

# Research on flue gas desulphurization with two sorbents by water spray in activated reactor

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**Abstract:** The experimental results of flue gas desulphurization with caustic lime and hydrated lime activated by water spraying in a desulphurization reactor are presented. The effects of Ca/S molar ratio, approach to saturation of flue gas, SO<sub>2</sub> concentration and gas velocity on sulfur retention efficiency and calcium utilization rate are investigated. Desulphurization characteristics of the two sorbents are compared. The mechanism of improving desulphurization efficiency by water spraying is analyzed. The results show that the activities of two sorbents are improved obviously by humidification with water spray and the caustic lime has better application prospect because of cheaper cost.

**Key words:** desulphurization; lime; water spray; activation

Sulfur dioxide emission and acid rain are two of the most important factors contributing to deterioration of global air environment. It is cost-effective to equip coal-fired boilers with efficient and economical desulphurization facility. Improved limestone injection process where the activation of unreacted lime is carried out in a separate chamber by water spray is regaining public attention<sup>[1]</sup>. Its simple process, compact set up, low capital and operational cost, and high desulphurization efficiency are very suitable for developing countries that burn coal with low and medium sulfur content.

The limestone injected into the furnace decomposes and reacts with a portion of sulfur dioxide in flue gas. But only 15% to 20% of the limestone is utilized in the furnace injection phase of the whole process because of limited residence time. In the activation reactor a portion of the remaining calcium oxide, which collides with water droplets, is converted to calcium hydroxide, the so-called "slurry droplet forms". Sulfur dioxide reacts rapidly with the freshly formed calcium hydroxide. In the mean time, the steam evaporated from atomized water droplets is absorbed by the surface of calcium oxide particles. It also can improve both the desulphurization efficiency and the utilization rate of the limestone. There are very complex physicochemical processes including gas-liquid-solid three phase flow, collision between solid particles and liquid droplets, evaporation of water droplets, ion reaction in liquid phase between the calcium hydroxide and sulfur dioxide

in the slurry droplets, and gas-solid reaction between calcium dioxide particles and sulfur dioxide in the flue gas, etc<sup>[2-4]</sup>. For better understanding of the desulphurization process with the two sorbents (caustic lime and hydrated lime) activated by water spray, macroscopic desulphurization experiments in the activation reactor were conducted under different operation parameters. The effects of Ca/S molar ratio, approach to saturation of flue gas, SO<sub>2</sub> concentration, gas velocity on sulfur retention efficiency and calcium utilization rate were investigated. The mechanism of improving desulphurization efficiency by water spraying is also analyzed.

## 1 Experimental

The desulphurization experiments with lime injection combined with humidification and activation were conducted on a set up shown in Fig. 1. The system consists of the oil-fired gas generator, the orifice meter, the SO<sub>2</sub> adding system, the sorbent feeding system, the activation reactor, two water atomizers, the dust collector, the FD fan and the ID fan. The reactor body is 400 mm in diameter and 6 m high. The K-type thermocouples were arranged at the inlet, at the outlet and at several elevations of the reactor for measuring gas temperature. There were seven gas sampling ports at the inlet, at the outlet and at five different elevations of the reactor. The SO<sub>2</sub> concentrations in the flue gas at the place before sorbent feeding and at the exit of the reactor were measured with the NGA 2000 gas analyzer from the Rosemount Company. So, the desulphurization efficiency could be calculated based on those SO<sub>2</sub> concentrations. The hot water bath for heating liquefied

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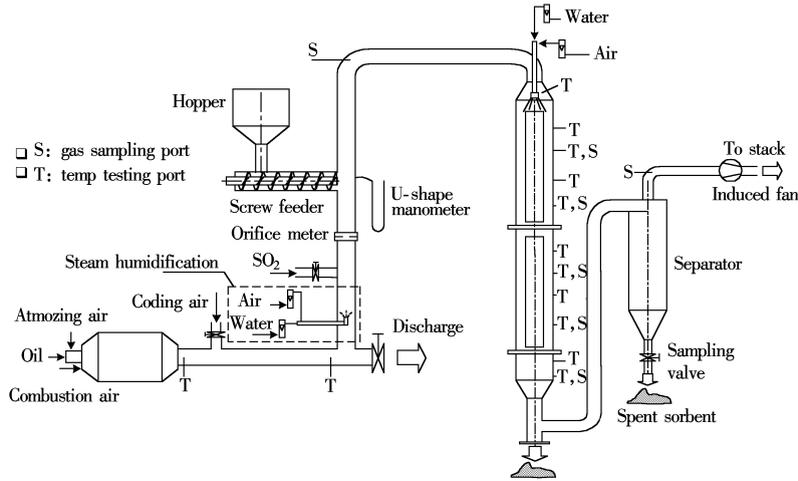


