Operation Results of the IHI Flue Gas Desulfurization System for the No. 1 Boiler at Reihoku Power Station of Kyushu Electric Power Co., Inc.*

Hiroo INOUE**

The IHI flue gas desulfurization system was completed for a new 700 MW coal-fired boiler in December 1995. The system is now operating very smoothly, achieving a removal efficiency of more than 90% for SO₂ and more than 85% for particulates. 100% availability has been maintained so far. Special features of the system are as follows:

1. A simultaneous SO₂ and particulates removal absorber with a forced oxidation system is used, which is the largest spray tower ever built in Japan.
2. Two variable pitch axial flow fans are positioned downstream of the absorber (C-Position).
3. Optimum FGD control system is installed to minimize the operating cost for AFC (automatic frequency control) operation of the power plant.

Key Words: Fossil Fuel Fired Power Generation, Optimal Control, Environmental Engineering

1. Introduction

The islands of Amakusa are located at the western end of Kumamoto Prefecture, forming a scenic spot that belongs to the Unzen-Amakusa National Park. Historically, the Amakusa-Shinabara Revolt, an armed uprising of the local Christians in the beginning of the Edo period, is widely known. Amakusa retains many traces of those days' Christian culture.

Kyushu Electric Power Co., Inc. constructed Reihoku Power Station, the latest middle-load power plant, as its largest coal-fired power station (700 MW) in Amakusa in order to reduce its dependence on oil as fuel, diversify power generation sources, and ensure stable power supplies to meet increasing demand. The power station started commercial operation in December 1995.

For the construction of the power station, we delivered a flue gas desulfurization system, together with a boiler and a flue gas denitrification system.

Among environmental protection systems, a flue gas desulfurization system is required to provide an especially high degree of reliability, comparable to that of the main equipment of a power station itself. The system we delivered adopted a simultaneous SO₂ and dust removal, forced oxidation process. The single absorber is the largest in scale in Japan and treats all the flue gas by itself. A control center integrates monitors and operates this flue gas desulfurization system together with a consolidated waste water treatment system, an ash treatment system, and a coal unloading and conveying system. For readers' reference, this paper summarizes and reports on a part of the results of operation of this system.

2. Reihoku Power Station

The main facilities of this Reihoku Power Station, constructed in Reihoku-cho, Amakusa-gun, Kumamoto Prefecture, are outlined below.

| Generator output: | 700 MW |
| Boiler evaporation: | 2 260 t/h |
| Fuel used: | imported coal |
| Dry type flue gas denitrification system: | ammonium selective catalytic reduction process |
| Dust collector: | |

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** Air Pollution Control Design Dept., Power Plant Division, Ishikawajima-Harima Heavy Industries Co., Ltd., 2-16 Toyosu 3-chome, Koto-ku, Tokyo 135-8733 Japan
electrostatic precipitator low-temperature dust collector
Flue gas desulfurization system: wet type limestone gypsum process
Stack Type:
steel structure supported stack
Height: 200 m

