Application of bag filter in integrated technology of dry desulfurization and dust collection

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Abstract A new technical route is explored to realize the integrated design of dry gas desulfurization and dust collection, combining dry duct injection technology with bag filter technology. Sodium bicarbonate (NaHCO3) was used as desulfurizer, outside and inside filtration bag filters were used as the main body of the reaction device. A series of experiments were carried out, and the temperature, NaHCO3 particle size, inlet SO2 concentration, sodium to sulphur ratio and dust concentration were evaluated. The results showed that the desulfurization reaction was mainly composed of two parts: the NaHCO3 injection section of duct and the filtration of bag filter. The desulfurization efficiency of the inside filtration was better than that of the outside filtration, and collection efficiency was maintained above 99.9%. From 130°C to 150°C, the desulfurization efficiency of both inside and outside filtration bag filter increased with temperature increased, but the efficiency decreased at the temperatures of 150°C~200°C because of the thermal decomposition reaction of sodium bicarbonate. After adding 1000mg·m⁻³ dust, the desulfurization efficiency of both the inside filtration and outside filtration bag filters increased by 10%, and the trend of desulfurization efficiency with temperature was the same as that before adding dust. It was found that the desulfurization reaction was better with the NaHCO3 particles size was smaller, and the inlet SO2 gas concentration had little effect on the desulfurization efficiency.

1. Introduction

Iron and steel industry plays an influential role in China's economic construction. In the complicated steel smelting process, sintering process is an important part and a vital factor causing regional air pollution. The SO2 from flue gas accounts for 60%, and the dust content is high. In recent years, China has imposed stricter restrictions on pollutant emissions from the iron and steel industry [1-2]. How to further control and reduce SO2 and dust emissions in flue gas has become an important part of air pollution control. The methods of flue gas desulfurization include the wet, semi-dry and dry methods [3]. Wet desulfurization includes limestone-gypsum process, ammonia-ammonium sulfate process, seawater desulfurization process and magnesium oxide process [4]. Semi-dry method includes SDA spray drying approach [5], circulating fluidized bed method, etc. Dry flue gas desulfurization technology includes dry calcium spraying desulfurization, close coherence tower desulfurization [6], MEROS desulfurization [7], new integrated desulfurization [8] and activated carbon desulfurization. In recent years, the dry desulfurization technology has become a mainstream technology because its desulfurization process does not consume water, has no problems such as corrosion and condensation,
and has advantages such as small footprint and no secondary pollution. Even though, it still has problems such as low desulfurization efficiency and high operating cost. As a stable and efficient dust removal equipment, bag filter is widely used in various fields of industry [9], and it has a certain desulfurization effect. But there are many uncertainties affecting the desulfurization efficiency of bag filter [9]. In order to solve these problems, this paper combines the entrained flow desulphurization technology with the bag dust removal technology, and plans to study an efficient and low-cost desulfurization and dust removal integrated device.

Desulfurization principle
In the process of removing SO\textsubscript{2} from dry sodium bicarbonate, it was primarily achieved by direct reaction of sodium bicarbonate with SO\textsubscript{2} and adsorption of sodium bicarbonate. The chemical reaction process mainly included the reaction of sodium bicarbonate with SO\textsubscript{2}, and the decomposition product sodium carbonate directly reacted with SO\textsubscript{2} to form NaSO\textsubscript{3}, as shown in formula (1). For studies on the thermal decomposition of sodium bicarbonate, Keener and Khang [10] had shown that NaHCO\textsubscript{3} began to decompose when the temperature was higher than 60°C, and the surface would undergo an activation reaction. Sodium bicarbonate could directly react with SO\textsubscript{2} when the temperature was over 140°C; and when the temperature was between 80°C and 140°C, sodium bicarbonate formed an intermediate product: Na\textsubscript{2}CO\textsubscript{3}, and then reacted with SO\textsubscript{2} to form sulfite. Finally, the sulphite reacted with oxygen to form sodium sulfate (Helfrich and Bortz, 1992) [11]. After the decomposition of sodium bicarbonate, a lot of pores are generated, and these pores could also exert an irreversible adsorption on SO\textsubscript{2}, so that SO\textsubscript{2} gas could be further removed. The desulfurization process of the integrated device consisted of two parts: the pipe spray section and the filter section of the bag filter. In the pipe injection part, sodium bicarbonate particles and flue gas flowed at high speed in the pipeline, fully mixed and a series of gas-solid reaction occurs. The main chemical reaction is shown in formula (1)(2)(3)(4). A normalized stoichiometric ratio, NSR, which was the molar ratio of NaHCO\textsubscript{3} to SO\textsubscript{2}, was used to describe the amount of sorbents injected for desulfurization.