Fig. 1 Schematic diagram of test rig

SO<sub>2</sub> tank and the electrical heating strip twisted on the SO<sub>2</sub> addition tube were used for the sake of smooth and even SO<sub>2</sub> addition. Calcium-based sorbent was injected into the gas stream via the screw feeder driven by variable speed motor. One of the two water atomizers was located at the upstream 10 m away from the reactor inlet. All the water droplets from it could evaporate into steam fully before entering the reactor. The other was mounted at the top of the reactor. The parameters range in the test are as follows<sup>[5,6]</sup>: Ca/S molar ratio is 1.5 to 3.0; flue gas temperature is around 150 °C; approach to saturation is 5 to 30 °C; SO<sub>2</sub> concentration is 600 to 3 500 mg/m<sup>3</sup>; gas velocity is 1.0 to 2.8 m/s.

The flow rate  $M_w$  of humidification water is based on the heat balance calculation as follows:

$$C_g^T T_g^{\text{in}} V_g^{\text{in}} + C_w^T T_w M_w = (C_g^T V_g^T + C_{\text{st}}^T M_w) T$$

where  $C_g$ ,  $C_w$ ,  $C_{\text{st}}$  are the specific heat at constant pressure of flue gas, water and steam, respectively;  $T_w$  is the water temperature;  $T_g$ ,  $T$  are gas temperatures before and after water spraying;  $V_g$  is the flow rate of the flue gas.  $\Delta T$ , the approach to saturation, is the difference between  $T$  and the saturated temperature.

Local caustic lime and hydrated lime from Tangshan, Nanjing were used as the sorbents in the test. Their size distributions and main components are listed in Tab.1 and Tab.2, respectively.

Tab.1 Size distribution of sorbent

| Size range/ $\mu\text{m}$ | Percentage of caustic lime/% | Percentage of hydrated lime/% |
|---------------------------|------------------------------|-------------------------------|
| > 75                      | 13.6                         | 0                             |
| 75 - 45                   | 7.2                          | 0.2                           |
| 45 - 30                   | 6.1                          | 1.6                           |
| 30 - 20                   | 6.7                          | 2.2                           |
| 20 - 10                   | 25.6                         | 8.6                           |
| 10 - 5                    | 17.9                         | 33.5                          |
| < 5                       | 22.9                         | 53.9                          |
| Mean size/ $\mu\text{m}$  | 32.67                        | 6.42                          |

Tab.2 Sorbent components

| Sorbent                     | Caustic lime | Hydrated lime |
|-----------------------------|--------------|---------------|
| $w(\text{SiO}_2)$           | 1.88         | 0.29          |
| $w(\text{Fe}_2\text{O}_3)$  | 0.30         | 0.12          |
| $w(\text{Al}_2\text{O}_3)$  | 1.04         | 0.42          |
| $w(\text{TiO}_2)$           | 0.04         | 0.01          |
| $w(\text{CaO})$             | 56.02        |               |
| $w(\text{CaCO}_3)$          | 5.88         | 4.90          |
| $w(\text{Ca}(\text{OH})_2)$ | 8.71         | 68.82         |
| $w(\text{MgO})$             | 0.69         | 0.24          |
| $w(\text{K}_2\text{O})$     | 0.08         | 0.01          |
| $w(\text{Na}_2\text{O})$    | 0.03         | 0.02          |
| $w(\text{SO}_3)$            | 0.35         | 0.32          |

## 2 Results and Discussions

### 2.1 Effect of Ca/S molar ratio on desulphurization efficiency

Fig.2 shows the effects of Ca/S molar ratio on desulphurization with two kinds of sorbents. The curves indicate that the desulphurization efficiency increases with Ca/S molar ratio, but the rising rate goes down for the higher Ca/S molar ratio. Increasing the Ca/S molar ratio results in an increase in sorbent particle concentration in flue gas and hence the increase in the

