Low-cost Adjustable Detonation Soot Blower Technologies for Boilers

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Boilers that use solid fuel as a heat source, such as Municipal Solid Waste (MSW) incineration power plants, use a soot blower, a device to remove dust adhering to the heat transfer tubes. With the recent deregulation of electric power, there is a demand for stabilization of power generation capacity and the introduction of steamless soot blowers that do not consume steam for dust removal is required. In response, Mitsubishi Heavy Industries, Ltd. has developed a detonation soot blower that removes dust using the force of shock waves generated by combustion (detonation), and is promoting the introduction of this device in actual equipment such as MSW incineration plants. This report presents the features of the detonation soot blower, its functional verification through in-house testing, and examples of its application to actual plants.

1. Introduction

In boilers that use solid fuel as a heat source (e.g., MSW incineration power plants and biomass thermal power plants), dust from the high-temperature flue gas adheres to the heat transfer tubes as the operation continues, causing a decrease in heat transfer performance and blockage of the gas flow path. As a measure against this, such boilers are equipped with a device to remove the adhered dust. Soot blowers that spray steam onto the heat transfer tubes are commonly used; however, they have some problem such as a decrease in power generation due to the consumption of steam for dust removal, and thinning of heat transfer tubes due to corrosion and wear.

With the recent deregulation of electric power, there is a demand for stabilization of power generation capacity and the introduction of soot blowers that do not consume steam for dust removal is required. In response, Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) Research & Innovation Center has been developing a device that uses detonation to remove dust. This device can blow away dust adhering to heat transfer tubes by discharging shock waves with detonation waves into the space inside the boiler.

This report describes the outline of the developed detonation soot blower, and presents the verification of its dust removal capability and auto-ignition prevention function through tests using our in-house facility, as well as a demonstration at an actual MSW incineration power generation plant. The demonstration test was carried out at the MSW incineration plant supplied to the customer by MHI Environmental Chemical Engineering Co., Ltd.

2. Outline and features of detonation soot blower

2.1 Outline of detonation soot blower

Figure 1 shows a schematic of the flow of the developed device. The device is attached onto a boiler (or a dump tank in the case of in-house testing). The pressure in the boiler or dump tank to which the device is connected is almost atmospheric. The detonation soot blower consists of four components: main unit, valve unit, cylinder unit, and control panel. The main unit is divided into the main combustor which is connected to the furnace, the pre-detonator which generates detonation

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waves, and the air curtain which prevents auto-ignition. The connection between the main combustor and the pre-detonator has a steeply expanded shape. The pre-detonator is U-shaped to shorten the overall length of the device. The air curtain blows air between the main combustor and the furnace interior to avoid auto-ignition of combustible mixtures.

Figure 2 shows the sequence of the shock wave discharging operation. Fuel gas (ethylene) and oxygen supplied from the cylinder unit are charged into the main unit (Figure 2-(1)) and ignited by the spark plug at the tail of the pre-detonator (Figure 2-(2)). A detonation wave is generated by the deflagration-detonation transition (DDT) in the pre-detonator and propagates to the main combustor (Figure 2-(3)), and a shock wave is discharged after the combustion is completed (Figure 2-(4)). The air curtain prevents the auto-ignition by cutting off the contact between the combustible mixture and the high temperature gas in the furnace. In actual plant, above sequence is operated once every few hours upon a command by remote instructions from the plant central control room.

