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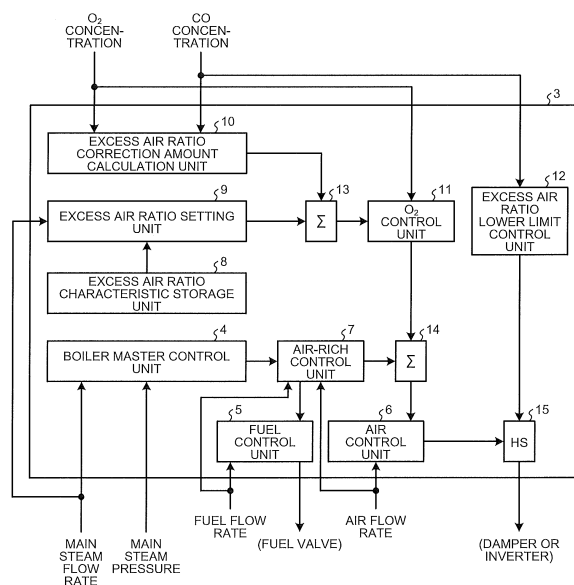
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(54) **COMBUSTION CONTROL SYSTEM, COMBUSTION CONTROL METHOD, COMBUSTION CONTROL PROGRAM, AND COMPUTER-READABLE RECORDING MEDIUM**

(57) To simply suppress a heat loss of an exhaust gas regardless of a type and a load of a boiler. In order for the object, the combustion control system includes: an excess air ratio setting unit that sets an excess air ratio which is a ratio of an amount of air to be input to a boiler relative to an amount of theoretical combustion air, based on a main steam flow rate from the boiler; an excess air ratio correction amount calculation unit that calculates a correction amount of the excess air ratio to make a heat loss caused by excess air and a heat loss caused by incomplete combustion be substantially equal to each other, based on oxygen concentration and carbon monoxide concentration in an exhaust gas from the boiler; and an oxygen control unit that generates an air setting correction signal for correcting a setting value of the air amount based on an excess air ratio corrected using the correction amount and the oxygen concentration in the exhaust gas.

FIG.2



Description

Field

5 **[0001]** The present invention relates to a combustion control system which controls combustion of fuel in a boiler, a combustion control method, a combustion control program, and a computer readable recording medium.

Background

10 **[0002]** Conventionally, various control methods have been attempted to achieve both energy saving and pollution prevention in a technique relating to a combustion process of a boiler. For example, a technique has been known in which optimal control at a low excess air ratio is performed by adjusting an air flow rate using an air setting signal that is obtained by adding a correction amount of oxygen (O_2) concentration obtained from carbon monoxide (CO) concentration to a signal to set a characteristic of an excess air ratio from a main steam flow rate of the boiler (for example, see

15 Patent Literature 1). The excess air ratio is defined as a ratio of an amount of air, which is actually input to the boiler, relative to an amount of theoretical combustion air, and also referred to as an air ratio. Here, the amount of theoretical combustion air is a minimum amount of air required for combustion per unit fuel. In the technique described in Patent Literature 1, when a fixed value or more of CO is generated, the CO concentration is suppressed by increasing the excess air ratio to prevent generation of smoke such as black smoke.

20 **[0003]** FIG. 8 is a graph schematically illustrating a relationship among an excess air ratio, a heat loss and heat efficiency. In FIG. 8, a straight line 101 indicates a heat loss caused by excess air, and a curved line 102 indicates a heat loss caused by incomplete combustion. The emission amount of excess air increases as the excess air ratio becomes larger than one according to the straight line 101, and thus, the heat loss increases and the fuel cost also increases. On the other hand, the heat loss caused by generation of CO increases as incomplete combustion occurs

25 when the excess air ratio is small according to the curved line 102, and smoke is generated when the excess air ratio exceeds a certain threshold.

[0004] In FIG. 8, a curved line 201 in the dotted line indicates heat efficiency of a boiler. According to the curved line 201, the heat efficiency becomes maximum in a zone D_1 including an excess air ratio at which the heat loss caused by the excess air and the heat loss caused by the incomplete combustion are at the same level, and the excess air ratio decreases as being spaced apart from the zone D_1 . Accordingly, theoretically, it is possible to cause the boiler to operate the most efficientl when the combustion control is performed in the zone D_1 . Hereinafter, the zone D_1 illustrated in FIG.

30 8 will be referred to as an ultra-low excess air combustion zone.

Citation List

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Patent Literature

[0005] Patent Literature 1: Japanese Examined Patent Publication No. 3-21808 Summary

40 Technical Problem

[0006] The above-described technique described in Patent Literature 1 sets the O_2 concentration as a main control target and performs control just for suppression of an increase in regard to the CO concentration. That is, the technique described in Patent Literature 1 basically performs the control in a zone D_2 (hereinafter, referred to as a normal optimum combustion zone D_2) where the excess air ratio is relatively small in a zone having the excess air ratio larger than that of the ultra-low excess air combustion zone D_1 illustrated in FIG. 8, and jut performs the control in the vicinity of a boundary between the ultra-low excess air combustion zone D_1 and the normal optimum combustion zone D_2 when the CO concentration increases. Thus, it is difficult to say that the technique described in Patent Literature 1 sufficiently suppresses the heat loss of an exhaust gas.

50 **[0007]** In addition, when the correction amount of the O_2 concentration is obtained from the CO concentration, the relationship therebetween varies depending on conditions such as a type of the boiler and a boiler load in the case of the technique described in Patent Literature 1, and thus, there is a problem that it is difficult to accurately set the correction amount of the O_2 concentration according to the condition.

