Discussion on the key technology of modification of desulfurization ultra-low emission in CFB boiler

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Abstract. Aiming at the key technology in the retrofitting process of desulfurization ultra-low emission of large scale CFB boilers, the paper puts forward the measures for improving the efficiency of desulfurization in the boiler and its optimization measures. Aiming at the application of flue gas circulating fluidized bed desulphurization process in the retrofit of desulfurization with ultra-low emission, the arrangement of pre-electric precipitator, the optimum desulphurization distribution ratio outside the furnace and the relationship between desulfurization efficiency and cost in the furnace are put forward. The research can provide references for the newly built and retrofitted large-scale CFB unit with CFB flue gas desulfurization system.

1. Introduction

Circulating fluidized bed (CFB) technology has emerged as a highly utilized steam generation technology owing to its features of fuel flexibility, high desulfurization efficiency, and the number of CFB boiler installations has been growing exponentially in the last decades\cite{1-2}. But in recent years, with the increasing severity of environmental protection policies, in particular, the release of the work plan for the comprehensive implementation of ultra-low emission and energy-saving renovation of coal-fired power plants (UNCEF (2015) 164), higher requirements for environmental protection emissions of CFB units are put forward: By 2020, all coal-fired power plants with retrofit conditions will strive to achieve ultra-low emissions (dust, SO\textsubscript{2} and NO\textsubscript{X} were not higher than 10, 35 and 50 mg/Nm\textsuperscript{3}, respectively.) (see Table 1). However, for active CFB units, It is very difficult to achieve ultra-low emission only by relying solely on internal desulphurization and low nitrogen combustion, ultra-low emission modification must be implemented.

| Indicator name | Concentration(mg/Nm\textsuperscript{3}) |
|----------------|------------------------------------|
| dust           | 10                                 |
| SO\textsubscript{2} | 35                                 |
| NO\textsubscript{X} | 50                                 |

\* with a base oxygen content of 6 %

2. Improving desulphurization efficiency in furnace

Prior to July 2014, Domestic CFB boiler to achieve standard discharge, SO\textsubscript{2} and NO\textsubscript{X} emission targets below 200 mg/Nm\textsuperscript{3} through a series of technical modifications(400 mg/Nm\textsuperscript{3} control in individual
areas). In order to ensure that the environmental protection emission is qualified, some units adopt low oxygen operation mode because of the unsatisfactory revamping effect\[3\]. Although the NO\textsubscript{X} emission is qualified, the boiler desulfurization efficiency is low and the ratio of calcium to sulfur is high, which results in the calcium oxide in fly ash up to more than 30%, thus affecting the boiler efficiency. Therefore, the desulfurization system in boiler should be effective before the ultra low emission modification.

2.1. Operation parameter optimization

In CFB boilers, there are contradictions between desulfurization and low nitrogen combustion in the furnace. NO\textsubscript{X} emissions are mainly affected by boiler coal quality, combustion temperature, combustion uniformity, reduction atmosphere in the furnace and so on\[4,5\]. SO\textsubscript{2} emission is mainly related to sulfur content, combustion temperature, combustion uniformity, oxidizing atmosphere in the furnace, limestone quality and reaction efficiency, separator efficiency and other factors\[5,6\]. It can be seen that the combustion temperature (bed temperature) and the redox atmosphere (operating oxygen) of gas-solid two-phase flow in CFB boiler are the decisive factors affecting NO\textsubscript{X} and SO\textsubscript{2} emissions.

2.1.1. Bed temperature optimization. Research shows that the optimum temperature range of desulfurization in CFB boiler furnace is 850-890 °C\[5,7\]. Based on the formation mechanism of NO\textsubscript{X}, the emission concentration of NO\textsubscript{X} rises sharply after the bed temperature exceeds 930 °C. Therefore, the bed temperature of CFB boiler is generally designed as no more than 880 °C (Figure 1). In this temperature range, it can not only guarantee the combustion efficiency of the boiler, but also improve the desulfurization efficiency, and at the same time restrain the formation of NO\textsubscript{X}\[8\].

