Low NOx combustion mechanism of coke oven gas with excess air coefficient and flue gas recirculation

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Abstract: With the more stringent NOx emission limit from the coking chemical industry, the coking production with only one type of low NOx combustion technologies cannot meet the emission requirement. Thus a new low NOx experimental system was developed with the help of the external flue gas recirculation (FGR) and reasonable excess air coefficient, where the goal is to reduce NOx emission effectively. And an experiment was carried out on the 18 kW coke oven gas (COG) combustion device, and the effects of excess air coefficient, the ratio of flue gas recirculation and air preheating temperature on the combustion characteristics and NOx formation were extensively studied. The results show that there is an important effect of excess air coefficient, ratio of FGR and air preheating temperature on the temperature distribution inside the furnace and the formation of NOx. When the air excess coefficient of 1.2 and an external flue gas recirculation rate of 20% to 25%, the emission of thermal nitrogen oxides can be significantly reduced

1. Introduction

The ministry of environmental protection promulgated the emission standards for coking chemical industry pollutants in 2012[1]: From January 1, 2015, The NOx emission limit for existing companies is 500 mg/m³. The emission limits imposed by some special areas are 150 mg/m³. Through investigations of most coking chemical companies, it is found that the nitrogen oxide content of flue gas in tamping coke ovens above 5.5 m is generally between 1200 and 1400 mg/m³, which seriously exceeds the emission limits, Therefore, the control of nitrogen oxides in the coking industry is imminent[2]. The low-nitrogen combustion technology of COG mainly focuses on how to avoid the formation of local high-temperature zone, so that the furnace temperature is evenly distributed along the high and horizontal directions, and the generation of thermal nitrogen oxides is reduced. Its main technologies include low nitrogen burners, flue gas recirculation and reasonable control of the air excess coefficient, etc. However, with low controllable precision, the industrial coke oven is bulky and complex, which takes a lot of manpower and material resources to directly test on the coke oven scale, and even causes environmental pollution.

Studies have shown that[3]when the temperature reaches 1800 K, the thermal NOx formation rate is significantly accelerated, and the growth rate will increase by 6 to 7 times for every 100 K increase in temperature. Baltasar et al.[4]believe that flue gas recirculation can significantly reduce NOx emissions without a significant impact on CO emissions by numerical simulations. Song Shao Peng et
al. [5] believe that flue gas recirculation mainly inhibits the formation of thermal NOx, and the effect on temperature is greater than the influence of oxygen partial pressure, simultaneously it has a certain inhibitory effect on rapid NOx formation. Wang Zhi Ning et al. [6] studied the influence of internal/external flue gas recirculation on NOx formation in natural gas combustion process on a 0.8 MW pilot test bench. It was found that when the external flue gas recirculation rate increased to more than 20%, the rapid NOx mechanism played a leading role in overall NOx formation. Through numerical simulation, Stanislaw Gamrat et al. [7] found the flue gas external circulation can produce a more uniform temperature field in the coke oven combustion chamber, and the amount of NOx produced linearly decreases with the strengthening of the flue gas recirculation through numerical simulation.

In order to meet the increasingly strict emission standards of the coking chemical industry, we design a laboratory-scale COG combustion test platform using a combination of flue gas recirculation technology and a reasonable control of the air excess coefficient. The effects of flue gas recirculation ratio, air excess coefficient and air preheating temperature on coke oven gas combustion stability, burnout rate, furnace temperature distribution and NOx formation characteristics were studied.

2. Test system

2.1. Experimental device

The test device is mainly composed of a burner with a nozzle, a pre-mixing chamber for flue gas, a mixed air heater, a flue gas cooler and a flue gas recirculation system. The burner nozzle is a non-premixed burner with a power of 18 kW. The structure parameters of the furnace body are reduced by 5 times in proportion to the 6.3 m coke oven vertical fire channel. The system is shown in Figure 1.

Seven temperature-measuring thermocouples of different heights are installed vertically in the furnace. The thermocouples T1 to T7 are installed vertically from the bottom of the furnace to the top of the furnace. The temperature measurement point mentioned in the later question represents the different height positions in the furnace of the furnace. The external flue gas recirculation system consists of the return pipe, a flue gas return regulating valve, a mixed air flow regulating valve, a wind-flue mixing chamber, an air preheater heater. The test data such as combustion air flow, flue gas return flow, air preheating temperature and flue gas analyzer are all fed back to the console in real time to accurately adjust various test parameters.

2.2. Fuel characteristics and experimental conditions

The test was carried out using the prepared COG, and its composition characteristics are shown in Table 1. The combustion furnace is first heated by liquefied petroleum gas (LPG). When the temperature exceeds 1600 K, the fuel is replaced with the COG. When the temperature of the combustion chamber is stable, and the instruments such as the flue gas analyzer and the gas analyzer are working normally, the experiment operation and data collecting begins.

![Figure 1. Low NOx experimental system](image)

1-Flue gas recirculation pipe; 2-Pre-mixing chamber; 3-Mixed air heater; 4-Furnace; 5-T1; 6-T7; 7-Fire hole; 8-Flue gas heat exchanger; 9-Flue gas analyzer; 10-Gas valve; 11-Air valve; 12-Blower; 13-Reflux gas valve.
3. Experimental results and analysis

3.1. Influence of air excess coefficient on NOX generation

The air excess coefficient has an important influence on the furnace combustion temperature. The furnace temperature distribution can reflect the combustion state of the COG, and the maximum temperature in the furnace plays an important role in controlling the generation of thermal NOX.

