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ARTICLE

RESEARCH ON THE APPLICATION AND ENVIRONMENTAL PROTECTION SIGNIFICANCE OF CIRCULATING FLUIDIZED BOILER

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ABSTRACT

This study discusses contribution of circulating fluidized boilers to environmental protection. Present situation of atmospheric pollution and the countermeasure of its treatment, working principle and characteristics of the type of the boiler, mechanism of desulfurization and mechanism deducing NOX discharge etc. were described.

KEYWORDS

Recycle fluidized boiler, environment, atmospheric pollution, working principle

1. STATUS QUO OF AIR POLLUTION IN OUR COUNTRY AND COUNTERMEASURES

In today's world, environmental problems have become the most serious challenge to human survival and development, and are one of the most important factors restricting economic and social development. With the development of the economy, the environmental pollution has been aggravated. The occurrence of abnormal phenomena such as "El Niño", "greenhouse effect", "ozone hole" in the atmosphere, "photochemical smog" and "acid rain" are all bad consequences of environmental pollution. During the "Eighth Five-Year Plan" period, our country's air pollution level intensified, with smoke and acid rain causing the greatest harm. A number of acid rain areas have been formed in Central China, Southwest China, East China and South China, and the area affected by acid rain accounts for 30% of the country's land area. The pH value of acid rain in the central area of central China where acid rain is the most serious is less than 4 on average, and the frequency is above 80%; the pH value of acid rain in southwest China is less than 5, and the frequency is more than 80%; the damage range of acid rain in East China and South China is wide, and the frequency is above 60%. Acid rain has gradually developed to northern our country.

The main reason for environmental deterioration is that industrial pollution is on the rise and is widely distributed. In addition to large industrial enterprises, small and medium-sized enterprises and township and village enterprises have also become important sources of pollution. According to the Bulletin of the State of the Environment of China, the pollutants in industrial waste gas showed an upward trend in 1995, of which SO_2 increased by 4.1% over the previous year (excluding township and village enterprises). The main reasons for the aggravation of industrial pollution are the backward production technology and equipment and the unreasonable layout. Extensive management increases pollution at the expense of the environment.

Boiler flue gas pollution is one of the important items of industrial pollution, and it is also an important factor causing air pollution (main pollutants are soot, SO_2 and NO_X). At present, our country's energy structure is dominated by coal, and more than 80% of the steam required by the industry (mainly used for power generation and heating) is generated by coal-fired boilers. Our country's coal consumption ranks first in the world, and this energy structure using coal as primary energy will continue for a long time in our country. A large amount of coal is burned, resulting in aggravated environmental pollution from coal-fired flue gas. Taking 1995 as an example, the amount of smoke and dust discharged into the atmosphere from coal-fired boilers reached more than 17.2 million tons, the amount of SO_2 reached more than 18 million tons, and the amount of NO_X was also as high as more than 10 million tons, and it was still increasing year by year. The annual loss due to boiler flue gas pollution is about 10 million yuan. Therefore, how to reduce the pollution of flue gas to the environment is a top priority.

According to the requirements put forward by the Fourth National Environmental Protection Conference held in July 1996, the prevention and control of industrial pollution should be strengthened at present. And proposed that by 2000, the total national pollutant discharge should be frozen at the level of 1995. The petrochemical industry is one of the country's pillar industries. Compared with other industries, it is a large energy consumer and a large polluter. All enterprises are equipped with various thermal power boilers or industrial boilers and other power equipment for production needs. Especially in recent years, in order to reduce production costs and save oil and gas resources, a large number of oil and gas boilers have been changed to coal-fired boilers. With the development of production, many coal-fired boilers will be deployed in the future, so coal consumption will increase significantly, and the accompanying flue gas pollution will also increase year by year. Therefore, taking effective measures to prevent and control flue gas pollution is one of the major issues we face.

The soot in the flue gas can be removed by various dust collectors. The dust removal equipment currently used mainly includes the following: cyclone dust collector (efficiency of about 80%), water film dust collector (efficiency of 94% to 96%), bag dust collector (efficiency of below 99%,

currently very Less used), electrostatic precipitator (efficiency can reach more than 99%). At present, water-film precipitators are used for small and medium-sized industrial boilers, and electrostatic precipitators for large and medium-sized power station boilers can generally meet the requirements of emission standards.