[0008] The present invention has been made in view of the above-described problems, and an object thereof is to provide a combustion control system, a combustion control method, a combustion control program, and a computer readable recording medium capable of simply suppressing a heat loss of an exhaust gas regardless of a type or a load of a boiler.

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Solution to Problem

[0009] To solve the problem described above and to achieve the object, a combustion control system according to the present invention is a combustion control system for controlling combustion of fuel in a boiler. The combustion control system includes: an excess air ratio setting unit configured to set an excess air ratio which is a ratio of an amount of air to be input to the boiler relative to an amount of theoretical combustion air, based on a main steam flow rate from the boiler; an excess air ratio correction amount calculation unit configured to calculate a correction amount of the excess air ratio to make a heat loss caused by excess air and a heat loss caused by incomplete combustion be substantially equal to each other, based on oxygen concentration and carbon monoxide concentration in an exhaust gas from the boiler; and an oxygen control unit configured to generate an air setting correction signal for correcting a setting value of the air amount, based on an excess air ratio corrected using the correction amount and the oxygen concentration in the exhaust gas.

[0010] In the above-described invention, the excess air ratio correction amount calculation unit of the combustion control system according to the present invention is configured to calculate the correction amount of the excess air ratio using a first heat loss calculation formula to calculate the heat loss caused by the excess air and a second heat loss calculation formula to calculate the heat loss caused by the incomplete combustion.

[0011] In the above-described invention, the excess air ratio correction amount calculation unit of the combustion control system according to the present invention is configured to calculate the correction amount of the excess air ratio using a first simplified heat loss calculation formula obtained by excluding calorie of the exhaust gas of the boiler from the first heat loss calculation formula and a second simplified heat loss calculation formula obtained by excluding an exhaust gas flow rate of the boiler from the second heat loss calculation formula.

[0012] In the above-described invention, the first heat loss calculation formula of the combustion control system according to the present invention includes an incomplete combustion factor which is a constant to prevent the carbon monoxide concentration in the exhaust gas from exceeding a regulation value.

[0013] In the above-described invention, the excess air ratio correction amount calculation unit of the combustion control system according to the present invention is configured to calculate the correction amount of the excess air ratio further using a third heat loss calculation formula to calculate a heat loss as an upper limit of an amount of carbon monoxide emission based on a set regulation value of the amount of the carbon monoxide emission.

[0014] In the above-described invention, the excess air ratio correction amount calculation unit of the combustion control system according to the present invention is configured to calculate the correction amount of the excess air ratio further using a third simplified heat loss calculation formula obtained by excluding calorie of the exhaust gas of the boiler from the third heat loss calculation formula.

[0015] In the above-described invention, the combustion control system according to the present invention further includes an excess air ratio characteristic storage unit configured to store an excess air ratio characteristic indicating a relationship between a load of the boiler and the excess air ratio. The excess air ratio setting unit is configured to set the excess air ratio by referring to the excess air ratio characteristic.

[0016] In the above-described invention, the combustion control system according to the present invention further includes an air-rich control unit configured to: perform control to increase a setting value of fuel to be supplied to the boiler after increasing a setting value of an amount of air to be supplied to the boiler first at time of increasing a load of the boiler; and perform control to decrease the setting value of the amount of air supplied to the boiler after decreasing the setting value of the fuel to be supplied to the boiler first at time of decreasing the load of the boiler.

[0017] A combustion control method according to the present invention is a combustion control method to control combustion of fuel in a boiler. The combustion control method includes: an excess air ratio setting step of setting an excess air ratio which is a ratio of an amount of air to be input to the boiler relative to an amount of theoretical combustion air, based on a main steam flow rate from the boiler; an excess air ratio correction amount calculation step of calculating a correction amount of the excess air ratio to make a heat loss caused by excess air and a heat loss caused by incomplete combustion be substantially equal to each other, based on oxygen concentration and carbon monoxide concentration in an exhaust gas from the boiler; and an oxygen control step of generating an air setting correction signal for correcting a setting value of the air amount based on an excess air ratio corrected using the correction amount and the oxygen concentration in the exhaust gas.

[0018] A combustion control program according to the present invention is a combustion control program that causes a combustion control system, which controls combustion of fuel in a boiler, to execute: an excess air ratio setting step of setting an excess air ratio which is a ratio of an amount of air to be input to the boiler relative to an amount of theoretical combustion air, based on a main steam flow rate from the boiler; an excess air ratio correction amount calculation step of calculating a correction amount of the excess air ratio to make a heat loss caused by excess air and a heat loss caused by incomplete combustion be substantially equal to each other, based on oxygen concentration and carbon monoxide concentration in an exhaust gas from the boiler; and an oxygen control step of generating an air setting correction signal for correcting a setting value of the air amount based on an excess air ratio corrected using the correction

amount and the oxygen concentration in the exhaust gas.

[0019] A non-transitory computer readable recording medium, according to the present invention, in which an executable program is recorded is a non-transitory computer readable recording medium in which an executable program is recorded, the program instructing a processor to execute: setting an excess air ratio which is a ratio of an amount of air to be input to the boiler relative to an amount of theoretical combustion air, based on a main steam flow rate from the boiler; calculating a correction amount of the excess air ratio to make a heat loss caused by excess air and a heat loss caused by incomplete combustion be substantially equal to each other, based on oxygen concentration and carbon monoxide concentration in an exhaust gas from the boiler; and generating an air setting correction signal for correcting a setting value of the air amount based on an excess air ratio corrected using the correction amount and the oxygen concentration in the exhaust gas.

