Evaluation of Ultralow Emission Performance of Magnesium Oxide (MgO) Wet Flue Gas Desulfurization Unit for Coal-fired Units

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Abstract. Performance tests and evaluations were carried out on the magnesium oxide (MgO) wet flue gas desulfurization unit being used in the ultra-low emission reform of coal-fired units. It is of reference for units that have not yet carried out ultra-low emission transformation. Taking a magnesium oxide (MgO) wet flue gas desulfurization device of a 350MW coal-fired unit that has completed ultra-low emission modification as the research object, the main performance indexes such as desulfurization efficiency, GGH air leakage rate and reducing agent consumption of the device were tested, and the system operation status were mastered. The test proves that when the magnesium oxide (MgO) wet flue gas desulfurization device used in the desulfurization ultra-low emission reform of the unit is operated under design conditions, it can maintain high desulfurization efficiency and low SO2 emission concentration for a long time, and the main design indicators can meet the design value requirements. The effect of GGH leakage rate on SO2 emission concentration is obvious, resulting in system desulfurization efficiency slightly lower than that of absorption tower desulfurization efficiency.

1. Foreword

With the full implementation of the ultra-low emission policy in coal-fired power plants, the emission concentration limit of SO2 in flue gas of coal-fired power plants has begun to implement the standard of 35mg/m3 (Standard dry, 6% O2, as the same below) [1]. The original desulphurization facilities in most coal-fired power plants have been unable to meet the requirements of ultra-low emission standards [2]. In this revamp, the main technical routes used in the desulfurization system are single tower and double cycle based on limestone and gypsum wet process, single tower capacitive tray, double tower double cycle and so on [3]. Each process has been widely used by its own technical characteristics. Magnesium oxide (MgO) wet flue gas desulphurization has been favored because of its high desulfurization efficiency, simple operation and difficult scaling. It is suitable for power plants where magnesium oxide is easily available and disposal of by-products is extensive [4].

Compared with limestone-gypsum wet desulfurization, the chemical reaction activity of magnesium oxide is much higher than that of calcium carbonate, so it has higher desulfurization efficiency. At the same time, because the liquid-gas ratio of the wet flue gas desulfurization process of magnesium oxide is small, it is about 1:3. The ratio of liquid to gas of calcium process is about 1:15,
so the investment cost of magnesium desulfurization system is obviously less than that of limestone gypsum wet desulfurization \[5\]. In addition, the pH value of magnesium desulfurization is generally controlled in the range of 6.0 ~ 6.5, and the corrosion of equipment is alleviated to a certain extent compared with that of limestone and gypsum wet desulfurization \[5-7\].

2. Methods and Contents for Research

Taking the ultra-low emission of magnesium oxide (MgO) wet flue gas desulfurization unit of a 350MW coal-fired unit as an example, the performance test of the unit after revamping of ultra-low emission is carried out. The performance tests of desulfurization unit were carried out under 100% designed sulphur content and 50% load 0.6% sulphur content respectively. The main test items are desulfurization efficiency, GGH air leakage rate, reducing agent consumption and so on. The test results are compared with the design values, and the operation status of the desulfurization unit is evaluated.

3. Performance Evaluation Test

3.1 System Survey

The installed capacity of No. 2 unit in a power plant is 350 MW. The boiler is produced by Ishikawa Island Mill Co., Ltd., the type is IHI-FW-SR, Single steam drum, natural circulation, reheat type, open air arrangement. The maximum of evaporation capacity is 1070 t / h, rated 1034 t / h. The MgO wet desulfurization process is adopted in the flue gas desulfurization system. The GGH heat exchanger is retained for one furnace and one tower. The low leakage air system of the original GGH is reformed, and the leakage rate is further reduced to less than 0.8%. After the revamping, desulfurization efficiency ≥ 98.50%, the stable emission concentration of GGH net flue gas SO2 is less than 35mg/m³ (standard state, dry base, 6% O2), which meets the national ultra-low emission standard.

