Boiler Combustion Solution for Reducing Fuel Costs

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ABSTRACT

Fuji Electric has launched a boiler combustion solution that is capable of reducing fuel costs by about 1% by improving combustion efficiency and reducing the heat loss of boiler exhaust gas. The solution decrease the O_2 concentration of boiler exhaust gas from 2.40% to 0.86% by applying ultra-low excess air ratio combustion control that supremely reduces oxygen fuel ratio. This results in a reduction of fuel cost by approximately 28 million yen a year at a 450 t/h boiler. Combining this solution with a laser CO analyzer capable of taking real-time measurements can suppresses CO concentration in boiler exhaust gas to meet environmental standards. Trial runs were conducted with a heat source boiler and good results were obtained.

1. Introduction

The basic policy in the "Long-term Energy Supply and Demand Outlook" of the Agency for Natural Resources and Energy stipulates that it is necessary to improve energy savings and enhance the efficiency of thermal power stations, while achieving safety, stable supply, economic efficiency and environmental compatibility. Furthermore, the energy-saving measures in the industrial sector are aiming to reduce fuel usage (heavy oil equivalent) 10.42 million kL by 2030 by adopting innovative technologies with comprehensive energy management for plants and factories utilizing the Internet of Things (IoT) and high-efficiency equipment installations such as high-performance boilers.

It is against this backdrop that Fuji Electric launched its boiler combustion solution in November 2015. The adoption of ultra-low excess air ratio combustion control (a technology previously not possible) has enabled the improvement of boiler combustion efficiency and the reduction of boiler fuel costs by approximately 1%.

2. Boiler Combustion Solution

The improvement of boiler energy efficiency was mostly supported by mechanical methods. For example, these included increasing the capacity of boilers, increasing the temperature and pressure of the boiler outlet main steam, and increasing the exhaust heat recovery. However, these methods have just about reached their limit. The boiler combustion solution is different than conventional methods in that it complements the conventional boiler control system with the addition of a software package and laser CO analyzer, enabling it to improve boiler combustion efficiency, i.e., boiler efficiency.

2.1 Boiler control and optimum combustion

Boilers are installed in many different types of places such as steam power plants that include businesses for supplying electricity, power producers and suppliers (PPSs) and independent power producers (IPPs), as well as private-use steam power stations for sending electricity and steam to the facilities inside factories and businesses, and heat supply facilities for producing steam and hot water.

In addition, boilers need to be able to supply a stable amount of steam at the regulated pressure and temperature even when the operating conditions of load-side equipment change. There are many boiler control methods available, and the most common methods are shown in Fig. 1.

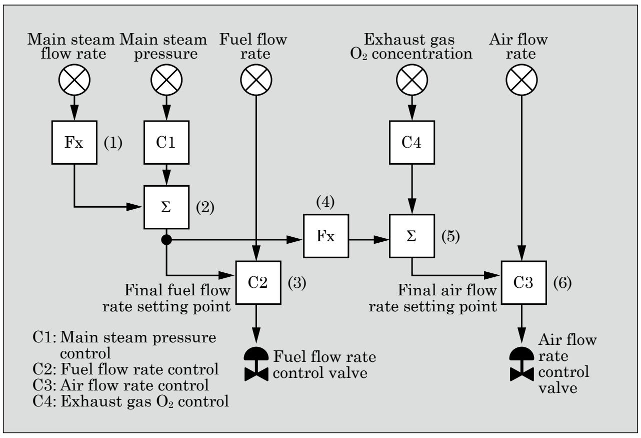

Fig.1 Basic block diagram of boiler automatic combustion control

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(1) Calculation of the fuel flow rate control setting value (see Fig. 1 (1))

Since the boiler outlet main steam flow rate signal initially changes when there is a change in the amount of steam used on the load-side of the boiler, the amount of fuel necessary for generating steam is calculated from this signal, and this value becomes the setting point for fuel flow rate control. When the main boiler outlet steam flow rate signal changes due to a fluctuation in the boiler load, the setting point of the fuel flow rate changes immediately, and this helps to improve fuel control.