SO_2 and NO_X in flue gas are the most harmful, and they will form acid rain after being discharged into the atmosphere. Its reaction formula is as follows:

$$SO_2 + \frac{1}{2}O_2 + H_2O \rightarrow H_2SO_4 \quad (1)$$

$$NO_2 + \frac{1}{4}O_2 + \frac{1}{2}H_2O \rightarrow HNO_3 \quad (2)$$

The formation of "acid rain" leads to acidification of the atmosphere, rivers, lakes, and soil, causing serious environmental pollution. In addition, NO_X is also one of the important pollutants in the formation of photochemical smog; at the same time, it can also cause the destruction of the ozone layer in the atmospheric stratosphere. In addition, SO_2 and NO_X are harmful to buildings and people, which is one of the causes of cancer.

At present, there is a lack of economical and practical removal methods for SO_2 and NO_X produced by coal-fired boilers in China. In the early 1980s, the petrochemical system introduced a set of flue gas desulfurization device and a set of denitrification device from Japan in the new boiler project of Ningxia Chemical Fertilizer, which not only has high investment cost, but also high operating cost. The set has been discontinued since then. The large coal-fired boilers in the domestic power system have not yet solved this problem well.

In the 1970s, a new type of coal-fired boiler, recycle fluidized boiler, was developed abroad. The boiler is highly adaptable to fuel, especially has the outstanding characteristics of desulfurization and inhibition of NO_X generation in the boiler, and the method is simple, economical and practical, so it is recommended by environmental protection organizations at home and abroad, and some people even call this boiler a "green boiler".

The development of recycle fluidized coal-fired technology in China is relatively late, but it has made rapid progress. Since 1986, it has moved from laboratory to industrial application. At present, a variety of products with a capacity below 75t/h have been put into production and application. Recycle fluidized boilers with capacities of 220t/h and above are also being developed and constructed.

At present, the recycle fluidized boiler is under development in China. Its superiority has not been fully recognized by most people, and its application is not yet widespread. In order to meet the requirements, put forward by the National Environmental Protection Conference, further control air pollution and reduce the emission of SO_2 and NO_X in flue gas, it is an ideal choice to actively promote and apply this kind of boiler in the future.

2. THE WORKING PRINCIPLE AND MAIN CHARACTERISTICS OF THE RECYCLE FLUIDIZED BOILER

2.1 Working principle

For many years, the small boilers used in our country (evaporation capacity of 35t/h and below) are generally dominated by layer-fired furnaces, while large and medium-sized boilers are dominated by pulverized coal furnaces. The layer combustion furnace directly sends large particle coal (generally ≤ 40mm) to the grate for relatively static combustion; the pulverized coal furnace is to grind the fuel coal into powder and then blow it into the furnace by wind to burn in a suspended state. The recycle fluidized boiler is a boiler with a new type of combustion that is different from the conventional one. It crushes the coal into small granular coal particles (generally less than 12mm) and then mixes them with a desulfurizer (generally limestone, with a particle size of about 1mm). are sent into the boiler furnace together to burn in a fluidized state. The structure of the boiler is divided into two parts: the first part consists of furnace (fast fluidized bed), gas-solid material separation equipment, solid material recycling equipment, etc. The above parts form a solid material circulation loop. The second part is the convection flue, which is equipped with superheater, economizer and air preheater and is similar to the conventional pulverized coal boiler.

A schematic diagram of the combustion system of a typical recycle fluidized boiler is shown in Figure 1. The fuel and desulfurizer are sent into the furnace through the hopper, and the primary air and secondary air required for combustion are sent from the bottom and side walls of the furnace respectively. The combustion of fuel is mainly completed in the furnace, and the unburned solid materials brought out of the furnace by the airflow are collected in the separation device and sent back to the furnace for re-burning through the return device. The separated flue gas is discharged through the convection flue, and the burnt-out ash is discharged from the bottom ash port.