3. Flue Gas Desulfurization System

3.1 Specifications
The principal specifications of the desulfurization system are as follows:
Type: wet type limestone gypsum process
Process: simultaneous SO₂ and dust removal forced oxidation
Number of trains
Flue gas: 2 trains
Absorber and gypsum: 1 train
Conditions of treated gas (IDF outlet, S content
design coal, MCR conditions)
Gas volume (wet): 2 218 550 m³(normal)/h
Gas temperature: 133°C
SO₂ concentration: 974 ppm
Dust concentration (dry): 100 mg/m³(normal)
Performance
Overall desulfurization efficiency: 90% or more
Desulfurization efficiency of absorber: 89.5% or more
Overall dust removal efficiency: 70% or more
Dust removal efficiency of absorber: 85% or more
COD concentration of waste water: 30 mg/l or less
F concentration of waste water: 240 mg/l or less
Gypsum quality
Purity: 95 wt% or more
Moisture content: 10 wt% or less
Main equipment
Absorber (spray type): 19.1 m(diameter) × 33.3 m(height) × one unit
FGD Boost-up fan (C-position)
Type: variable pitch, axial flow type
Number: 2 sets
Capacity: 30 000 m³/min
Pressure: 5.49 kPa (560 mmAq)
Motor output: 3450 kW
Gas-gas heater
Type: vertical shaft regenerative rotary type
Number: 2 sets
Heat transfer area: 29 040 m²
Absorber upper-stage recirculating pump
Capacity × head: 53.5 m³/min × 28.5 m
Number: 5 sets
Absorber lower-stage recirculating pump
Capacity × head: 53.5 m³/min × 24 m
Number: 5 sets
Oxidizing air blower
Capacity: 95 m³ (normal)/min
Pressure: 88.26 kPa (0.9 kg/cm²)
Number: 3 sets (including one stand-by set)
Gypsum separator
Type: basket type centrifuge
Size: 60 in.
Number: 9 sets (including one stand-by set)
Cera pump for transporting limestone under pressure
Transport capacity: 150 t/h
Limestone silo: 1 630 m³ (good for nine days)
Utilities and subsidiary raw materials
Make-up water: 73 t/h
Maximum power consumption: 10 MW (during MCR)
Limestone powder: 8.3 t/h
Caustic soda: 300 kg/h (concentration: 25 wt%)
By-product (gypsum): 15.7 t/h (moisture content: 10 wt%)

3.2 Basic plan
This flue gas desulfurization system was simplified on the process side in order to reduce maintenance, power, and other operation expenses. In addition, since the Reihoiku Power Station is a middle load thermal power plant, we adopted an optimum control system that fully follows up the AFC of the unit and that also pursues stable and economical operation.

The main techniques, including new ones, adopted in the basic plan are briefly described below.
(1) Simultaneous SO₂ and dust removal, forced oxidation process
Of our simultaneous desulfurization and oxidation processes, the ash separation type has been in operation smoothly in new thermal power plants since 1991[1]. The simultaneous SO₂ and dust removal type, with an oxidation tower installed separately, has also been in smooth operation in other new thermal power plants since 1986[2]. Meanwhile, in enlarging the absorber size to a diameter of 19.1 m for the Reihoiku Power Station, we referred to the performance and the experience of operation of the single train system (absorber diameter: 18.3 m) of a 700 MW coal-fired unit that started operation in 1983[3]. Through the integration of these technologies, the simultaneous SO₂ and dust removal, forced oxidation process was applied to the 700 MW coal-fired unit, thus simplifying the system in order to curtail power consumption, operation control load, and maintenance expenses and also reduce scaling in the absorber and the COD in waste water.
Installation of a FGD boost-up fan at the C-position

Installation of a FGD boost-up fan at the downstream side of an absorber (C-position) reduced the volume of treated gas by the actual gas standard and also reduced the draft loss, because only one absorber is involved. Thus it became possible to cut back on power consumption. In consideration of the limited installation space, we adopted a desulfurization fan of the single-boost type (made by IHI). In addition, continuous rinsing equipment was installed to deal with scaling in the fan rotor blade and the hub.

Optimum control system in middle load thermal power operation and DSS (daily start and stop)

To deal with significant changes in the load of the unit and fluctuations in operating conditions such as start and stop of the unit, start of the mill system, and changeover of coal brands, an optimum control system, including control of the number of absorber recirculating pumps, was adopted, thus ensuring stable follow-up of the desulfurization system load, energy savings, and labor savings in operating the system.

3.3 Processes

This desulfurization system consists of a flue gas system, which sends flue gas from the boiler to the absorber and sends treated gas into the stack, an absorption system, which removes SO₂ and dust and generates gypsum through the reaction of SO₂ and limestone slurry, a gypsum system, which concentrates and separates gypsum slurry and recovers gypsum as wet powder, and a limestone system, which transfers limestone powder into the silo and supplies it to absorber as limestone slurry (Figure 1).

3.3.1 Flue gas system

Untreated gas from the boiler enters the gas-gas heater (on the untreated gas side), together with a part of the treated gas that is recycled from through the bypass duct to prevent the untreated gas from leaking forth.

