Research on the Application of Fly Ash Reburning Technology in Circulating Fluidized Bed Thermal Boiler Based on Generation Mechanism

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Abstract: It is difficult to improve the efficiency of CFB boiler burning anthracite. The main reason is that the primary loss rate of anthracite fuel is low. Circulating fluidized bed boiler has been widely popularized at home and abroad because of its great advantages such as strong adaptability of coal and good environmental protection characteristics, and it is developing towards large scale. Why the efficiency of CFB burning anthracite is not improved has not been explained fundamentally. The combustion technology of circulating fluidized bed boilers has been rapidly developed by virtue of its own advantages. It has become the best commercialized combustion technology at present, and is moving toward supercritical and large-scale. Due to the large proportion of inferior coal such as stone coal and high-sulfur anthracite in China's coal resources, the coal source of each power plant is variable and the coal quality is unstable. Based on the analysis of the direction of the generation mechanism, this paper further discusses the application of fly ash backfire technology in circulating fluidized bed thermal boiler.

1. Introduction

Circulating fluidized bed boilers are widely popularized at home and abroad due to their great advantages such as strong adaptability to coal types and good environmental protection characteristics, and are developing towards large scale. Circulating fluidized bed boiler combustion technology has developed rapidly with its own advantages and has become the most commercialized clean combustion technology at present. It is moving towards supercritical and large-scale development [1]. After all, the application history of circulating fluidized bed is shorter than that of layer-fired furnace and chamber-fired furnace, and its inherent laws are not known by people. Why the efficiency of circulating fluidized bed burning anthracite is not high has not been fundamentally explained [2]. How to improve the high-temperature desulfurization efficiency in circulating fluidized bed furnace, improve the utilization rate of desulfurizer, and how to reduce the carbon content in fly ash and improve the combustion efficiency have received extensive attention from researchers at home and abroad. Although circulating fluidized bed combustion technology has many advantages such as large load regulation range and wide combustion adaptability, due to the large proportion of inferior coal such as stone coal and high-sulfur anthracite in China's coal resources, and the variety of coal sources and unstable coal quality in various power plants [3]. For circulating fluidized beds burning anthracite, fly ash reburning technology is an effective method to greatly improve boiler efficiency.

Circulating fluidized bed boilers are favored for their unique advantages. Some fluidized bed boilers, especially circulating fluidized bed boilers burning anthracite, have high carbon content in fly ash and low utilization rate of desulfurizer [4]. Regardless of whether the cyclone separator used is high temperature, medium temperature or low temperature, and whether the separator is cyclone or inertia type, the carbon content in fly ash of the tail dust collector is generally higher [5]. The screened qualified coal enters the spiral coal feeder from the coal hoppers on both sides of the boiler, and enters the furnace along with the secondary air for sowing coal. The cold air is sent into the air chamber by the blower through the air preheater and then enters the furnace through the air cap. The two are evenly mixed to form a fluidized combustion mode [6]. If the circulation ratio is low, the

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corresponding separator efficiency is also low, and more unburned particles cannot be separated from the separator and discharged out of the flue, which is an important aspect of low boiler efficiency [7]. Anthracite has low volatile and poor reactivity. Under the conditions of combustion temperature and residence time at which bituminous coal can obtain ideal burnout degree, the combustion reaction rate of anthracite is much lower [8]. Based on the analysis of generation mechanism, this paper further discusses the application of fly ash reburning technology in circulating fluidized bed thermal boilers.

2. Characteristics and Working Principle of Fly Ash Reburning Technology

The fly ash underfeed reburning system consists of a fly ash separation device, a fly ash feeding device, a spraying device, a wear-resistant elbow, an underfeed nozzle, a blockage removing device, a conveying gas source and the like to form a stable, reliable and easy-to-adjust fly ash pneumatic conveying system. For CFB boilers burning anthracite fuel, since the circulation ratio should not be too high, it is necessary to adopt a low circulation ratio, which will inevitably lead to low efficiency, which is determined by its nature. Due to this drawback of circulating fluidized bed, despite all efforts, it cannot change the appearance of low efficiency. If we want to make a fundamental change, we must have new ideas. Fly ash reburning technology is coming into being. Different from the conventional method of returning the separated fly ash to the furnace on the bed surface, in the underfeed reburning system, the separated fly ash is fed into the bed from the underfeed nozzle located at the bottom of the dense phase bed through the pneumatic conveying pipeline, through the air chamber and the air distribution plate, and the flow rate is controlled by the fly ash feeding device and sprayed by the ejector, thus realizing cyclic combustion. The fly ash separation device can be a high-temperature separator located at the furnace outlet, a medium-temperature separator, or a dust collector at the tail of a boiler, which is used for efficiently separating fly ash particles with high carbon content. If the particles are too coarse, the total area of combustion heat exchange will be relatively reduced and the burnout time will be prolonged. However, if the particles are too fine, they will be entrained by fluidizing air into the furnace and fly out of the dense phase area, or even out of the furnace to burn.

