Influence Law of Combustion in the Furnace Affected by Accurate Air Distribution

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Abstract. In thermal power plant, the quality of combustion air distribution directly affects the stability and efficiency of boiler operation. The reasonable air-coal ratio can provide protection for the security and stability of unit operation and reduce energy waste. In the course of the actual operation, the air-coal ratio is immeasurable in every combustion area. The coal and air need to feed according to experience and higher or lower air-coal ratio is unavoidable. In this paper, the boiler of a power plant is selected as research objects and adopts the fluent software to study combustion conditions in furnace. The combustion effect is researched by adjusting temperature and quantity of primary air when the secondary air is fixed. The best temperature and quantity of primary air and air-coal ratio can be get. These study results provide a further evidence for high efficient and safe operation of boilers.

1. Introduction

With the development of China's economy, the power grids is growing and thermal power units capacity is rising. However, the power sector will continue to be dominated by coal-fired power plants. The boiler is the source of the whole energy conversion for a thermal power unit. Combustion of pulverized coal is very important and the key of the efficient energy transmission and energy transformation in boiler. Because of the complexity of combustion process, for steady and complete combustion and lower NOX emission, the ratio of air and pulverized coal needs keeping in a reasonable range of power generation. In reality, in order to ensure full combustion, the actual air quantity must be more than the theoretical air quantity. The actual ratio of coal-air cannot be managed during combustion process. air distribution has direct impact on boiler operation and need to be adjusted for coal property, characteristics of combustion equipments and coal distribution mode in different burner. Usually, boiler manufacturer and DCS manufacturer don't provide specific burning strategy and options. The staff distribute the air with experience and make the coal variation stay consistent with the air variation simply. Larger or smaller air quality is inevitable and can cause waste of energy. Statistically, over 75 percent of waste are caused by air distribution [1, 2]. In recent years, China’s increase gradually in energy conservation and emission reduction of the power. There's no question that accurate air distribution becoming a significant mean for raise unit economy and decrease the pollutant emissions. The air accurate distribute by changing secondary air in thermal power units usually. But there is currently no study of air accurate distribute by changing primary air. So it is necessary to get a rational ratio of coal-air and a method of accurate air distribution in
order to ensure coal combustion in appropriate oxygen conditions by changing primary air. Based on 600 MW subcritical opposite firing boiler, furnace combustion is simulated with FLUENT software package in different primary air quality. In contrast with actual situation, the results provide further evidence for accurate air distribution. So this study has the important theory significance and the practical application.

2. The Numerical Modelling
The software Ansys ICEM has been used to draw a grid of boiler and burners in this study. In order to accurate simulate the combustion conditions form burners outlets to furnace, a group opposite burners are retained. Others are replaced by round holes. The numerical modeling is shown in Fig. 1.

![Boiler Modelling](a) Boiler Modelling ![Opposite Burners Modelling](b) Opposite Burners Modelling

**Fig 1.** The numerical modeling

3. Results and Discussions
In order to study influence law of combustion in the furnace, different primary air temperature and different primary air quality are selected to simulate (see Table.1).

| Condition | primary air temperature(℃) | primary air quality(t/h) | secondary air quality(t/h) |
|-----------|-----------------------------|--------------------------|---------------------------|
| Condition 1 | 70                          | 20                       | 40                        |
| Condition 2 | 80                          | 20                       | 40                        |
| Condition 3 | 90                          | 20                       | 40                        |
| Condition 4 | 80                          | 25                       | 40                        |
| Condition 5 | 80                          | 30                       | 40                        |

3.1. Influence of combustion affected by primary air temperature
The models of different primary air temperature are built, temperature and velocity distribution on cross-section of burners are shown in Fig.2. With the increase of primary air temperature, the temperature of burners outlet rise and high temperature zones increase. The simulation results show that the primary air temperature is 70°C, the highest temperature in furnace is 1545.7473°C, the primary air temperature is 80°C, the highest temperature in furnace is 1555.2095°C, and the primary air temperature is 90°C, the highest temperature in furnace is 1564.121°C. That means the highest temperature in furnace increases linearly with the increase of primary air temperature. Besides, the burn center move downward slightly, high temperature zones concentrating more on lower portion between burners and over-fire air. However, the temperature near the furnace water wall and burners
increases, the risk of water wall burn out and coking increase with the increase of primary air temperature. But primary air temperature has no obvious influence on velocity fields.

![Temperature fields on cross-section of furnace](a)

![Velocity fields on cross-section of furnace](b)

**Fig 2.** Temperature and velocity fields on cross-section of furnace in different primary air temperature

The flow fields in furnace are shown in Fig.3. As can be seen from the figure, primary air temperature has almost no influence on flow fields.

