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ANALYSIS OF OXYGEN ENRICHED COMBUSTION CHARACTERISTIC OF 350 MW UTILITY BOILER BASED ON COMPUTATIONAL FLUID DYNAMICS

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Three dimensional model of 350 MW utility boiler furnace was established by CFD to explore the combustion characteristics of pulverized coal at different O_2 / CO_2 ratios. The temperature field, sub-concentrations distributions, burner wall heat loads and movement trajectories of pulverized coal particles were analyzed and compared with those in the air atmosphere. The numerical results shows: the furnace temperature increases as the value of O_2 concentration and the peak value of radiation appears at 20 metres in furnace; Oxygen enrichment combustion process can effectively reduce the exhaust flue gas temperature; The combustion condition with 30 % oxygen concentration is the closest to air combustion.

Key words: boiler furnac; coal-O_2/CO_2; numerical simulation; physial model; NO/SO_2

INTRODUCTION

Worldwide, tangential firing and hedging combustion are the mainstream combustion technology of large boiler, and the tangential firing technology in China is getting mature [1]. Recently, the opposed firing technologies in China also develop rapidly. A lot of large units more than 300 MW adopt the opposed firing technology [2, 3]. However, the rapid development of thermal power generation has leaded to a large number of greenhouse gas emissions and environmental pollution caused by sulfur oxides and nitrogen oxides [4].

More and more attention was paid to oxygen enriched combustion technology at home and abroad in recent years. As a combustion way with development potential, oxygen-enriched combustion technology can not only reduce carbon emissions, and can effectively reduce the emissions of oxysulfide and nitrogen oxides [5-6]. In China, oxygen enriched combustion technology started fairly late, but relative experimental studies have been finished. Moreover, this technology has been applied to small boilers [7]. However, it is quite difficulty to apply the oxygen enriched combustion technology to large-scale utility boilers at present, which is due to the less theory and related experiment. In addition, the understanding of internal temperature, pressure, pollutant emissions in boiler which is applied to this technology is incomplete.

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NUMERICAL SIMULATION

Model building

As a research object 350 MW swirling pulverized coal furnace was researched. The width, depth and height of this utility boiler are 18 300 mm, 15 800 mm, and 52 467 mm respectively. The boiler adopts a new type of swirling burner with internal DC and outer swirling flow. The total number of burners is 30. And the arrangement adopts front and back boiler wall cross collocation for boiler. That is to say, fifteen burners are arranged on both sides. The arrangement has three layers, and there are five burners on each layer.

Physical models and boundary conditions

The random orbit method was used by pulverized coal particle phase flow. The pulverized coal combustion used power/diffusion control combustion model. The volatile devolatilization model chose double competing reaction pyrolysis model. The radiative heat transfer adopted P-1model [8-9]. The NO_X model is a generative model of solid fuel. This simulation mainly considers generation of thermal and fuel NOx. The former is calculated based on generalized Zeldovich, and the latter is divided into volatile NOx and char NOx based on Desoete mechanism. The volatile NOx can be changed to NO and some N_2, and NOx-Char can be changed to NO.

The air supply mode of burner is the mixture of primary air and secondary air. The pulverized coal flow at inlet is defined as 0,5 kg/s, and the inlet temperature is 400 K. Correspondingly, the inlet velocity is 15 m/s. In a way of surface, the pulverized coal particles are injected into the boiler furnace from the inlet of inner primary air and the external primary air. As shown in Table 1 and Table 2, specific parameters are set. The proportion of O_2 / CO_2 in oxygen rich combustion process is shown Table 3, where the amount of pulverized coal in each working condition is consistent.

