State-of-the-art Technologies for the 1,000-MW 24.5-MPa/600°C/600°C Coal-fired Boiler

Kazuhito Sakai
Shigeki Morita
Takashi Sato

OVERVIEW: The No. 2 Unit of the Haramachi Thermal Power Station of the Tohoku Electric Power Co., Inc. is a highly efficient coal-fired plant that has achieved an operating pressure of 24.5 MPa and a steam temperature of 600°C/600°C for the first time in Japan. Babcock-Hitachi K.K. (BHK) has supplied the 2,890-t/h boiler, which uses newly developed high-strength materials for the high temperature operating conditions of the main steam and reheat steam. Consequently, the power plant has achieved a high gross plant efficiency of 44.76% (higher heating value basis) at the rated load. Furthermore, state-of-the-art low NOx combustion technologies have been applied to reduce emissions. This paper describes the latest technologies used by BHK to make the plant more efficient and environmentally friendly, as well as achievements during the commissioning of the boiler confirmed in 1998.

INTRODUCTION
WITH the strong demand for Japanese utility companies to reduce air pollutant emissions, particularly CO2, there has been a drastic improvement in steam conditions of thermal power plants in Japan, as shown in Fig. 1. Since 1995, steam conditions started to improve remarkably, and in 1997 Babcock-Hitachi K.K. achieved temperatures as high as 593°C/593°C at the No. 2 Unit of the Matsuura Thermal Power Station for the Electric Power Development Co., Ltd. (EPDC). In consideration of the green house effect, Tokoku Electric Power Co. decided to improve the steam parameters up to 24.5 MPa/600°C/600°C at the No. 2 Unit of the Haramachi Thermal Power Station (Fig. 2), for which BHK has supplied a 2,890-t/h coal-fired boiler. The plant started commercial operation successfully in July 1998, and its advanced steam conditions are currently the highest in Japan.

This paper describes the main design features of the Haramachi No. 2 boiler that enable the boiler to operate at a steam temperature of 600°C/600°C.

MAIN DESIGN FEATURES OF THE BOILER
Benson-type boiler, which offers sliding pressure operation, was selected to satisfy the need for high efficiency and operating flexibility. Boiler design...
emphasized the use of high-strength materials for handling high steam temperatures.

Fig. 3 shows a side view of the boiler. A spirally wound water wall is used to maintain a balanced metal temperature profile at all loads. The heating surface of superheaters and reheaters has been increased slightly to increase steam temperature. However, increase of the heating surface has been kept low by optimizing the furnace size so that the boiler’s dynamic response is improved. Furthermore, a three-stage superheater spray system is used to control the main steam temperature, and gas-recirculation and gas-biasing dampers are included to overcome performance differences when firing different coals.

Use of High-strength Materials

For high-temperature steam conditions, it is essential to use high-strength materials to reduce wall thickness of pressure parts, resulting in low thermal stress and pressure drop.

- After extensive testing, austenitic steel, SUS304J1HTB (18Cr9Ni 3CuNbN), has been selected for pendant superheaters. This material has significantly high creep strength in high temperatures.3)
- Another high-strength austenitic steel, SUS321J1HTB (18Cr10NiTiNb), has been selected for pendant reheaters.
- Reliable ferritic piping, STPA28 (9Cr1MoVNb), has been selected for main steam pipings and high-temperature superheater headers. Rolled-plate-type piping made of the same steel has been used for reheater outlet headers and hot reheat pipings.

The use of these materials keeps the wall thickness in high temperature zones similar to that of conventional boilers.

Combustion System

Following the development of Hitachi NR burner, which is based on the innovative concept of in-flame NO\textsubscript{x} reduction, BHK developed an NR2 burner, which has strengthened high temperature reducing flame and has achieved extremely low NO\textsubscript{x} emissions and high combustion efficiency.4) This is the fourth application of this burner, which enables a low amount of excess air at the economizer outlet (15%) when firing various kinds of imported coals.

Burner capacity has been increased in recent years,
as shown in Fig. 4. This aims at rationalization and simplification of the combustion system to reduce costs and the amount of maintenance work, which will be advantages for the users. Accordingly, 42 large-capacity burners (12.4-t/h each), which are the largest in Japan, were installed at this boiler.

The combustion system is also equipped with large-capacity roller-type pulverizers (MPS300) with rotating classifiers which improve the pulverized coal fineness.

These new technologies for the combustion system, as well as the improved steam conditions, improve the boiler efficiency a great deal.

