A Large-Capacity Pressurized-Fluidized-Bed-Combustion-Boiler Combined-Cycle Power Plant

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OVERVIEW: To improve the thermal efficiency and environmental characteristics of coal-fired power-generation systems, The Chugoku Electric Power Co., Inc. and the Hitachi Group developed the first commercial 250-MW PFBC (pressurized fluidized bed combustion) combined-cycle power plant in Osaki. The Osaki PFBC plant was commissioned, and its commercial operation began on Nov. 30, 2000. We will describe the main features of the equipment and several trial-operation results of the Osaki PFBC plant. The plant has a combined-cycle arrangement with the gas turbine and steam turbine producing an output of approximately 15 and 85%, respectively, of the total electricity. It also has a pressurized-fluidized-bed-combustion boiler, which generates steam to drive the steam turbine. The gas from the boiler is directed to a two-stage multi-cyclone, which drives the gas turbine. The boiler consists of two vessels with two furnaces.

INTRODUCTION

AS global environmental problems are becoming an important matter of international concern, the demand for coal-fired thermal power stations that can reduce the CO_2 emissions through the improvement of their thermal efficiency and minimize the emissions of SOx, NOx, soot, and dust from the boilers is increasing. This can be achieved by the development of a new power-generation system.

Recently, the Hitachi Group supplied the Osaki Power Station of The Chugoku Electric Power Co., Inc., with a 250-MW pressurized-fluidized-bed-combustion (PFBC)-boiler combined-cycle power plant as Unit 1-1. This is a compact, efficient, and environmentally friendly coal-fired thermal-power plant. To develop this power plant, from its design and fabrication to installation and test operation, the Hitachi Group led comprehensive discussions with The Chugoku Electric Power Co., Inc., that included a joint study at the 4-MW test plant of the Thermal Power Generation Technical Center of the company. Following the completion of the installation that took some 40 months after the start of the construction work in November 1995, the overall test operation began in March, 1999. The plant was put into commercial operation in November, 2000.

Fig. 1— 250-MW Pressurized-Fluidized-Bed-Combustion-Boiler Combined-Cycle Power Plant Delivered to Osaki Power Station of The Chugoku Electric Power Co., Inc. (Series 1, Unit 1-1).

This article describes the 250-MW PFBC power-plant project and the results of the test operation of the plant [1,2)].

Fig. 1 shows a bird's-eye view of The Chugoku Electric's Osaki Power Station that houses the main equipment fabricated by the Hitachi Group. Figs. 2 and 3 show the main equipment.

The boiler is a twin-furnace type. The steam turbine and gas turbine are laid out in a T shape.

250-MW PFBC PLANT EQUIPMENT

General System Configuration

The general system configuration of the plant is shown in Fig. 4, and the principal specifications of the plant are listed in Table 1.

Unit 1-1 that was delivered to The Chugoku Electric's Osaki Power Station is a combined-cycle

Fig. 2— Twin-Furnace Boiler ("W.B.") of the Power Station.

power-generation system, in which the steam turbine is driven by steam generated by a PFBC boiler housed in a pressure vessel and the gas turbine is driven by gas from which the dust is removed by two series of 12 two-stage cyclones (a multi-cyclone housed in an exclusive pressure vessel). By using limestone as the boiler-bed material, we could desulfurize the furnace gas and significantly reduce the SOx emissions. The boiler is a twin-furnace, twin-tower type, and the gas turbine is a single-shaft type. The fuel coal is fed into the boiler in the form of coal-water paste (CWP), a mixture of coal, limestone that serves as the desulfurizing agent and bed material, and water.

The Main Equipment

Boiler

The fuel is burned under an in-furnace pressure of approximately 1 MPa, whereby the hearth load is increased and the required furnace cross-section area is reduced (i.e., the furnace is compact). Appropriate steps were taken to ensure uniform flow, stability, temperature uniformity, and so on, of the fluidized bed. They include the use of inclined front- and rear-end walls, a uniform arrangement of the heat-exchanger tubes in the furnace, and the installation of many air-distribution nozzles in the hearth at equal intervals$^{3)}$. In the fuel-supply system, a mixture of fuel coal, limestone, and water (CWP), prepared outside the pressure vessel, is fed into the fluidized-bed-combustion furnace inside the pressure vessel. This system reduced the number of through pipes in the pressure vessel and improved the safety of the furnace. To enable good controllability of the boiler operation and easy transportation and installation of the boiler (the project site is located on an island in the Inland Sea of Seto), we developed a twin-furnace, twin-tower boiler ("W.B."). This boiler was shipped in the form of modules from the Kure Works of Babcock-Hitachi K.K.