(2) Final fuel flow rate setting point (see Fig. 1 (2))

The main steam pressure control value is calculated so that the boiler outlet main steam pressure complies with the specified setting point. The setting point for the fuel flow rate is configured by the boiler outlet main steam flow rate signal in order to improve control, but this signal is compensated via the output of the main steam pressure control value calculation in order to obtain the final fuel flow rate setting point. In this manner, it is possible to implement the boiler outlet main steam pressure control for maintaining boiler outlet steam pressure at a constant value, while also improving the fuel control at times of boiler load fluctuation.

(3) Boiler fuel control (see Fig. 1 (3))

Based on the final fuel flow rate setting point, the fuel flow rate control value is calculated and the boiler fuel is controlled.

(4) Air flow rate setting (see Fig. 1 (4))

The proper amount of air is calculated so as to burn the fuel that corresponds to the final fuel flow rate setting value, and the value of this calculation becomes the air flow rate setting point.

(5) Final air flow rate setting (see Fig. 1 (5))

The control value for the O_2 concentration in the boiler exhaust gas is calculated, and the final air flow rate setting point is obtained by additionally adjusting the air flow rate setting point so that the exhaust gas O_2 concentration becomes the control target value.

(6) Boiler air control (see Fig. 1 (6))

Based on the final air flow rate setting point, the air flow rate control value is calculated and the boiler air volume is controlled.

2.2 Structure and features of boiler combustion solution

The theoretical air volume and excess air ratio are very important components of boiler combustion. The theoretical air volume in the boiler combustion represents the amount of air used when complete combustion is carried out with fuel and air mixed in an ideal state. However, actual boilers emit more CO and black smoke than the environmental standard value due to the incomplete combustion even when the theoretical air volume is supplied to the boiler. Therefore, it is necessary to supply the boiler with an amount of air in excess of the theoretical air volume so that the amount of CO and black smoke emissions do not exceed the environmental standard value. As shown in Formula 1, the excess air ratio is the ratio between the actual amount of air supplied to the boiler and the theoretical air volume.

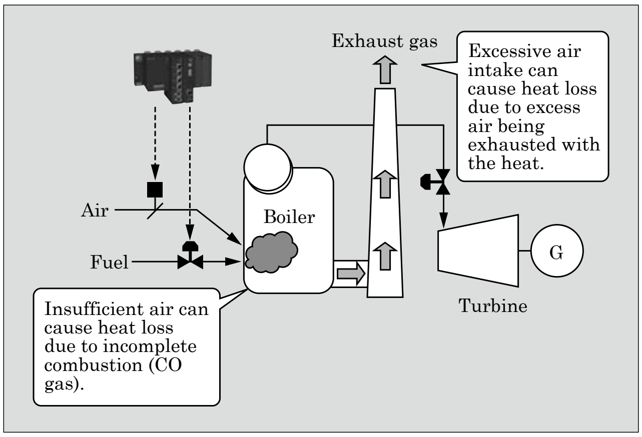

Fig.2 Heat loss in boiler combustion

$$\text{Excess air ratio} = \frac{\text{Actual amount of supplied air}}{\text{Theoretical air volume}} \quad \text{...(1)}$$

The heat loss in boiler combustion shown in Fig. 2 is largely influenced by the excess air ratio. For instance, if the amount of air supplied to the boiler exceeds the proper amount for burning the fuel (i.e., the excess air ratio is too large), there will be extra air that does not contribute to combustion, and this air will take away from the heat energy inside the boiler, thus causing heat loss to occur since the heat energy will be emitted from the smokestack as exhaust gas. On the other hand, if the amount of air supplied to the boiler is insufficient for burning the fuel (i.e., the excess air ratio is too small), CO and black smoke will occur due to incomplete combustion, and heat loss will occur due to incomplete combustion since these will be emitted from the smokestack as exhaust gas.

