hole apertures is closely related to the momentum of oxygen when injected into the air pipe, and therefore also affects the diffusion of oxygen in the air. In order to get the best inner and outer spray hole apertures, this section optimizes the inner and outer spray hole apertures one by one. Let the diameter of the oxygen injection ring tube be d. Firstly, the aperture diameter of the inner oxygen injection ring is specified as a constant value, and the following five different working conditions are given to determine the best outer aperture diameter: working condition c-1: d1=0.26d; working condition c-2: d2=0.28d; working condition c-3: d3=0.30d; working condition c-4: d4=0.32d; working condition c-5:d5=0.34d. The simulation results The coefficient of variation distributions of velocity, temperature and concentration, and the mean turbulent kinetic energy distributions for the five operating conditions from the data analysis are shown in Fig. 5 and Fig. 6.

As shown in Figure 5, the coefficient of variation of the velocity distribution, temperature distribution, and oxygen molar concentration distribution of the oxygen injector air duct outlet cross-section tends to decrease and then increase with the increase of the outer jet orifice diameter, and reaches the minimum in the c-2 working condition, which can be explained by Figure 6. In the c-1 condition, the oxygen momentum is larger, and the average turbulent kinetic energy in the orifice section, the oxygen injector as a whole and the mixed gas outlet section all reach the maximum, which are higher than the other conditions, which leads to a strong mixed gas disturbance and does not achieve sufficient mixing within a limited distance; in the c-3 condition, the average turbulent kinetic energy of the oxygen injector as a whole is equal to the c-1 condition, and the turbulent kinetic energy of the mixed gas outlet section is also Therefore, the distribution of various coefficients of variation in Fig. 5 is close to that of the c-1 case, and the mixed gas is strongly disturbed, and the mixing effect is not sufficient; in the c-4 and c-5 cases, it can be seen from Fig. 6 that the average turbulent kinetic energy of the nozzle section, the oxygen injector as a whole and the mixed gas outlet section in both cases are significantly lower than those of the first three cases, and the mixing intensity is not sufficient, so the distribution of various coefficients of variation in Fig. 5 is not sufficient. In the same conditions, c-3 working condition to take the oxygen injection ring outside the orifice diameter of 0.28d, turbulent kinetic energy to achieve can make the gas mixture mix fully without disturbing too strong or too weak state, so choose the outside of the orifice diameter of 0.28d for the best.

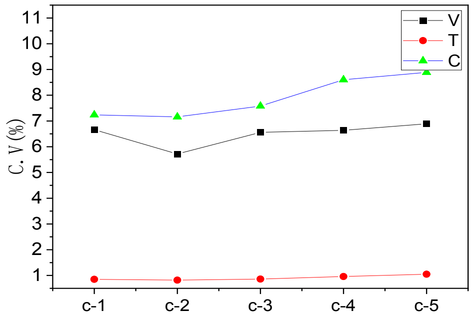

Fig.5 Variation coefficient distribution under different working conditions.

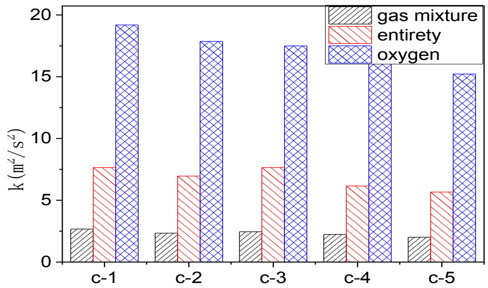

Fig.6 The average turbulent kinetic energy distribution under different conditions

The inner hole is optimized on the basis of choosing the outer spray hole diameter of 0.28d, and setting the diameter of the oxygen injection ring tube as d. The following five different working conditions are given to determine the optimal outer hole diameter: working condition d-1: d1=0.31d; working condition d-2: d2=0.34d; working condition d-3: d3=0.37d; working condition d-4: d4=0.40d; working condition d-5:d5=0.43d. The average turbulent kinetic energy distribution of the coefficient of variation of velocity, temperature and concentration for the five conditions from the data analysis of the simulation results are shown in Fig. 7 and Fig. 8.

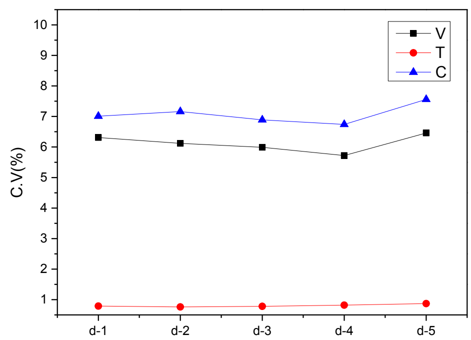

Fig.7 variation coefficient distribution under different working conditions.

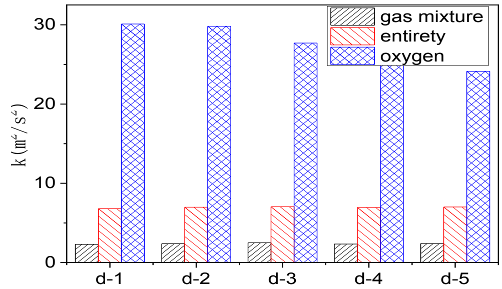

Fig.8 The average turbulent kinetic energy distribution under different conditions

As can be seen from Figure 7, with the increase of the inner jet aperture diameter, the variation trend of the coefficient of variation of each parameter of the oxygenator air duct outlet section is different: the coefficient of variation of the velocity distribution is decreasing and then increasing. The coefficient of variation of temperature distribution does not change obviously, but the overall trend is to increase; the coefficient of variation of concentration distribution is more complicated, first increasing to d-2 condition, then decreasing to the minimum to d-4 condition, and finally continuing to increase. From Figure 8, it can be seen that the average turbulent kinetic energy of the oxygen outlet section gradually decreases as the aperture diameter of the inner jet increases, while the average turbulent kinetic energy of the oxygen injector as a whole and the mixed gas outlet section does not change significantly, but the change trend is the same. A reasonable explanation for the variation trend of each parameter in Figure 7 cannot be found from Figure 8. However, it can be found that although the coefficient of variation of temperature distribution is not the smallest in d-4 working condition, the coefficient of variation of velocity distribution and concentration distribution reaches the smallest value, and it is known that the oxygen injection effect is optimal in d-4 working condition, i.e., when the inner orifice diameter is 0.4d.

5. Conclusion

In order to get the oxygen injector that meets the actual application of engineering, the local optimization of the ring oxygen injector was carried out, and the influence of the diameter of the oxygen injection ring, the influence of the length of the air pipe and the influence of the aperture diameter inside and outside the oxygen injection ring were analyzed. The research results show that the oxygen injection ring diameter of 0.7071D has the best mixing effect between oxygen and air under the same conditions; the length of the air duct reaches 1.4D to achieve the requirement that the coefficient of variation of velocity distribution, concentration distribution and temperature distribution of the oxygen injector exit section is less than 10%; the oxygen injection effect is optimized when the outer hole of the oxygen injection ring is 0.28d and the inner hole is 0.4d.

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