JFE TECHNICAL REPORT
No. 16 (Mar. 2011)

# CFB Combustion Control System for Multiple Fuels†

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**Abstract:**

*JFE Engineering has developed a new combustion control system that is capable of achieving the stable combustion for various multi-waste-fuels in the circulating fluidized bed boiler (CFB). This system has advanced control functions with a rule-based type multi-purpose control. This device is applied to furnace temperature control, exhaust gas stabilization control, and blowing control of slaked lime for the reduction of HCl. The application test was conducted in two CFB plants and the effect was confirmed that the furnace temperature and exhaust gas condition could be stabilized, and the fun driven power could be reduced by the reduction of combustion air.*

Photo 1 KISHU PAPER Co., Ltd. CFB Boiler

## 1. Introduction

Recent years have seen heightened demand for high efficiency boilers, which use waste-derived fuels such as wood biomass, plastics, refuse paper and plastic fuel (RPF), waste tires, sludge, and other recycled materials in place of fossil fuels. The circulating fluidized bed boiler (CFB) is a boiler, which is applicable to these diverse waste-derived fuels. The circulating fluidized bed boilers are already used in a wide range of industries, including paper manufacturing companies, as a substitute for oil boiler.

JFE Engineering has an extensive supply record of CFB boilers to date, including coal single fuel combustion, plastics single fuel combustion, and wood biomass single fuel combustion systems. The company also delivered two multi fuel combustive CFB boilers to paper manufacturing companies in 2008 (**Photo 1**).

In combustion of waste-derived fuels, fluctuations in the combusting point, local high temperature, instability of the properties of the combustion gas, and similar problems tend to occur as a result of fluctuations in the properties of the fuels. Furthermore, when multiple types of fuels are combusted by mixture, the changes in the combustion condition become even more complex. Therefore, the authors developed a combustion control system which makes it possible to realize optimum stable combustion, including mixed combustion of these diverse waste-derived fuels, and confirmed its effects by conducting application tests at commercial plants. The results are reported in this paper.

## 2. Outline of CFB Boiler Process

The CFB boiler is a type of fluidized bed combustion boiler in which fuel particles are fluidized by the combustion air. As advantages, the fluidization rate is comparatively rapid, and a circulating circuit for collecting scattering particles is provided at the outlet of the combustion chamber. This combustion method has the following features[1,2)].

† Originally published in *JFE GIHO* No. 25 (Feb. 2010), p. 11–16

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(1) High Fuel Adaptability

Because the combustion reaction proceeds in the entire furnace height direction and a circulating circuit for the fluidized particles exists, the CFB boiler has a long reaction time of combustion. For this reason, its adaptability to diverse fuels is high, and mixed combustion of multiple fuels is easy. Its desiccation capacity is also high due to the holding heat quantity of the fluidized particles, enabling direct feed of fuels with a high percentage of moisture content without advance desiccation.

(2) Low Environmental Load

For SOx, dry-type furnace desulfurization is possible by direct injection of limestone into the furnace. Generation of thermal NOx is suppressed due to the comparatively low combustion temperature (850–950°C), and fuel NOx is also reduced by multistage injection of combustion air.

(3) Low Air-Ratio Combustion Possible

The excess air ratio can be set low because the relative velocity between the fuel particles and combustion air is large due to high-speed fluidization, supporting a favorable solid-gaseous reaction.

(4) Economical Equipment (Low Installation Cost)

Because the environmental load is low and special flue gas treatment equipment is not necessary, the equipment composition can be simplified, reducing equipment costs.

A flowchart of a CFB boiler system is shown in **Fig. 1**.

The combustion chamber comprises a membrane-type water wall, which secures high air tightness and reduces heat loss by radiation. Particles are fluidized by supplying primary combustion air from air nozzles in the bottom of furnace. The fuels are directly thrown into the lower furnace, and that are rapidly stirred and mixed with the fluidized particles in the furnace by this primary combustion air. To realize low NOx combustion, secondary combustion air is injected from the middle of furnace, forming a so-called reduction combusting zone in the space under this stage.

A collecting section (cyclone) which captures fluidized particles and unburned combustible content, and particle recirculation pipe which returns the collecting fluidized particles and other matter to the furnace are provided at the outlet at the furnace top. In the cyclone, these are separated into flue gas and fluidized particles, ash with a comparatively large particle size, etc. The flue-gas which is separated in the collecting section is transported to the convectional heat transfer section together with comparatively small ash, etc. After dedusting by a bag filter, this is released into the atmosphere by way of a chimney. The fluidized particles and relatively large ash recovered by the cyclone are recirculated and returned to the lower furnace as fluidized particles via the seal section and particle recirculation pipe, and the unburned combustible content is after-burned.