Our boiler combustion solution minimizes heat loss, while improving the heating efficiency of the boiler. Figure 3 shows the optimum combustion zone for the boiler. This figure is a graph that shows the relationship between excess air induced heat loss and incomplete combustion induced heat loss.

As shown in the figure, the zone for minimizing the total heat loss (i.e., the combination of heat loss due to both excess air and incomplete combustion) is in the ultra-low excess air ratio combustion zone located to the left of the conventional air ratio combustion zone.

This concept has been known for a long time, but up until now, the technology for successively and stably implementing continuous automatic operation in this region did not exist. However, Fuji Electric has established a technology by combining our uniquely developed combustion calculation with our quick-response laser CO analyzer. We will now describe the basic way of thinking regarding this technology.

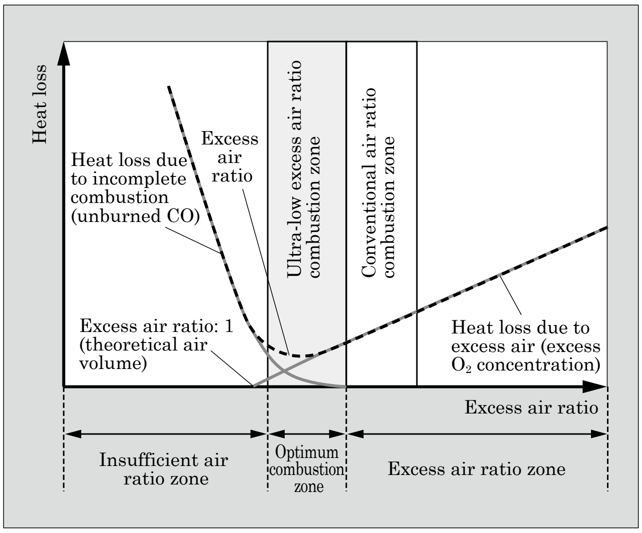

Fig.3 Optimum combustion zone for boiler

Excess air induced heat loss and incomplete combustion induced heat loss can generally be represented by Formula (2) and Formula (3).

$$L_{air}=\frac{1}{0.21}C_{PA}\ (T_o - T_I)\ (G \times O_2) \quad \text{.........} (2)$$

$$L_{co}=G \times CO \times H_{co} \quad \text{.........} (3)$$

L_{air} : Heat loss due to excess air
L_{co} : Heat loss due to incomplete combustion
C_{PA} : Specific heat of air (kJ/Nm^3·K)
T_o : Air temperature in the boiler exhaust gas (K)
T_I : Forced draft fan inlet air temperature (K)
G : Boiler exhaust gas flow rate (Nm^3/h)
O_2 : Boiler exhaust gas O_2 concentration (%)
CO : Boiler exhaust gas CO concentration (ppm)
H_{co} : Quantity of heat of CO (kJ/Nm^3)

The exhaust gas flow rate G can be determined by the calculation to the extent that the components of the fuel are known in advance. However, since there is variation in the components of the fuel used in actual boilers, the components are not consistently constant. Furthermore, there are also cases of mixed-fuel combustion. Therefore, the optimum heat loss calculation used in Formula (2) and Formula (3) is not practical since too many parameters need to be determined and assigned.

Fuji Electric has developed a proprietary control logic that makes use of a theoretical formula for combustion based on thermodynamics and combustion reactions, both of which have never been applied to conventional boiler control. During on-site testing, this control logic automatically set multiple parameters that needed to be determined and assigned for each steam load of the boiler, while also facilitating practical combustion inside the ultra-low excess air ratio combustion zone.

The boiler combustion solution has the following features.