3.2 Magnesium Oxide Desulfurization Principle

MgO is a basic metal oxide. The flue gas is washed with Mg(OH)2 slurry digested by MgO powder and water. Mg (OH)2 reacts with SO2 in flue gas to produce MgSO3 crystal. When the MgSO3 in the absorber reaches a certain concentration, it can be removed to the byproduct treatment system by removing the pump \[8-9\]. The main chemical reaction processes are as follows:

\[
\text{(1)} \quad \text{Mg(OH)}_2+\text{SO}_2\rightarrow\text{MgSO}_3+\text{H}_2\text{O}
\]

\[
\text{(2)} \quad \text{MgSO}_3+\text{H}_2\text{O}+\text{SO}_2\rightarrow\text{Mg(HSO}_3)_2
\]

\[
\text{(3)} \quad \text{Mg(HSO}_3)_2+\text{Mg(OH)}_2+4\text{H}_2\text{O}\rightarrow2\text{MgSO}_3+3\text{H}_2\text{O}
\]

3.3 Desulfurization Efficiency Test

Desulfurization efficiency is one of the important indexes for evaluating the performance of desulfurization units \[10\]. During the test, the sampling tube with heat tracing is inserted into each measuring point in turn. The flue gas was entered into the infrared flue gas analyzer after the pre-treatment device. The SO2 and O2 measurements of the gas analyzer were read respectively, and the values during the test were averaged. Then the actual desulfurization efficiency is calculated by the following formulas:

\[
\eta=\frac{C_1-C_2}{C_1} \times 100\%
\]

C1- is converted to the standard state, and the concentration of SO2 in the original flue gas under 6% O2 is obtained;

C2- is converted to the standard state, and the concentration of SO2 in the net flue gas under 6% O2 is obtained.
The test results of desulphurization efficiency and GGH leakage rate under 100% load show that the average concentration of GGH inlet SO₂ in flue gas was 2761 mg/m³. The average concentration of net flue gas GGH inlet SO₂ is 34 mg/m³. The average concentration of SO₂ at the exit of GGH is 20 mg/m³. The desulfurization efficiency of absorption tower is 99.28%, and the desulfurization efficiency of the system is 98.77%, which meet the design value of desulfurization efficiency ≥ 98.50%. The air leakage rate of GGH is 0.51%, which meets the design requirement of GGH air leakage rate ≤ 0.8%.

### Table 1  Desulfurization Efficiency and GGH Air Leakage under 100% Load

| Item                  | Original Flue Gas (GGH Original Flue Gas Inlet) | Net Flue Gas (GGH Net Flue Gas Outlet) | Net Flue Gas (GGH Net Flue Gas Inlet) |
|-----------------------|-----------------------------------------------|---------------------------------------|---------------------------------------|
|                       | T1    | T2    | T3    | T4    | T5    | T1    | T2    | T3    | T4    | T5    | T1    | T2    | T3    | T4    | T5    |
| P1                    | 2789  | 2729  | 2758  | 2747  | 2755  | 32    | 37    | 35    | 32    | 34    | 22    | 17    | 20    | 22    | 21    |
| P2                    | 2784  | 2744  | 2803  | 2759  | 2774  | 39    | 38    | 32    | 31    | 39    | 20    | 18    | 22    | 19    | 22    |
| P3                    | 2724  | 2753  | 2795  | 2741  | 2763  | 27    | 32    | 33    | 29    | 35    | 17    | 18    | 19    | 18    | 20    |
| Average Value of SO₂  |        |       |       |       |       | 2761  |       |       |       |       | 34    |       |       |       | 20    |
| Tower Desulfurization Efficiency | 98.77  | 99.28 |
| Total Desulfurization Efficiency | 98.77  | 99.28 |
| GGH Air Leakage Rate   | 0.51  |       |       |       | 0.51  |       |       |       |       |       |       |       |       |       |       |

The test results of desulphurization efficiency and GGH leakage rate under 50% load show that the average concentration of GGH inlet SO₂ in flue gas was 1528 mg/m³. The average concentration of net flue gas GGH inlet SO₂ is 22 mg/m³. The average concentration of SO₂ at the exit of GGH is 17 mg/m³. The desulfurization efficiency of absorption tower is 98.92%, and the desulfurization efficiency of the system is 98.56%, which meet the design value of desulfurization efficiency ≥ 98.50%. The air leakage rate of GGH is 0.32%, which meets the design requirement of GGH air leakage rate ≤ 0.8%.

### Table 2  Desulfurization Efficiency and GGH Air Leakage under 50% Load

| Item                  | Original Flue Gas (GGH Original Flue Gas Inlet) | Net Flue Gas (GGH Net Flue Gas Outlet) | Net Flue Gas (GGH Net Flue Gas Inlet) |
|-----------------------|-----------------------------------------------|---------------------------------------|---------------------------------------|
|                       | T1    | T2    | T3    | T4    | T5    | T1    | T2    | T3    | T4    | T5    | T1    | T2    | T3    | T4    | T5    |
| P1                    | 1287  | 1232  | 1276  | 1245  | 1217  | 17    | 17    | 19    | 20    | 18    | 13    | 13    | 13    | 13    | 13    |
| P2                    | 1277  | 1243  | 1265  | 1251  | 1239  | 17    | 18    | 19    | 20    | 17    | 13    | 14    | 16    | 14    | 13    |
| P3                    | 1275  | 1262  | 1273  | 1239  | 1246  | 17    | 17    | 17    | 20    | 17    | 13    | 14    | 13    | 16    | 13    |
| Average Value of SO₂  | 1528  |       |       |       |       | 22    |       |       |       |       | 17    |       |       |       |       |
| Tower Desulfurization Efficiency | 98.92  | 98.56 |
| Total Desulfurization Efficiency | 98.92  | 98.56 |
| GGH Air Leakage Rate   | 0.32  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |

