Commencement of the Commercial Operation of World's Top Performing 900 MW Unit "Maizuru No.1 Thermal Power Station of The Kansai Electric Power Co., Inc."

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The commercial operation of Maizuru No.1 Thermal Power Station of The Kansai Electric Power Co., Inc. commenced in August 2004. It is a state-of-the-art coal-fired supercritical pressure plant that has a capacity of 900 MW. Mitsubishi Heavy Industries, Ltd. (MHI) set up the key equipment such as boiler, steam turbine, control system, etc., that employ MHI advanced technologies. This report gives a brief overview of the advanced MHI technologies applied in the boiler and steam turbine of this plant.

1. Introduction

In recent years, growing concern about environmental problems has led to demand for reduced emissions of CO_2 gas, which has a large impact on greenhouse effects. In order to meet such demands, it is necessary to reduce the amount of CO_2 gas emissions by converting fuel energy more efficiently into electric energy, thus reducing the amount of fuel consumed in the power plant. The Maizuru No.1 Thermal Power Station is designed to increase power generating efficiency by applying high- temperature and high-pressure steam condition and efficiency-enhancing technologies to the boiler and turbine equipment.

At the same time, in order to make plant equipment economical while maintaining reliability to cope with recent trends in the deregulation of power production, motor driven start-up boiler feedwater pump and boiler circulation pump are not installed as part of measures to arrange the plant equipment in a more rational manner. The boiler is also designed to fire a wide variety of coals in the world. A highly reliable control system to cope with various kinds of coal has been adopted in order to facilitate more efficient operation. The turbine is of a large capacity cross compound type, and further better performance are achieved by fully three-dimensional flow design including an improved stationary blade seal fin structure for the low-pressure turbine and utilizing the grooved stationary blade for low-pressure last stage blade based on designs established in similar type of preceding machines.

2. Boiler

2.1 Supercritical sliding pressure operation once-through boiler

The major specifications of the boiler are shown in **Table 1**, while a side view of the boiler is shown in **Fig. 1**.

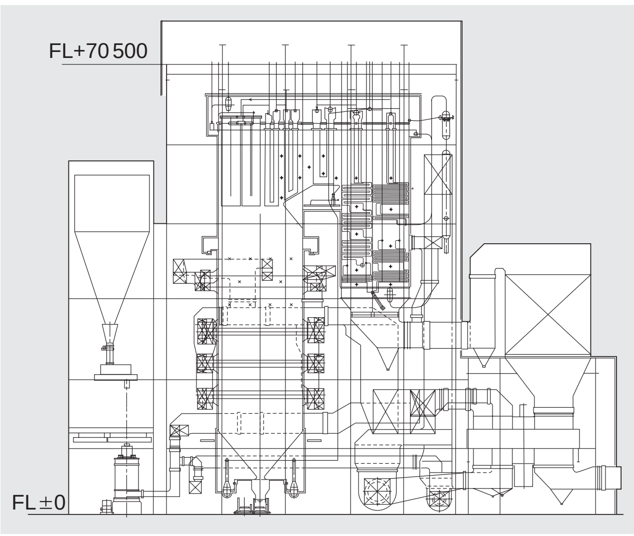

Fig. 1 Side view of boiler

Table 1 Major Specifications of boiler

Boiler type	Radiant reheat vertical furnace waterwall sliding pressure operation once-through boiler (Semi-indoor type)	
At maximum continuous load	Main steam flow rate	2 570 000 kg/h
	Steam pressure at superheater outlet	25.40 MPa
	Steam temperature at superheater outlet	598 °C
	Steam temperature at reheater outlet	598 °C
Fuel		Coal, heavy oil (30 % capacity)
Combustion system		Circular firing by A-PM burner and A-MACT
Pulverized coal combustion system		Unit direct pressurizing system
Draft system		Balanced draft
Steam temperature control system	Main steam	Feed water/fuel ratio, spray
	Reheat steam	Gas biasing damper
		Spray (for emergency use)

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(1) Adoption of vertical tube waterwall furnace system

The Maizuru No. 1 boiler is a first coal-fired supercritical sliding pressure operation once-through boiler for the Kansai Electric Power Co., Inc. It is the tenth boiler among the vertical tube type supercritical sliding pressure operation boilers delivered by MHI. The vertical tube waterwall furnace system, which uses rifle tubes, has the following advantages compared with spiral furnace waterwall systems.

