Field tests and optimal operation research of WFGD for a 600MW power plant

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Abstract. In this paper, wet desulfurization system for a certain 600 MW coal-fired power unit was studied. The field tests were conducted on the limestone wet flue gas desulfurization system of a coal-fired unit. The influence of absorber entrance concentration of SO\(_2\) at different loads, as well as the absorber slurry pH value under variable numbers of slurry circulating pumps on desulfurization efficiency were tested. The experiment results also drawn that the start and stop effects of circulating pump on the efficiency of desulfurization rate under different load and the relationship of the slurry density and gypsum quality. On the basis of operation cost analysis, overall power consumption of desulfurization system and the emission fee would be reduced. The optimal operation mode of the slurry circulating pump is given, and the pH value and slurry density are determined.

1. Introduction

Limestone wet flue gas desulfurization technology (WFGD) is currently the most mature desulfurization technology, most widely used in thermal power plant. The operating cost of desulfurization system includes electricity fee, water supply fee, absorbent raw material cost, emission fee and other parts of the composition, among which electricity charges and absorbent consumption fee account for 80% of the total cost, and power consumption is the main factor of the desulfurization system cost directly affecting the desulfurization operation cost.

According to the references [1-2], the main technical indicators affecting the performance of WFGD are entrance concentration of SO\(_2\), flue gas volume, liquid-gas ratio, absorber slurry pH, absorber slurry density and so on, among which only liquid-gas ratio, pH and slurry density can be adjusted in desulfurization system on operation. In this paper, due to the flue gas desulfurization system of 600MW unit, the major operation of the desulfurization efficiency factors were tested from the references [3-5], aiming at reducing the operating costs of the desulfurization system, especially the power consumption rate and tapping energy saving potential by optimizing the desulfurization system operating mode.
2. Field test

2.1. Desulfurization system
This paper studies the wet desulfurization system with 3 slurry circulation pumps of a 600 MW power unit, and the absorption tower system is shown in Fig. 1. According to the reference [1], the WFGD system consists of flue gas system, sulfur dioxide absorption system, gypsum dewatering system, absorbent preparation system and utility system constitute. Interrelated devices comprise a booster fan, absorption tower, an oxidation wind machine, slurry circulating pumps, etc. The main task of WFGD system with forced oxidation is to remove sulfur dioxide from flue gas and to produce gypsum as a saleable product. The raw flue gas was boosted to the absorber through flue gas inlet duct, which is located above the slurry tank. The raw flue gas flow upwards and contact slurry drops containing suspended limestone sprayed from the spray levels counter currently to remove the sulfur dioxide in flue gas after entering the scrubber. The slurry drops fall down to the slurry tank after reacting with the flue gas. The slurry is injected into the absorber over several spray levels each with a dedicated recirculation pump. Each spray bank is provided with numerous spray nozzles for a proper atomization of the slurry. The spray levels were named the A, B and C spray level from the bottom up, respectively. The clean flue gas leave the absorber through the outlet duct after removing the entrained water droplets. The water droplets in flue gas were removed by a mist eliminator to control the erosion of following equipment. The most important process in the WFGD system is the absorption of sulfur dioxide. Sulfur dioxide is absorbed in the spray absorption zone by reacting with the limestone slurry drops, so the chemical absorption in the absorber is the most complicated and important step in scrubber.

![Diagrammatic sketch of spray tower](image-url)
2.2. Influence of absorber entrance concentration of SO2 on the desulfurization efficiency

Coals with different sulfur containment are used as fuel when the loads are full capacity of 600MW and the valley load of 300MW at night. The desulfurization efficiency is tested to be influenced by absorber entrance concentration of SO2 for the variation in coal. During the tests, slurry pH value is controlled to be constant, and the number of operating slurry circulating pumps is three. It can be seen from Fig. 2 that the desulfurization efficiency decrease with the rise of SO2 concentration, the rate of decline in efficiency is greater at low load than high load. When the SO2 concentration reaches a certain critical concentration, the desulfurization efficiency declines rapidly.

The results can be explained as the partial pressure of SO2 in fuel gas increases as the increase of SO2 concentration, which leads to increase of partial pressure of SO2 on gas-liquid interface and makes the gas-liquid reaction away from the gas-liquid interface-oriented direction, not conducive to SO2 absorption in the liquid phase. On the other hand, ion concentration in the absorbent main body of liquid phase changes little, as well as the liquid absorption capacity. Despite an increase in SO2 concentration resulting in increased total uptake, total uptake still less than the increase of entrance SO2 concentration, so desulfurization efficiency shows a declining trend with the increase in entrance of SO2 concentration. At a lower load, SO2 partial pressure is higher, resulting in a more obvious reduction in efficiency. When the concentration greater than a limit, the desulfurization efficiency will begin to decline, indicating that the active ingredient in the slurry has been insufficient to reflect all of SO2.