![Figure 1. Relationship between bed temperature and desulfurization efficiency.](image)

2.1.2. Operating oxygen optimization. Properly adjusting the running oxygen quantity can effectively improve the mixing degree of gas-solid two-phase, achieve the effect of staged combustion, and effectively control the NO\textsubscript{X} emissions at the same time. If the oxygen content is too large, the heat loss of exhaust smoke and the power consumption of the fan will be increased. On the contrary, although the power consumption of the fan and the amount of NO\textsubscript{X} will be decreased, the loss of combustible matter and incomplete combustion heat of fly ash will be increased, and the efficiency of SO\textsubscript{2} removal will be reduced. At the same time, the amount of limestone is obviously increased. Considering the coordinated control of NO\textsubscript{X} and SO\textsubscript{2} emissions, the oxygen content of boiler is controlled at 2.5% ~ 3.0% in operation(50~100%BMCR), which ensures the original information inhibition of NO\textsubscript{X} and the removal efficiency of SO\textsubscript{2}. 


2.1.3. **Optimum molar ratio of calcium to sulfur in furnace.** Limestone desulfurization heat loss in the furnace will have a certain effect on boiler efficiency[9]. The formula for calculating the heat loss of limestone desulfurization is as follows:

$$q_f = \frac{S_{tar}(57.19\beta_f K_{glb} - 152\eta_d)}{Q_f}$$

*β*: Decomposition rate of calcium carbonate in desulfurized limestone (98%); *K*: Calcium-sulfur molar ratio; *η*: Sulphur removal efficiency; *S*: Sulfur content of coal; *Q*: Heat input per unit mass fuel.

From formula (1) it can be seen that the molar ratio of calcium to sulfur in the furnace will directly affect *q_f*. Figure 2 shows the relationship between desulfurization efficiency, Ca/S and boiler efficiency changes. When *η_d/K_{glb}*>36.87, the influence of desulfurization on boiler efficiency is a positive effect. If we continue to increase the calcium and sulfur molar ratio of the boiler, the desulfurization efficiency will increase slowly, and the impact on the boiler efficiency will gradually become a negative effect. Long operating results of boilers show that the optimum molar ratio of calcium to sulfur in furnace is 1.3–2.0.

![Figure 2](image_url)

**Figure 2.** Effect of Ca/S on boiler efficiency and desulfurization efficiency in furnace.

Desulfurization optimization in the furnace also includes the following: (1) The boiler cyclone separator can further improve the efficiency, ensure that more unreacted CaO are sent back to the furnace, and improve the utilization ratio of desulfurizer. (2) Limestone system optimization and particle size optimization; (3) Desulfurization control system margin optimization in response to AGC instructions.

3. **Retrofit of desulfurization system outside the furnace**

At present, the ultra-low emission transformation of CFB unit usually adopts two different technical routes, one is containing desulfurization and nitrogen suppression in the furnace, the selective non-catalytic reduction (SNCR) denitrification technology and flue gas circulating fluidized bed desulfidation outside the furnace; the other is containing desulfurization and nitrogen suppression in the furnace, the selective non-catalytic reduction (SNCR) denitrification technology and limestone-gypsum desulphurization outside the furnace and wet type electrostatic precipitator. Both the two technical routes mentioned above can realize the ultra-low emission of SO₂, NOₓ and dust. Three kinds of technologies such as desulfurization in the furnace, flue gas circulating fluidized bed desulfidation outside the furnace and SNCR are all widely used in the CFB boilers.
In January 2017, the State Ministry of Environmental Protection issued the Technical Policy on pollution Control of Thermal Power plants, which clearly stipulates that circulating fluidized bed desulphurization outside the furnace technology should be used in arid and water-short areas, as well as in areas with large environmental capacity. When the units with capacity of 300MW or less burning medium and low sulfur coal, flue gas desulfurization facilities should be built. At the same time, by comparing the technology and economy of circulating fluidized bed desulphurization and limestone gypsum wet desulfurization (Table 2), it is concluded that the investment, operation and maintenance cost of wet desulfurization process are all higher than those of circulating fluidized bed desulfurization system. The circulating fluidized bed desulfurization process has the advantages of small occupation, convenient operation and so on. Therefore, the circulating fluidized bed desulfurization process combined with CFB furnace desulfurization will be a suitable technical route for the CFB units to carry out the retrofit of ultra-low emission of SO2.