The results show that the desulfurization system can obtain higher desulfurization efficiency under 100% and 50% load conditions. The outlet concentration can meet the requirement of ultra-low emission standard, but there is a phenomenon that the desulfurization efficiency of absorber is a little higher than that of system desulfurization. This is mainly caused by the air leakage in the GGH system, which leads the original flue gas to enter the net flue gas directly from the inside of the GGH without the absorption tower. The ratio of SO₂ leaked from GGH system to the emission is 41.17%. The result shows that the GGH air leakage rate has an obvious effect on SO₂ emission concentration [11-13].

3.4 Efficiency Statistics of MgO Consumption and Desulfurization

During the performance test, the CEMS test data of the original / net flue gas components under 100% load conditions were statistically analyzed and corrected according to the correction coefficient calculated in the calibration table. According to the statistical data, when the SO₂ concentration of the original flue gas is in 1952-2761mg/m³, the average desulfurization system efficiency is 98.64-98.95% under 100% load condition, which meet the requirement of the guaranteed performance value of the
desulfurization system efficiency ≥ 97.9%. At the same time, according to the laboratory analysis data of MgO and the statistical data of desulfurization efficiency, it is calculated that under 100% load condition, the MgO consumption of the original flue gas SO₂ concentration is between 1.41-1.99t/h and 1.41-1.99t/h when the 1952-2761mg/m³ concentration of the original flue gas is in the condition of 100% load. It can meet the requirement of MgO average consumption ≤ 2.6t/h.

### 3.5 Slurry Analysis on Absorption Column

During the performance test, a total of 4 sampling and analysis of the slurry in the absorber were carried out, the results of which are detailed in Table 4. The results show that the pH value of the absorber slurry is between 6.46-6.75, which is slightly higher than the range of pH between 5.5-6.5 recommended by the technical agreement. However, considering that other operating parameters are basically normal, no fine adjustment has been made.

### 3.6 Quality Analysis on Desulfurization Wastewater

During the performance test, the total discharge of wastewater during the test period is counted by the field table, and the average value is calculated. Because the operation mode of desulfurization wastewater treatment system is intermittent operation, only 12.7 m³/h of desulphurization wastewater flow is counted in the statistical average period, which meets the requirements of current operation. Desulfurization wastewater water quality analysis results are detailed in Table 5. In the result of water quality analysis of desulfurization wastewater on August 25, the test value of sample CODcr is 149 mg/L, which does not meet the standard requirement of < 100mg/l, and the other indexes all meet the requirements of relevant standards.

### Table 3 Efficiency Statistics of MgO Consumption and Desulfurization

| Test Data | Test Data Statistics of Performance |
|-----------|-----------------------------------|
| Time      | 8.24                              |
|           | 09:00-11:30                       |
|           | 13:30-17:30                       |
|           | 13:30-17:30                       |
|           | 13:30-14:30                       |
| Average Load MW | 350.5  |
|            | 351.7                             |
| SO₂ Concentration of Original Flue Gas | 2761  |
| mg/m³      | 2589                              |
| SO₂ Concentration of Net Flue Gas | 34    |
| mg/m³      | 33                                |
| Desulfurization System Efficiency % | 98.77 |
|            | 98.72                             |
|            | 98.64                             |
|            | 98.95                             |
| Standard Dry Flue Gas Flow m³/h | 935091 |
|            | 936225                            |
|            | 929720                            |
|            | 937741                            |
| Purify of MgO % | 84.16  |
| Consumption of MgO t/h | 1.99 |
|            | 1.87                              |
|            | 1.83                              |
|            | 1.41                              |

### Table 4 Results of Slurry Analysis on Absorption Column

| Sample Name                  | Sampling time | pH   | Density (g/L) | Cl (mg/L) | SO₃⁻(mg/L) | SO₄²⁻(g/L) |
|------------------------------|---------------|------|---------------|-----------|------------|------------|
| Slurry in Absorption Column  | 08.24 10:10   | 6.70 | 1238          | 5426      | 1.2×10⁴    | 143.4      |
| Slurry in Absorption Column  | 08.25 09:30   | 6.46 | 1212          | 6670      | 1.1×10⁴    | 159.7      |
| Slurry in Absorption Column  | 08.26 09:40   | 6.66 | 1207          | 4686      | 1.4×10⁴    | 124.2      |
| Slurry in Absorption Column  | 08.27 09:25   | 6.75 | 1236          | 5896      | 1.4×10⁴    | 148.1      |