Advantageous Effects of Invention

[0020] According to the present invention, it is possible to simply suppress the heat loss of the exhaust gas regardless of the type and the load of the boiler by calculating a correction amount of an excess air ratio to make a heat loss caused by excess air and a heat loss caused by incomplete combustion be substantially equal to each other, based on oxygen concentration and carbon monoxide concentration in the exhaust gas from the boiler.

Brief Description of Drawings

[0021]

FIG. 1 is a diagram illustrating a schematic configuration of a combustion system which includes a combustion control system according to a first embodiment of the present invention.

FIG. 2 is a block diagram illustrating a functional configuration of the combustion control system according to the first embodiment of the present invention.

FIG. 3 is a graph schematically illustrating an excess air ratio characteristic stored in an excess air ratio characteristic storage unit of the combustion control system according to the first embodiment of the present invention.

FIG. 4 is a graph for describing meaning of an incomplete combustion factor.

FIG. 5 is a graph schematically illustrating an example of an operation of a boiler which is controlled by the combustion control system according to the first embodiment of the present invention.

FIG. 6 is a graph illustrating a relationship among three heat loss calculation formulae which are applied in a second embodiment of the present invention.

FIG. 7 is a graph illustrating the overview of operation of a combustion system 1 according to the second embodiment of the present invention.

FIG. 8 is a graph schematically illustrating a relationship among an excess air ratio, a heat loss and heat efficiency.

Description of Embodiments

[0022] Hereinafter, modes for carrying out the present invention (hereinafter, referred to as "embodiments") will be described with reference to the drawings.

(First Embodiment)

[0023] FIG. 1 is a diagram illustrating a schematic configuration of a combustion system which includes a combustion control system according to a first embodiment of the present invention. A combustion system 1 illustrated in FIG. 1 is provided with a boiler 2 which burns a fuel to generate steam and discharge an exhaust gas (combustion gas) caused by the combustion of fuel via a discharge path such as a chimney and a combustion control system 3 which comprehensively controls an operation of the combustion system 1. The combustion system 1 has various instruments to measure or set each of a fuel flow rate and an air flow rate that flow into the boiler 2, the main steam flow rate and the main steam pressure at a steam outlet of the boiler 2, temperature of an exhaust gas, O₂ concentration, and CO concentration at an exhaust gas outlet of the boiler 2, the ambient temperature of the boiler 2. In addition, the air flow rate input into the boiler 2 is adjusted by an inverter or an air damper based on the control of the combustion control system 3. Incidentally, a type of the boiler 2 is not particularly limited in the first embodiment.

[0024] FIG. 2 is a block diagram illustrating a functional configuration of the combustion control system 3 according to the first embodiment. The combustion control system 3 illustrated in FIG. 2 is provided with a boiler master control unit 4, a fuel control unit 5, an air control unit 6, an air-rich control unit 7, an excess air ratio characteristic storage unit 8, an excess air ratio setting unit 9, an excess air ratio correction amount calculation unit 10, an O₂ control unit (oxygen

control unit) 11, an excess air ratio lower limit control unit 12, adders 13 and 14, and a high selector 15.

[0025] The boiler master control unit 4 generates a boiler master signal to set an operation of the boiler 2, that is, an increase or a decrease of output of the boiler 2 based on measured values of the main steam flow rate and the main steam pressure, and outputs the generated signal to the air-rich control unit 7. The boiler master signal is a signal to control the boiler 2 such that the main steam pressure is constant and includes each setting signal of the air flow rate and the fuel flow rate.

[0026] The fuel control unit 5 performs control of the fuel flow rate using the setting signal of the fuel flow rate (hereinafter, referred to as a fuel setting signal), which is set based on the boiler master signal, as a target. The fuel control unit 5 is configured using, for example, a PID controller and outputs a signal to adjust an opening position of a fuel valve that inputs the fuel into the boiler 2.

[0027] The air control unit 6 performs control of the air flow rate using the setting signal of the air flow rate (hereinafter, referred to as an air setting signal), which is set based on the boiler master signal and an O₂ concentration correction signal of the O₂ control unit 11 to be described later, as a target. The air control unit 6 outputs a control signal to control the inverter or the air damper according to the air setting signal. The control signal for air is output to the high selector 15. The air control unit 6 is configured using, for example, a PID controller.

[0028] The air-rich control unit 7 performs air-rich control to form excess air by increasing increase the O₂ concentration and setting the CO concentration to substantially zero, for example, at the time of changing the boiler load of the boiler 2. The air-rich control unit 7 performs control using a difference in responsiveness between fuel and air. To be specific, the air-rich control unit 7 performs control at the time of increasing the boiler load such that a setting value of the fuel to be supplied to the boiler 2 is increased after a setting value of the amount of air to be supplied to the boiler 2 is increased first. In addition, the air-rich control unit 7 performs control at the time of decreasing the boiler load such that the setting value of the amount of air to be supplied to the boiler 2 is decreased after the setting value of the fuel to be supplied to the boiler 2 is decreased first. As such control is performed, it is possible to prevent generation of large-scale incomplete combustion when the boiler load changes and to suppress generation of black smoke. Incidentally, the air-rich control unit 7 outputs the air setting signal and the fuel setting signal included in the boiler master signal when the boiler load does not change.

[0029] The excess air ratio characteristic storage unit 8 stores the excess air ratio according to the boiler load. FIG. 3 is a graph schematically illustrating an excess air ratio characteristic stored in the excess air ratio characteristic storage unit 8. In the case of the excess air ratio characteristic illustrated in FIG. 3, the excess air ratio becomes smaller as the boiler load increases. Incidentally, the excess air ratio characteristic illustrated in FIG. 3 is mere an example and may vary depending on a type or the like of the boiler 2, of course. For example, a characteristic set by performing various types of measurement at the time of test operation of the boiler 2 or a predetermined characteristic depending on a type of the boiler 2 may be applied as the excess air ratio characteristic.