The untreated gas enters the absorber after being cooled down there through heat exchange with low-temperature treated gas on the outlet side of the absorber. The flue treated gas is dust-removed, desulfurized, and cooled down to the saturation temperature in the absorber. Then it is demisted by a mist eliminator on the absorber and one at the inlet of the DSF (desulfurization fan). After its pressure is increased by the DSF, it is sent to the gas-gas heater, where its temperature is raised through heat exchange with high-temperature untreated gas. Then it is discharged into the air through the stack.

3.3.2 Absorption system

The untreated gas that is discharged from the gas-gas heater enters a spray type absorber, where the SO₂, dust, and other impurities in the gas are absorbed and removed by a spray-injected liquid that contains limestone. The SO₂
thus absorbed is oxidized with oxygen contained in the air blown into the liquid in absorber and is immediately turned into gypsum. The principal reactions in the absorber are as follows:

Desulfurization: \( \text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3 \)

Oxidation: \( \text{H}_2\text{SO}_3 + 1/2 \text{O}_2 \rightarrow \text{H}_2\text{SO}_4 \)

\( \text{H}_2\text{SO}_4 + \text{CaCO}_3 + \text{H}_2\text{O} \rightarrow \text{CaSO}_4 + 2\text{H}_2\text{O} + \text{CO}_2 \uparrow \)

The gypsum slurry produced by the reaction in the absorber is fed continuously from the absorber to the gypsum system so that the gypsum slurry concentration in the absorber is kept at 10 wt%.

3.3.3. Gypsum system The liquid taken from the absorber is neutralized with caustic soda to pH7 in a neutralization tank to deposit impurities such as Al, F, etc. It is then concentrated in a thickener to 25 wt% and sent to basket type gypsum separators, where it is recovered in the form of gypsum with a moisture content of 10 wt% or less. The overflow liquid from the gypsum thickener is reused for the wash water for the absorber mist eliminator, for the solvent for the limestone slurry, and for the make-up water for the absorber. Meanwhile, a part of the overflow liquid is sent to the waste water treatment system in order to reduce the chloride ion concentration in the desulfurization system to 10,000 ppm or less.

3.3.4 Limestone system From a limestone vessel through a limestone transfer piping, limestone powder is fed into the limestone silo, where it is stored. Further, it is fed into a limestone slurry pit through a limestone service silo. In the pit, it is mixed with an overflow liquid from the slurry thickener. With its concentration adjusted to 20 wt%, necessary quantities of limestone slurry are fed into the absorber.

3.4 Control

An integrated control center is constructed to monitor, control, and operate in an integrated manner not only the desulfurization system but also the total waste water treatment system, the coal unloading and conveying system, and the ash treatment system and also to promote automatic operations to ensure more rationalization and labor saving in operations.

A Centralized Operation Board which houses four CRT units, is installed in the integrated control center and used to monitor, control, and operate the system mentioned above.

The desulfurization system is monitored, controlled, and operated entirely through CRT operations.

4. Operating Results

Trial runs of all the equipment in single units were started in late October 1994, followed by consolidated water trial runs in March 1995. Trial runs with actual gas were started toward the end of April 1995. These trial runs were completed satisfactorily, thereby verifying that the designed performance and functional requirements were exactly met.

4.1 Desulfurization, dust removal, and oxidation performance

(1) Performance Tests

In response to loads on the unit side, performance tests were made under the maximum load (735 MW), 700 MW, 525 MW, 350 MW, 210 MW, and 105 MW. The results of these tests verified that the simultaneous \( \text{SO}_2 \) and dust removal, forced oxidation process fully met the designed performance requirements. As a typical example, Table 1 shows the results of the test at the unit output of 700 MW.

(2) Oxidizing Air Reduction Tests

Under various test conditions, A/S (the ratio of oxidizing air blown in to the quantity of \( \text{SO}_2 \) absorbed) control was adopted and tests were made to reduce the quantity of oxidizing air. It was thus found that the quantity of oxidizing air that could be reduced under
Table 2 Oxidizing air reduction tests