2.2 Main Features

(1) Wide adaptability of fuel

Due to the special hydrodynamic characteristics of the recycle fluidized boiler, it has a strong adaptability to the fuel. It can burn both high-quality coal and various inferior fuels, such as high-ash coal, high-sulfur coal, high-moisture coal, coal gangue, peat, oil shale, petroleum coke, tailings, etc., and even the slag discharged from the chain furnace or the gasifier of the fertilizer plant can be mixed with the fuel coal for combustion. The boiler has no restriction on the level of volatile content (Var) in the industrial analysis of fuel coal, which overcomes the disadvantage that

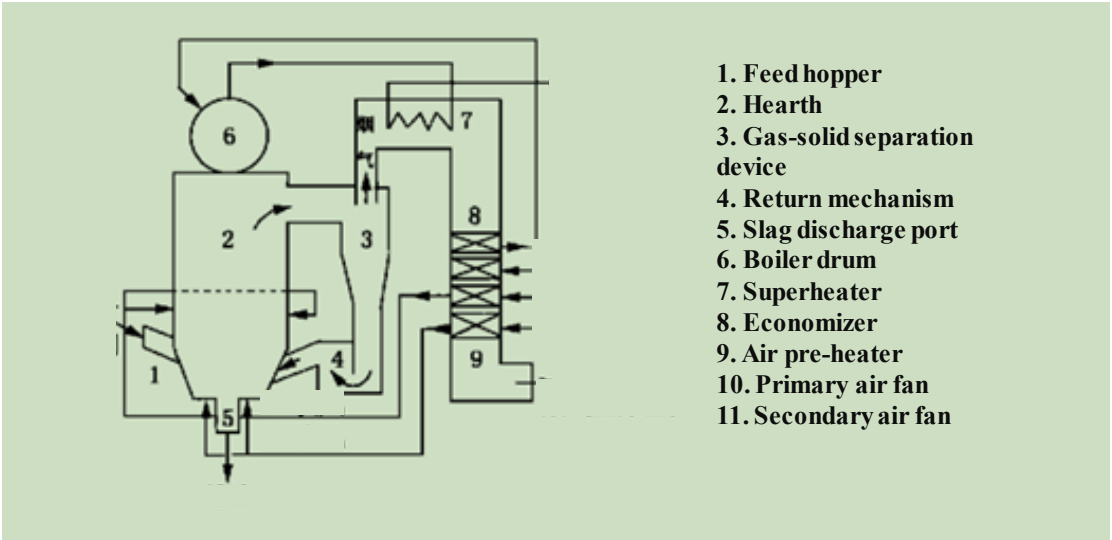

Figure 1. Schematic diagram of the combustion system of the recycle fluidized boiler

the chain furnace is only suitable for high-volatile fuel coal.

(2) High combustion efficiency

Due to the good gas-solid mixing and high combustion rate of the recycle fluidized boiler, especially the fly ash separation device is installed, so that most of the unburned fuel can be recycled into the furnace for combustion, thereby reducing the loss of incomplete combustion and improving the combustion efficiency. The combustion efficiency is usually in the range of 97.5% to 99.5%, which is comparable to that of pulverized coal boilers.

(3) Efficient desulfurization

In the past, the methods to control SO_2 in boiler flue gas usually include flue gas desulfurization and clean coal technology. The flue gas desulfurization technology is generally imported technology, and the investment is large. Clean coal technology refers to burning coal with low sulfur content or reducing the sulfur content of fuel coal by methods such as coal washing, so as to achieve the purpose of reducing SO_2 in flue gas. This method has great limitations, in addition, the system is complex and has few applications. The desulfurization of the circulating fluidized bed boiler is realized by adding a solid desulfurizer (mainly limestone at present) directly in the fuel coal or in the furnace. The method is simple and the desulfurization efficiency can reach 85% to 90%.

(4) Low nitrogen oxides (NO_x) emissions

This is another very attractive advantage of CFB boilers. Operational experience shows that the NO_X emission range of this boiler is 50-200ppm. The low NO_X emission is achieved by the use of low temperature combustion (<1000°C) and staged combustion technology. At present, there is no better removal method for NO_X in general boiler flue gas.