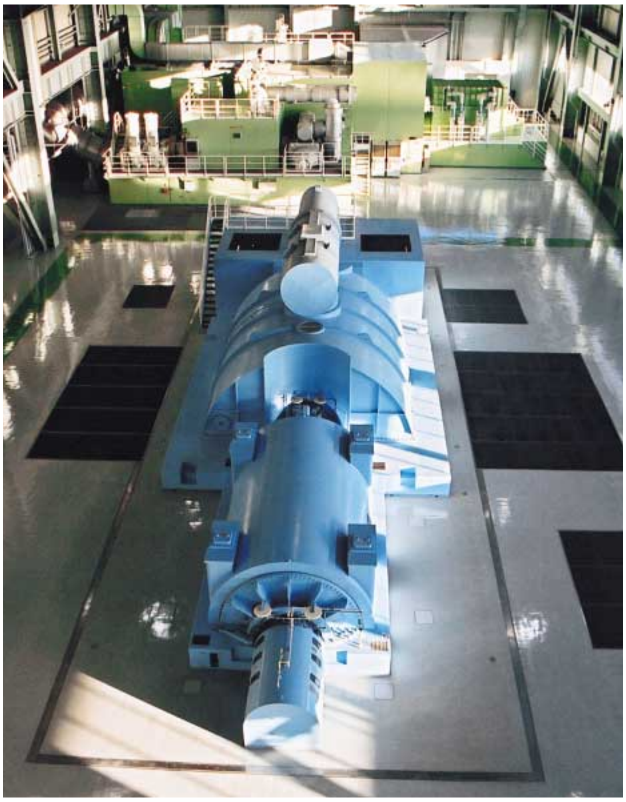


Fig. 3— Steam Turbine (Bottom) and Gas Turbine (Top) of the Power Station.

The fluidized-bed temperature is 865°C. The bed height varies from 2.5 to 4.0 m to enable changing the effective area of the heat-exchanger tubes laid out in the bed and adjusting the amount of steam generated by the boiler. The flue gas from the boiler is first cleaned from soot and dust by two-stage cyclones until the soot and dust concentration drops below 1,000 mg/m^{3}N and is then fed to the gas turbine.

Sulfur oxides (SOx) in the furnace gas are desulfurized by the limestone in the furnace and the limestone fed into the furnace together with coal. The formation of nitrogen oxides (NOx) is prevented by low-temperature combustion and the emissions of NOx are reduced by the use of flue-gas denitrification equipment (catalytic and non-catalytic denitrification). Thus, the boiler is environmentally friendly.

Gas turbine and steam turbine

The gas turbine is similar to the one installed at The Chugoku Electric's Yanai Power Station but was modified for PFBC. To ensure that the turbine blades can withstand the coal-ash-bearing hot gas (approximately 840°C) from the boiler, the thickness of both the rotating blades and stationary blades was

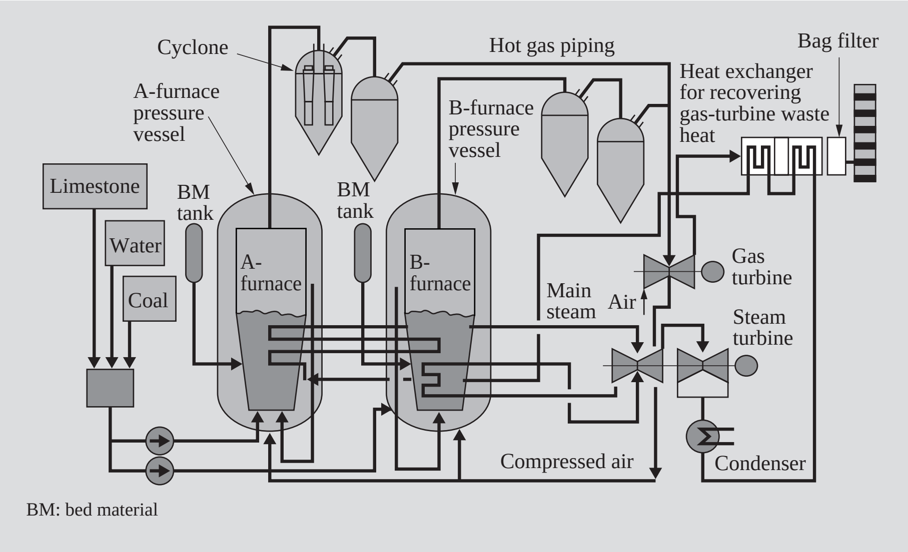


Fig. 4— General System Configuration of the 250-MW PFBC Power Plant.
Fuel, compressed air, and water are fed into the twin-furnace, twin-tower boiler. As the fuel burns in the boiler, steam and high-pressure gas are generated.

increased and the blade coating characteristics were improved. A combination of an exclusive motor and exclusive combustors is used to start the gas turbine. The amount of air fed into the boiler is controlled by a compressor inlet pressure-reducing valve installed in the gas-turbine-compressor air-inlet duct and a guide vane installed at the compressor air inlet.