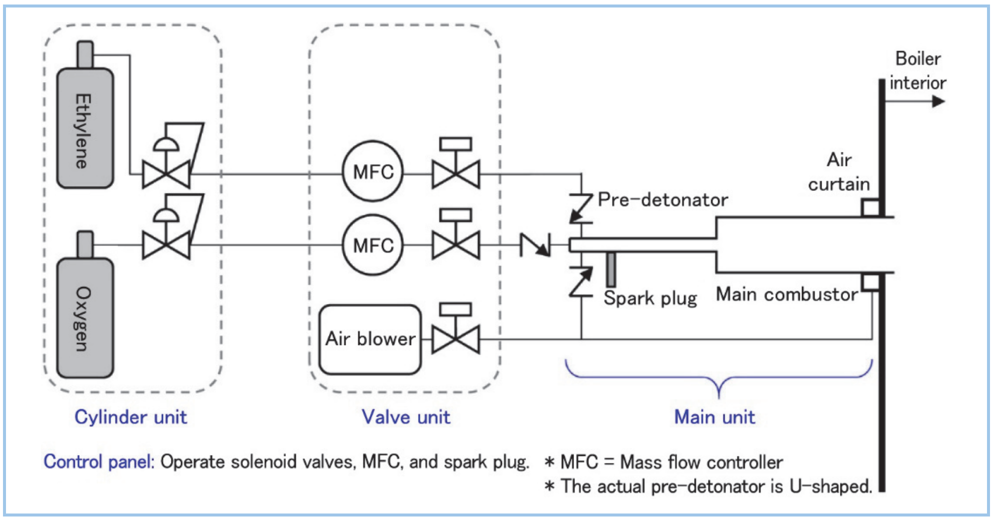

Figure 1 Schematic of detonation soot blower

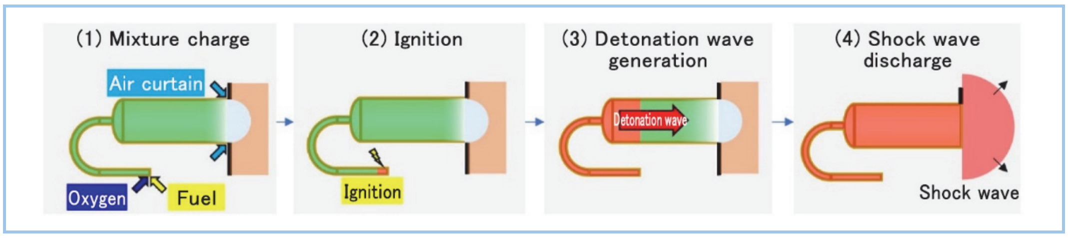

Figure 2 Sequence of detonation soot blower operation

2.2 Features of detonation soot blower

The features of the detonation soot blower is as follows : (1) a simple combustor structure that can reduce maintenance costs, (2) power adjustment is possible, and (3) filling pressure is almost equal to the inner pressure of the boiler. The following paragraphs describe these features in more detail.

(1) Possibility of reducing maintenance costs

The combustor has a simple structure and has no moving parts unlike steam soot blowers. Therefore, expensive parts replacement of the combustor is not necessary and maintenance cost can be reduced.

(2) Adjustable power output

From the viewpoint of gas fuel consumption, etc., it is desirable to operate at the minimum output to obtain necessary dust removal capacity. The output of this device can be adjusted by the mixture charging amount.

(3) Almost same charging pressure as boiler internal pressure

The pre-detonator and main combustor are always connected to the interior of the boiler, and mixture charging is performed at the same pressure, so the gas supply pressure only needs to be able to cover the pressure loss in the gas supply system. Therefore, gas with a pressure of less than 1 MPa can be used, and the valve unit and the device main unit are not subject to the High Pressure Gas Safety Act.

3. Functional verification of detonation soot blower

3.1 Verification of detonation wave generation and output adjustment functions

To verify that the detonation soot blower can discharge shock waves and that the output can be adjusted, the operation sequence was conducted with a prototype installed in our in-house test facility (dump tank), and the pressure history in the main combustor and in the dump tank (in front of the main combustor outlet nozzle) was observed. **Figure 3** shows a schematic of the equipment installation and the pressure measurement positions of the test.

Figure 4 shows the pressure measurement results. The measured pressure in the main combustor (left side of Figure 4) shows that the peak pressure in the main combustor was close to the CJ pressure (detonation wave pressure in the Chapman-Jouguet theory) when the mixture charging amount was larger than a certain level. Then it was confirmed that detonation waves could be generated in the main combustor as shown in Figure 2-(3). And the measured pressure in the dump tank (right side of Figure 4) showed that the peak pressure increased with the mixture charging amount. This confirms that the dust removal capacity can be adjusted by the mixture charging amount.

