Operating Performance and Latest Technology of DeNOx Plants for Coal-Fired Boilers

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ABSTRACT: In the last quarter century, air pollution has become a global environmental problem. To remove NOx in flue gas emitted from thermal power plants, many DeNOx plants (NOx removal plants) have been constructed in and are being planned for Japan, the US, the EC, and Asia. DeNOx plants for coal-fired boilers require high technology system and catalyst designs because the flue gas contains high amounts of NOx, SOx and dust. Hitachi developed a unique plate-type catalyst which has high resistance to erosion and plugging with dust. It supplied the first DeNOx plant for a coal-fired boiler in 1983 and has since then supplied many plants, including recent ones for 1,000-MW coal-fired boilers. In this paper we describe the features of the DeNOx plants for coal-fired boilers, introduce the plate-type catalyst, and discuss the long-term operating performance of the plants and the latest scale-up technologies, such as an advanced control system, being incorporated in the plants for large-scale boilers.

INTRODUCTION

With the rapid progress of industrialization, air pollution has become a global environmental problem in the last quarter century. As early as 1963, Hitachi commenced studies on DeNOx catalysts and found that a titanium dioxide catalyst is a highly active catalyst which has high resistance to SOx poisoning. Hitachi developed a unique plate-type catalyst that is highly resistant to erosion and plugging with dust in flue gas. DeNOx plants apply to the NOx contained in the flue gas a selective catalytic reduction (SCR) process in which ammonia is used as a reducing agent, decomposing the NOx into harmless N2 and H2O through the action of the catalyst. Hitachi began the commercial application of DeNOx plants in Japan in 1977 and has supplied more than 200 plants in Japan, the US, the EC, and Asia.

Recently, DeNOx plants have mainly been used for large coal-fired boilers. Despite their complexity, the DeNOx plants have been operating successfully, increasing the performance of the plants and contributing to environmental protection. The developments of catalysts and reactor designs have been crucial to the successful operation of the DeNOx plants. In the paper, the features of DeNOx plants for coal-fired boilers are described, introducing the plate-type catalyst and discussing the long-term operating performance of the plants and the latest scale-up technologies, such as an advanced control system, being incorporated in the plants for large-scale boilers.

Fig. 1—Considerations on DeNOx Plant for Coal-Fired Flue Gas.
constructed or are planned in these regions for coal-fired boilers. Hitachi supplied the first DeNOx plant for The Tohoku Electric Power Co., Inc.’s coal-fired boiler at its Sendai Power Station in 1983. Since then, it has supplied many plants, including recent plants for 1,000-MW coal-fired boilers for the Shinchi Unit No. 1 of Soma Kyodo Power Co., Ltd., etc.

**FEATURES OF DeNOx PLANTS FOR COAL-FIRED BOILERS**

The main characteristics of coal-fired flue gas and catalyst requirements and design features of DeNOx plants are shown in Fig. 1. Since the coal-fired flue gas contains a high amount of NO\textsubscript{x}, SO\textsubscript{x} and dust, the selection of a catalyst with high resistance to erosion and plugging with dust is very important, especially for the high dust loading system in which the boiler exhaust gas flows directly into the DeNOx plant. It is also important to keep the catalyst dry during operation and shut-down because the catalyst can be deteriorated by alkaline metals in the dust when wet. In the design of the reactor, a suitable gas velocity and uniform distributions of gas and dust should be considered.

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Fig. 2—Hitachi Plate-Type Catalyst.
*Main features are:*—high activity and long life, high erosion resistance to dust, high plugging resistance to dust, low pressure loss, and compact, rigid and easy to handle.

*1: Addition of catalyst. The figure in parentheses shows percentage to the initially loaded catalyst.
*2: Replacement for the catalyst with a specially low SO\textsubscript{2} to SO\textsubscript{3} conversion rate.