[0030] The excess air ratio setting unit 9 calculates the boiler load using the measured value of the main steam flow rate, calculates the excess air ratio depending on the boiler load with reference to the excess air ratio characteristic stored in the excess air ratio characteristic storage unit 8, and outputs the calculated excess air ratio to the adder 13.

[0031] The excess air ratio correction amount calculation unit 10 calculates an amount corresponding to the heat loss caused by the excess air using a measured value of the O₂ concentration and an amount corresponding to the heat loss caused by the incomplete combustion using a measured value of the CO concentration, and calculates the correction amount of the excess air ratio by comparing the two amounts. Hereinafter, the heat loss caused by the excess air and the heat loss caused by the incomplete combustion will be described, and then, a relationship among these heat losses and the amount actually calculated by the excess air ratio correction amount calculation unit 10 will be described.

[0032] A heat loss air L_{AIR} caused by excess air is given by the following Formula (1) (example of a first heat loss calculation formula).

$$L_{AIR} = C_{PA} \cdot (T_O - T_I) \cdot (G \cdot D(O_2) / 0.21) \cdot \alpha \quad (1)$$

[0033] Here, C_{PA} is specific heat of air (= 1.3 [kJ/Nm³·K]), T_O is temperature (°C) of ambient air of the boiler 2, T_I is temperature (°C) of an exhaust gas of the boiler 2, G is an exhaust gas flow rate (Nm³/h), D(O₂) is O₂ concentration in the exhaust gas, and α is an incomplete combustion factor which is defined as a constant smaller than 1. The meaning of the incomplete combustion factor α will be described later.

[0034] A heat loss L_{CO} caused by incomplete combustion is given by the following Formula (2) (example of a second heat loss calculation formula).

$$L_{CO} = G \cdot D(CO_{out}) \cdot H_{CO} \quad (2)$$

[0035] Here, $D(\text{CO}_{\text{out}})$ is CO concentration in the exhaust gas, and H_{CO} is heating value of CO (= 12634 [kJ/Nm³]).

[0036] FIG. 4 is a graph for describing the meaning of the incomplete combustion factor α and is the graph obtained by enlarging the vicinity of the ultra-low excess air combustion zone. In the ultra-low excess air combustion zone D_1 , the heat loss caused by the incomplete combustion is relatively small as compared to the heat loss caused by the excess air under general regulation of CO concentration in an exhaust gas of a boiler. Thus, the CO concentration has a possibility of exceeding a range assumed as a regulation value of the CO concentration when obtaining the CO concentration at an intersection P at which the heat loss caused by the excess air in the general sense from which the incomplete combustion factor α is excluded from Formula (1) and the heat loss caused by the incomplete combustion given from Formula (2) are equal to each other. Thus, the heat loss caused by the excess air is apparently shifted from a straight line 101 to a straight line 103 by multiplying the heat loss caused by the excess air in the general sense by the incomplete combustion factor α , smaller than one, and an intersection R is obtained by shifting a point Q having a desirable CO concentration in the first embodiment. In this sense, the incomplete combustion factor α is desirably set as a value that prevents the CO concentration at the intersection R from exceeding a regulation value of CO concentration at a location at which the combustion system 1 is installed. For example, a value set based on the test operation of the boiler 2 may be applied as the value of the incomplete combustion factor α , or a predetermined value may be applied depending on a type of the boiler 2. In addition, the value of incomplete combustion factor α is changed depending on the boiler load, and thus, a plurality of incomplete combustion factors may be used depending on a boiler load band in some cases. Further, theoretically, there may be a case where the incomplete combustion factor α is larger than one.

[0037] In the first embodiment, the excess air ratio correction amount calculation unit 10 calculates amounts obtained by excluding exhaust gas flow rate G from each of Formulae (1) and (2) through division, that is,

$$L_{\text{AIR}}' = L_{\text{AIR}}/G = C_{\text{PA}} \cdot (T_{\text{O}} - T_{\text{I}}) \cdot (D(\text{O}_2)/0.21) \cdot \alpha \quad (3)$$

$$L_{\text{CO}}' = L_{\text{CO}}/G = D(\text{CO}_{\text{out}}) \cdot H_{\text{CO}} \quad (4),$$

instead of calculating Formulae (1) and (2). Formula (3) is an example of a first simplified heat loss calculation formula, and Formula (4) is an example of a second simplified heat loss calculation formula. The excess air ratio correction amount calculation unit 10 calculates Formulae (3) and (4) because the exhaust gas flow rate G is included in both right sides of Formulae (1) and (2), and there is no influence of the exhaust gas flow rate G at the time of determining a magnitude relationship between the heat loss caused by the excess air and the heat loss caused by the incomplete combustion. In this manner, Formulae (3) and (4), obtained through simplification by excluding the exhaust gas flow rate G that is not measured by a general boiler, are used in the first embodiment, and thus, the amount of calculation of the excess air ratio correction amount calculation unit 10 is small, and it is possible to efficiently calculate and compare the heat loss caused by the excess air and the heat loss caused by the incomplete combustion.

[0038] The excess air ratio correction amount calculation unit 10 generates, when $L_{\text{AIR}}' > L_{\text{CO}}'$, a correction amount setting signal to relatively decrease the excess air ratio and outputs the generated signal to the adder 13. Moreover, the excess air ratio correction amount calculation unit 10 generates, when $L_{\text{AIR}}' \leq L_{\text{CO}}'$, a correction amount setting signal to relatively increase the excess air ratio and outputs the generated signal to the adder 13.