(5) Simple fuel pretreatment system

The coal feeding particle size of the recycle fluidized boiler is generally less than 12mm, so compared with the pulverized coal boiler, the fuel preparation system is greatly simplified. In addition, this kind of boiler can directly burn high-moisture coal (more than 30% moisture), so no special treatment system is required when burning high-moisture fuel.

(6) It is easy to realize comprehensive utilization of ash and slag

The combustion process of recycle fluidized boiler belongs to low temperature combustion. At the same time, the excellent burnout conditions in the furnace make the ash content of the boiler low, which belongs to low temperature burning through. It is easy to realize comprehensive utilization of ash and slag, such as cement admixture or building material. At the same time, low temperature burning through is also conducive to the extraction of rare metals in the ash.

(7) Large load adjustment range and fast adjustment rate

The load adjustment range of this kind of boiler is 100% to 50% (some products can reach 30%), and it can still burn stably at low load, keeping the steam parameters at the boiler outlet unchanged. The load regulation rate is also very fast, typically up to 4% per minute.

(8) Moderate investment and operating costs

The investment and operating costs of recycle fluidized boiler are slightly higher than those of conventional pulverized coal boilers, but 15% to 20% lower than those of pulverized coal boilers equipped with desulfurization devices.

3. DESULFURIZATION MECHANISM OF RECYCLE FLUIDIZED BOILER

Sulfur is a flammable substance. In the boiler furnace, the sulfur in the fuel is easily oxidized with the combustion-supporting air to form sulfur dioxide. The reaction formula is as follows:

$$S + O_2 \rightarrow SO_2 \quad (3)$$

The combustion desulfurization process of the recycle fluidized boiler is to send the desulfurizer (usually limestone or dolomite) into the furnace, and then react with the SO_2 gas generated by the combustion to achieve the purpose of desulfurization.

The reaction between the solid desulfurizer and SO_2 gas includes two main processes: the process of rapidly decomposing the desulfurizer into CaO and the relatively slow CaO sulfation process. The reaction formula is as follows:

$$CaCO_3 \rightarrow CaO + CO_2 \quad (4)$$

$$CaO + SO_2 + \frac{1}{2}O_2 \rightarrow CaSO_4 \quad (5)$$

The optimal reaction condition of the reaction formula (4) is to heat to 500-900°C, the CO_2 generated after the reaction is discharged from the boiler with the flue gas, and the remaining CaO is a porous oxide, which is easily oxidized with SO_2. Through the reaction formula (5), CaO and SO_2 are oxidized to form relatively stable $CaSO_4$, which is discharged from the boiler with the slag. However, the reaction temperature should not exceed 1200°C, otherwise the reverse reaction will occur and SO_2 gas will be released again.

In the recycle fluidized boiler, due to the unique design and operating conditions, the main circulation loop of the entire recycle fluidized boiler operates within the optimal temperature range (850-900°C) for desulfurization. At the same time, due to the internal and external circulation of solid materials in the furnace (through the separation device and the return device), the residence time of the desulfurizer in the furnace is greatly prolonged, and the average residence time is usually up to tens of minutes. In addition, the strong turbulent mixing in the furnace is also very beneficial to the combustion desulfurization process of the recycle fluidized boiler. When the Ca/S ratio is 1.5 to 2.5, the desulfurization efficiency usually reaches 90%.

MECHANISM OF REDUCING NO_X EMISSIONS FROM RECYCLE FLUIDIZED BOILER

NO accounts for more than 95% of the nitrogen oxides generated during the combustion of fuel. According to the mechanism of NO_X generation, in coal-fueled combustion equipment, there are mainly two types of NOX generated: (1) Thermal NO_X: NO_X generated by the oxidation of N_2 in the combustion air at high temperature; (2) Fuel NO_X: NO_X produced by the oxidation of organic nitrogen compounds in the fuel during combustion.