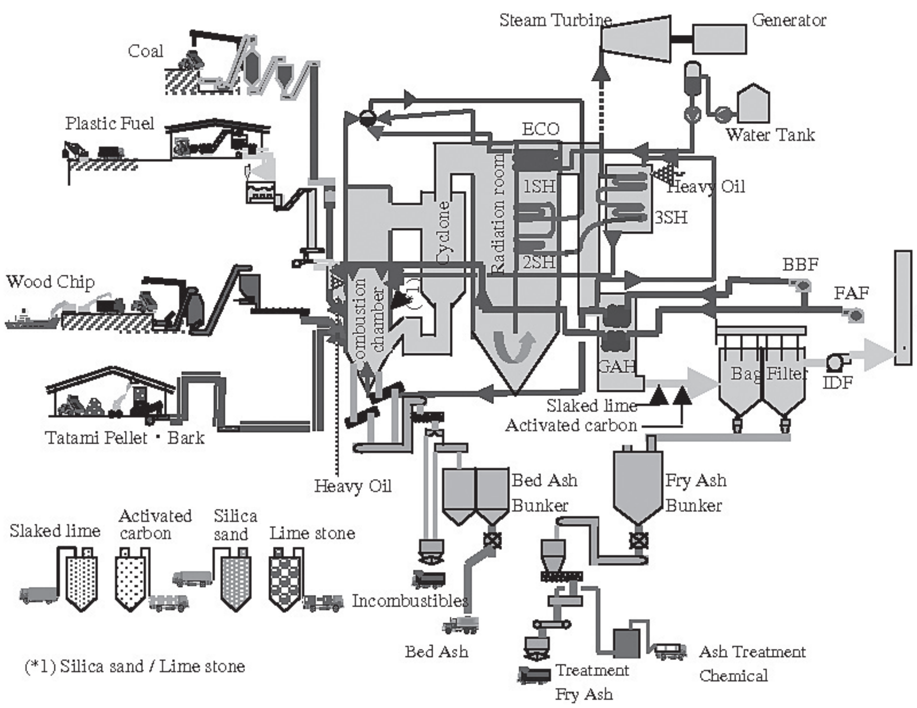


Fig. 1 Schematic flow of CFB boiler (KISHU PAPER Co., Ltd.)

## 3. Features of Control in CFB Boiler

In CFB boilers supplied by JFE, advanced control is realized by adoption of the following control methods in addition to normal boiler control.

### 3.1 Boiler Master and Fuel Injection Rate Control

Normally, with turbine generators, power generation (or power transmission) control is performed by the demand of power generation (power transmission), and the boiler master performs proportional-integral-derivative control (PID control) of the main steam pressure. In the method adopted here, the output from the boiler master is used as the command value for the fuel input calorie. After assigning the input calorie rates of the respective fuels, which have been set in advance, the charging amounts of the fuels are determined from the unit calorie of each fuel. For the charging systems of each fuels, participation in boiler master pressure control (or not) is selected, and constant input calorie control is performed for the nonparticipating charging systems. With this method, it is possible to maintain a constant total input calorie and suppress fluctuations in boiler output, even when the input calorie ratios of the respective fuels are changed and during backup with another fuel due to troubles in one of the fuel charging systems.

In order to eliminate deviations in boiler master output and the combustion air rate due to changes in the unit calorie of the fuels, calorie compensation control is performed, in which the boiler master output is corrected by a compensation value obtained from the ratio of the predicted main steam flow rate obtained from the fuel charging rate in operation and the actual main steam flow rate.

### 3.2 Automation of Boiler Operation

In JFE Engineering's CFB boilers, operation of the boiler is automated so that all processes can be performed using one button by an automated sequence, which includes starting and stopping of the auxiliary equipment. This also includes the turbine generator when this equipment is installed.

- Start sequence (auxiliary start, ignition and pressurization, main fuel switching, turbine start, generator circuit breaker close, load increase)
- Stop sequence (load decrease, generator circuit breaker open, turbine stop, boiler stop, auxiliary stop)

Plant control in normal operation is also virtually completely automated. At the CFB plants supplied by JFE Engineering, which are currently in operation, nighttime operation is performed by a 2-person system.