- Low pressure drop: Pressure drop is low since mass velocity in the waterwall tubes is low, and the power consumption of the boiler feed pump can be saved while the design pressure of the feed water system can be reduced.
- Simple structure: Since the simplified structure facilitates support of the furnace, the number of attachement can be reduced, and the reliability, ease of installation, and maintainability of the system can be increased (**Fig. 2**).
- Uniformity of temperature: Since the ratio of the friction loss of the heating section to the total pressure drop of the waterwall tubes is small, variation in flow when furnace heat absorption varies is less thereby making it possible to maintain smaller temperature variation.
- Less adhesion of ash: Since the tubes are arranged in the vertical direction in the coal-fired boiler, slag can fall easily and, hence, the amount of ash that adheres to the waterwall is small.

The vertical tube type supercritical sliding pressure operation once-through boiler has been attracting much attention recently in Europe and the U.S.

(2) High operating performance

In terms of steam temperature characteristics, the main steam and reheat steam temperature could be maintained as planned for all types of coals used within the appropriate ranges at the steam temperature guarantee load range by the control parameters such as superheater spray and gas biasing dampers.

In order to simplify the plant and save the cost, gas re-circulation fans and a boiler circulation pump for heat recovery during start-up were not installed in this boiler. Excellent load change characteristics and start-up times could be obtained as planned during trial-operations. The pulverizer capacity was reduced by permitting the operation with using all of 6 pulverizers for a part of design coal.

2.2 Realization of low NOx emission

MHI's advanced low NOx combustion system was adopted in this plant in order to meet the stringent guaranteed NOx emission within whole of operating range from the synchronization during start-up to full load. The system consists of an MHI circular firing system, A-PM (Advanced-Pollution Minimum) burner, in-furnace NOx reduction system (A-MACT), high fineness MRS (Mitsubishi Rotary Separator) pulverizer, and an Selective Catalytic NOx Removal System (SCR).

(1) A-PM (Advanced-Pollution Minimum) burner

A separated wind box type A-PM burner was adopted in this plant and NOx is reduced by further promoting concentrated and lean combustion compared with a conventional continuous wind box type PM burner. As a result, the number of the wind box dampers has been reduced, and access to the burner area has been improved. Furthermore the maintainability, reliability, and durability of the system have been remarkably improved (**Fig. 3**).

(2) In-furnace NOx System (A-MACT)

Low NOx emissions and unburned combustibles have been realized simultaneously through the application of the A-MACT in which combustion air is injected in order to complete the combustion of unburned combustibles after a sufficient NOx reduction region has been secured in the upper portion of the main burner.

(3) High fineness MRS (Mitsubishi Rotary Separator) pulverizer

High fineness characteristics could be obtained using a rotary separator, thereby realizing further reductions in NOx emissions and unburned combustibles.

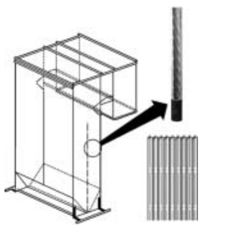
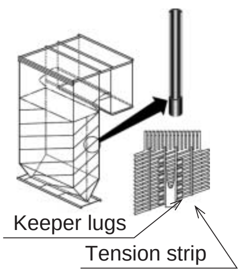
Item	Vertical waterwall furnace	Spiral wound furnace
Furnace structure	Simple 	Base 

Fig. 2 Comparison of furnace structures

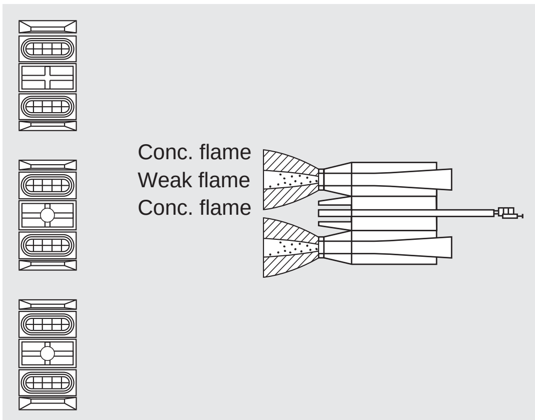


Fig. 3 A-PM burner

(4) Selective Catalytic NOx Removal System (SCR)

SCR was adopted to further reduce NOx emissions. **Figure 4** shows the measured values of NOx emissions at the outlet of the boiler. Excellent performance characteristics were obtained across all load regions.

