The NOx of Grate-Fired Furnaces Reduction strategy

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Abstract. According to the operating characteristics of Coal Grate-Fired Furnaces, the causes of nitrogen oxides formation in Coal Grate-Fired Furnaces were analyzed, the measures to reduce nitrogen oxides emissions were introduced in principle, and according to the actual situation, the engineering measures for reducing nitrogen oxides in Coal Grate-Fired Furnaces were proposed.

1. Introduction

According to the “Statistical Bulletin on National Economic and Social Development”, in 2017, China’s crude coal output was 3.52 billion tons, it is 3.3% points higher than 2016, the number of coal exports decreased by 7.0 percentage points, and the imports increased by 6.1 percentage points, and raw coal consumption increased significantly compared with 2016. However, more than 80% of coal resources are used for direct combustion of power plant boilers and industrial boilers. The chemical elements such as nitrogen, sulfur and mercury in coal will form pollutants such as nitrogen oxides, sulfur dioxide and mercury compounds after direct combustion. Nitrogen oxides, as one of the main pollutants, have a great impact on human health and environment[1-2].

By the end of 2016, there are about 412,000 coal-fired industrial boilers in use in China, the concentration of NOx emitted by industrial boilers is 400-800 mg/m³, and millions of tons of NOx are emitted from industrial boilers every year, which causes serious environmental pollution. The number of layer-fired chain grate boilers occupies an important proportion in coal-fired industrial boilers, GB13271-2014“Discharge Standard of Boiler Air Pollutant” clearly puts forward the limit value of nitrogen oxide emission concentration of layer-fired boilers at 300 mg/m³, the emission concentration limit of nitrogen oxides is 200 mg/m³ in key areas. There are great differences in furnace structure, combustion mode and combustion temperature between chain boilers and utility boilers, the flue gas denitrification technology of utility boilers can not be directly applied to chain boilers, so it is of great significance to develop low nitrogen combustion technology for chain boilers.

2. The Introduction of Chain Boiler

Chain boilers are generally divided into two types: double-drum horizontal type and single-drum vertical type. They have the advantages of high mechanization, stable combustion, easy operation, wide adaptability of coal, low concentration of boiler smoke and dust. There is no relative movement between fuel and grate, and the coal seam is ignited from top to bottom in time gradient. On the grate length gradient, the combustion, coke combustion and burnout of fuel are analyzed by drying and volatilization. The combustion process of chain boilers has no periodicity, but it has section character.
3. Main Formation Mechanism of NOx in Chain Boiler
Nitrogen oxides produced during coal combustion mainly exist in the form of NO and NO\textsubscript{2}, and their proportion is related to combustion temperature. In the normal operation of chain boiler, the ignition of coal is homogeneous, and the combustion temperature is generally about 1350°C. The proportion of NO in the nitrogen oxides produced is larger.

Nitrogen oxides can be generated in three ways: Thermal NOx, Prompt NOx and Fuel NOx. Thermal NOx: Nitrogen oxides formed by oxidation of N\textsubscript{2} in the air during combustion at high temperature. Because the decomposition of nitrogen molecule requires large activation energy, the most influential factor on the formation of Thermal NOx is temperature, followed by the concentration of oxygen and reaction time (residence time). Prompt NOx: hydrocarbon fuels are formed under the condition of \( \alpha < 1 \), which is mainly affected by fuel characteristics, temperature and other factors. Fuel NOx: oxidized products of nitrogen-containing functional groups in fuels after thermal decomposition, mainly affected by temperature, oxygen concentration, fuel properties and other factors.

Because the combustion temperature of chain boilers is relatively low, fuel-type nitrogen oxides are the main source of nitrogen oxides. Fuel-type nitrogen oxides are the products of the interaction between nitrogen elements in coal and oxygen elements in air during coal combustion, the formation process of fuel-type nitrogen oxides is shown in Fig.1.

4. The status of Laminar-Fired Boiler
Coal bed combustion has a long history, and experimental research was the main method in the early stage. Rosin et al. studied the ignition of chain boiler through experimental system. The factors affecting the ignition were divided into upper radiation and lower airflow. The upper radiation was mainly affected by radiation temperature, air velocity and particle size. The lower airflow was mainly affected by air temperature, flow velocity, particle size and moisture[4]. On the basis of Rosin, Dunningham et al. increased the influence of ignition by fire source. It was found that under the condition of open fire ignition, the ignition events were greatly shortened[5]. Grumell et al. divided the bed into ignition zone, combustion zone and burnout zone by measuring the parameters of bed atmosphere and temperature. As shown in Figure 2, the main factors affecting the bed combustion were analyzed, including fuel type, ash content, moisture content, primary air speed, coal expansion, bed resistance and grate temperature[6].
By combining the analysis of gases in the fuel layer, the measurement of air velocity under the fuel layer and the measurement of the temperature field of the fuel itself, Kenori divided the combustion process of the fuel layer on the grate into three areas: volatilization analysis, coke gasification and coke combustion. The bed combustion scheme is shown in Fig. 3. O$_1$N is the isotherm of volatilization analysis, O$_2$K is the isotherm of pure coke precipitation, O$_3$O$_4$O$_5$O$_6$WKO$_3$ is the bed gasification zone, O$_5$O$_6$O$_7$DCW is the bed oxidation zone, WO$_5$O$_6$DCW is the ash burnout zone[7].