\begin{align}
2\text{NaHCO}_3 + \text{SO}_2 &\rightarrow \text{Na}_2\text{SO}_3 + 2\text{CO}_2 + \text{H}_2\text{O} \quad (1) \\
2\text{NaHCO}_3 &\rightarrow \text{Na}_2\text{CO}_3 + \text{CO}_2 + \text{H}_2\text{O} \quad (2) \\
\text{Na}_2\text{CO}_3 + \text{SO}_2 &\rightarrow \text{Na}_2\text{SO}_3 + \text{CO}_2 \quad (3) \\
\text{Na}_2\text{SO}_3 + 1/2\text{O}_2 &\rightarrow \text{Na}_2\text{SO}_4 \quad (4)
\end{align}

The sodium carbonate, sulfate and the like which were formed by the reaction of the pipeline and the unreacted sodium hydrogencarbonate and dust are collected by the filter bag, and a complex filtration layer was formed on the surface of the filter bag. The SO\textsubscript{2} gas in the tank would also continue to react with the particles in this bed. The reaction and aggregation of particles were a dynamic process, similar to a reaction bed of variable thickness. When the thickness of the bed was lower, the bed was mainly composed of a chemical reaction and the step of limiting the desulfurization reaction was a chemical reaction process; When the bed became thicker, the diffusion resistance of SO\textsubscript{2} passing through the ash layer was the main factor limiting the desulfurization process.

2. Materials and experimental methods

2.1. Experimental materials
In this experiment, SO\textsubscript{2} cylinder gas was used to simulate the polluted gas, sodium bicarbonate was used as the desulfurizing agent, and talc powder was used to simulate industrial dust, and compressed air was used as carrier gas to transport talcum powder. The sodium bicarbonate (food grade, purity 99.5%) was ball milled at a different ball-to-ball ratio with a ball mill, and the particle size distribution was measured by LS13320 which is a Beckman Coulter laser analyzer. The mass median diameter of the sodium bicarbonate was 1\textmu m and 50\textmu m. Talc powder was a natural magnesia silicate mineral with
the better follow ability to transport carrier gas in a variable cross-section flow field. Its unique layered structure gives it a large specific surface area and a strong adsorption capacity. It also had better electrical insulation and stable chemical properties, which were similar to industrial dust. According to the characteristics of the flue gas, the filtering media was made of PPS scrim with PTFE membrane. PPS fiber had excellent acid resistance, alkali resistance and hydrolysis resistance, the useful temperature above 220°C, weight per unit area ≥ 530g/m², effective service life ≥ 30 000 hours. The PTFE membrane had a high collection rate of dust and the surface tension was low. High-concentration dust was not easy to form a knot on the surface of the filter bag. The pores on the surface of the bag would not be blocked and would fall off from the surface of the filter material after reaching a certain thickness, so that the resistance in the bag filter system was stable and could operate normally.

2.2. Experimental setup and process
The whole experimental system (Figure 1.) consisted of dust generation system, desulfurization pipeline, bag filter, heating system, draft fan and smoke detection system. Both the pipeline and the reactor body were heated by electric tracing ribbon, and the temperature measured by temperature controller at point 1, 2, 3 (Figure 1.). Thus the temperature loss of the gas between the tub furnace and the fabric filter was almost negligible. The length of the pipeline was 3 m and the baghouse-type bag filter was 1.5 m high and the bottom area is 0.6m * 0.6m, and 4 filter bags with a total filtration area of 1.2 m² were installed in the bag filter. The gas flow rate through the entrained reactor was 36 m³/h, and the residence time of the particle in the gas before the bag filter was 0.15-0.2 s.

The dust generation system composed of a dust aerosol generator (TopasSAG-420) and an air compressor. Compressed air was used as carrier gas to transport sodium bicarbonate and talcum powder, the carrier gas dispersed the shear force of turbulent gas and dispersed the powder in the nozzle to form aerosol, then injected into the pipeline. Finally, the purified gas was discharged through the fan. The flue gas detection system included the test of SO₂ concentration in the injection and filter section, and the collection of outlet particles. Testo350 flue gas analyzer, MRU-MGA5 infrared flue gas analyzer and Laoying 3012H automatic soot sampler were used to measure the concentration of flue gas.