### Table 2. Comparison of technology and economy between wet desulfurization and circulating fluidized bed desulfurization.

| Item                          | Wet desulfurization process | Circulating fluidized bed desulfurization process |
|-------------------------------|-----------------------------|-----------------------------------------------|
| Technology maturity          | maturity                    | maturity                                      |
| Operation performance        | widely used                 | hundreds of units                             |
| Desulphurization efficiency  | High than 98%               | High than 95%                                 |
| Calcium sulfur ratio         | 1.03~1.05                   | 1.3~1.8                                       |
| System resistance            | low                         | high                                          |
| SO\(_3\) and Hg removal effect| 30%                         | 90%                                           |
| Flue and chimney anticorrosion| requirements without GGH   | none                                          |
| inlet dust requirements      | less than 20mg/Nm\(^3\)    | none                                          |
| Desulfurization waste        | yes                         | no                                            |
| System power consumption     | 3000kW                      | 1000kW                                        |
| Operation requirements       | high                        | low                                           |
| Desulphurizer monovalent     | limestone. between 100 and 200 | quicklime. between 350 and 500                 |
| Cover area                   | ~2500m\(^2\)               | ~1500m\(^2\)                                  |
| Investment cost \(^a\)       | +27500000 yuan              | standard                                      |
| Operation and maintenance cost \(^a\) | +10000000yuan per year | standard                                      |
| Combined cost \(^b\)         | +2920000yuan per year       | standard                                      |

\(^a\) Taking 2×300MW retrofit unit as an example, the coal sulphur content is designed at 0.5 and the annual operating hours are calculated as 3600h.

\(^b\) Desulfurization system service life is calculated on a 15-year basis, combined annual cost equal to investment cost divide by 15 and sum operating cost maintenance cost.

#### 3.1. Brief introduction of circulating fluidized bed desulfurization process

Circulating Fluidized bed Desulfurization process is shown in figure 3. The circulating fluidized bed desulfurization process has hundreds of operating performance in China, the maximum capacity of the unit has reached the 660MW unit with and two desulphurization towers[10]. This process has the advantages of mature technology, simple system, low energy consumption, no waste water and low operating and maintenance cost. It is suitable for a CFB boiler burning low sulfur coal and desulfurization in the furnace.
3.2. Arrangement of pre-ESP

When CFB units carry out SO$_2$ ultra-low emission retrofit by adding circulating fluidized bed desulphurization process and adopting high density bag dust collector, whether the existing ESP is removed or not is technically feasible. According to the site layout, the design of large CFB boiler is always compact layout, if the existing ESP is removed and abandoned, the layout of circulating fluidized bed desulphurization system outside the furnace will be more convenient. In terms of project cost, demolition of the ESP takes a lot of time and effort. Therefore, whether the desulphurization system is equipped with a pre-ESP needs compare technical and economic of the retrofit.

Figure 3. Circulating Fluidized bed Desulfurization process.

Figure 4. Trend of desulphurization calcium-sulphur molar ratio when the pre-ESP is put in and out of the furnace.
Taking a 350 MW CFB Boiler as the experimental object, simulation of working conditions with or without pre-ESP by commissioning and withdrawing from ESP, finally compare the operating cost of desulfurizer outside the furnace to determine the optimal selection scheme. During the test, the boiler operates at full load, the SO₂ concentration at the inlet of the desulfurizer is 800mg / Nm³, and the average SO₂ concentration at the outlet is 30 mg/Nm³.