(a) Applicable regardless of the type of boiler fuel or use of mix-fuel combustion.
(b) Capable of control at the optimum excess air ratio for every boiler load.
(c) Capable of suppressing CO emissions in the boiler exhaust gas to maintain compliance with environmental standards.
(d) Capable of preventing abnormal increases in the CO in the boiler exhaust gas. Combustion in the ultra-low excess air ratio combustion zone is susceptible to there being an excess amount of CO in the boiler exhaust gas due to insufficient air when there is temporary fluctuation in the excess air ratio. As a countermeasure against this, the boiler combustion solution makes use of a laser CO analyzer that is capable of high-speed measurement of the CO concentration in the boiler exhaust gas, while also employing control software (boiler exhaust gas CO abnormality high-blocking control) for suppressing the CO concentration in the boiler exhaust gas to a value below the prescribed upper limit in the case of every boiler behavior.
(e) Capable of being installed regardless of the manufacturer of existing boiler control systems, and does not require significant remodel to existing boiler combustion control systems.

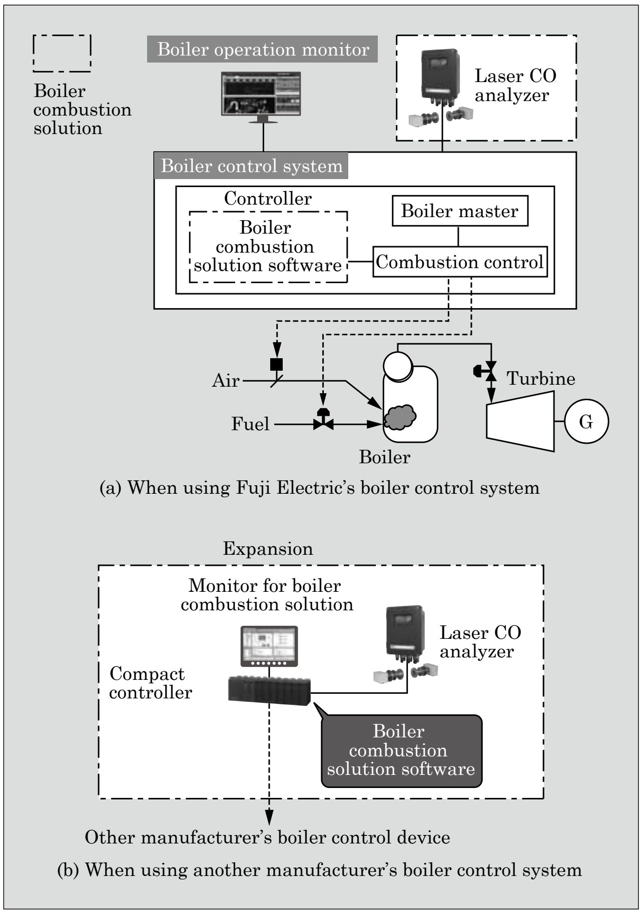

Fig.4 Installation method for boiler combustion solution

The installation method for the boiler combustion solution is shown in Fig. 4.

2.3 High-speed measurement of CO concentration

In this boiler combustion solution, high-speed measurement of the CO concentration in the boiler exhaust gas is an important functionality for achieving ultra-low excess air ratio combustion.

(1) Boiler exhaust gas CO abnormality high-blocking control

Boiler combustion solutions burn the fuel in the boiler in a state of ultra-low excess air, and implement control while continuously producing extremely small amounts of incomplete combustion inside the furnace on a regular basis. Furthermore, as shown in Fig. 3, incomplete combustion increases like a cubic curve if the excess air ratio falls below a certain threshold (increase in the concentration of exhaust gas CO), and black smoke is generated if below a certain excess air ratio.

Therefore, even if boiler behavior is represented by the following 3 scenarios, the prevention of excessive incomplete combustion using the high-speed response laser CO analyzer can be referred to as boiler exhaust gas CO abnormality high-blocking control.

(a) When the boiler burner is ignited and there is a temporary change in the balance between the amount of fuel and air in the boiler

(b) When automatic control is implemented for the fuel and air amount as a result of a change in the calorific value of the fuel, and there is a temporary change in the excess air ratio, regardless of there being no fluctuation in the steam load of the boiler

(c) When the air and fuel amount is controlled via air-rich (excessive air) control in order to prevent black smoke from occurring, and there is a temporary change in direction that makes the excess air ratio decrease at times of sudden increase in the steam load of the boiler

(2) Optimum combustion logic computation

In addition to the above mentioned boiler exhaust gas CO abnormality high-blocking control, the CO concentration signal is also used as follows in ultra-low excess air ratio combustion control to reduce the amount of fuel.