Table 1 **Simulation parameters**

parameter	wind speed	temperature
Inner primary air	15 m/s	450 K
Outer primary air	17 m/s	450 K
Secondary air	23 m/s	610 K

Table 2 **Axial and tangential velocity of secondary air under different swirling intensity**

n	0,79	0,97	1,28	1,37
Axial velocity m/s	19,.05	18,02	16,85	15,56
Tangential velocity m/s	11,01	12,62	14,14	15,56

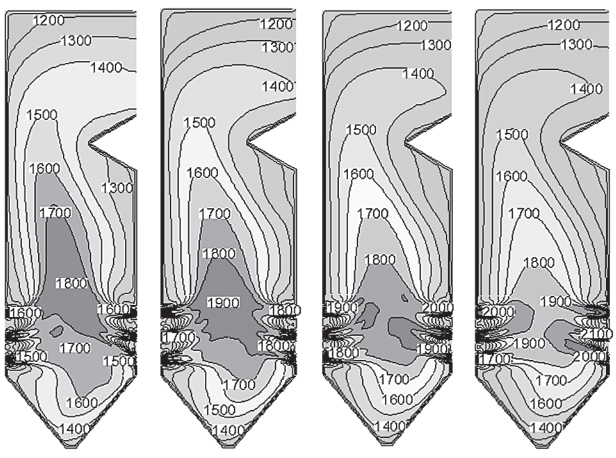
Table 3 **Simulated condition**

mode	mode 1	mode 2	mode 3	mode 4
O_2/CO_2	21 / 79	25 / 75	30 / 70	35 / 65

RESULTS AND DISCUSSION

Distribution of temperature field in the furnace cross section

Figure 1 is the temperature distribution at longitudinal section of furnace under different operating conditions. The results show that temperature of burner outlet is the highest, and the reaction is the strongest. The chamber temperature decreases along the height of furnace. The maximum temperature of center of furnace corresponding to operating condition 1 was low obviously, and the high temperature area is significantly large. The central area of flame is close to the center of furnace. If O_2 concentration is increased, the center area of flame becomes shorter. The high temperature region gradually decreases and shrinks to the burner position. The highest temperature of furnace flame rises, and temperature gradient increases, so that the temperature distribution in furnace is more uniform. In condition 3, the central area of flame tends to the center of furnace, which moves upper along the furnace height.



1 2 3 4

Figure 1 The temperature of furnace center-section under different operating conditions

Distribution of radiant force in furnace cross section

Figure 2 is the average radiant force in the cross section of furnace height under different operating conditions. It could be seen that the distribution of average radiation at cross section of furnace under different operating conditions was similar to air atmosphere, which showed an increase-decrease trend along furnace height. The maximum radiation force was at a furnace height of 2 000 mm. When O_2 concentration increased, peak value of radiant force shifted gradually to the low-order, which was caused by the ahead of reaction of pulverized coal particles in oxygen-enriched condition. From the analysis of operating condition 1, it could be found that the average radiant force was the lowest when the furnace height was less than 2 000 mm, and it might even lower than air atmosphere. When the furnace height was more than 2 000 mm, the attenuation of radiant force was the smallest. Therefore, the average radiant force of its outlet is highest. From the analysis of 2 - 4 operating conditions, the maximum radiant force increases with O_2 concentration, and the radiant force at outlet decreases with O_2 concentration. Accordingly, the radiant force of furnace chamber is closely related to the gas temperature of furnace chamber.

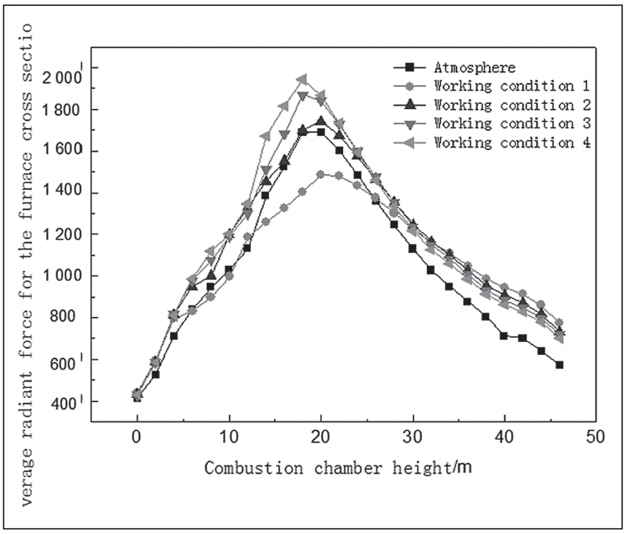


Figure 2 The distribution of average radiation force along the furnace height under different operatin conditions