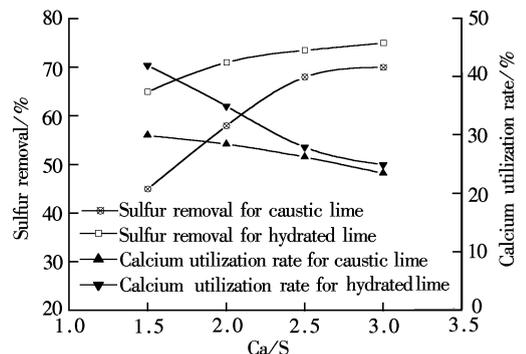


Fig.2 Sulfur removal efficiency vs. Ca/S molar ratio ( $\Delta T = 10$  °C,  $C_{\text{SO}_2} = 1\ 430$  mg/m<sup>3</sup>,  $V = 2$  m/s)

number of sorbent particles captured by water droplets, which improves the sulfur retention efficiency. For constant approach to saturation and amount of spray water, however, a higher Ca/S molar ratio definitely leads to a smaller H<sub>2</sub>O/Ca molar ratio and poorer activation effect of the sorbent. As a result, both the rising rate of sulfur retention efficiency and the calcium utilization rate decrease with increasing Ca/S molar ratio.

## 2.2 Effect of approach to saturation on desulphurization efficiency

The spray-water flow rate, based on the approach to saturation, affects directly the H<sub>2</sub>O/Ca molar ratio, the amount of sorbent particles captured by water droplets, the evaporation time of water droplets and humidified sorbent particles, and the relative humidity of the flue gas. Therefore, the approach to saturation has strong effect on the desulphurization efficiency. As shown in Fig.3, the closer to the saturated temperature, the higher the sulfur retention efficiency, and the efficiency at  $\Delta T = 5^\circ\text{C}$  is higher than that at  $\Delta T = 30^\circ\text{C}$  by about 25%. But too small  $\Delta T$  is not desirable because it will cause condensation and corrosion to form in the reactor, the flue gas duct and the stack.

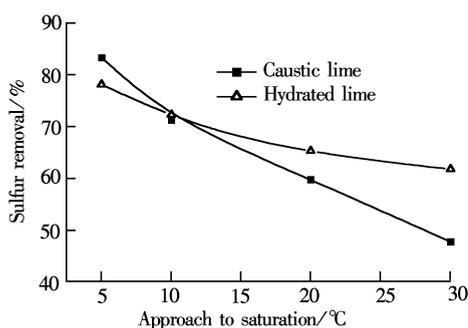


Fig.3 Sulfur removal efficiency vs. approach to saturation ( $C_{\text{SO}_2} = 1430 \text{ mg/m}^3$ ,  $\text{Ca/S} = 2.5$ ,  $V = 2 \text{ m/s}$ )

## 2.3 Effect of sulfur dioxide concentration on desulphurization efficiency

The effect of SO<sub>2</sub> concentration in the flue gas on the desulphurization efficiency is shown in Fig.4. With constant flow rate of spray water, the increase in SO<sub>2</sub> concentration results in the slight decrease in a desulphurization efficiency for the two sorbents. Normally, the efficiency increases with the SO<sub>2</sub> concentration in the flue gas from the point of view of chemical reaction dynamics. But for the constant Ca/S molar ratio, higher SO<sub>2</sub> concentration requires more sorbent. Limited by the constant approach to saturation, the flow rate of spray water should be kept

the same. It is impossible for less spray water to activate more sorbent as effectively as expected. The comprehensive effect of these two factors mentioned above leads to a slight decrease in desulphurization efficiency as SO<sub>2</sub> concentration rises. This is one of the reasons why the desulphurization technology with spray water activation is suitable for coal with low and medium sulfur content instead of coal with high sulfur content.