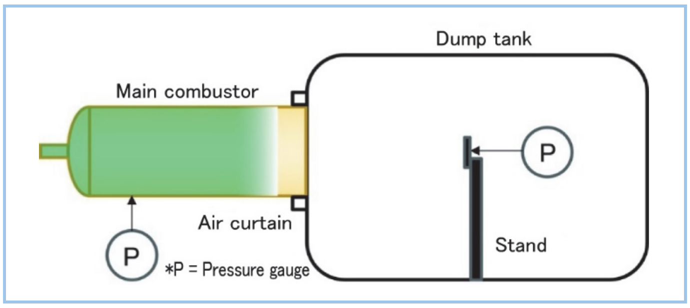

Figure 3 Appearance, schematic, and pressure measurement positions of dump tank test

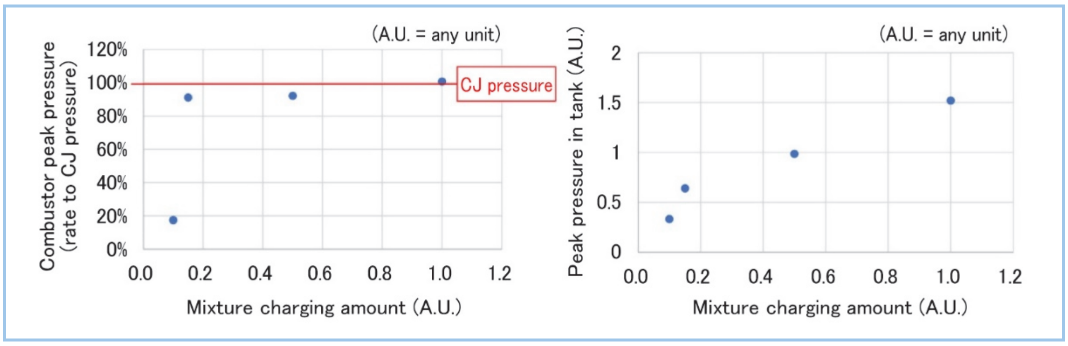

Figure 4 Pressure measurement result of dump tank test

3.2 Verification of auto-ignition prevention function of air curtain

In the case of an environment where the gas temperature is high, there is a concern that auto-ignition may occur during the mixture charging process, making it impossible to discharge shock waves into the furnace. To confirm that the air curtain can prevent auto-ignition, a mixture charging sequence was conducted with a prototype installed in our in-house test facility (single-burner furnace). **Figure 5** shows a schematic of the single-burner furnace test. In the test, the range of operating conditions that could avoid auto-ignition during mixture charging was recorded while changing the furnace gas temperature and velocity (evaluated for the “Testing section” in the figure) and the air curtain flow rate.

Figure 6 shows the temperature range where auto-ignition can be avoided. By comparing cases with different air curtain flow rates, it was confirmed that the operable temperature range increases as the air curtain flow rate is increased (i.e., for the same air curtain flow rate, the lower the gas flow velocity in the furnace, the wider the operable range). It was also found that the dust removal device can be operated in domestic MSW incinerator where a boiler superheater is deployed (assumed temperature: approximately 600°C, assumed flow velocity: approximately 3.0 m/s) while preventing auto-ignition.