[0039] The excess air ratio correction amount calculation unit 10 includes two pulse generators, for example. One pulse generator of the two pulse generators operates when $L_{\text{AIR}}' > L_{\text{CO}}'$, and the other pulse generator operates when $L_{\text{AIR}}' \leq L_{\text{CO}}'$. The correction amount of the excess air ratio is adjusted by the number of pulses generated by the pulse generator. Incidentally, the configuration of the excess air ratio correction amount calculation unit 10 for output of the correction amount is not limited thereto.

[0040] The adder 13 calculates an excess air ratio added with the correction amount by adding an excess air ratio setting signal output from the excess air ratio setting unit 9 and the correction amount setting signal output from the excess air ratio correction amount calculation unit 10, and outputs an O_2 concentration setting signal, obtained by converting the excess air ratio into a setting value of O_2 concentration, to the O_2 control unit 11.

[0041] The O_2 control unit 11 outputs a correction signal the air setting amount (hereinafter, referred to as an air setting correction signal), for correction of the O_2 concentration with respect to the measured value of the O_2 concentration using the O_2 concentration setting signal as a target, to the adder 14. The O_2 control unit 11 is configured using, for example, a PID controller.

[0042] The adder 14 outputs an air setting signal, added with the O_2 concentration correction by adding the air setting signal output from the air-rich control unit 7 and the air setting correction signal output from the O_2 control unit 11, to the air control unit 6.

[0043] The excess air ratio lower limit control unit 12 outputs an air setting signal to rapidly increase the amount of air

inside the boiler 2 when the excess air ratio reaches a lower limit setting value based on the measured value of the CO concentration. This value of the air setting signal is an amount of air that enables a value of the excess air ratio to be larger than a lower limit of the ultra-low excess air combustion zone D_1 illustrated in FIG. 8. Incidentally, when a laser CO analyzer is used as a CO concentration meter, high-speed measurement of CO concentration is possible, and it is possible to promptly extract an abnormality of CO concentration.

[0044] The high selector 15 selects a signal that increases the amount of air among the air setting signals output, respectively, from the air control unit 6 and the excess air ratio lower limit control unit 12 and outputs the selected signal to the air damper or the inverter. The high selector 15 selects the air setting signal output from the air control unit 6 during the normal operation and selects the air setting signal output from the excess air ratio lower limit control unit 12 when the CO concentration indicates an abnormal value.

[0045] The combustion control system 3 having the above-described functional configuration is a computer that is realized using a processor which includes a CPU (Central Processing Unit), various arithmetic circuits, a ROM (Read Only Memory) to which a program to start a predetermined OS is installed in advance, a RAM (Random Access Memory) which stores operational parameters, data or the like of various processes, and the like. Among the above-described parts, a combustion control program according to the first embodiment is installed in the ROM in advance. In addition, the combustion control program according to the first embodiment can also be recorded in a non-transitory computer readable recording medium in which an executable program is recorded. Incidentally, the record of the combustion control program into the ROM or the recording medium may be performed at the time of shipping the computer or the recording medium as a product or performed using download via a communication network. The communication network used here is realized using, for example, the existing public network, LAN (Local Area Network), WAN (Wide Area Network), and the like, and may be wired or wireless.

[0046] FIG. 5 is a graph schematically illustrating an example of an operation of the boiler 2 which is controlled by the combustion control system 3. Incidentally, scales of the vertical axes representing the boiler main steam flow rate, the O_2 concentration of the exhaust gas, and the CO concentration of the exhaust gas, respectively, are different from each other in FIG. 5.

[0047] Periods $t \leq t_1$, $t_2 \leq t \leq t_3$, and $t \geq t_4$ schematically illustrate a state change during the operation of the boiler 2 in the ultra-low excess air combustion zone D_1 illustrated in FIGS. 4 and 8. During these periods, the boiler 2 operates in a state where the boiler main steam flow rate, the exhaust gas O_2 concentration, and the exhaust gas CO concentration are kept substantially constant. In this manner, the combustion control with excellent heat efficiency is realized by positively controlling the CO concentration to perform the combustion control in the ultra-low excess air combustion zone in the first embodiment.

[0048] Meanwhile, a period $t_1 < t < t_2$ schematically illustrates a state change when the boiler load increases, and a period $t_3 < t < t_4$ schematically illustrates a state change when the boiler load decreases. When the boiler load changes, the air-rich control unit 7 performs the above-described air-rich control such that the O_2 concentration is temporarily increased and the CO concentration is decreased to substantially zero, for example. During these periods, the boiler 2 operates in a state where the excess air ratio is larger than the ultra-low excess air combustion zone D_1 illustrated in FIGS. 4 and 8.

[0049] According to the above-described first embodiment of the present invention, the combustion control of the boiler in the ultra-low excess air combustion zone is performed by calculating the correction amount of the excess air ratio to set the heat loss caused by the excess air and the heat loss make by the incomplete combustion be substantially equal to each other, based on the oxygen concentration and the carbon monoxide concentration in the exhaust gas from the boiler and correcting the excess air ratio, and thus, it is possible to simply suppress the heat loss of the exhaust gas regardless of the type and the load of the boiler. As a result, the heat efficiency of the boiler increases, and it is possible to reduce the fuel for combustion.

[0050] In addition, it is possible to reliably suppress the CO concentration within the range of regulation according to the first embodiment by calculating the correction amount of the excess air ratio to make the heat loss caused by the excess air and the heat loss caused by the incomplete combustion be equal to each other using the incomplete combustion factor which is a constant configured to prevent the carbon monoxide concentration in the exhaust gas from exceeding the regulation value.