## 4. Problems in CFB Boiler Control and Solution in JFE Engineering's System

As fuels for use in CFB boilers, coal and similar fuels, which show little deviation in properties, are replaced with diverse types of waste-derived fuels, in which properties display wide deviations. This results in fluctuations in the combusting point/combustion condition, local high temperature, instability in the properties of the combustion gas, and similar problems caused by fluctuations in the properties of the fuels. Moreover, when multiple types of fuels are mixed, the changes in the combustion condition become even more complex.

As a solution to these problems, JFE Engineering developed a new combustion control system with functions including rule-based multipurpose control, with the aim of obtaining a more optimal and stable combustion condition. This is a technology which complements the conventional control systems based mainly on PID control. The optimized and more advanced control systems are described below.

### 4.1 Furnace Temperature Optimization Control

In conventional combustion air flow control, the air flow rate settings for primary combustion air (2 points) and secondary combustion air (2 points) are given as a function of the fuel input calorie at the respective points in times. In this case, the combustion velocity, floating point, main combusting point, burnout point, etc. change, depending on changes in the input ratio/properties of the fuels and the boiler load. In some cases, this results in deviations and local rise in the furnace temperature. On the other hand, in order to suppress thermal NOx, it is necessary to keep the furnace temperature within a certain range, and to prevent generation of clinker, the temperature in the entire furnace must not exceed 1 000°C. Prevention of excessive rises in the temperature of downstream parts, such as the cyclone outlet temperature, is also important from the viewpoint of protection of the bag filter and other equipment.

Therefore, using the combustion control system, JFE Engineering developed a control system using rule-based control, in which the target temperatures in the various parts of the furnace are set based on the fuel charging ratio and past temperature records, and the balance of the combustion air flow rates from the four air injection ports is adjusted so as to follow those targets.

In this combustion air balance control, control is performed so that well-balanced combustion of the charged fuel is maintained in all parts of the furnace as far as possible, and the temperatures in the various parts of the furnace are smoothed by changing the balance of air injected into the furnace for the four inlets. For example, when the ratio of fuels with high holding calories and

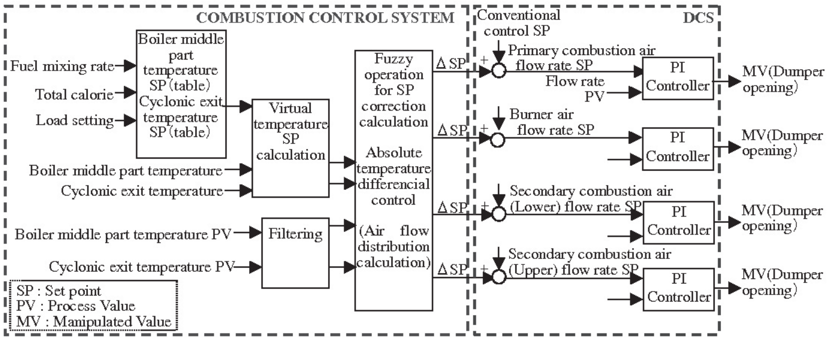


Fig. 2 Conversion air balance control flow diagram

rapid combustion velocities is high, and in the case where it results in temperature rise in the center of the furnace, control is performed so that the main combusting point is shifted to the downstream side by increasing the primary combustion air ratio.

The concrete control procedure is as follows (**Fig. 2**).

(1) Determination of Target Temperatures

Using the fuel input ratio, total holding calorie of the fuels, and boiler load as inputs, the target temperatures at the middle of the furnace and at the outlet of the cyclone are determined from tables.

(2) Calculation of Virtual Target Temperature

The purpose of this control system is not to adjust all temperatures to the target temperatures, but to obtain a certain stable condition with a balance in which the respective temperatures approach the target temperatures while continuing to satisfy multiple constraints. Therefore, a virtual target temperature is set between the present temperature and the target temperature, and control is performed so as to follow that temperature. It is possible to adjust the weighting of the conditions using parameters.

(3) Calculation of Air Distribution Balance

Correction values for the combustion air flow rates from the four inlets are determined from the present temperatures in the respective parts of the furnace and the virtual target temperature by rule-based calculations.

### 4.2 Exhaust Gas Lower Concentration Stabilization Control

In order to reduce NOx, which is particularly a problem in the exhaust gas composition, it is basically desirable to set the $O_2$ concentration at the outlet of the furnace to a low value. However, if the $O_2$ concentration is reduced excessively, the CO concentration will increase due to increases in unburned gas and unburned fixed carbon. Furthermore, changes in the $O_2$ concentration also influence the SOx concentration and the temperature in various parts of the furnace.