2.3 Coping with various kinds of coal

The boiler is designed to be compatible with a wide range of bituminous coals (a total of 81 types of design coal) supplied from various countries throughout the world.

Table 2 shows the properties of the various coals used during trial-operations. MHI confirmed that the optimum steam temperature characteristics and combustion characteristics could be obtained with various kinds of coal through the flexible control system.

2.4 Boiler performance

The boiler efficiencies achieved in the performance test results are shown in Fig. 4. As can be seen from the results, excellent performance levels could be obtained through the adoption of the A-PM burner with high combustion performance, A-MACT, and MRS pulverizer. Actually measured values of boiler efficiency sufficiently surpassed the guaranteed values in a load range from 100% to minimum of 30%. It could be confirmed that the adoption of this equipment contributes significantly to the highly efficient operation of the plant.

2.5 Zone module construction method

In order to shorten the construction time at the site, the boiler was divided into seven modules (1500 t max) that were manufactured at MHI's Philippine module center and assembled in the power plant on site. (**Fig.5**).

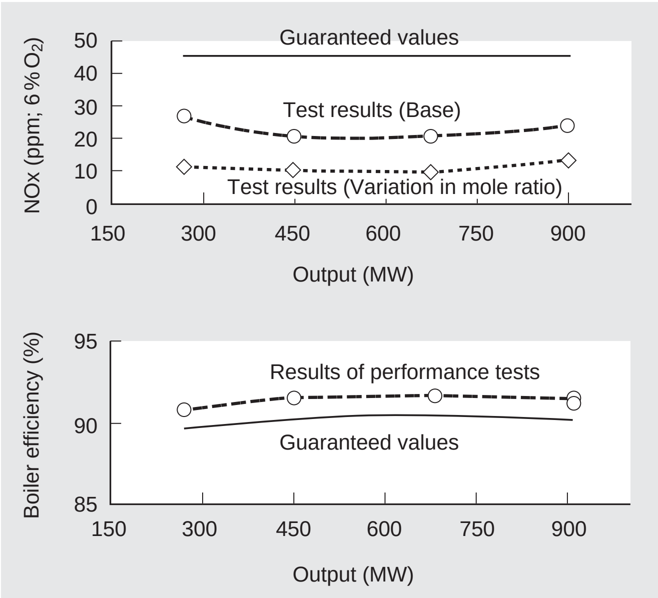


Fig. 4 Track record of NOx and boiler efficiency

Fig. 5 Transport of boiler module

Table 2 Coal properties

		Australian B coal	Indonesian B coal mixed with Australian B coal	Chinese D coal mixed with Australian B coal
Higher heating value (kJ/kg)		28 180	28 640	27 650
Total moisture content (wt%)		8.3	8.9	12.1
Proximate analysis	Inherent moisture (wt%)	2.9	4.0	5.2
	Fixed carbon (wt%)	51.3	44.6	53.5
	Volatile matter (wt%)	30.8	40.3	28.7
	Ash content (wt%)	15.1	11.1	12.6
Fuel ratio (-)		1.67	1.11	1.86
Ultimate analysis	Carbon (wt%)	69.0	70.6	70.8
	Oxygen (wt%)	9.0	10.6	9.9
	Hydrogen (wt%)	4.4	5.3	4.2
	Nitrogen (wt%)	1.62	1.29	0.99
	Sulfur (wt%)	0.45	0.80	0.85
Grindability (HGI)		54	47	57

3. Steam turbines

The main turbine is of a cross compound CC4F-46 type. External and cross sectional views of the turbine are shown in **Figs. 6** and **7**, respectively, while its major specifications are shown in **Table 3**.