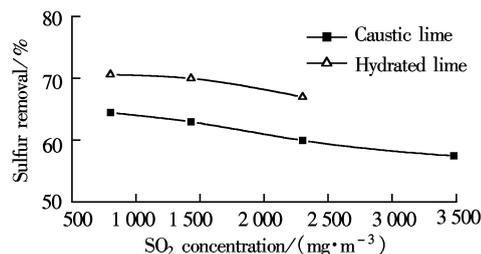


Fig.4 Sulfur removal efficiency vs. SO<sub>2</sub> concentration ( $\text{Ca/S} = 2.5$ ,  $\Delta T = 10^\circ\text{C}$ ,  $V = 1 \text{ m/s}$ )

## 2.4 Effect of gas velocity on desulphurization efficiency

As the flue gas velocity goes up, the turbulivity of gas is enhanced and the mixture of gas, water droplets and sorbent particles becomes more intensive, which is beneficial to increasing the desulphurization efficiency. On the other hand, the residence time of the gas and the slurry of water droplets and sorbent particles becomes shorter and hence the reaction time of desulphurization is shortened correspondingly. As a result, the sulfur retention efficiency declines gradually. Fig.5 depicts the sulfur removal efficiency curve under different gas velocities. It implicates gas velocity as a very important parameter for activation reactor design. But too low a gas velocity requires a larger section of the reactor and hence higher capital cost.

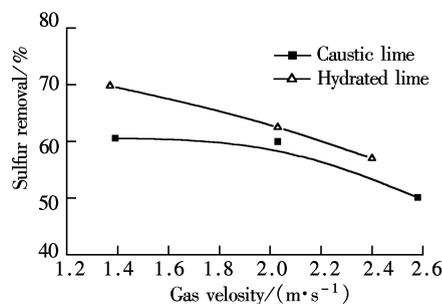


Fig.5 Sulfur removal efficiency vs. gas velocity ( $\Delta T = 10^\circ\text{C}$ ,  $\text{Ca/S} = 2.5$ ,  $C_{\text{SO}_2} = 1430 \text{ mg/m}^3$ )

## 2.5 Comparison between the effects of activation with caustic lime and hydrated lime

Fig.2 to Fig.5 show two desulphurization

efficiency curves with caustic lime and hydrated lime under the same experimental conditions. There is no obvious difference between them. From the point of view of the activation mechanism, the reaction in the liquid phase between the freshly formed calcium hydroxide and sulfur dioxide solved in slurry droplets plays a dominant role in water spray activation. It is the key measure for improving sulfur retention efficiency to increase collision probability between sorbent particles and water droplets, and to prolong the existence time of the slurry droplets. Since there is no essential difference between the reactions for caustic lime and hydrated lime, the hydrated lime has no better sulfur retention effect than caustic lime. Considering that the former is more expensive, the latter is a more ideal sorbent.

### 3 Conclusion

The desulfurization technology with water spray activation improves sulfur retention efficiency when the approach to saturation is in proper proportion in order to keep the desulfurization product dry and to prevent the flue gas from condensation. Under the conditions of Ca/S molar ratio of 2.5, approach to saturation of 10 °C, gas velocity of 2 m/s and inlet SO<sub>2</sub> concentration of 1 430 mg/m<sup>3</sup>, the desulfurization efficiency in the activation reactor reaches 76%.

A higher Ca/S molar ratio, and a lower approach to saturation and flue gas velocity are beneficial to improving the sulfur retention efficiency. The

desulfurization efficiency higher than 80% can be reached at the approach to saturation of 5 °C. With constant spray water, increasing SO<sub>2</sub> concentration results in a decrease in desulfurization efficiency. In contrast to hydrated lime, the caustic lime is better for the sorbent of desulfurization with water spray activation.

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## 2 种脱硫剂喷水增湿活化烟气脱硫研究

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**摘要** 本文介绍了在增湿活化反应器中喷入雾化水滴采用生石灰和熟石灰烟气脱硫的试验结果. 研究了钙硫摩尔比、烟气露点温距、二氧化硫浓度和烟气流速等因素对脱硫效率和脱硫剂钙利用率的影响规律. 比较了 2 种脱硫剂的脱硫特性, 分析了喷水增湿改善脱硫效率的机理. 结果表明, 喷水增湿活化明显改善了 2 种脱硫剂的活性, 生石灰比熟石灰具有价格优势因而市场前景更好.

**关键词** 脱硫; 石灰; 喷水; 活化

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