Luo Yonghao's team of Shanghai Jiaotong University proposed a double arch structure and studied the effects of combustion characteristics of different coal types, air staged combustion and fuel staged combustion on the emission of nitrogen oxides. It was found that different coal types had different exhaustion time and burning intensive area in the furnace, and both air staged combustion and fuel staged combustion could be significantly reduced. The effect of low NOx emission is that the air staged combustion is affected by the residence time in the reduction zone and the secondary air volume, and the fuel staged combustion is affected by the amount of reburning fuel, the residence time in the reburning zone and the excess air coefficient in the main combustion zone [8-10].

Gao Jianmin's team of Harbin University of Technology found that the unit test-bed can simulate the combustion process and NOx generation process of chain grate boiler, and the combustion and NOx generation processes are basically the same[11]. The team analyzed the effects of coking residence time, coking temperature and catalyst loading on NO reduction from 1.7-2.8mm coal coke. The combustion process and NO release of coke layer at different coke/O$_2$ ratios and temperatures were studied. It was found that the reduction layer of coke could better inhibit NO emission, but was affected by heat transfer and temperature [12-13].

5. Measures to Reduce NOx Emission

5.1 Measures to Reduce NOx in Principle

The formation of fuel-type NOx is affected by temperature, oxygen concentration and fuel properties. Therefore, the main methods to reduce the formation and emission of NOx are as follows:

1. Reducing oxygen concentration: reducing excess air coefficient in furnace, reducing oxygen concentration in ignition zone.

2. Sufficient residence time: Nitrogen in fuel is not easy to produce NOx at low oxygen concentration, and the NOx generated is reduced by homogeneous or multi-phase reaction.

3. Reduce the peak temperature: When oxygen is sufficient, the hot air temperature can be lowered or the NOx generation can be reduced by flue gas recirculation.

4. Adding reductant: generating CO, NH$_3$ and other reducing gases, reducing and decomposing NOx.

5.2 Engineering Practice of Chain Boiler

Large-scale boilers usually adopt the method of injecting reducing agent to the furnace or tail heating surface to reduce NO X. There are mainly two kinds of reduction methods: selective catalytic reduction of ammonia (SCR) and selective non-catalytic reduction (SNCR). However, the two methods require higher flue gas temperature conditions. Because of the large load variation, the
temperature window is unstable and other factors, result in the reduction denitrification method is not suitable for industrial chain boiler. There are several ways of engineering renovation application:

(1) Air Classified Combustion: Air Classified Combustion is a technology used in almost all combustion modes to reduce NOx. The aim is to avoid reducing excess air coefficient and NOx generation in areas where the temperature is too high and the formation of NOx is easy. The principle is shown in Figure 4.

![Fig. 4 Air classification schematic diagram](image)

(2) Fuel-staged combustion: also known as "reburning method", which uses three-stage combustion, the furnace is divided into main combustion zone, reburning zone (or reduction zone) and burnout zone. The primary fuel which accounts for about 80%-85% of the total fuel is fed into the main combustion zone, and NOx is generated under the condition of excess air ratio > 1. The remained secondary fuel of 15%-20% is fed into the reburning zone, which ensures excess air ratio < 1. Under the experimental conditions, the emission reduction of 50%-60% NOx can be achieved[3-4]. The principle is shown in Fig. 5.

![Fig.5 The Fuel-staged combustion schematic diagram](image)

(3) Flue gas recirculation: Part of low-temperature flue gas is directly fed into the furnace, or mixed with air (primary or secondary air) and fed into the furnace. Because the flue gas absorbs heat and dilutes the concentration of oxygen, the combustion speed and furnace temperature are reduced, and the thermal NOx is reduced. If fuel classification is used, flue gas recirculation is generally used to transport secondary fuel. The reduction degree of NOx by flue gas recycling is mainly affected by the ratio of flue gas recycling and excess air coefficient. In operation, the circulation ratio should not be too high or too low, and the effect of too low is not obvious. Excessive high NO recycling will increase the amount of NO and lead to the enrichment of NOx.

(4) Coke reduction: The coke particles in the flue gas are sent back to the combustion chamber to reduce NOx and incomplete combustion loss. By collecting coke particles in tail flue and nitriding with urea, the reduction capacity of coke is strengthened and the emission of NOx is reduced.

6. Conclusions
(1) The causes of different types of NOx formation are analyzed. Because of the low temperature in the furnace, the fuel type is the main type of NOx formation in the laminated-fired boiler.

(2) In principle, the method of reducing NOx is analyzed, and the renovation measures for reducing NOx emission of stratified-fired boilers are put forward, such as Air Classified Combustion, Fuel-staged combustion, Flue gas recirculation and Coke reduction.

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