The high-pressure turbine is manufactured based on a double-flow design in which the main steam inlets are located at four positions. Each flow is formed of one control stage and ten reaction stages. The intermediate pressure turbine is manufactured based on a double-flow design in which reheat steam inlets are located at four positions. Each flow is formed of seven reaction stages. The low-pressure turbine is also manufactured based on the double-flow design.

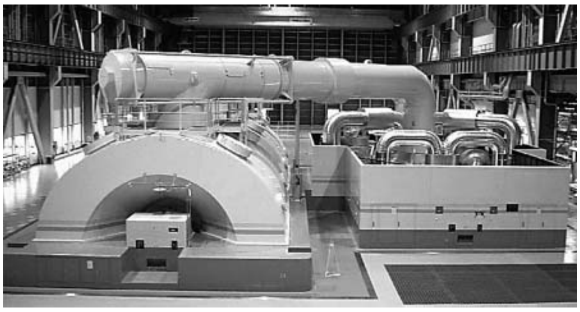


Fig. 6 View of main turbine

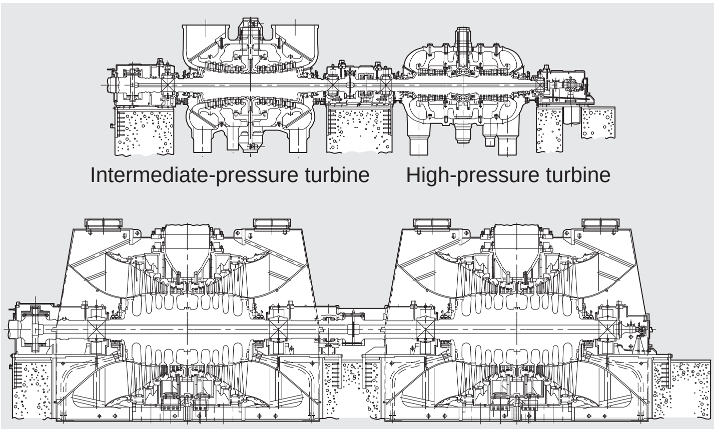


Fig. 7 Sectional view of main turbine assembly

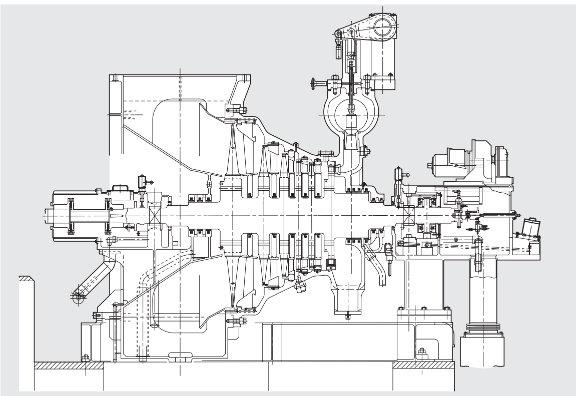


Fig. 8 Sectional view of BFP turbine assembly

Each flow is formed of nine reaction stages including the last stage blades of 46 inch integral shroud blades (ISB).

As part of measures against increases in temperature of the high-pressure and intermediate pressure turbines due to steam temperatures of as high as 600°C and in order to increase performance through the application of fully three-dimensional design blades to all reaction stages, a highly reliable design was adopted in this plant. This design was originally established at the Matsuura No.2 unit of Electric Power Development Co., Ltd.(1), the Misumi No.1 unit of Chugoku Electric Power Co., Inc.(2), and the Tachibana-wan No.2 unit of Electric Power Development Co., Ltd.(3), which are the preceding plants of this plant, and improved upon in the current plant.

Figure 8 shows the cross section of the boiler feed pump turbine (BFPT), while **Table 4** shows the major specifications of the system. In the BFPT, a 500 mm ISB single- flow turbine of the latest design with increased reliability and performance is adopted in place of the 12 inch double-flow turbine used in the conventional 1000 MW class thermal power stations, so that one BFPT can be operated up to the main turbine of 600 MW based on an increase in the capacity of the single turbine.