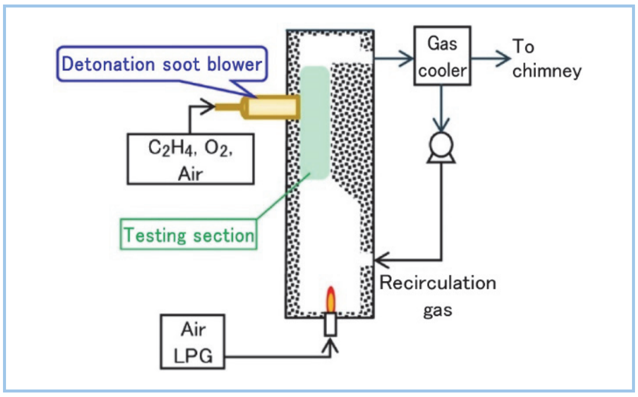

Figure 5 Flow schematic of single-burner furnace test

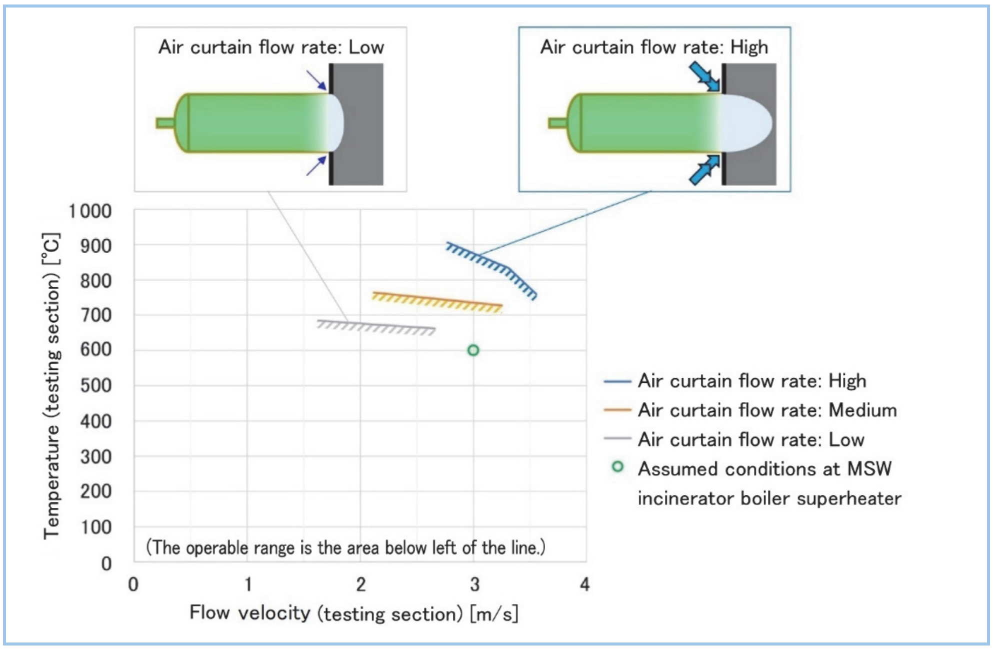

Figure 6 Results of single-burner furnace test (operable temperature and flow velocity range)

4. Application of detonation soot blower to actual equipment

4.1 Results of long-term demonstration for the economizer in the actual plant

The detonation soot blower was installed at the economizer of MHI's customer facility (MSW incinerator power plant) and operated for about six months to demonstrate its dust removal performance in actual equipment. **Figure 7** shows the device installation site. A single unit of the detonation soot blower was used for dust removal of the entire economizer. The device installed in the actual equipment was operated, and the shock wave pressure propagating into the furnace was measured. **Figure 8** shows the measurement results. Comparing cases with different mixture charging amounts showed that that the shock wave pressure increased as the mixture charging amount was increased. It was confirmed that the dust removal capacity can be adjusted by the mixture charging amount also in actual equipment.

The ash removal capacity in the long-term operation period was evaluated by the overall heat transmission coefficient of the economizer part. **Figure 9** shows the evaluation equation. By having the customer operate the plant under different operating conditions (mixture charging amount and operating frequency) of the detonation soot blower, the effect on the economizer's heat transfer performance was evaluated. **Figure 10** shows the transition of the overall heat transmission coefficient over the long-term operation period. When the mixture charging amount for the detonation soot blower was small, the overall heat transmission coefficient was lower than that when the steam soot blowers were used. However, when the mixture charging amount was increased by adjusting the output, the overall heat transmission coefficient was almost the same as that when the steam soot blowers were used. Furthermore, when the operating frequency was increased, the overall heat transmission coefficient was increased to a level higher than that when the steam soot blowers were used. As a result of this demonstration, it was confirmed that a single unit of the detonation soot blower achieves the dust removal capacity equivalent to three units of steam soot blowers in the economizer area, and that the dust removal performance can be changed by adjusting the output and operating frequency.