Distribution of species concentration field in combustion chamber

Figure 3 indicates the average O_2 concentration under different operating conditions. Thus, the O_2 concentration in operating conditions 1 - 4 has the same change trend with air atmosphere, and they all increase at first then decrease, finally, they reach steady state. In other word, O_2 concentration increased rapidly when the furnace height was less than 1 100 mm. When the furnace height was 1 100 mm, O_2 concentration began to decrease. When the furnace height was about 2 000 mm, the downtrend began to gradually slow and even to be stable. This shows that the burning process of pulverized coal is mainly concentrated in the region that the height is less than 2 000 mm. Only a little of incomplete combustion of pulverized coal was risen with flue gases to 2 000 mm so as to complete combustion. Compared with different operating conditions, with the increase of O_2 concentration, the total concentration of O_2 also increased. However, the peak was not completely consistent with growth rate; when the height was more than 2 000 mm, O_2 concentration tended to be stable in operating 2 - 4conditions, which has obvious differences with changes of O_2 concentration under air atmosphere and operating condition 1. This indicated that in operating 2-4 conditions, pulverized coal of furnace has been completed the combustion process in burner area.

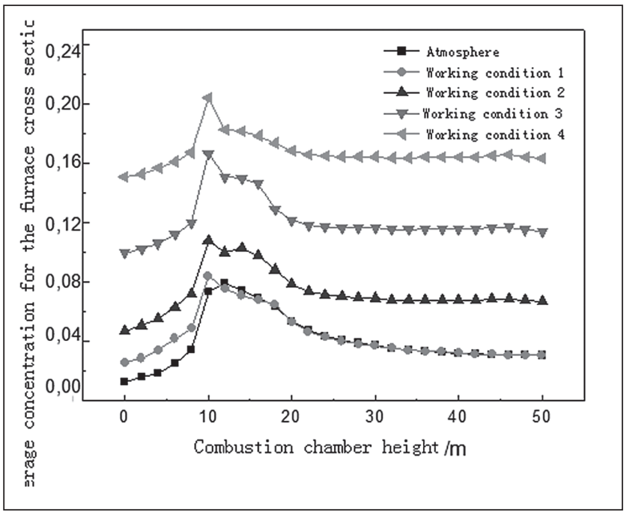


Figure 3 The concentration profiles of O2 along the furnace height under different operating conditions

In Figure 4, the variation trends of CO_2 concentration under different operating conditions were roughly the same, which increased at first and then decreased along the furnace height. The minimum concentration of CO_2 was concentrated on the height of 1 000 - 2 000 mm. Under oxygen enriched atmosphere, CO_2 concentration was between 75 %-93 %, which was significantly higher than that in air atmosphere. From the analysis of operating condition 1 - 4, with the increase of O_2 concentration, the minimum value of CO_2 concentration moved down along the furnace direction. The reason is that with the increase of O_2 concentration, the pulverized coal is burned in advance, but the combustion process is still concentrated on burner area. The concentration of CO_2 decreases with the increase of O_2 concentration. It is due to the violent turbulent perturbation. The O_2 entering in furnace can exchange heat with flue gas and pulverized coal in furnace quickly, thus expediting the combustion reaction.

Figure 6 shows the CO average concentration under different conditions. It can be found that the maximum value of average concentration of CO is basically located between 1 000 - 2 000 mm of furnace height. The CO concentration increases at first and then decreases under different conditions. The distribution of CO is corresponding to and distribution of CO_2 in Figure 5. That is to say, the formation region of CO is mainly focused on section of burner. Then, massive CO reacts with O_2 to form CO_2. Based on the analysis of operating conditions 1 - 4, with the concentration of O_2, peak value of CO concentration moves up along furnace height. The main reason is that a large number of pulverized coal cannot react with air in furnace quickly after entering the furnace, thus massive CO is formed. Then, with the continuous supply of oxygen in furnace and the increase of mixed time, massive CO reacts, and CO con-