(a) Calculation of optimum excess air ratio

(b) Control for suppressing boiler exhaust gas CO to meet environmental standards

2.4 Laser CO analyzer

Fuji Electric's laser gas analyzers were the first of its kind on the Japanese market and have obtained a proven track record for quality. Figure 5 shows the configuration of the laser CO analyzer. It has the following features.

(1) High-speed response

Since the sensor component is directly inserted into the exhaust gas duct of the boiler, there are no time delays due to gas sampling, and as such, changes in the gas concentration inside the gas duct are detected instantly (Response time: 1 to 2 seconds).

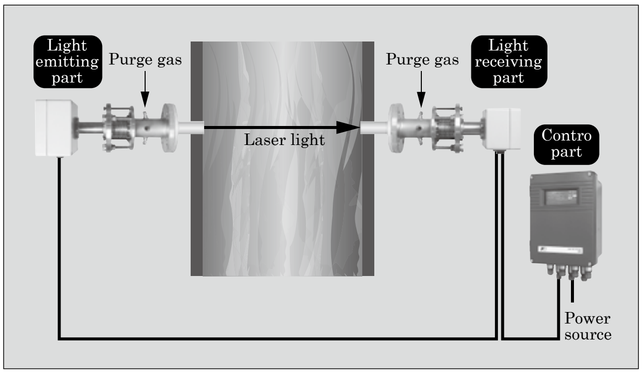

Fig.5 Configuration of laser CO analyzer

(2) Easy maintenance

The direct-insert system makes daily maintenance, such as filter replacement in the gas sampling system, unnecessary, and calibration work only needs to be performed once every 6 months.

(3) Low interference of other gases on the CO measurement

Since the infrared wavelengths absorbed by the CO gas do not overlap with the wavelengths of other gases or moisture, this gas analyzer is theoretically not susceptible to interference from other gases.

3. Results of Boiler Combustion Solution Trial Run in Heat Source Boiler

In March 2016, a heat source boiler with a boiler capacity of 450 t/h was newly installed in Paris by RCU as a wide-ranging infrastructure installation for supplying hot water at a pressure of 1.5 MPa. The boiler combustion solution was employed for this installation. Good results were obtained in the automatic control test, and up until now, the solution has been utilized smoothly.

Good results have also been obtained in both the automatic control test for ultra-low excess air ratio combustion and the emergency stop test for the boiler combustion solution.

3.1 Overview of trial run equipment

Since the control device of the boiler was manufactured by another company, the Fuji Electric compact controller, which comes equipped with a software package for controlling boiler combustion, was designed so that it could be stored in the wall-mounted panel. This panel is compact with a height of 760 mm, a width of 600 mm, and a depth of 300 mm. In addition, the signals for communicating with the boiler control system consist of approximately 10 control and interlock signals and 20 monitoring signals, thus establishing process I/O connectivity.

Table 1 Boiler overall specifications

Item	Specification
Boiler capacity	450 t/h (max.) hot water
Boiler outlet main steam pressure	1.5 MPa (max.)
Boiler outlet main steam temperature	171 °C (max.)
Fuel	Natural gas
Boiler exhaust gas temperature	176 °C (max.)
Natural gas flow rate	36,830 Nm^3/h (max.)