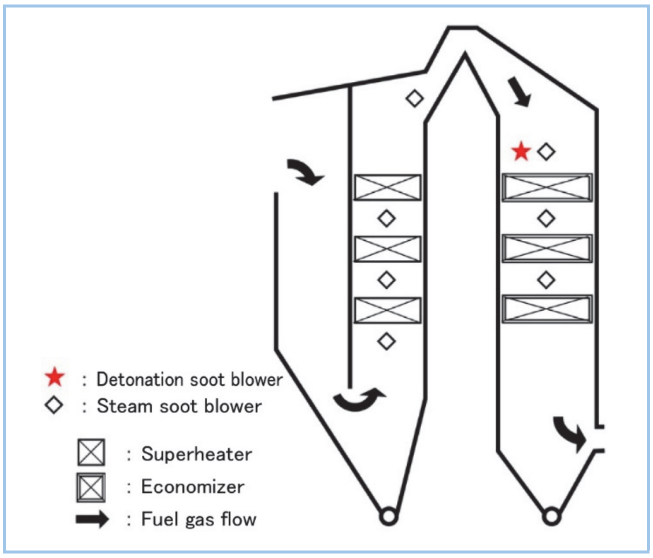

Figure 7 Soot blower installation positions for actual economizers

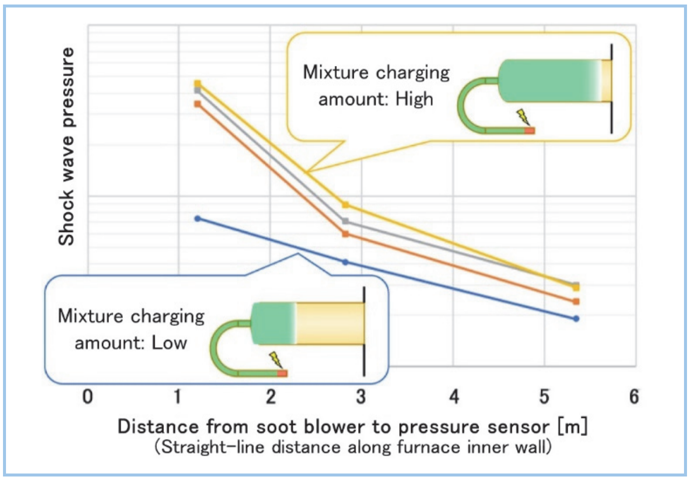

Figure 8 Pressure measurement results in actual economizer test

Overall heat transmission coefficient evaluation equation

$$K_w = Q_w/(A\Delta T_{LM})$$

$$Q_w = G_w(H_{w\_out} - H_{w\_in})$$

K_w : Overall heat transmission coefficient on water-side of economizer
Q_w : Heat absorption of economizer heat transfer tube
A : Effective heat transfer area of economizer heat transfer tube
ΔT_{LM} : Logarithmic mean temperature difference between gas and water in economizer heat transfer tube
G_w : Water flow rate in economizer heat transfer tube
H_{w_in} : Water enthalpy at economizer heat transfer tube inlet
H_{w_out} : Water enthalpy at economizer heat transfer tube outlet

Figure 9 Evaluation equation of overall heat transmission coefficient for economizer

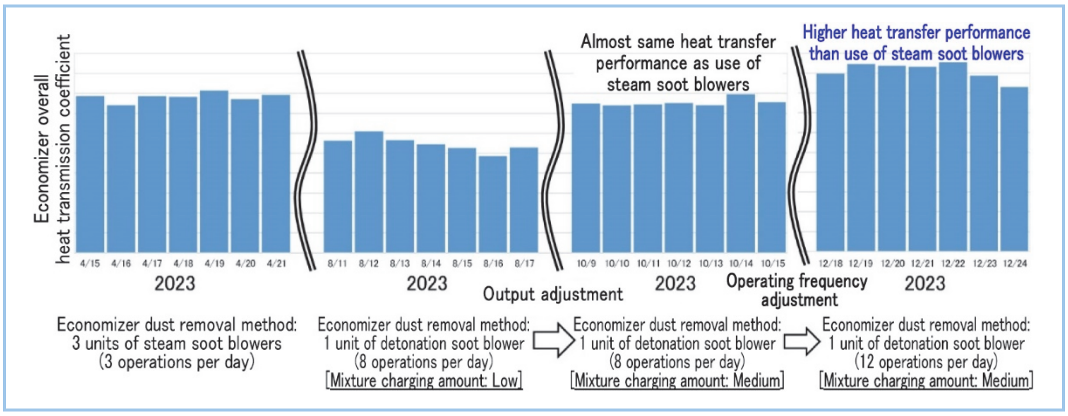

Figure 10 Effect of dust removal method on overall heat transmission coefficient found in actual economizer test

4.2 Demonstration of detonation soot blower for the superheater in the actual plant

Currently, the detonation soot blower is installed at the superheater of MHI's customer facility (MSW incinerator power plant) and under long-term operation. **Figure 11** shows the device installation state. A single detonation soot blower is used for dust removal of all stages of the superheater.