Therefore, a rule-based type multipurpose control system was developed, taking into account the inverse relationship between NOx and CO, and a total consideration of all operational indexes, such as constraints of SOx and furnace temperature.

In this control, a total judgment of the combustion condition is made by rule-based control, and the $O_2$ concentration target is changed corresponding to the furnace operational indexes/constraints.

The concrete method of revising the target value is outlined below (**Fig. 3**).

(1) The $O_2$ concentration set point (SP) is set based on the present boiler load.

(2) The set point is corrected based on the temperature in the middle of furnace.

(3) The set point is corrected based on the cyclone outlet temperature.

(4) Corrected values are determined by rule-based control based on the CO, NOx, and SOx concentrations.

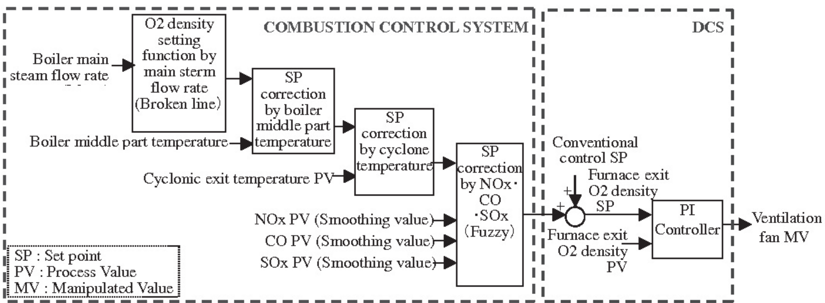


Fig. 3 Exhaust gas stabilization control flow diagram

The present optimum value is determined so as to satisfy all of these conditions, and this is used as the corrected $O_2$ concentration value.

### 4.3 Control of Slaked Lime Blowing Rate for HCl Reduction

In control of the slaked lime blowing rate for HCl reduction, application of feedback control is difficult because of the large amount of dead time in measurement/control, as well as fluctuations in dead time, due to delays in measurements by the analyzer, time lag in the chemical reaction, the effect of slaked lime deposition in the bag filter, etc. Therefore, the blowing rate is set by a function of the boiler load. Furthermore, due to deviations in the amount of HCl generation, a larger setting value is generally adopted considering the risk of exceeding the regulating value.

In this work, a control system which determines the amount of slaked lime blowing by rule-based control, based on the predicted amount of HCl generated in the future using operational data, was developed in order to optimize slaked lime consumption.

Considering dead time, this control system performs control with a long cycle of 5–15 min.

The concrete control method is outlined below.

(1) Prediction of Future HCl Concentration (**Fig. 4**)

A predictive standard value for the HCl concentration is obtained from the slope of the previous and present HCl sampling values, the previous actual amount of slaked lime, and other information. In cases where the fuel input ratio or the boiler load will change subsequently, between the present sampling and the next sampling, the predictive value is corrected considering these changes.

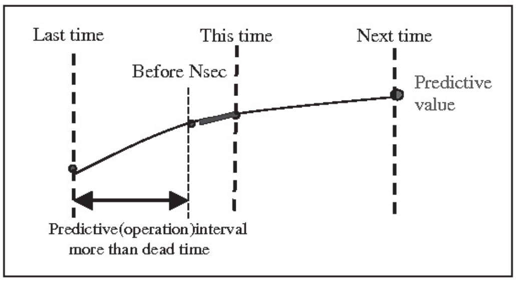


Fig. 4 Concept of future HCl density estimate

| Deviation of object \ Direction of change in the future | Decrease | Keep | Increase |
|---|---|---|---|
| Negative largeness | Decrease | Small decrease | Keep |
| Negative smallness | Small decrease | Keep | Small Increase |
| 0 | Keep | Keep | Increase |
| Positive smallness | Keep | Small Increase | Increase |
| Positive largeness | Keep | Small Increase | Large increase |

Fig. 5 Gain decision rule table

(2) Decision of Operational Value by Rule-Based Control (**Fig. 5**)

Control gain is determined by rule-based control from the value of deviation of the object and the direction of change in the future predictive value, and the amount of correction is determined by multiplying the result by the deviation of the future predictive value.

Decision of gain by rule-based control was adopted in order to set the appropriate nonlinear gain corresponding to the future condition of deviation of the object.