**Fig. 3—Operational Performance of DeNOx Plants for Coal-Fired Boilers at High Dust Loading (catalyst addition and replacement record). The chart shows typical plants only.**
Also noteworthy is that during pilot tests of catalysts for wet bottom boilers with 100% ash recirculation in Germany, the activity of the catalyst decreased rapidly as a result of arsenic adsorption. To resolve this problem, we developed a catalyst resistant to arsenic and began supplying it to commercial DeNOx plants in Germany in 1988.1)

HITACHI PLATE-TYPE CATALYST
Hitachi’s plate-type catalyst, shown in Fig. 2, is made up of plate catalyst elements approximately 1 mm thick arranged in parallel. The element consists of a center plate coated with the catalyst material. This type of catalyst has many unique advantages such as high resistance to erosion and plugging and low pressure loss. Hitachi manufactures the plate-type catalyst at its own factory.

OPERATING PERFORMANCE OF DeNOx PLANTS FOR COAL-FIRED BOILERS
Fig. 3 shows a record of the operation of DeNOx plants for coal-fired boilers at high dust loading. All plants use the plate-type catalyst. Catalyst additions and replacements are also shown in the chart. Although the life of the catalyst depends considerably on its operating conditions, the longest operation without catalyst addition or replacement is over 10 years.

Changes in catalyst performance over time are checked by plant performance tests and sample catalyst tests. The sample catalysts are installed in the reactor and taken out for periodic analyses. Fig. 4 shows the changes in catalyst activity over time as measured by sample catalysts at DeNOx plants for coal-fired boilers at high dust loading. The longest uses of a catalyst so far are 14 years at the Sendai Nos. 2 and 3 units and 13 years at the Mizushima Nos. 1 and 2 units. (The latest data were taken in 1996.) These catalysts showed no erosion and still maintain considerable catalyst activity. Maintenance work for the DeNOx plants during their annual shut-down consisted of just cleaning the inside of the reactors. The long life and low-maintenance requirements of the plate-type catalyst contributed to the reduced operating cost of the DeNOx plants. Moreover, the power plants have never had to be shut down as a result of a DeNOx plant failure. Thus, the DeNOx plants are considered to be highly reliable.

LATEST TECHNOLOGIES FOR DeNOx PLANTS FOR COAL-FIRED BOILERS
Although many DeNOx plants for coal-fired boilers have shown to operate reliably, continuing efforts are being made for better DeNOx performance, higher reliability and lower operating costs of the plant.

The latest technologies being incorporated in the DeNOx plants for coal fired boilers are as follows.
(1) Scale-up technology for DeNOx plants for large-scale boilers

Recently, large-scale boilers with a capacity of 1,000 MW have been constructed in Japan. The DeNOx plants for these boilers are so large that scale-up technology must be studied carefully and applied to these plants.

a) Uniform gas flow in large DeNOx reactors:
   It is important to obtain uniform gas flow to improve DeNOx performance and prevent erosion and plugging of the catalyst with dust. The optimal shape of the reactor and arrangement of the guide vanes for obtaining a uniform gas flow were usually determined by a flow model test. Recently, however, flow patterns in the duct and reactor have been analyzed by computer. Fig. 5 shows the analytical model and a comparison of the flow patterns upstream of the catalyst layers by computer analysis and by flow model test. The results coincide well and the gas flow is almost uniform. Fig. 6 shows the optimal shape of the reactor and arrangement of the guide vanes. These guide vanes, called screen plates, are different from the conventional guide vanes. They work as if a large number of small guide vanes were installed. (The structure is our patent.)

b) Uniform distribution of injected ammonia:
   It is also important to obtain uniform distribution of injected NH₃ to improve DeNOx performance. A lattice-type NH₃ injection grid has been applied and the quantity of injected NH₃ to each section of the duct has been adjusted by flow adjustment valves.