Figure 4 shows the trend of desulphurization calcium-sulphur molar ratio when the pre-ESP is put in and out of the furnace. It can be seen from figure 4 that the mole ratio of calcium to sulfur in CFB flue gas desulfurization system is 0.3-0.6 lower than that when pre-ESP is put into operation. So it is possible to improve the economy of desulfurization outside the furnace by the installation of pre-ESP before the circulating fluidized bed desulfurization system. Therefore, in the process of SO₂ ultra-low emission retrofit, the existing ESP should be reused. The electric-bag dust collector can only remove the bag area and keep the electric area, and the electric field of the ESP can be saved, which can fully benefit the ESP and further reduce the cost of the retrofit. It also improves the economy of the desulfurization system outside the furnace.

3.3. Optimum ratio of desulphurization efficiency inside and outside the furnace

In circulating fluidized bed desulfurization process, the desulfurization efficiency in the furnace and Ca/S are directly related to the formation of NOₓ in the furnace and the SO₂ concentration at the inlet of the desulfurization system outside the furnace, and the amount of denitrification reductant urea and desulfurizing agent consumption of circulating fluidized bed outside the furnace are also affected. At last the environmental protection operation economy is finally affected. Therefore, for the CFB boiler with ultra-low emission retrofit, it is necessary to carry out economic optimization experiments according to the actual operation conditions of the boiler and the cost of desulfurization and denitrification to obtain the optimum ratio of desulfurization efficiency inside and outside of CFB boiler at different operating condition. In the test at a 300MW grade CFB boiler the boiler burning the coal with sulfur content of 0.8%, and the concentration of SO₂ at the inlet of circulating fluidized bed desulfurization system outside the furnace was controlled by adjusting the amount of desulphurization and calcium injection in the furnace. On the premise of ensuring that SO₂ reached 30mg/Nm³ and NOₓ reached 45 mg/Nm³, the different desulfurization efficiency in the furnace corresponds to the amount of de-NOx reducing agent urea and the lime used as desulfurizer in the furnace were obtained, and operating conditions under the optimum desulfurization ratio inside and outside the furnace were finally determined, shown in figure 5.

![Figure 5. The relationship between desulphurization efficiency, cost and calcium sulphur ratio inside the furnace.](image-url)
It can be seen that in figure 5 when the SO\textsubscript{2} emission concentration at the outlet of furnace is 800 mg/Nm\textsuperscript{3}, the cost of desulfurization and denitrification is the lowest and the economy is the best. When the desulfurization efficiency in the furnace is lower than 72\%, the influence of desulfurization in the furnace on the formation of NO\textsubscript{X} is small. In this case, although the cost of NO\textsubscript{X} removal is low, because the SO\textsubscript{2} emission concentration at the inlet of the desulfurization system outside the furnace is high, the amount of desulfurizer outside the furnace is higher, so the removal cost is higher. With the increasing of desulfurizer in furnace, the desulfurization efficiency in the furnace is improved continuously, and the mass concentration and denitrification cost and calcareum-sulfur molar ratio increase further, but the concentration of NO\textsubscript{X} increases under the catalysis of desulfurizer, finally the cost of denitrification is bound to increase. So there is an optimal condition of economic operation of the CFB boiler with desulfurization system inside an outside the furnace.

4. Conclusions
(1) Before the retrofit of ultra-low emission, the CFB boiler should be optimized for desulfurization and nitrogen suppression and also combustion adjustment should be carried out.

(2) Circulating fluidized bed desulphurization technology combined with desulfurization inside the furnace of a CFB boiler is an ideal technical route to realize SO\textsubscript{2} ultra-low emission at present, but the retrofit project should be adapted to choose the appropriate technical route according to the actual situation of the units.

(3) On the optimization of dust collector, it is recommended to reduce the cost of retrofit and to improve the economy of desulfurization system outside the furnace by removing the bag area for electric bag dust collector and keeping one or two electric fields for ESP.

(4) After the revamping of CFB boiler with ultra-low emission, the optimum desulphurization distribution ratio test should be carried out to obtain the most economical condition of the boiler to achieve better economy.

Acknowledgement
This work is financially supported by the National Key Research & Development Program of China (NO. 2016YFB0600201).

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