[0051] In addition, the calculation is simplified according to the first embodiment since the calculation is performed using the calculation formulae from which the exhaust gas flow rate of the boiler is excluded at the time of calculating the correction amount of the excess air ratio to make the heat loss caused by the excess air and the heat loss caused by the incomplete combustion be equal to each other. As a result, it is unnecessary to measure the exhaust gas flow rate, that is not generally measured nor calculate the amount of the exhaust gas from a fuel component, and it is possible to efficiently calculate the correction amount in the first embodiment.

[0052] In addition, it is possible to set an optimal excess air ratio according to a characteristic of the boiler according to the first embodiment since the excess air ratio is set using the excess air ratio characteristic that indicates the relationship between the load of the boiler and the excess air ratio.

[0053] In addition, it is possible to perform the combustion control that can respond to the change of the boiler load according to the first embodiment by performing the CO control in the ultra-low excess air combustion zone during when the operation of the boiler is stable and performing the air-rich control to form the excess air state when the boiler load is changed.

[0054] Incidentally, the incomplete combustion factor is not required if the CO concentration when the heat loss caused by the excess air and the heat loss caused by the incomplete combustion, calculated without using the incomplete combustion factor, are equal to each other is a value that has no problem in terms of the regulation, and thus, the calculation of Formula (3) may be performed by setting $\alpha = 1$ in the first embodiment.

[0055] In addition, the excess air ratio correction amount calculation unit 10 may calculate the first heat loss calculation formula (Formula (1)) and the second heat loss calculation formula (Formula (2)) instead of the first simplified heat loss calculation formula (Formula (3)) and the second simplified heat loss calculation formula (Formula (4)) in the first embodiment.

(Second Embodiment)

[0056] A second embodiment of the present invention is characterized by performing control such that a CO emission amount is kept to be constant regardless of a load of a boiler while considering a regulation value of the CO emission amount (CO regulation value) to be set depending on a location to which the boiler is installed and the like. The setting of the CO regulation value may be realized by inputting a regulation value to a combustion control system according to the second embodiment in advance using a device for setting such as an input device or realized by performing setting (or update) using communication via communication network. A configuration of the combustion control system according to the second embodiment is the same as the configuration of the combustion control system 3 that has been described in the first embodiment.

[0057] In the second embodiment, the following Formula (5) that does not include the incomplete combustion factor α is used as a first heat loss calculation formula to give a heat loss caused by excess air.

$$L_{AIR2} = C_{PA} \cdot (T_O - T_I) \cdot (G \cdot D(O_2) / 0.21) \quad (5)$$

[0058] In addition, a heat loss corresponding to an upper limit of CO emission set based on the CO regulation value is used in addition to Formula (5) and the heat loss L_{CO} caused by the incomplete combustion of Formula (2) (the second heat loss calculation formula) described above. A heat loss L_{COlim} as the upper limit of the CO emission based on the CO regulation value is given by the following Formula (6) (example of a third heat loss calculation formula).

$$L_{COlim} = G \cdot D(CO_{lim}) \cdot H_{CO} \quad (6)$$

[0059] In Formula (6), $D(CO_{lim})$ on the right side is CO concentration at the upper limit of the CO emission calculated based on the CO regulation value. The CO regulation value is a value that is set in advance according to a condition of laws and regulations of the location to which the boiler 2 is installed.

[0060] In the second embodiment, the excess air ratio correction amount calculation unit 10 outputs a correction amount setting signal to the adder 13 by performing an operation to compare a magnitude relationship among Formulae (5), (2) and (6). Thus, the excess air ratio correction amount calculation unit 10 calculates the following Formulae (7), (4) and (8), obtained by excluding the exhaust gas flow rate G which is commonly included in the respective Formulae (5), (2) and (6) through division, instead of calculating Formulae (5), (2) and (6) in the second embodiment.

$$L_{AIR2}' = L_{AIR} / G = C_{PA} \cdot (T_O - T_I) \cdot (D(O_2) / 0.21) \quad (7)$$

$$L_{CO}' = L_{CO} / G = D(CO_{out}) \cdot H_{CO} \quad (4)$$

$$L_{COlim}' = L_{COlim} / G = D(CO_{lim}) \cdot H_{CO} \quad (8)$$

[0061] Formula (7) is an example of the first simplified heat loss calculation formula that is applied in the second embodiment, and Formula (8) is an example of a third simplified heat loss calculation formula.

[0062] FIG. 6 is a graph illustrating a relationship among the three heat loss calculation formulae applied in the second embodiment and the graph obtained by enlarging the vicinity of the ultra-low excess air combustion zone. FIG. 6 illustrates a straight line 104 (corresponds to Formula (8)) to give the heat loss as the upper limit of the CO emission based on the CO regulation value in addition to the straight line 101 (corresponds to Formula (7)) to give the heat loss caused by the excess air, and the curved line 102 (corresponds to Formula (4)) to give the heat loss caused by the incomplete combustion. As illustrated in FIG. 6, the heat loss as the upper limit of the CO emission based on the CO regulation value is constant regardless of an excess air ratio.

[0063] Specific processing of the excess air ratio correction amount calculation unit 10 will be described. The excess air ratio correction amount calculation unit 10 first outputs a minimum value $\min(L_{AIR2'}, L_{COlim'})$ by comparing a heat loss $L_{AIR2'}$ caused by excess air and the heat loss $L_{COlim'}$ as the upper limit of the CO emission based on the CO regulation value. Subsequently, the excess air ratio correction amount calculation unit 10 compares the minimum value $\min(L_{AIR2'}, L_{COlim'})$ and the heat loss Leo' caused by the incomplete combustion. When $\min(L_{AIR2'}, L_{COlim'}) > Leo'$ as a result of the comparison, the excess air ratio correction amount calculation unit 10 generates a correction amount setting signal to relatively decrease the excess air ratio and outputs the generated signal to the adder 13. On the contrary, when $\min(L_{AIR2'}, L_{COlim'}) \leq L_{CO}$ as a result of the comparison, the excess air ratio correction amount calculation unit 10 generates a correction amount setting signal to relatively increase the excess air ratio and outputs the generated signal to the adder 13.