2.3. Influence of starting and stopping slurry circulating pump on the desulfurization efficiency

In field operation, the liquid-gas ratio is adjusted by the start and stop of the slurry circulation pump, the higher the liquid-gas ratio is, the greater the mass transfer area is, the greater the effective surface area is, so that the rate of mass transfer can be enhanced.
The large liquid-gas ratio is conducive to the strengthening of the mass transfer performance, and thus can improve the desulfurization efficiency. Entrance SO$_2$ concentration in this experiment is about 1200mg/m$^3$ and pump C is started under different loads. The experiment result can be analyzed from Fig.3, C pump is started at any load will increase the liquid-gas ratio so as the desulfurization efficiency, about 3.5% increase at 300MW, 5.5% increase at 600MW, increased with the load increase. Desulfurization rate increases with the liquid-gas ratio increases, but the growth rate is getting smaller and smaller. In the relatively small stage of the liquid-gas, increasing the liquid-gas ratio can more effectively improve the desulfurization efficiency according to the references [6-7]. Since liquid-gas ratio is relatively small at high load, the desulfurization efficiency changes greatly among the start-stop in a pump.

2.4. Desulfurization efficiency varies on pH value

The absorber slurry pH value is the core index of limestone wet FGD system adjusted in running, which has a great impact on the desulfurization efficiency, the use of limestone and gypsum quality. Load at 500MW, the entrance SO$_2$ concentration 1800mg/m$^3$, pH between 5.7 and 5.9, desulfurization efficiency of different operating conditions and actual calcium sulfur molar ratio are analyzed, among which Ca/S is calculated by CaSO$_4$·2H$_2$O, CaSO$_3$·0.5H$_2$O, CaCO$_3$ in plaster.
Fig. 4 indicates that, in the experimental range, the desulfurization efficiency and Ca/S increase with the increase of pH values, but the efficiency increase is getting smaller and smaller. The desulfurization efficiency increases more greatly when the pH value is less than 5.8 than when the pH value greater than 5.8, with a slowing down increase. Ca/S changes the opposite way. The same test at 600MW load, the entrance concentration of SO$_2$ 850mg/m$^3$, are conducted to study the desulfurization efficiency variation on pH at different liquid-gas ratios. Data from Fig. 5 show the pH value impacts efficiency more greatly in the two operating pump than three operating pump. The liquid film enhancement factor is greater when liquid to gas rate is relatively low according to the references [8-10], in which condition, pH has more obvious influence on the desulfurization efficiency.

2.5. Influence of slurry density
The slurry density determines whether the dehydration of gypsum in the system aiming at maintain a better reaction environment in tower body. Fig. 6 suggests CaSO$_4$$\cdot$2H$_2$O and CaCO$_3$ variation in plaster with the changes of the absorber slurry density. CaSO$_4$$\cdot$2H$_2$O content increases with the rise of slurry density, while the CaCO$_3$ content is just opposite, but the reduction will be smaller when slurry density increases.

3. Optimal operation of WFGD
The aim of the field tests is to obtain the optimal operating conditions under different loads and different inlet SO$_2$ concentrations. By adjusting the pH value of the slurry and the density of the slurry, the efficiency of limestone utilization can be improved while considering the efficiency of desulfurization. The operation cost of the desulfurization system can be reduced when optimal operation mode of the slurry circulating pump is chosen.

3.1. Control of pH and slurry density
The increase of pH will also lead to the increase of Ca/S, the increase of the residual amount of limestone in the slurry, the large moisture will be attached to the gypsum meanwhile. Based on the field tests of pH value, the pH value has a great influence on desulfurization efficiency when the pH is less than 5.8. However, it has a weaker effect on desulfurization efficiency when the pH is higher than 5.8 and the increase of pH is not conducive to the crystallization of gypsum. When the Ca/S value is about 1.01, which is less than the performance. The recommended value of pH is around 5.8.

As the density of the slurry increases, the desulfurization efficiency will decrease. The slurry density directly affects the quality of the gypsum. It can be obtained from the test results that the CaCO$_3$ content changes little with the slurry density when the slurry density is greater than 1170 kg/m$^3$, indicating that limestone has been thoroughly utilized. The recommended value of slurry density should be less than 1170kg/m$^3$ in actual operation.