The key to reduce the carbon content of fly ash is to improve the burn-out degree of fine particles that pass through the furnace once but are not burnt out and have few cycles. The concept of fly ash reburning, the so-called fly ash reburning, is to send the fly ash from the tail flue back into the furnace. For this reason, a fly ash collector should be installed in the tail flue to return the collected fly ash. The fly ash feeding device plays a role in controlling the flow rate of fly ash for back combustion. It is better to adopt non-mechanical air control valve for high-temperature or medium-temperature fly ash, while electric air lock or screw feeder is commonly used for fly ash of tail dust collector. For circulating fluidized bed boilers, when the feed particle size distribution is constant, the particle size that can fly out of the bed to participate in material circulation is determined by the operating wind speed, and the combustion efficiency of fine particles is determined by factors such as separation efficiency [9]. The underfeed nozzle is the most critical component in the system. It is located in a very harsh working environment. The outer side is severely scoured and abraded by high-temperature solid bed particles, while the inner side is abraded by high-speed ash-containing gas-solid two-phase flow. In the start-up stage of the boiler or when the fly ash underfeed reburning system is not put into operation, the underfeed nozzle is completely in a dry burning state, so it must be made of high-quality materials with high temperature resistance, oxidation resistance and abrasion resistance.

3. Efficiency Analysis of Circulating Fluidized Bed Boiler

Analyzing the calculation formula of boiler efficiency anti-balance, the two biggest losses affecting efficiency are smoke exhaust loss and mechanical incomplete combustion loss. No matter how low the temperature of the reburning fly ash is, it enters the bottom of the dense phase bed through the underfeed nozzle and mixes with a large number of hot bed material particles to carry out strong heat and mass transfer, rapidly heats up and starts combustion. In order to reduce the smoke exhaust loss, it is nothing more than optimizing the excess air coefficient and minimizing the smoke exhaust temperature. The latter is also limited by corrosion of the rear heating surface, which is the same as that of ordinary boilers. Because the latter is more influential and has more characteristics related to circulating fluidized bed, the focus of this study is also focused on this. After the particles combusted in the dense phase zone enter the dilute phase zone with relatively low temperature, they can still maintain high temperature for continuous burnout.

The calculation formula for incomplete combustion loss of fly ash in circulating fluidized bed boilers is derived:

$$S_{fh} = q_{fh} = \beta(1-\eta_f)(1-\varepsilon)/[1-(1-\varepsilon)\eta_f] \tag{1}$$

In the formula, β is the lean phase combustion share, n_f is the separator efficiency, and ε is the ignition loss rate of combustible particles for one cycle. The incomplete combustion loss S_{fh} of fly ash is related to three factors: lean phase combustion fraction β, separator efficiency η_f, and combustion loss rate ε of combustible particles circulating once.

The dense phase region of the circulating fluidized bed is usually in a bubbling fluidized bed or a turbulent fluidized bed state. Fly ash particles fed back into the furnace through bottom feeding are violently rolled and rubbed together with a large number of bed material particles in the bed, so that the ash shell on the outer layer of the fly ash particles can be ground off to expose the black core inside, which is conducive to burnout.

Under certain conditions, the circulation ratio K is only related to the separator efficiency η_f in value:

$$K = \alpha_{fh} A_{ad} \eta / (1-\eta_f) \tag{2}$$

In the formula, α_{fh} is the fly ash share and A_{ad} is the ash content of the fuel. For certain furnace types and known fuels, α_{fh} and A_{ad} are constants, and the independent variable η_f is derived when:

$$\partial K / \partial \eta_f = \alpha_{fh} A_{ad} / (1-\eta_f)^2 \tag{3}$$

For a certain share of fuel and fly ash, the increase of separator efficiency η_f will inevitably be accompanied by the increase of circulation ratio K, and the corresponding fluidization speed will also be increased, resulting in an increase in power consumption.

At present, it is still difficult to produce separators with high separation efficiency, and too high circulation ratio will also bring the above adverse effects, so domestic circulating fluidized bed boilers are mostly of low and medium circulation ratio. The bottom feed reburning fly ash particles are fed into the furnace from the bottom of the dense phase layer, which greatly increases its residence time in the dense phase layer, thus prolonging the total residence time in the furnace, and is very important for the burnout of fly ash [10]. For circulating fluidized bed boilers burning anthracite fuel, due to the low primary ignition loss rate, although the fuel particles can basically burn out after a limited number of cycles, if the circulation rate is low, the corresponding separator efficiency is also low. The burning fly ash particles still maintain a high temperature after entering the dilute phase region, and the residence time in the dilute phase region is further burnt out, and a high burn-out degree can be obtained after one cycle. Therefore, the ideal burn-out effect can be obtained even at medium and low circulation rates by using fly ash bottom feeding reburning method.

4. Conclusions

Fly ash underfeed reburning technology can be used not only in newly designed bubbling fluidized bed and circulating fluidized bed boilers, but also in the renovation and improvement of the original fluidized bed boilers, as well as in the transformation of pulverized coal boilers and chain boilers into fluidized bed boilers. Fly ash recycling system is technically feasible and has good economic benefits when applied to circulating fluidized bed boilers. In order to reduce the smoke exhaust loss, it is nothing more than optimizing the excess air coefficient and minimizing the smoke exhaust temperature. The concentration of fly ash in the furnace and the flue at the tail of the furnace increases after the fly ash is used for reburning. The increase is related to the share of reburning, but the total amount of ash discharged remains unchanged. With the increase of circulation ratio and fluidization wind speed, the carbon content in fly ash decreases, while the desulfurization efficiency increases, but the increase slows down. For circulating fluidized bed boilers, when the feed particle size distribution is constant, the particle size that can fly out of the bed to participate in material circulation is determined by the operating wind speed, and the combustion efficiency of fine particles is determined by factors such as separation efficiency. Fly ash bottom feed reburning technology is especially suitable for the combustion of anthracite, lean coal and other low volatile coal and bituminous coal with low volatile and high heat value. For a circulating fluidized bed boiler burning anthracite and adopting low circulation rate, its combustion efficiency must be low.

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