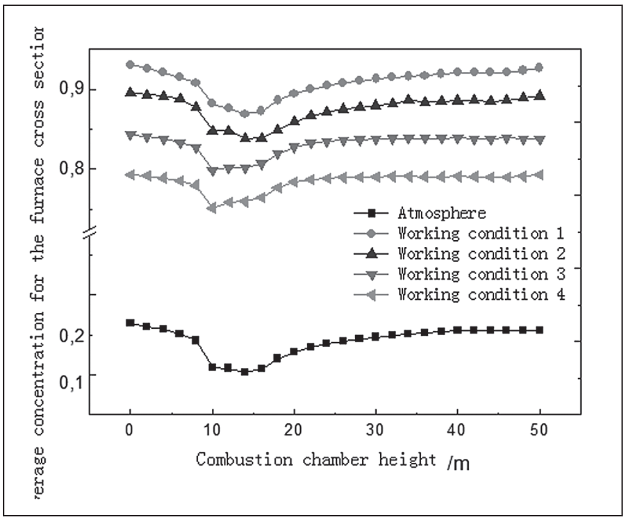


Figure 4 The concentration profiles of CO2 along the furnace height under different operating conditions

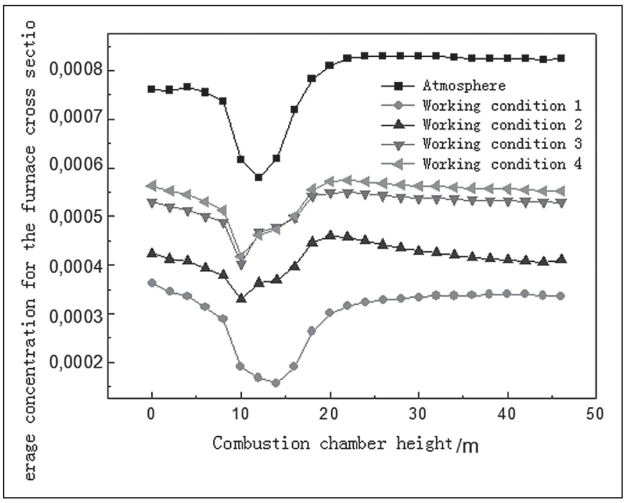


Figure 5 The concentration profiles of CO along the furnace height under different operating conditions

tent decreases. Compared with the combustion effect in air atmosphere and oxygen-enriched atmosphere, the difference of CO concentration is obvious. The concentration of CO increases with the increase of proportion of mixing CO_2. Therefore, this conclusion is consistent with that of references. Oxygen-enriched combustion has adverse effects on the control of CO and the economical efficiency of combustion. The economic problem of CO control in oxygen-enriched combustion is not discussed in this article.

Figure 6 shows the average concentration distribution of NO in the direction cross section of furnace height under different operating conditions. It can be found that the variation of NO concentration on the furnace height is similar to variation trend of CO_2 in Figure 4. The reasons are analyzed: massive pulverized coal at burner outlet in reacts, and a lot of NO is produced. Under the influence of reflux area, strong reducing atmosphere of fuel combustion causes decrease of NO. Then, due to the mixing effect of primary air and secondary air, NO increases once again, so that the coal can burn further, resulting in the increase of NO content. Because NO reacts with coke to form N_2, NO decreases once again at a later stage. For another, the dilution effect of combustion products also leads to a further decrease of NO concentration. Compared with air atmosphere, the content of NO is decreased greatly under operating condition 1 - 4. The main reason is to rapid NO_X and thermal NO_X caused by N_2 are avoided in the oxygen enriched atmosphere. And CO_2 with high concentration in oxygen enriched atmosphere will react with carbon to form CO. So then, the reduction reaction between NO and NO_X will take place on the focal surface to decrease the emission of NO_X. Furthermore, the production of NO will increase with the increase of O_2 concentration oxygen enriched combustion. The reason is that the total flue gas entering the furnace will decrease with the increase of flue-gas concentration, resulting in the increase of NO concentration.