![Flow field in furnace in different primary air temperature](fig3)

**Fig 3.** Flow field in furnace in different primary air temperature
The temperature distribution curve along the height of the furnace is shown in Fig. 4(a). The abscissa represents the height of furnace. As can be seen from the figure, the flame center in position of 25 meter that the position between burners and over-fire air. There are 5 temperature drops in outlets of burners and over-fire air. As can be seen from Fig. 4, the outlet temperature of furnace is almost the same, but the temperature of combustion zone in furnace centre increase as the nuclear temperature rises. Besides, the burn center moving downward. The reason is: the primary air temperature increase, the coal need less energy and get to ignition points more easily and the ignition time advances. The temperature distribution curve of cross-section of burners is shown in Fig. 4(b). With the primary air temperature increase from 70°C to 90°C, average temperature gradient in the centre of furnace decrease and temperature gradient near the furnace water wall increase. It means that the heat transfer coefficient near the furnace water wall increases and the boundary layer of heat transfer tends to thin. It can be seen from Fig. 4 that the temperature increase and distribution more uniform in the centre of furnace with the primary air temperature increase. It means that coal-fired combustion more fully.

![Fig 4. The temperature distribution curve](image)

The oxygen content distribution of cross-section of burners is shown in Fig. 5. The oxygen-rich primary air carry pulverized coal spouted from the burner nozzles. Oxygen consumption is biggest in the centre of furnace and the recirculation zone of secondary air. With the primary air temperature increase, the temperature drop gradient in the outlet of burners increase and oxygen -free area in the centre of the furnace enlarge. The reason is: the increased primary air temperature tends to combustion early and oxygen -free area in the centre of the furnace enlarge. It is benefit for reduce NOX generate.

![Fig 5. The oxygen content distribution of cross-section of burners](image)
3.2. Influence of combustion affected by primary air quality

The models of different primary air quality (20t/h, 25t/h and 30t/h) are built in condition of same primary air temperature (80°C). The temperature distribution of furnace is shown in Fig.6 and the temperature distribution curve along the height of the furnace is shown in Fig.7. The increased primary air quality can help to combustion fully of pulverized coal. That cause advance ignition, high-temperature region concentration, move downward of the burn center and increase of maximum temperature in furnace. With the increase of primary air quality, the high temperature area shows reducing tendency and the temperature apogee moves down along the height of the furnace. Besides, the average temperature in the centre of furnace increase and the burn center move downward.

![Fig 6. The temperature distribution of furnace](image)

![Fig 7. The temperature distribution curve along the height of the furnace](image)

The temperature distribution on cross-section of burners with different primary air quality are shown in Fig.8. With the increase of primary air quality, the temperature of burners outlet rise and high temperature zones increase and temperature gradient near the furnace water wall decrease. The combustion duration extend. So increasing the primary air quality increases the high temperature zones and heat transfer uniformity of horizontal gas duct, decrease temperature gradient near the furnace water wall and enhance heat transfer.
Fig 8. The temperature distribution on cross-section of burners

The oxygen content distribution with different primary air quality are shown in Fig.9. Oxygen concentration gradient neighboring flame decrease and pulverized coal burning stability. But the oversized primary air quality will tend to increase oxygen concentration and excess air coefficient in outlet of furnace, the combustion efficiency will decrease. So NOX concentration will increase. The oxygen distribution curve on cross-section of burners with different primary air quality are shown in Fig.10. With the primary air quality increase, oxygen concentration increase in outlet of burners, the oxygen concentration drop gradient decrease and oxygen -free area in the centre of the furnace shrank. It means that reducing atmosphere reduce and oxidizing atmosphere enhance. It is tend to increase combustion efficiency in outlet of burners and NOX concentration near burners.

Fig 9. The oxygen content distribution with different primary air quality

Fig 10. The oxygen distribution curve on cross-section of burners with different primary air quality
4. Conclusion
Based on 600 MW subcritical opposite firing boiler, furnace combustion is simulated with FLUENT software package in different primary air temperature and quality. Conclusions are as follows.

1) With the increase of primary air temperature, the temperature of burners outlet rise and high temperature zones increase. The burn center move downward slightly, high temperature zones concentrating more on lower portion between burners and over-fire air. But primary air temperature has no obvious influence on velocity fields.

2) The average temperature gradient in the centre of furnace decrease and temperature gradient near the furnace water wall increase with the primary air temperature increase.

3) With the primary air temperature increase, the oxygen drop gradient in the outlet of burners increase and oxygen-free area in the centre of the furnace enlarge. It is benefit for reduce NOX generate.

4) With the primary air quality increase, the increased primary air quality can help pulverized coal to burn fully. That cause advance ignition, high-temperature region concentration, move downward of the burn center and increase of maximum temperature in furnace. The combustion duration extend and heat transfer uniformity of horizontal gas duct, decrease temperature gradient near the furnace water wall and enhance heat transfer.

5) With the primary air quality increase, oxygen concentration gradient neighboring flame decrease and pulverized coal burning stability, oxygen concentration increase in outlet of burners, the oxygen concentration drop gradient decrease and oxygen-free area in the centre of the furnace shrank. It is tend to increase combustion efficiency in outlet of burners and NOX concentration near burners.

When the secondary air is fixed, the best temperature and quality of the primary air should be determined by the study to realize accurate air distribution.

References

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