Table 3 Major Specifications of Main Turbine

Item	Specifications
Type	Cross compound quadruple exhaust flow, reheat regenerative condensing turbine
Output (rating)	900 MW
Steam conditions	
Main steam pressure	24.5 MPa
Main steam temperature	595 °C
Reheat steam temperature	595 °C
Rotational speed	Primary turbine 3 600 rpm
	Secondary turbine 1 800 rpm
Degree of vacuum	−96.3 kPa
Last stage blade length	1 170 mm (46 inches)
Feed water heater	8-stage

Table 4 Major Specifications of BFP Turbine

Item	Specifications
Type	Single cylinder single-flow type condensing turbine
Output (rating)	16 100 kW
Steam conditions	
Main steam pressure	0.89 MPa
Main steam temperature	374.4 °C
Rotational speed (rating)	5 850 rpm
Degree of vacuum	−96.3 kPa
Last stage length	500 mm

3.1 Features of main turbine

In the main turbine of the Maizuru No. 1 Unit, based on the track records of the same types of preceding turbines, consideration has been paid to a design that copes with an increase in the main steam and reheat steam.

Ferritic heat resisting steels such as modified 12Cr forged steel, 12Cr cast steel, and 9Cr forged steel are used widely as high temperature materials for the high pressure and intermediate pressure turbines. An advanced 12Cr forged steel with Co (MTB10A) developed as a 630°C class material was adopted in the rotating blades near the inlet of the high-pressure turbine. In addition, a modified 12Cr forged steel (TMK-1) with sufficient creep strength capable of enduring 600°C class operation and a good track record of use was adopted in this plant as high- and intermediate-pressure rotor material. Moreover, 12Cr cast steel (MJC-12) with excellent creep strength was adopted as the stationary member material for the nozzle chamber, inner casing, blade ring, and intermediate pressure turbine inlet flow guide.

The performance of the above turbine was also increased by improving the stationary blade seal fin structure and moisture removal efficiency through the adoption of grooved blades for the low pressure last stage blades.

3.2 Features of BFP turbine

Since a design that avoids any resonance of the blades during operation cannot be implemented for a BFPT that runs at variable speeds, the blades of BFPT must have an enough safety factor in terms of strength in order to withstand such resonances. The ISB structure, which has a damping of ten times or more that of the conventional group blade structures, is very effective in reducing vibrational stress.

The reliability of the 500 mm ISB is remarkably increased based on a 0.6 scale design of the 3600 rpm, 33 inch ISB which has an excellent operational track record. Further, turbine performance is also increased by the adoption of a fully three-dimensional flow design that contributes significantly to an increase in the performance of the plant.

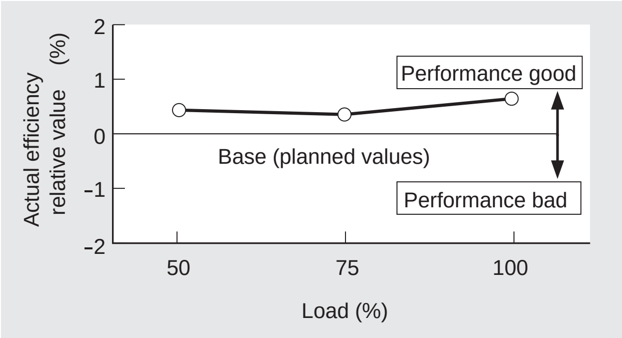


Fig. 9 Turbine performance test results for Maizuru No. 1 Unit

3.3 Performance

In addition to incorporating technologies established with a 1 000 MW, 600°C class turbine, plant performance has been further increased through the effective application of a range of advanced technologies. As a result, actual turbine efficiency was as shown in **Fig. 9**, which is indicative of a large capacity, highly efficient steam turbine.

4. Conclusion

With the completion of the Maizuru No. 1 Thermal Power Station, technologies in which economic efficiency and high reliability can co-exist have been established. MHI has confidence that these technologies will contribute greatly to the design of forthcoming plants in the future. In addition, MHI will make every effort to further develop and improve the technologies demanded by the society. Lastly, MHI wishes to express its sincere appreciation to everyone of the Kansai Electric Power Co., Inc. who guided us on the operation and design of this plant and to all others concerned for their support and encouragement.

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