The amount of thermal NO_X generation is mainly related to temperature, oxygen concentration and residence time in high temperature area; The amount of fuel NO_X generation is mainly related to fuel nitrogen content, temperature and excess air coefficient. Figure 2 shows the formation of NO_X in the furnace at different combustion temperatures. When the maximum temperature T_{max} < 1500k, the fuel NO_X is dominant; when T_{max} > 1900k, the proportion of fuel NO_X decreases; when T_{max}>2200～2300k, fuel nitrogen has no effect on NO_X. In the pulverized coal boiler, the maximum temperature T_{max} in the furnace is above 1500k, and the NO_X generated when coal is burned not only comes from the nitrogen contained in the fuel, but also a considerable part from the nitrogen in the air (thermal NO_X). Usually, the proportion of thermal NO_X to the total NO_X generated is in the range of 25% to 50%. The NOX emission concentration of pulverized coal boilers is generally 400-600 ppm.

The recycle fluidized boiler operates in the bed temperature range of 850~900℃ (T_{max} < 1500k). The NO_X generated by coal combustion is mainly fuel NO_X, and the thermal NO_X generation is very small, usually less than 10% of the total NOX emission. Therefore, because the combustion temperature of the circulating fluidized bed boiler is much lower than that of ordinary boilers, it produces less NO_X than other boilers. According to information, the amount of NO_X produced by the combustion of circulating fluidized bed boilers is generally reduced by more than 30% compared with other boilers.

In addition, the use of staged combustion technology in recycle fluidized boiler is another important factor in reducing NO_X generation. Based on the difference in the proportion of fuel in different combustion zones

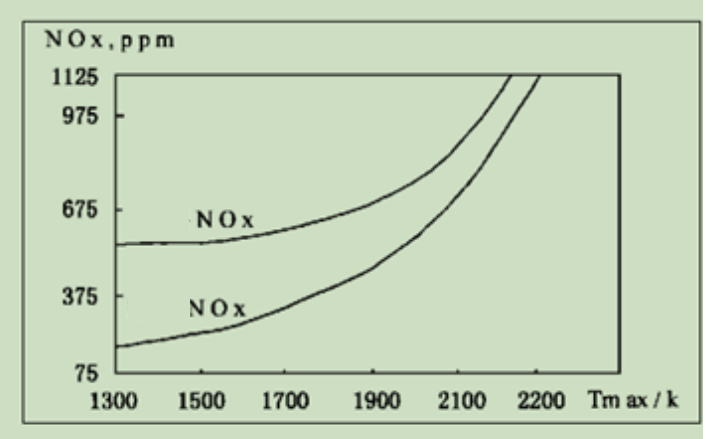

Figure 2. The relationship between NO_x generation and temperature in the boiler

of the furnace, different amounts of air are supplied in proportion. The staged combustion formed in this way is very effective in controlling the emission of fuel NO_x. The organization of the generated NO_x is reduced. At the same time, the coke concentration in the recycle fluidized boiler is relatively high, which is also very beneficial to the reduction of the generated NO_x ($NO+C \rightarrow 1/2N_2+CO$). According to the actual test results, the NO_x emission concentration of the circulating fluidized bed boiler is generally 50-200PPm, which can meet the requirements of environmental protection regulations in developed countries.

5. CONCLUSION

Since the recycle fluidized boiler was successfully developed in our country in the late 1980s and applied to practical projects, it has achieved good economic and social benefits in industrial production due to its unique advantages. The recycle fluidized boiler is a new type of coal-fired boiler that is different from the conventional ones. Its biggest advantage, in addition to its strong adaptability to fuel, is that it can carry out desulfurization (SO_2) during the combustion process by mixing solid desulfurizers (limestone, etc.). At the same time, by adopting low temperature combustion and staged combustion technology, the amount of NO_x generated during the combustion process can be reduced. Both functions are carried out in the boiler furnace. The method is simple, the effect is good, and it is economical and applicable. In order to control air pollution and reduce the emission of SO_2 and NO_x in boiler flue gas, recycle fluidized boilers should be preferred in the construction of self-provided thermal power plants or boiler rooms in the future.

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