Erection Technique
The latest ACE (area composite erection) method has been used to install the boiler. The unique features of this method are synchronized erection of pressure and non-pressure parts, large modules of boiler components, and a floor-unit lifting method including steel braces and gratings. Large modules as heavy as 2,100 tons were lifted by a new oil jack system, and the erection sequence was rationalized through a detailed study using a 3-dimensional CAD system.

ACHIEVEMENTS IN THE COMMISSIONING
The plant was first ignited in August and synchronized in October 1997. Commissioning continued with four imported coals until the beginning of July 1998, when commercial operation started successfully as planned.

Stable operation under the advanced steam parameters was confirmed for both static and dynamic modes. The boiler performed as follows during the commissioning.

Combustion Performance
The combustion test results for the four coals met the guaranteed values for NO\textsubscript{x} emissions and unburned carbon in ash (UBC) with sufficient margins, as shown in Table 1.

It was confirmed that the Oxygen (O\textsubscript{2}) content at the economizer outlet of the boiler was reduced to as low as 1.5%, (against the planned value of 2.6%) for low to medium fuel ratio coals with only a marginal increase of UBC. This result significantly improved boiler efficiency. The following oxygen contents have been set at the rated load in response to fuel ratio, considering the operational margin in view of coal analysis variation.

- Low fuel ratio coal: 2.0%
- Medium fuel ratio coal: 2.3%
- High fuel ratio coal: 2.6%

Performance Test Results
The advanced steam parameters together with the

![Fig. 4—Increase of Burner Capacity. Burner capacity has gradually increased and Haramachi No. 2 Unit has the largest capacity in BHK’s supply record.](image)

![Fig. 5—Performance Test Results. These data verify that the improved steam conditions improve efficiency of the thermal power plant.](image)

| Table 1. NO\textsubscript{x} and UBC at 1,000 MW |
|-----------------|-----------------|-----------------|
| NO\textsubscript{x} (@6\%O\textsubscript{2}) | UBC         |
| S coal          | ≤ 180 ppm      | ≤ 5%            |
| M coal          | 120 ppm        | 0.5%            |
|                 | 161 ppm        | 3.9%            |

![Table 1. NO\textsubscript{x} and UBC at 1,000 MW.](image)
latest combustion technologies significantly improved plant and boiler efficiency. Fig. 5 shows the results of the performance tests. The achieved gross plant efficiency (higher heating value basis) is as high as 44.76% at the rated load.

**Minimum Load**

A trial test was conducted to determine the minimum possible operation load without oil burner or igniter support. The minimum load was 14.5% (turbine load), which is the lowest load ever achieved by coal-firing only. This result verified the remarkable performance of flame stability with NR2 burners.

Fig. 6 shows a photograph of the burner flame during the test. The flame is very bright and stable.

**CONCLUSIONS**

The Haramachi No. 2 boiler, which has the most advanced steam conditions (24.5 MPa/600°C/600°C) in Japan, represents an important step in developing more efficient boilers. The next step is to complete the design of the 1,050-MW coal-fired boiler for the No. 2 Unit of the Tachibanawan plant for EPDC. This boiler will have conditions of 25 MPa/600°C/610°C. The boiler will use ferritic (HCM12A and NF616) pipings applied for the first time. BHK trusts it will be possible to advance steam conditions in power plants to as much as 30 MPa/630°C/630°C in the near future, and the ultimate target is 700°C class plant, which could compete with other high-efficiency plants such as IGCC. BHK continues to play a key role in the development of advanced steam boilers and to contribute environmental protection.

**REFERENCES**


**ABOUT THE AUTHORS**

Kazuhito Sakai

Joined Babcock-Hitachi K.K. in 1982, and now works at the Performance Design Section in the Thermal Power Design Dept. at the Kure Division. He is currently engaged in the design and development of utility boilers. Mr. Sakai is a member of the Thermal and Nuclear Power Engineering Society, and can be reached by e-mail at sakai@kure.bhk.co.jp.

Shigeki Morita

Joined Babcock-Hitachi K.K. in 1978, and now works at the Thermal Power Design Dept. at the Kure Division. He is currently engaged in the design and development of utility boilers. Mr. Morita is a member of the Japan Society of Mechanical Engineers and the Thermal and Nuclear Power Engineering Society, and can be reached by e-mail at morita@kure.bhk.co.jp.

Takashi Sato

Joined Babcock-Hitachi K.K. in 1980, and now works at the Materials Research Department at Kure Research Laboratory. He is currently engaged in the research on the high temperature strength of new steels and welding materials. Mr. Sato is a member of the Society of Materials Science Japan and the Iron and Steel Institute of Japan and the Japan Society of Mechanical Engineers, and can be reached by e-mail at sato-t@crl.bhk.co.jp.