[0064] The content of the processing of the combustion control system 3 except for the above-described processing of the excess air ratio correction amount calculation unit 10 is the same as that of the first embodiment.

[0065] FIG. 7 is a graph illustrating the overview of operation of the combustion system 1 according to the second embodiment. FIG. 7 illustrates each relationship between each of the CO emission amount, the boiler load, and the heat loss of the exhaust gas, and the excess air ratio based on the CO regulation value. The CO emission amount caused by the boiler 2 is constant regardless of the excess air ratio (a straight line 301). The case where the excess air ratio decreases as the boiler load increases is exemplified as the relationship between the boiler load and the excess air ratio (a curved line 302). In regard to the relationship between the exhaust gas the heat loss and the excess air ratio, the emission amount of the excess air increases as the excess air ratio increases more than one (a straight line 303). As apparent from FIG. 7, the combustion control system 3 according to the second embodiment can operate the boiler 2 with the constant CO emission amount regardless of the boiler load. This is because the excess air ratio correction amount calculation unit 10 sets the correction amount of the excess air ratio by referring to the upper limit of the CO emission based on the CO regulation value in the second embodiment.

[0066] According to the second embodiment of the present invention described above, the heat efficiency of the boiler is improved, it is possible to reduce the fuel for combustion, and it is possible to reliably control the CO concentration within the range of regulation, which is similar to the first embodiment. In addition, it is unnecessary to measure the exhaust gas flow rate, that is not generally measured nor calculate the amount of the exhaust gas from a fuel component, and it is also possible to efficiently calculate the correction amount in the second embodiment.

[0067] In addition, it is possible to keep the CO emission amount to be constant regardless of the boiler load according to the second embodiment since the correction amount of the excess air ratio is set by referring to the upper limit of the CO emission based on the CO regulation value. As a result, it is unnecessary to perform the operation by setting the incomplete combustion factor for each boiler load similarly to the first embodiment, and thus, it is possible to perform the combustion control of the boiler more easily. In particular, when it is necessary to set the incomplete combustion factor by test operation of the boiler, it is possible to save time and effort at the time of installing the boiler since such test operation itself is not required.

[0068] Incidentally, the excess air ratio correction amount calculation unit 10 may calculate the first heat loss calculation formula (Formula (5)), the second heat loss calculation formula (Formula (2)) and the third heat loss calculation formula (Formula (6)) instead of the first simplified heat loss calculation formula (Formula (7)), the second simplified heat loss calculation formula (Formula (4)) and the third simplified heat loss calculation formula (Formula (8)) in the second embodiment.

[0069] The modes for carrying out the present invention have been described as above, but the present invention is not necessarily limited only to the first and second embodiments. That is, the present invention may include various embodiments and the like that are not described herein.

Reference Signs List

[0070]

- | | |
|---|----------------------------|
| 1 | COMBUSTION SYSTEM |
| 2 | BOILER |
| 3 | COMBUSTION CONTROL SYSTEM |
| 4 | BOILER MASTER CONTROL UNIT |

5	FUEL CONTROL UNIT
6	AIR CONTROL UNIT
7	AIR-RICH CONTROL UNIT
8	EXCESS AIR RATIO CHARACTERISTIC STORAGE UNIT
5 9	EXCESS AIR RATIO SETTING UNIT
10	EXCESS AIR RATIO CORRECTION AMOUNT CALCULATION UNIT
11	O ₂ CONTROL UNIT
12	EXCESS AIR RATIO LOWER LIMIT CONTROL UNIT
13, 14	ADDER
10 15	HIGH SELECTOR

Claims

- 15 1. A combustion control system for controlling combustion of fuel in a boiler, the combustion control system comprising:
 - an excess air ratio setting unit configured to set an excess air ratio which is a ratio of an amount of air to be input to the boiler relative to an amount of theoretical combustion air, based on a main steam flow rate from the boiler;
 - 20 an excess air ratio correction amount calculation unit configured to calculate a correction amount of the excess air ratio to make a heat loss caused by excess air and a heat loss caused by incomplete combustion be substantially equal to each other, based on oxygen concentration and carbon monoxide concentration in an exhaust gas from the boiler; and
 - an oxygen control unit configured to generate an air setting correction signal for correcting a setting value of the air amount, based on an excess air ratio corrected using the correction amount and the oxygen concentration in the exhaust gas.
2. The combustion control system according to claim 1, wherein
 - 30 the excess air ratio correction amount calculation unit is configured to calculate the correction amount of the excess air ratio using a first heat loss calculation formula to calculate the heat loss caused by the excess air and a second heat loss calculation formula to calculate the heat loss caused by the incomplete combustion.
3. The combustion control system according to claim 2, wherein
 - 35 the excess air ratio correction amount calculation unit is configured to calculate the correction amount of the excess air ratio using a first simplified heat loss calculation formula obtained by excluding calorie of the exhaust gas of the boiler from the first heat loss calculation formula and a second simplified heat loss calculation formula obtained by excluding an exhaust gas flow rate of the boiler from the second heat loss calculation formula.
4. The combustion control system according to claim 2, wherein
 - 40 the first heat loss calculation formula includes an incomplete combustion factor which is a constant to prevent the carbon monoxide concentration in the exhaust gas from exceeding a regulation value.
5. The combustion control system according to claim 2, wherein
 - 45 the excess air ratio correction amount calculation unit is configured to calculate the correction amount of the excess air ratio further using a third heat loss calculation formula to calculate a heat loss as an upper limit of an amount of carbon monoxide emission based on a set regulation value of the amount of the carbon monoxide emission.
6. The combustion control system according to claim 5, wherein
 - 50 the excess air ratio correction amount calculation unit is configured to calculate the correction amount of the excess air ratio further using a third simplified heat loss calculation formula obtained by excluding calorie of the exhaust gas of the boiler from the third heat loss calculation formula.
7. The combustion control system according to claim 1, further comprising
 - 55 an excess air ratio characteristic storage unit configured to store an excess air ratio characteristic indicating a relationship between a load of the boiler and the excess air ratio, wherein the excess air ratio setting unit is configured to set the excess air ratio by referring to the excess air ratio characteristic.
8. The combustion control system according to claim 1, further comprising