3. Results and discussions
3.1. Effect of temperature on desulfurization efficiency
Experimental conditions: the filtration gas velocity was 0.5 m/min, and the inlet SO₂ concentration was 1000mg/ mg•Nm⁻³, desulfurizer particle size D₅₀=1μm, NSR=1.5. Flue gas temperature was one of the important factors affecting the desulfurization efficiency. The experiment was carried out at 130°C-200°C, results were shown in Figure 2(a). From 130°C to 150°C, the desulfurization efficiency of both inside filtration and outside filtration bag filter increased with temperature increased, but the
efficiency decreased at the temperatures of 150°C to 200°C because of the thermal decomposition reaction of NaHCO₃. The inside filtration type bag filter had much better desulfurization efficiency than the outside, and the desulfurization efficiency was higher about 6% in each temperature range. It could be seen from the figure Figure 2(b), SO₂ removal of the inside filtration in the injection section is about 20% higher than that of the outside filtration, which is the main reason why the desulfurization efficiency of inside filtration bag filter is better. The SO₂ removal of the injection section of the outside filtration could reach to 35%. Their desulfurization efficiency increased with the increase of temperature, but the filter section showed the opposite law.

From the chemical reaction between NaHCO₃ and SO₂, it could be seen that temperature has a great influence on the desulfurization efficiency. A study on the decomposition law of NaHCO₃ [12] showed that NaHCO₃ decomposed from 100°C to 185°C, the thermal decomposition rate of sodium bicarbonate is the largest at the temperature of 150°C, which is helpful to the desulfurization reaction. Therefore, the desulfurization efficiency of the integrated device is the best at this temperature. At lower temperature, the reaction activity of sodium bicarbonate was higher and it was easier to decompose into sodium carbonate. At this time, the absorption rate of SO₂ was closed to that of Na₂CO₃, and the pore of NaHCO₃ itself was more abundant, which promoted the desulfurization reaction. When the temperature was higher than 150°C, the reaction activity of sodium bicarbonate decreased, so the desulfurization efficiency decreased gradually.

3.2. Effect of sodium to sulfur ratio on the removal of SO₂
Sodium to sulfur ratio was one of the important parameters affecting the control of desulfurization chemical reactions. When the filtration velocity was 0.5 m/min, the inlet SO₂ concentration was 1000 mg*Nm⁻³, NaHCO₃ particle size was 1μm, this paper explored the effect of sodium to sulfur ratio on desulfurization efficiency under the condition of flue gas temperature of 150 °C. Figure 3 showed that the desulfurization efficiency of the whole device increased with the increase of NSR. When NSR>1.5, the increase in desulfurization efficiency decreased, and the trend gradually became gentle. When NSR=1.5, the desulfurization efficiency of the inside filtration bag filter could reach to 91%, which was 7% higher than the desulfurization efficiency of the outside filtration bag filter. In the whole process, the desulfurization efficiency of the inside filtration bag filter was better than that of outer-filtering. Theoretically speaking, when the NSR<1, the desulfurizing agent provided could not satisfy the amount of SO₂ reaction in the flue gas. At this moment, the removal of SO₂ depended on the amount of desulfurizer. However, when the desulfurizer was added excessively, that was, when NSR>1, the increase of desulfurizer efficiency would gradually decrease, and the utilization rate of
desulfurizer would also decrease. Based on the principle of economy and environmental protection, other experimental studies in this paper were based on the ratio of sodium to sulfur of 1.5.

3.3. Effect of particle size on desulfurization efficiency

The particle size is an important factor affecting the thermal decomposition process of sodium bicarbonate and the occurrence of desulfurization reaction. Under the conditions of a filtration velocity of 0.5 m/min, an inlet SO2 concentration of 1000 mg•Nm⁻³, NSR=1.5, the flue gas temperature of 150°C, investigated the effect of particle size on the desulfurization efficiency of the integrated unit. Whether it was for outside filtration or inside filtration bag filter (Figure 4), the desulfurization reaction was better, when NaHCO3 particles size was smaller. No matter the NaHCO3 particle size was 1um or 50um, the desulfurization efficiency of the inside filtration was better than that of outside filtration.

![Figure 3. The SO2 removal of different NSR.](image)

![Figure 4. The SO2 removal of different particle size.](image)

Dry gas desulfurization with sodium bicarbonate was a gas-solid non-catalytic reaction. Its complexity lied in three processes: the diffusion of SO2 gas in the pore of sodium bicarbonate particles, the diffusion of reaction gas in the product layer, and the interfacial chemical reaction between reaction gas and sodium bicarbonate. The particle size of sodium bicarbonate was different, and its specific surface area was also different, and even a difference of ten times could be produced. Tiny particles had a larger surface area and high reactivity, and thermal decomposition would produce a lot of micropores on the surface of desulfurizer, which accelerated the process of the gas-solid non-catalytic reaction. Therefore, smaller particle size of sodium hydrogen carbonate contributed to the progress of the desulfurization reaction.