### Table 5 Results of Quality Analysis on Desulphurization Wastewater

| Item            | 08.24 10:00 | 08.25 16:00 | 08.26 10:00 | 08.27 10:30 | standard |
|-----------------|-------------|-------------|-------------|-------------|----------|
| pH              | 7.66        | 7.81        | 8.58        | 7.88        | 6~9      |
| Suspended Matter (mg/L) | 15.5 | 14.0 | 68.1 | 19.7 | ≤100mg/l |
| CODcr(mg/L)     | 83          | 149         | 98          | 92          | <100mg/l |
| F(mg/L)         | 15.6        | 20.1        | 20.8        | 15.7        | 10/15/30 |
| Sulfide (mg/L)  | 0.026       | 0.029       | 0.029       | 0.037       | 0.5/1/2/0 |
| Cr(mg/L)        | 0.104       | 0.089       | 0.074       | 0.080       | 1.5      |
| As(mg/L)        | 0.0072      | 0.010       | 0.0077      | 0.0013      | 0.5      |
| Pb(mg/L)        | 0.0021      | 0.0054      | 0.0017      | 0.0013      | 1.0      |
| Ni(mg/L)        | 0.012       | 0.014       | 0.014       | 0.010       | 1.0      |
| Zn(mg/L)        | 0.0041      | 0.0048      | 0.0034      | 0.0037      | 2.0/3/0/5.0 |
3.7 Quality Analysis on By-product

During the performance test, a total of 5 by-product quality analysis tests were conducted, the specific test results are detailed in Table 6. The results show that the content of Cl\(^-\) in the by-product is 0.27%, which exceeds the design value of < 0.01 wt%, and the F\(^-\) content is 0.037%, which exceeds the design value of < 0.01 wt%. The average value of attached water is 15.30%, which exceeds the design value of ≤ 15%. The other indicators meet the design value requirements. The reason that the content of Cl\(^-\), F\(^-\) exceeds the standard is that the content of Cl\(^-\), F\(^-\) in coal is high, and the high content of Cl\(^-\) affects the dehydration effect of by-product to some extent\(^{[14-15]}\).

| Sampling Time | pH     | Attached Water (%) | MgSO\(_4\cdot7\)H\(_2\)O (%) | MgSO\(_3\cdot x\)H\(_2\)O (%) | MgCO\(_3\)+CaCO\(_3\) (%) | Cl\(^-\) (%) | F\(^-\) (%) |
|---------------|-------|--------------------|-----------------------------|-----------------------------|---------------------------|-------------|------------|
| 08.20 10:50   | 7.83  | 14.01              | 9.00                        | 70.42                       | 3.56                      | 0.40        | 0.037      |
| 08.24 10:05   | 7.95  | 14.71              | 13.94                       | 69.46                       | 3.38                      | 0.16        | 0.038      |
| 08.25 16:00   | 7.90  | 14.26              | 9.55                        | 66.48                       | 2.10                      | 0.18        | 0.035      |
| 08.26 09:31   | 7.73  | 16.15              | 9.76                        | 71.91                       | 0.10                      | 0.25        | 0.033      |
| 08.27 09:31   | 7.82  | 17.37              | 12.49                       | 67.94                       | 0.01                      | 0.34        | 0.041      |
| Average Value | 7.85  | 15.30              | 10.95                       | 69.24                       | 1.83                      | 0.27        | 0.037      |
| Design Value  | 6–9   | ≤15%               | <15%                        | ≥65%                        | <3%                       | <0.01 wt%  |

4. Conclusion

The test results show that the magnesium oxide (MgO) wet flue gas desulphurization unit can keep high desulfurization efficiency and low SO\(_2\) emission concentration for a long time when it is operated under the design conditions. The main design indexes can meet the requirements of design value, and the process characteristics can meet the requirement of ultra-low emission.

The desulphurization efficiency of absorber is slightly higher than that of system in the desulphurization units with GGH. This is mainly caused by the air leakage in the GGH system, which leads the original flue gas to enter the net flue gas flue directly from the inside of the GGH without the absorber, and the influence of the GGH air leakage rate on the SO\(_2\) emission concentration is obvious. Therefore, the effective control of GGH air leakage rate is a key factor to improve the desulfurization efficiency of the system.

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