c) Long-term economical operation:
   Long-term economical operation of the DeNOx plant is achieved by the catalyst addition method and the long life of the applied catalyst. The plate-type catalyst is particularly advantageous when the addition method is used because additional catalysts can be stacked directly on the existing catalyst in the vertical gas flow arrangement. Space for additional catalysts is available on the existing catalyst layer. The long life of the catalyst results from minimizing the deterioration of the catalyst and ensuring the mechanical strength of the catalyst over long-term operation. Fig. 6 shows the reactor structure which incorporates these scale-up technologies.
Fig. 7 shows the exterior view of the DeNOx plant for the 1,000-MW coal-fired boiler for the Shinchi Power Station Unit No. 1 of Soma Kyodo Power Co., Ltd. Table 1 shows the design specifications and performance test results. DeNOx efficiency is 80%. The design NH$_3$ slip is 3 ppm, which was lowered from the conventional 5 ppm to counteract the influence on the downstream equipment (such as plugging of the air preheater). The DeNOx plant is located between the boiler and air preheater and the dust concentration in the flue gas is 20 g/m$^3$. The performance test results show that the NH$_3$ slip is less than 0.1 ppm at the initial stage of operation and the performance of the DeNOx plant fully meets the specifications.

(2) Application of advanced control system

The DeNOx plant is controlled to maintain the required DeNOx performance (DeNOx efficiency and NH$_3$ slip) at all times following operation of a boiler. This is done by controlling the quantity of injected NH$_3$. In DeNOx plants for coal-fired boilers, the inlet NO$\text{x}$ often varies depending on the type of coal and the combustion conditions of the boiler. To deal with this variation, a feedback signal for the outlet NO$\text{x}$ was added to the control circuit. However, the time-constant of the change in the outlet NO$\text{x}$ corresponding to a change in the quantity of injected NH$_3$ is as large as...
10 minutes. Since the outlet NO\textsubscript{x} does not change simultaneously with the NH\textsubscript{3} injection, the feedback control is not sufficient for controlling at load changes. Therefore, we tried adding an NH\textsubscript{3} preceding injection circuit. The quantity of NH\textsubscript{3} injected is increased or decreased quickly by using signals such as the boiler load signal (MWD) and the mill start-stop signal at load changes. Even with the addition of the NH\textsubscript{3} preceding injection circuit, however, the NH\textsubscript{3} injection is not always controlled properly for handling the required DeNO\textsubscript{x} reaction for various load changes, various load change rates, and on-off of burners. Therefore, the NH\textsubscript{3} preceding injection circuit was replaced with fuzzy control. The fuzzy controller added to the control system generates a signal for correcting the mole ratio (that is, a signal for increasing or decreasing the quantity of NH\textsubscript{3} injected) to compensate for the delayed response in the DeNO\textsubscript{x} reaction from the NH\textsubscript{3} injection.

The signals are generated based on the fuzzy control rule using feed-forward signals such as load change rate, outlet NO\textsubscript{x} concentration change rate, deviation of outlet NO\textsubscript{x} concentration from the setting value, and timing of start-up and shut-down of the mills. The effectiveness and controllability of fuzzy control were studied and confirmed by computer simulation prior to implementation.
to their application. Fuzzy control was applied to the Matsuura Unit No. 2 of Electric Power Development Co.

Table 2 shows a comparison of the outlet NOx with fuzzy control and that with NH3 preceding injection control. Fuzzy control reduced the deviations (max. to min. value) from the setting value of the outlet NOx (40 ppm) considerably and reduced the deviation by approximately 40% at one hour average value.

Fig. 8 compares the NH3 injection and the outlet NOx at a load change by fuzzy control and by NH3 preceding injection control. Fuzzy control considerably reduced the excessive NH3 injection and the deviation of the outlet NOx. The application of fuzzy control is not only economical but also effective for counteracting the influence on the downstream equipment resulting from the reduction of NH3 slip.

CONCLUSIONS

The longest use of a Hitachi plate-type catalyst at a DeNOx plant for a coal-fired boiler at high dust loading has already reached 14 years. The plant has never experienced a shut-down as a result of any failure of the DeNOx plant. Thus, the DeNOx plant has been shown to be highly reliable.

The scale-up technology for obtaining uniform gas flow and uniform ammonia injection for the DeNOx plant was applied to the DeNOx plants for 1000-MW coal-fired boilers. Its effectiveness was demonstrated by the excellent performance of the DeNOx plant for the Shinchi Unit No. 1 of Soma Kyodo Power Co., Ltd.

Fuzzy control was applied to the Matsuura Unit No. 2 of Electric Power Development Co. and its effectiveness was demonstrated by the considerable reduction in the excessive NH3 injection and deviation of the outlet NOx.

REFERENCES


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