<table>
<thead>
<tr>
<th>Item</th>
<th>Test No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test conditions</td>
<td></td>
<td>Drayton</td>
<td>Nantong</td>
<td>Drayton</td>
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<tr>
<td>Power generated (MW)</td>
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<td>700-325</td>
<td>700-350</td>
<td>210-700</td>
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<td>Absorber pH</td>
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<td>4.8-5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Oxidizing air flow</td>
<td></td>
<td>Reduce considering operating conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test results</td>
<td></td>
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<tr>
<td>SO2 (ppm)</td>
<td></td>
<td>Absorber 490-630</td>
<td>288-334</td>
<td>351-623</td>
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<td></td>
<td></td>
<td>Inlet</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>27-50</td>
<td>12-28</td>
<td>33-61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Absorber</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Outlet</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Nantong</td>
<td></td>
<td></td>
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<tr>
<td>COD (mg/L) in FGD</td>
<td></td>
<td>13</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>waste water</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Byproduct gypsum (wt%)</td>
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<td>97.2</td>
<td>98.1</td>
<td>97.1</td>
</tr>
<tr>
<td>Moisture (wt%)</td>
<td></td>
<td>8.6</td>
<td>7.6</td>
<td>8.3</td>
</tr>
</tbody>
</table>

The conditions of maintaining the desulfurization efficiency, the COD in FGD waste water, and the required gypsum properties was equivalent to the A/S value of 3.0 to 3.2.

The A/S control of the quantity of oxidizing air supplied in those tests made it possible to reduce the quantity of oxidizing air to 35 to 40% of the initial planned value and thereby materialize a reduction in power expenses. Table 2 shows the conditions and the results of the tests.

4.2 Optimum control

(1) Load Follow-up Tests

Follow-up tests were made on the flue gas desulfurization system under increased and decreased load conditions with the unit output varied between 350 MW, 525 MW, and 700 MW and the load changed at the rate of 4% per minute to 5% per minute. Figure 2 shows the results of these tests. The results of follow-up tests on the flue gas control, limestone slurry supply control, and other control systems were also satisfactory. Changes in the pH in the absorber were stable, staying between the highest of 5.2 and the lowest of 4.8 against the preset pH of 5.0. The SO2 concentration at the outlet of the absorber stayed between 25 and 65 ppm after the load was stabilized. With regard to lower desulfurization efficiency when the load was increased, oxidizing air supply control and limestone supply control were tuned to the start-up of the recirculating pumps of the absorber, so that the desulfurization efficiency became equal to or better than the performance when the load was stable.

(2) Control of the Number of Recirculating Pumps of the Absorber

For the purpose of the control of the number of recirculating pumps of the absorber, two modes were set: the start-up mode at the start-up of the boiler and the mode of controlling the number of recirculating pumps after the attainment of the target load. To deal with middle load operation and AFC operation, the control was performed so that the operating value of the SO2 concentration at the outlet of the absorber became 40 ppm to 65 ppm. When the load was increased, the rise in the SO2 concentration at the outlet of the absorber that would result from the increased load was prevented by performing the oxidizing air supply process in a total quantity (one oxidizing air blower) control mode until the lapse of a certain time.

Fig. 2 Result of load change tests

Fig. 3 AFC operation
after the completion of the load increase. Figure 3 shows the follow-up state of the flue gas desulfurization system under varied boiler load conditions. The pH in the absorber was stable in the range of 5.1 to 4.9 against the preset value of 5.0, and the SO2 concentration at the outlet of the absorber was also 10 to 55 ppm. These results verified the full performance of this control.

4.3 Results of a check on the desulfurization system during metal check

About two months after the start of actual gas operation of the flue gas desulfurization system, a check was made of the inside of the system. It was thereby confirmed that there were no problems in the system.

4.3.1 Absorber No scaling was observed on the side walls, internal pipes, or spray nozzles. As a result of the pouring of humidifying water aimed at preventing blockage, no blockage or scaling was observed in the pipe sparger supplying oxidizing air.

4.3.2 FGD boost-up fan As a result of continuous washing with water, little scaling was observed in the blades or hub of the rotary part contacting waste gas.

5. Conclusion

Trial runs were completed of the flue gas desulfurization system for the overseas coal burning boiler installed in the Reihoku Power Station of the Kyushu Electric Power Co., Inc. It was thereby confirmed that the system met the designed performance and functional requirements. The results of the trial runs of this system are summarized below.

1. The simultaneous SO2 and dust removal, forced oxidation process was comparable to the ash separat-

References