Figure 2 shows the temperature distribution of the furnace after the flue gas recirculation ratio is 0, the preheating temperature of the air is 650 °C under different air excess coefficients. With the increases of the air excess coefficients, the temperature in the furnace generally rises briefly and then decreases. According to the analysis, when the air excess coefficient is less than 1.10, the COG is not sufficiently contacted with oxygen, resulting in a lower overall temperature in the furnace. The increase of the air excess coefficient causes the air inlet flow rate to increase, which lengthens the flame height of the Combustion, resulting in a rapid drop in the temperature of the T1 thermocouple located at the bottom of the furnace. Figure 3 shows the variation of NOx production and maximum furnace temperature with air excess coefficient. In the low air excess coefficient, the amount of NOX generated is large, and the amount of NOX is mainly controlled by the fast type NOX generation mechanism. When the air excess coefficients is higher than 1.1, the maximum temperature in the furnace gradually decreases, and the amount of NOX is gradually decreased. This is due to the relatively sufficient combustion of COG and a reduction in local high temperature zones. It is worth noting that when air excess coefficient is between 1.10 and 1.25, the maximum temperature and the rate of NOx production show a high degree of consistency. With the rapid decrease in the maximum temperature and the slow recovery, the amount of NOX produced rapidly drops, and then becomes a slow decline. This is because when the temperature rises above 1700 K, the generation of NOx is controlled by the fast type NOx turn to the thermal type NOx control. When air excess coefficients is greater than 1.15, the volume of the furnace having a temperature higher than 1700 K is reduced, and the amount of NOx generated is decreased. Therefore, when the air excess coefficient is controlled to 1.2, the maximum temperature in the combustion furnace can be lowered, and the generation of NOx can be effectively controlled.
3.2. Influence of flue gas recirculation on NOx generation

The flue gas recirculation ratio has an important impact on NOx emissions. Figure 5 shows the variation of NOx and the maximum temperature in the furnace with the flue gas recirculation ratio when the coke oven gas flow rate is 2.84 m³/h, the mixed air preheating temperature is 550 °C, and the air excess coefficient is 1.2. In the absence of flue gas recirculation, the temperature difference in the furnace is about 100 K. When the flue gas circulation is introduced, the temperature difference is reduced to less than 40 K. It can be seen that the introduction of flue gas recirculation can produce a more uniform temperature field in the combustion chamber. The numerical simulation experiment of COG combustion by Stanislaw Gamrat et al.[7] was verified. It can be seen from Figure 6 that when the flue gas circulation rate is increased from 0 to 20%, the amount of NOx produced is reduced by 48%, and then flue gas recirculation ratio is increased, and the NOx content changes slowly.

In summary, it can be concluded that when the air excess coefficient is 1.2 and the flue gas recirculation ratio is 20%, the generation of NOx in the combustion furnace can be significantly reduced, but excessively high circulation amount also brings various degrees of side effects. Therefore, it is recommended that the maximum smoke circulation rate should not exceed 25%.

3.3. Effect of air preheating temperature on NOx formation and COG combustion characteristics

When the COG is burned, the flame profile is completely invisible, and the furnace is bright yellow,
and the combustion is relatively stable. During the entire test, the smoke analyzer almost failed to detect the formation of CO, and no black carbon was formed on the fire hole.

![Graph showing NOx emissions and air preheating temperature](image1)

![Graph showing temperature distribution](image2)

Comparing Figure 3 and Figure 4, when the preheating temperature of the combustion air is lowered by 100 K, the content of nitrogen oxides is decreased by 36% at this time. It can be seen that the generation of NOx is mainly controlled by the mechanism of the generation of thermal NOx. Figure 6 shows that the increase in air preheating temperature can directly increase the average temperature of COG combustion, the average temperature in the furnace rises by 47 K for every 50 K increase in air preheating temperature. Figure 7 is a comparison of COG and LPG combustion, the temperature distribution at different locations within the furnace when the average temperature in the furnace is the same. COG and LPG show the same trend of temperature change. However, the maximum temperature of LPG combustion is higher than COG, and the temperature at the inlet is lower than COG.

4. Conclusion and discussion

In this paper, a new low NOx experimental system for reducing NOx emissions from COG was designed and developed. The parameters of air excess coefficient, flue gas recirculation ratio and air preheating temperature were studied, the conclusions are as follows:

As the air excess coefficient increases, the amount of NOx decreases rapidly, and as it continues to increase, the rate of decline becomes slower. Controlling the air excess coefficient to 1.2 has an important effect on lowering the maximum temperature in the furnace and reducing the amount of NOx produced. Flue gas recirculation not only makes the temperature distribution in the furnace more uniform, but also reduces local high temperature areas and significantly reduces NOx emissions. The increase of air preheating temperature can directly increase the average temperature of COG combustion, the average temperature in the furnace rises by 47 K for every 50 K increase in air preheating temperature. When the air excess coefficient is 1.2 and the flue recirculation ratio is 20%, the NOx production amount can be reduced by 40%.

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