The steam turbine uses a heat cycle whereby the gas-turbine waste heat is recovered by the steam-turbine condensate and feed-water system. In addition, to improve the plant thermal efficiency, a TCDF-33.5 steam turbine that can be operated under large loads was adopted.

Control System

Because a PFBC power plant has many auxiliary devices to be controlled, as well as many final controlling elements, the control system required for such a plant is necessarily large in scale. In addition, because of the long-time constants of the fuel and air supply systems of the boiler, it is necessary to ensure high controllability of boiler operation, including steam-temperature control by the fluidized bed height and temperature, and a high level of automatic control to enable boiler operation by a small number of people. Thus, the present PFBC power plant has an integrated monitor-and-control system, “HIACS-7000,” developed as a high-reliability, high-speed data-transmission network system based on a large-capacity, high-speed controller. This is the first time that the HIACS-7000 system was installed in a thermal power plant. This monitor-and-control system has the following features.

TABLE 1. Principal Specifications of the 250-MW PFBC Power Plant
This plant uses a “two-stage cyclone + bag filter” system, not a conventional ceramic-filter system, to remove soot and dust from the boiler flue gas.

Item	Specifications
Type	Pressurized-fluidized-bed-combustion-boiler combined-cycle power plant
Plant output	250 MW
Steam turbine output	215 MW
Gas turbine output	44 MW
Steam conditions	16.6 MPa 566/593˚C
Soot & dust removal system	Two-stage cyclone + bag filter
Desulfurization process	Desulfurization of furnace gas
Denitrification process	Catalytic + non-catalytic denitrification
Fuel-supply system	Wet type (coal + water + limestone)
Gas-turbine starting system	Starter motor + starter combustor
Plant gross thermal efficiency	41.5%

(1) The control system is composed of a central monitor panel, computers, and controls. The central monitor panel consists of an automation panel equipped with five CRT displays, a large screen, and auxiliary panels for independent operation. Centralized operations, including the operation of electrical equipment, are all performed by means of the CRT displays. To enable handling huge volumes of monitor information, we used a high-function, high-performance CRT processor (see Fig. 5).

(2) In automating the control operations, the control functions were distributed between the control computers and control devices for optimum results.

Fig. 5— Central Control Room.
The central control room contains an automation panel, a large screen, and auxiliary panels for independent operation.

All plant operations, from the start of the seawater system to the operation of the plant under a full load to the shut-down of the plant, were made sequential on a system-by-system basis to implement a fully-automated plant based on control computers. For routine operations, we adopted a remote, sequential control to minimize labor costs in plant operation.

(3) For the main control equipment, such as the boiler control, turbine control, and sequence control, the HIACS-7000 system was used to configure horizontally-distributed control systems. The integration of controls by using a large-capacity, high-performance controller and the use of a high-speed data-transmission network (100 Mbit/s) enabled implementing a CRT-based operation of the entire plant and establishing a good human interface.

(4) Instead of a conventional wired interlock of auxiliary devices, a programmable control module (PCM) and a remote process-input-and-output (PI/O) device were used. This significantly reduced the number of auxiliary relay panels and converter panels and enabled flexible response to field modifications. Because the remote PI/O devices were installed in the field, the cable work could be reduced dramatically.

TEST-OPERATION RESULTS

Plant Performance

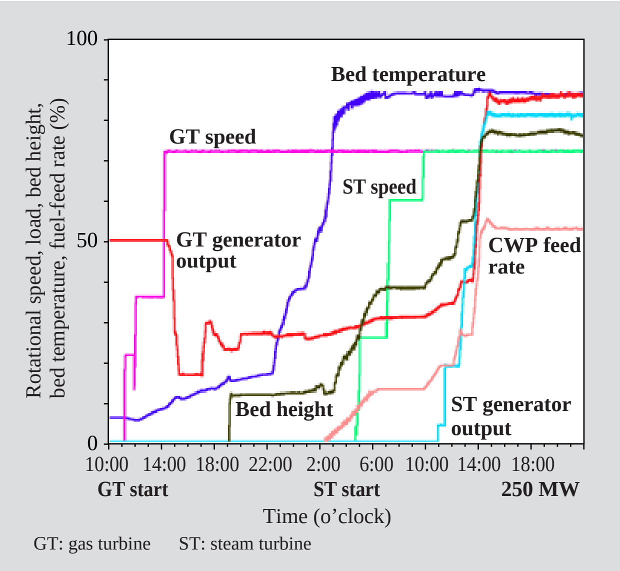
To evaluate the plant performance during the hours of a season in which the atmospheric temperature at the site of the plant is almost the same as the atmospheric temperature for which the plant was designed, in May 2000, the plant was subjected to test operation under a rated output of 250 MW. We found that every piece of equipment of the plant met its planned output and efficiency. All the functions of the PFBC boiler worked as planned, including the in-furnace desulfurization, non-catalytic denitrification (injection of an ammonia gas into the hot gas pipe at the furnace outlet), dust removal by two series of two-stage multicyclones, etc. The planned figures for the emissions of NOx, SOx, and soot and dust were met completely (see Table 2).