At the long-term operation, the frequency of normal operation (the rate of times a shock wave was successfully discharged into the furnace without causing auto-ignition to all operations) of the device installed on the actual equipment was checked. The vertical axis of **Figure 12** shows the frequency of normal operation. Although ignition occurred when the air curtain flow rate was low, it could be prevented by increasing the flow rate. From this fact, it was verified that the auto-ignition prevention effect of the air curtain is effective also in actual equipment.

Currently, the plant is operated by the customer while changing the operating conditions (mixture charging amount and frequency of operation) of the detonation soot blower and we plan to demonstrate through long-term operation that the device can achieve the same or a higher dust removal performance than steam soot blowers.

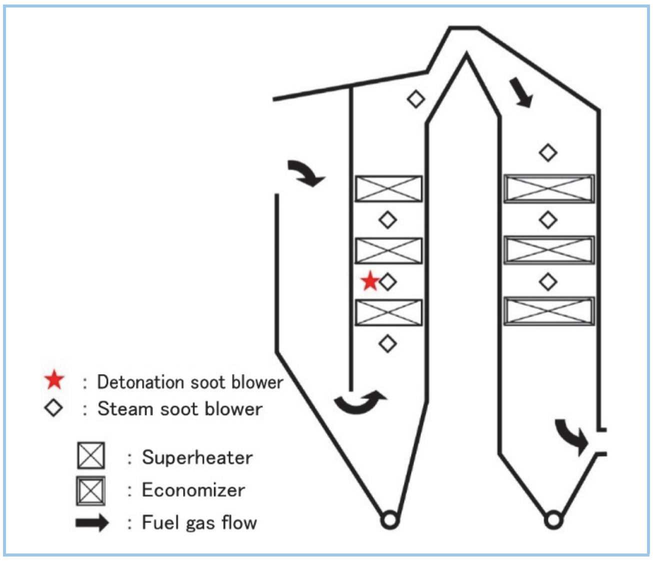

Figure 11 Soot blower installation positions for actual superheaters

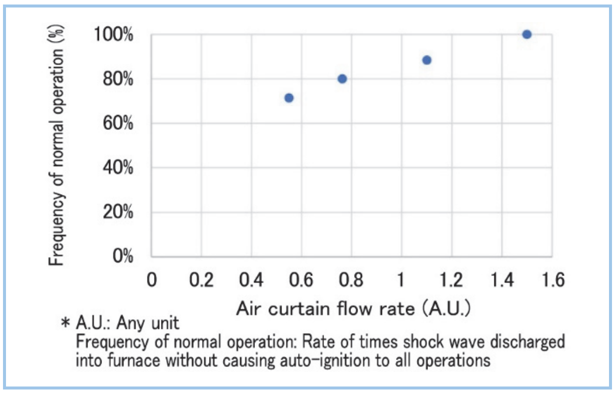

Figure 12 Auto-ignition prevention effect of air curtain observed in actual superheater test

5. Conclusion

In response to the need for soot blowers that do not use steam in boilers using solid fuel as a heat source, MHI has developed a detonation soot blower that uses detonation to remove dust. The detonation soot blower can blow away dust adhering to heat transfer tubes by discharging shock waves generated by detonation waves into the space inside the boiler. The features of the detonation soot blower include (1) a simple combustor structure that can reduce maintenance costs, (2) adjustable power output, and (3) almost the same charging pressure as the boiler internal pressure.

The functions of the developed device were verified in our in-house test facility, and it was confirmed that detonation waves can be generated in the main combustor, that the dust removal capacity can be adjusted by the mixture charging amount, and that the air curtain prevents backfire during operation of the device even in environments where the gas in the furnace is at a high temperature.

The detonation soot blower was installed at the economizer of MHI's customer facility (MSW incinerator power plant) and operated for about six months to demonstrate that a single detonation soot blower has the dust removal capacity equivalent to three units of steam soot blowers for the economizer and that the dust removal performance can be changed by adjusting the output and frequency of operation. Currently, the device is installed at the superheater and under long-term operation.

MHI Group will continue to provide products and services that can meet the needs of customers and the demands of society, such as the stabilization of plant operation and the improvement of power generation efficiency.

References

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