## 5. Results of Application Test to Actual Equipment

### 5.1 Outline of Test

The development of a test device for this combustion control system and tests in which the developed device was applied to commercial CFB boiler plants were carried out over a 3-year period beginning in fiscal year 2006. The tests were conducted by installing the test devices in CFB boilers supplied by JFE Engineering at the Iwakuni Power Plant (completed in 2005) of Iwakuni Wood Power Co., Ltd. and Kishu Works (completed in 2008) of Kishu Paper Co., Ltd. The tests were performed with mixed combustion at both plants, using rough wood and architectural scrap wood at the Iwakuni Power Plant and wood chips, plastics, coal, and bark or tatami mat pellets at Kishu Works.

Outlines of the CFB boiler equipment at Iwakuni Power Plant, Iwakuni Wood Power Co., Ltd. and Kishu Works, Kishu Paper Co. Ltd. are shown in **Table 1**.

### 5.2 Composition of Control System

An outline of the composition of the control system is shown in **Fig. 6**.

Table 1 Plant data of CFB boiler (Iwakuni Wood Power Company, Ltd. and KISHU PAPER Co., Ltd.)

| | Iwakuni Wood Power Company Ltd. | KISHU PAPER Co., Ltd KISHU WORKS |
|---|---|---|
| Boiler type | Natural Circuration, single Drum Type | Natural Circuration, single Drum Type |
| Generating sterm | 45 t/h | 130 t/h |
| Steam pressure | 5.7 MPa | 10.3 MPa |
| Steam temprature | 453℃ | 533℃ |
| Fuel | Raw wood chip/ Constructive scrap wood chip | Plastic/Wood chip/ Coal/Bark/Mat pellet |
| Commissioned date | Dec. 2005 | Aug. 2008 |

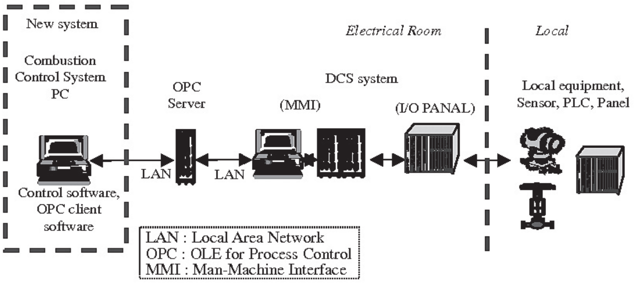


Fig. 6 Outline of control system

As the basic concept, the existing control system by distributed control system (DCS) was used as-is, and the Personal computer of the new combustion control system was installed separately from the DCS and made correction calculations in parallel with the DCS. A more optimum operating condition is obtained by giving the results to the existing DCS control system as correction values.

Therefore, the data communication tags and logic for which adds the correction values from the combustion control system was added to the existing DCS. Data communications between the combustion control system and the existing DCS are performed via a newly installed OPC server.

### 5.3 Test Results and Discussion

(1) Furnace Temperature Optimization Control

An example of the test results at the Iwakuni Power Plant is shown in **Fig. 7**.

In this case, operation using the new combustion control system and operation using only the conventional control were compared for two conditions, these being rough wood : architectural scrap wood ratios of 30 : 70 and 45 : 55. When the architectural scrap ratio was high and the combustion rate was rapid (rough wood : architectural scrap wood ratio = 30 : 70), the effect of the combustion control system in reducing the temperature in the middle of the furnace was clearly apparent.

The effectiveness of the new system in smoothing the furnace temperature and maintaining soundness (<950°C) was also confirmed under the other condition.

(2) Exhaust Gas Lower Concentration Stabilization Control

The results of the test at Kishu Works are shown in **Fig. 8**.

Use of the new combustion control system resulted in a low $O_2$ concentration at the outlet of the economizer, in other words, operation with low total combustion air. In the high load region, this effect suppressed the NOx concentration when the new control system was used. In the low load region, the new control system displayed a particularly remarkable effect in reduction of the CO concentration. The SOx concentration showed an increasing tendency, but did not reach the control value (300 ppm), and thus was not on a level which was considered a problem.