Plant Starting/Stopping

The characteristics of the process of starting the plant in a cold mode, from the start of the gas turbine to the attainment of a rated load, are shown in Fig. 6.

TABLE 2. Plant Performance (Planned Figures vs. Measured Results)
Both the environmental-performance and thermal-efficiency results met the planned figures completely.

Item		Planned figures	Measured results
Plant gross thermal efficiency		41.5%	Above 42%
Desulfurization	SOx concentration at flue inlet	76 ppm	7.1 ppm
	Desulfurization efficiency	≥ 90%	97.7%
Denitrification	Efficiency of non-catalytic denitrification	37%	38%
	Efficiency of catalytic denitrification	85%	88.3%
	NOx concentration at flue inlet	≤ 19 ppm	14.4 ppm
Soot and dust removal	Cyclone efficiency	97.1%	97.2%
	Concentration at gas-turbine inlet	≤ 1,000 mg/m^{3}N	≤ 533 mg/m^{3}N
	Concentration at bag-filter outlet	≤ 9 mg/m^{3}N	≤ 3.5 mg/m^{3}N



GT: gas turbine ST: steam turbine

Fig. 6— Measured Cold-Start Characteristics (Nov. 9-10, 2000).
After the gas turbine is started, fuel is fed into the boiler to generate steam, which drives the steam turbine.

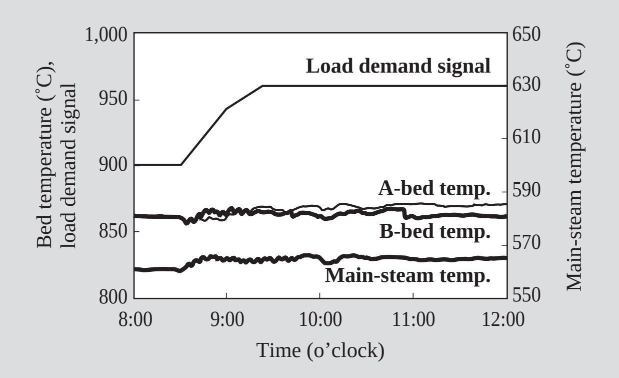


Fig. 7— Plant Behavior at Load Change (May 11, 2000).

One of the characteristics of the process of starting a PFBC plant is that once the plant equipment is synchronized with the electric power system, the gas turbine generator is operated as a synchronous motor by the electric power from the system, whereby the gas-turbine compressor is driven to feed the combustion air into the furnace. As the fuel is fed into the furnace and the temperature and height of the fluidized bed increase, the boiler generates steam and hot gas from the burning coal. In this process of a load increase, the gas turbine generator switches from the synchronous motor to a synchronous generator.

Change in Plant Load

In a PFBC boiler, both the bed temperature and the main-steam temperature change according to the change in the fuel-feed rate. Therefore, to protect the equipment, it is necessary to maintain both temperatures within a certain range on a stable basis.

In the present boiler, the bed height and the fuel-feed rate are adjusted to enable stable control of the bed and main-steam temperatures. When the bed height is changed, the area of contact between the heat exchanger and fluidized bed in the furnace changes, causing the quantity of the heat transferred from the furnace to the steam to change. As a result, both the bed temperature and the steam temperature change. Therefore, a PFBC plant needs a control system capable of keeping the bed and main-steam temperatures within the prescribed limits by controlling the fuel-feed rate and the bed height simultaneously. The present PFBC plant uses a system that controls the main steam temperature by the fuel-feed rate, which enables comparatively good plant operability and bed-temperature control with a comparatively large tolerance to the bed height.

The measured characteristics of the plant behavior during a load change are shown in Fig. 7.

CONCLUSIONS

We described the equipment of 250-MW Series 1, Unit 1-1 that was delivered to Osaki Power Station of The Chugoku Electric Power Co., Inc., as well as the results of the test operation.

The PFBC plant went through the test operation smoothly, satisfactorily, demonstrating the planned performance. We intend to test the reliability of the PFBC equipment on the basis of operation results, which will be accumulated in the future.

In concluding this paper, we would like to thank all the people of The Chugoku Electric Power Co., Inc., for their generous and extensive guidance and cooperation in all phases of the present PFBC project for Osaki Power Station, from plant planning to plant construction and test operation.

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