3.4. Effect of SO2 inlet mass concentration on desulfurization efficiency

The SO2 inlet concentration affects the rate of chemical reaction of the desulfurization reaction. Therefore, under the conditions of temperature was 150°C, NSR=1.5, desulfurizer particle size was D50=1μm and the filtration velocity is 0.5 m/min, the experiment was carried out by introducing different concentrations of SO2. The experimental results (Figure 5) showed that with the increase of the concentration of imported SO2, the desulfurization efficiency of the inside filtration bag filter decreased slightly. For the outside filtration bag filter, the change in the concentration of imported SO2 had little effect on its desulfurization efficiency. With the increase of SO2 concentration, the gas-solid mass transfer resistance of the reaction between SO2 and desulfurizer was increased, and the total mass transfer resistance was also increased. Although the increase of SO2 concentration increased the partial pressure of SO2 gas in flue gas, the driving force of SO2 mass transfer also increased, the increase of absorption rate could be less than the increase proportion of concentration value. Therefore, the desulfurization efficiency tended to be opposite to the change in SO2 concentration. However, in
general, the increase in SO$_2$ concentration had little effect on the desulfurization effect of the desulfurization and dust removal integrated device.

![Graph showing SO$_2$ removal vs. SO$_2$ inlet concentration](image)

**Figure 5.** The SO$_2$ removal of different inlet concentration.

3.5. Effect of concentration of 1000 mg•m$^{-3}$ dust on desulfurization efficiency

1000 mg•m$^{-3}$ talcum powder was added to simulate industrial soot. The experiments were carried out from 130°C to 200°C, under the conditions of filtration velocity was 0.5m/min, the inlet SO$_2$ concentration was 1000 mg•Nm$^{-3}$, desulfurizer particle size was 1μm, NSR=1.5. After the addition of dust, the desulfurization efficiency both inside and outside filtration filters were increased by about 10%. With the increase of temperature, the desulfurization efficiency of the inside filtration bag filter first increased and later decreased, which was the same as that when only the desulfurizer was sprayed (figure 6(a)). The outside filtration bag filter increased with temperature; the desulfurization efficiency increased first, then decreased and next increased slowly, which was similar to that of desulfurization temperature when only desulfurizer was injected. At the temperature from 150° C to 160 ° C, when no powder was added, the desulfurization efficiency of the outside filtration bag filter was 93%, and the optimum desulfurization efficiency of the inside filtration bag filter could reach to 96%.

![Graph showing SO$_2$ removal vs. Temperature](image)

**Figure 6(a).** The SO$_2$ removal at industrious concentration of 1000mg•m$^{-3}$.

**Figure 6(b).** Desulfurization efficiency of injection section section.

For the injection section, after adding 1000mg•m$^{-3}$ of dust, the desulfurization efficiency of the injection section of the outside filtration bag filter increased by 3%, while the inside filtration bag filter increased by 20%. The addition of dust formed a turbulent state in the pipeline, which made SO$_2$ react more fully with sodium bicarbonate, then the thickness of the filter layer formed by the sodium
bicarbonate, dust and sulfate on the surface of the bag filter increased faster. As the pressure loss of the bag filter increases, the filtration wind speed inside filtration tank decreased, and the residence time of SO₂ inside filtration tank and the pipeline increased, so the desulfurization reaction proceeded more fully. Most of the sodium bicarbonate reacted with SO₂ in the injection section, resulting in a declining trend in the desulfurization efficiency of the filtration section.

4. Conclusions

(1) Through the research on the integration of desulfurization and dust removal by spraying sodium bicarbonate into the dry process pipeline, it is found that: the desulfurization efficiency of the inside filtration bag filter was better than that of the outside filtration bag filter, and the dust removal efficiency of both was maintained above 99.9%.

(2) Sodium-sulfur ratio is one of the important parameters affecting the control of desulfurization chemical reaction. The removal of SO₂ increased with the increase of sodium-sulfur ratio. When NSR>1.5, the increase of desulfurization efficiency decreased and gradually became gentle. When NSR=1.5, the desulfurization efficiency of the inside filtration bag filter could reach to 91%, which was 7% higher than the desulfurization efficiency of the outside filtration bag filter. In the whole process, the desulfurization efficiency of the inside filtration filter bag was better.

(3) In the integrated device, with the increase of the concentration of the inlet SO₂, the desulfurization efficiency of the inside filtration bag filter was slightly reduced; while for the outside filtration bag filter, the change of the inlet SO₂ concentration had little effect on the desulfurization efficiency.

(4) When the temperature was 130°C-150°C, the desulfurization efficiency of both inside and outside filtration bag filter increased with temperature gone up, then decreased from 150°C to 200°C. After adding 1000mg·m⁻³ dust, the desulfurization efficiency of both inside and outside filtration bag filters increased by 10%, and the removal of SO₂ with temperature was the same as that before adding dust.

(5) The desulfurization reaction was better, when NaHCO₃ particles size was smaller.

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