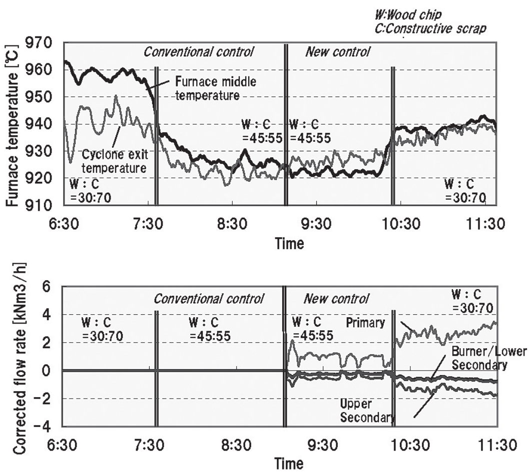


Fig. 7 Result of the furnace temperature control

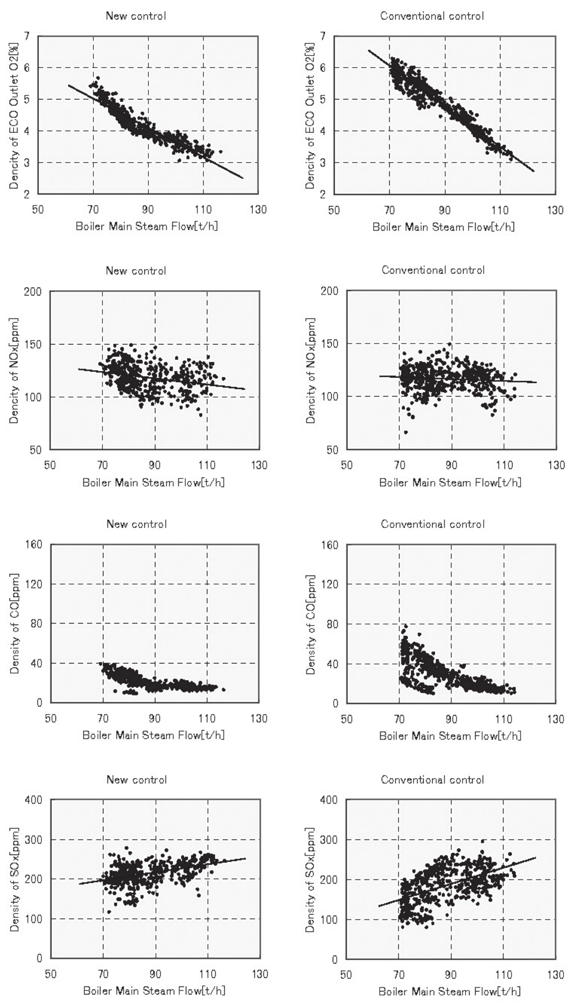


Fig. 8 Result of the exhaust gas stabilization control

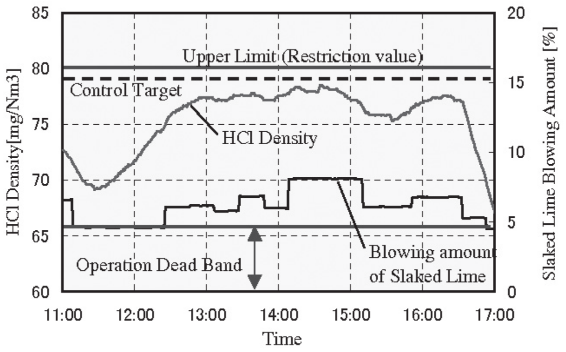


Fig. 9 Result of the slaked lime blowing control

In the test as a whole, NOx and CO concentration reduction effects were obtained, and suppression of the other indexes to levels which are not problems could be confirmed. Moreover, the test also confirmed that the new system is effective in reducing fan power consumption because the total amount of combustion air is reduced by the application of this system.

(3) Control of Slaked Lime Blowing for HCl Reduction

The results of the test at the Iwakuni Power Plant are shown in **Fig. 9**.

Control by the combustion control system was performed using 78 mg/Nm$^3$ as the HCl concentration control target value. The control value for the HCl concentration is 80 mg/Nm$^3$.

In control of slaked lime blowing, the blowing rate was discretely changed in a relative to the fluctuations in the HCl concentration. As a result, the control system followed the target value without exceeding the control value, and when the HCl concentration decreased, the blowing rate was reduced to the lower limit. Thus, the test confirmed that HCl could be controlled to below the control value by slaked lime blowing at the necessary minimum limit.

## 6. Conclusion

In this work, a combustion control system for CFB boilers with functions including rule-based multipurpose control was developed, and the effect of optimizing the respective control systems was confirmed by conducting application tests in which the developed system was applied to commercial CFB boiler plants.

In the future, JFE Engineering plans to adopt this combustion control system as standard equipment on the CFB boilers which it supplies, and will also carry out development aiming at further improvement in control performance.

In conclusion, the authors wish to express their deep appreciation to Iwakuni Wood Power Co., Ltd. and Kishu Paper Co., Ltd. for their generous cooperation in the commercial plant tests carried out in the development of this control system.

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