Figure 7 denotes the average SO_2 concentration in the cross section of furnace height under different operating conditions. The average concentration of SO_2 at the outlet of furnace is 3 136 ppm in air atmosphere. Nevertheless, the average concentration of SO_2 in operating condition 1-4 is 562 ppm, 1 135 ppm, 1 652 ppm and 2 247 ppm. That is to say, the control of SO_2 in oxygen-enriched atmosphere is much better than that in air atmosphere. The concentration of SO_2 increases with the increase of O_2 concentration in oxygen-enriched atmosphere. The main reason is the differences of CO_2 concentration in different reaction atmospheres. Therefore, there are differences during production of COS in combustion process. The production of COS increases with the increase of CO_2 atmosphere, which further affects the existence of some S in COS form. Compared with the air atmosphere, COS is not produced. Analysis of mechanism of forming COS: in oxygen-enriched conditions, the concentration of CO_2 in reaction atmosphere is high. And pulverized coal particles in combustion reaction are surrounded by a large number of CO_2, the carbon element which has a strong reductive effect in pulverized coal particles reduce CO_2 to CO. Then, CO reduces a large amount of SO_2 produced by pulverized coal combustion into sulfur. Moreover, sulfur reacts with CO further to form COS. It must be noted that COS and SO_2 are harmful atmospheric pollutants which are needed to be further processed.

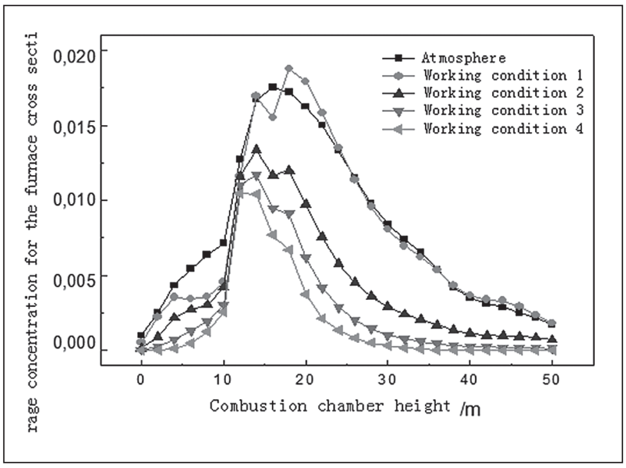


Figure 6 The concentration profiles of NO along the furnace height under different operating conditions

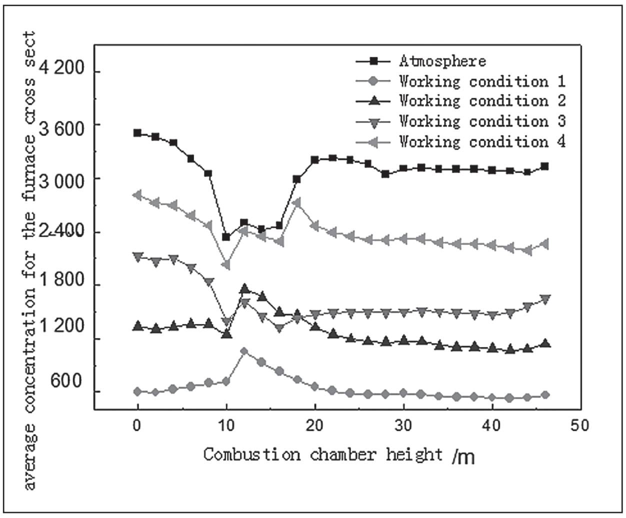


Figure 7 The concentration profiles of SO2 along the furnace height under different operating conditions

CONCLUSIONS

The peak of radiometric force in furnace is about 20 meters height of furnace. In oxygen-enriched atmosphere, the gas temperature increased with the increase of O_2 concentration. When the concentration of O_2 was 21 %, the temperature in the furnace was lower than that in air atmosphere. When the concentration of O_2 was 30 %, the combustion in furnace was equivalent to combustion supporting air. The concentration of O_2 had a great effect on the combustion stability of pulverized coal in furnace. The increase of O_2 concentration enhanced the combustion of pulverized coal, accelerated the burning velocity, and narrowed the high temperature zone in furnace.

Compared with the air atmosphere, the oxygen-enriched atmosphere could effectively reduce the production of NO and SO_2. The production of NO increased with the increase of O_2 concentration. The main reasons: thermal NO_X and prompt NO_X could be controlled effectively and CO with high concentration caused the reduction reaction of NO and circular NO_X on focal surface. The production of SO_2 increased with the increase of O_2 concentration in oxygen-enriched atmosphere. The main reason: CO_2 with high concentration was reacted with carbon to produce CO, and then SO produced by the pulverized coal combustion was reduced to the elemental sulfur. And COS was formed by the reaction between CO and elemental sulfur further.

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