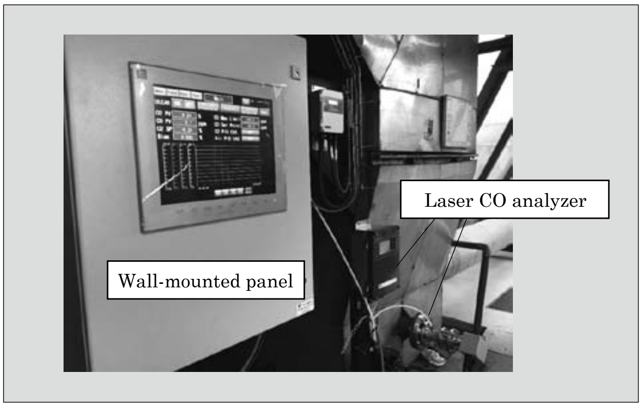

Fig.6 Installation state of wall-mounted panel and laser CO analyzer

Table 1 shows the basic overview of the specification of the boiler, and Fig. 6 shows the installation state of the wall-mounted panel that houses the boiler combustion solution, as well as the laser CO analyzer.

3.2 Trial run results

(1) Automatic control test for ultra-low excess air ratio combustion

Figure 7 shows the results of activating the boiler combustion solution and implementing the automatic control test for ultra-low excess air ratio combustion at a burner load of 50%.

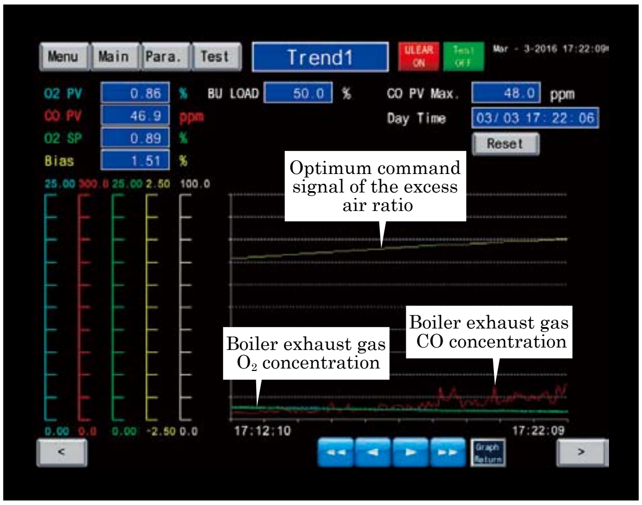

Fig.7 Automatic control test results for ultra-low excess air ratio combustion

Fig.8 Emergency stop test results for boiler combustion solution

Since the boiler exhaust gas O_2 concentration is reduced from 2.40% to 0.86%, improvements in exhaust gas heat loss account for a reduction in yearly fuel costs by approximately 28 million yen.

(2) Emergency stop test for the boiler combustion solution

Figure 8 shows the results of the emergency stop test in which the boiler combustion solution was immediately stopped. The boiler combustion solution takes fully into account the safety of boiler plants, and as such, it undergoes emergency stop when there is a malfunction with related equipment, disconnection of I/O cables, abnormality in the maximum upper and lower limits of a process, control mode failure, etc. When the boiler combustion solution undergoes emergency stop and is disconnected from the boiler control system, the system is automatically restored to the boiler exhaust gas O_2 control state that existed previous to employing the boiler combustion solution so that control can continue to be implemented via the excess air ratio.

Figure 8 shows trend charts for process values that were recorded in the results of the boiler combustion solution trial run. Some of the values include the optimum command signal value of the excess air ratio, the boiler exhaust gas O_2 concentration and boiler exhaust gas CO concentration. The center portion of the chart shows continuous control in a state in which the boiler combustion solution undergoes emergency stop and the optimum command signal of the excess air ratio simultaneously drops sharply, while the value of the boiler exhaust gas CO concentration is nullified and the boiler exhaust gas O_2 concentration rises.

4. Postscript

We have described the boiler combustion solution for decreasing fuel costs. We are currently developing systems that utilize IoT and are offering our customers, including those who are located far distances away, services for monitoring the state of boiler combustion and for performing maintenance, while also continuing to pursue the development of tools that support mutual information exchange. In the future, we plan to develop high added-value information and control systems, as well as solution packaged software suites and services so that we can provide new value for our customers.

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