3.2. Optimization of slurry circulation pump
Starting the slurry circulation pump will increase the liquid-gas ratio and improve the desulfurization efficiency, but it will also increase the energy consumption of the system. The pressure drop of the WFGD will increase, causing the load of the booster fan to increase and the power consumption. Under the premise of meeting the environmental requirements of desulfurization efficiency, the liquid-gas ratio should not be too large.

It can be seen from the tests that the effect of starting the pump on the efficiency is higher under high load, and the pump can not bring the benefit under the high load condition. Therefore, it is recommended that it is not necessary to pursue high desulfurization efficiency, and this operation mode is the most economical. When the concentration of the inlet SO$_2$ rises to a critical value, the operation of the two pumps will not meet the environmental minimum emission efficiency standard. An extra slurry circulating pump needs to be opened at this time, the SO$_2$ concentration are defined as the critical values under different loads using two pumps. When the SO$_2$ concentration is greater than the critical value, three pumps are required to operate. And the two pumps are used for combined
operation when the concentration is less than the critical concentration. At the boundary, the pH can be adjusted to ensure the efficiency requirement. According to the field tests analysis, the critical concentration of inlet SO\(_2\) of a 600 MW unit (the efficiency is equal to 90% under the condition of pH=5.8) and the load are shown in Table 1.

| Load (MW) | 350  | 400  | 450  | 500  | 550  | 600  |
|-----------|------|------|------|------|------|------|
| SO\(_2\) critical concentration (mg/m\(^3\)) | 1379 | 1306 | 1233 | 1161 | 1088 | 1016 |

4. Conclusion

(1) In the WFGD system, with the increase of the concentration of the inlet SO\(_2\), the desulfurization efficiency decrease, and the influence effect under the low load condition is greater than the high load condition.

(2) The number of slurry circulating pump can improve the desulfurization efficiency, and the effect increases with the increase of the load. However, starting the circulating pump will increase power consumption. Considering the operation cost, the optimal operation mode of circulating pump are given.

(3) The desulfurization efficiency increases with the pH value, and its influence effect is different under different liquid-gas ratios. The smaller the liquid-gas ratio, the greater the influence of pH value. The pH value is recommended as 5.8 for best desulfurization efficiency and gypsum quality.

(4) In order to ensure the utilization of limestone, it is recommended that the slurry density should be less than 1170 kg/m\(^3\).

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References

[1] Yi Zhong, Xiang Gao, Wang Hu, et al, (2008) A model for performance optimization of wet flue gas desulfurization systems of power plants, *Fuel Processing Technology*, vol. 89 pp 1025-1032.

[2] K.A. Galos, T.S. Smakowski, J. Szlugaj, (2003) Flue-gas desulphurisation products from Polish coalfired power-plants, *Appl Energy*, vol. 75 (3–4) pp 257-265.

[3] Cao Zhi-yong, Lu Jian-wei, Shi Bin, Li Hui (2010) Experimental Study on Optimal Adjustment of Flue Gas Desulfurization System of 1000 MW Unit, *East China Electric Power*. vol. 38 pp 1615-1617.

[4] Gu Jin fang, Mao Rui, Lin Wei (2008) Operation optimization for desulphurization systems, *East China Electric Power*. vol. 36 pp 115-118.

[5] Long Hui, Zhong Ming-hui (2006) Main factors affecting the power consumption rate of wet FGD equipment for 600 MW power unit, *Electric Power*. vol. 39 pp 74-77.

[6] C. Carletti, C. De Basio, E. Makila, J. Salonen, T. Westerlund (2015) Optimization of a wet flue gas desulfurization scrubber through mathematical modeling of limestone dissolution experiments, *Ind. Eng Chem Res.*, vol. 54 pp 9783-9797.

[7] Du Qian, Ma Chun yuan, Dong Yong (2006) The Impact of the pH Value of Circulating Slurry on a Wet Flue-Gas Desulfuration Process, *Journal of Engineering for Thermal Energy and Power*, vol. 21 pp 491-495.

[8] J.Warych, M.Szymanowski (2001) Model of the wet limestone flue gas desulfurization process for cost optimization, *Ind. Eng.Chem. Res.* vol. 40 pp 2597–2605.

[9] S. de Gisi, A. Molino, M. Notarnicola, (2017) Enhancing the recovery of gypsum in limestone-
based wet flue gas desulfurization with high energy ball milling process: a feasibility study, 
*Process Saf Environ Protect*, vol. 109 pp 117-129.

[10] L.E. Kallinikos, E.I. Farsari, D.N. Spartinos, N.G. Papayannakos, (2010) Simulation of the 
operation of an industrial wet flue gas desulfurization system, *Fuel Process Technol*, vol. 91 
pp 1794-1802.