an air-rich control unit configured to:

perform control to increase a setting value of fuel to be supplied to the boiler after increasing a setting value of an amount of air to be supplied to the boiler first at time of increasing a load of the boiler; and
perform control to decrease the setting value of the amount of air supplied to the boiler after decreasing the setting value of the fuel to be supplied to the boiler first at time of decreasing the load of the boiler.

9. A combustion control method to control combustion of fuel in a boiler, the combustion control method comprising:

an excess air ratio setting step of setting an excess air ratio which is a ratio of an amount of air to be input to the boiler relative to an amount of theoretical combustion air, based on a main steam flow rate from the boiler;
an excess air ratio correction amount calculation step of calculating a correction amount of the excess air ratio to make a heat loss caused by excess air and a heat loss caused by incomplete combustion be substantially equal to each other, based on oxygen concentration and carbon monoxide concentration in an exhaust gas from the boiler; and
an oxygen control step of generating an air setting correction signal for correcting a setting value of the air amount based on an excess air ratio corrected using the correction amount and the oxygen concentration in the exhaust gas.

10. A combustion control program that causes a combustion control system, which controls combustion of fuel in a boiler, to execute:

an excess air ratio setting step of setting an excess air ratio which is a ratio of an amount of air to be input to the boiler relative to an amount of theoretical combustion air, based on a main steam flow rate from the boiler;
an excess air ratio correction amount calculation step of calculating a correction amount of the excess air ratio to make a heat loss caused by excess air and a heat loss caused by incomplete combustion be substantially equal to each other, based on oxygen concentration and carbon monoxide concentration in an exhaust gas from the boiler; and
an oxygen control step of generating an air setting correction signal for correcting a setting value of the air amount based on an excess air ratio corrected using the correction amount and the oxygen concentration in the exhaust gas.

11. A non-transitory computer readable recording medium in which an executable program is recorded, the program instructing a processor to execute:

setting an excess air ratio which is a ratio of an amount of air to be input to the boiler relative to an amount of theoretical combustion air, based on a main steam flow rate from the boiler;
calculating a correction amount of the excess air ratio to make a heat loss caused by excess air and a heat loss caused by incomplete combustion be substantially equal to each other, based on oxygen concentration and carbon monoxide concentration in an exhaust gas from the boiler; and
generating an air setting correction signal for correcting a setting value of the air amount based on an excess air ratio corrected using the correction amount and the oxygen concentration in the exhaust gas.

FIG.1

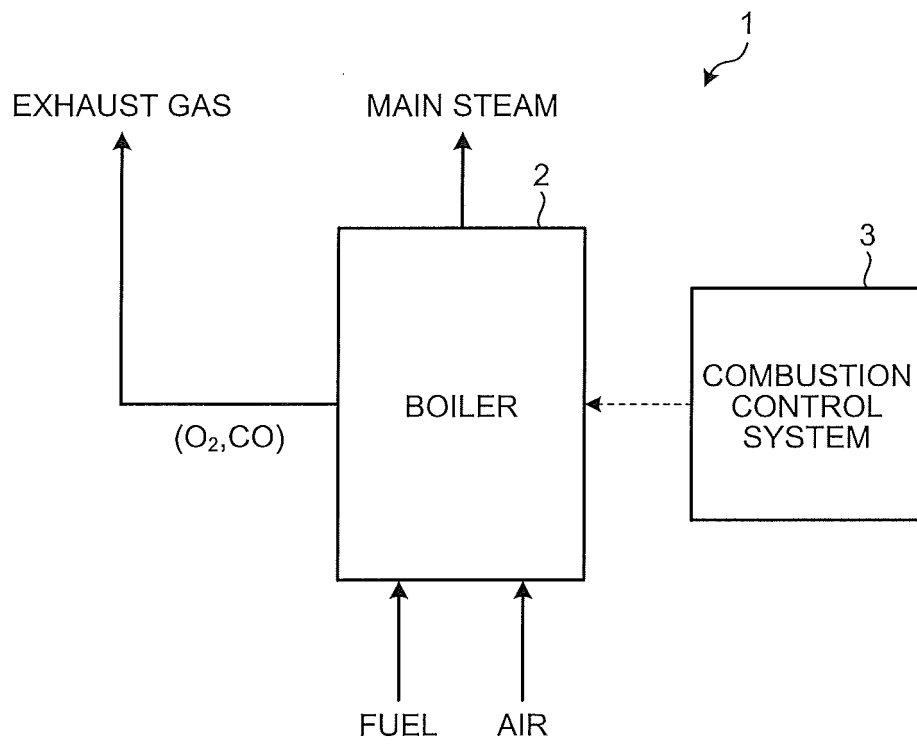


FIG.2

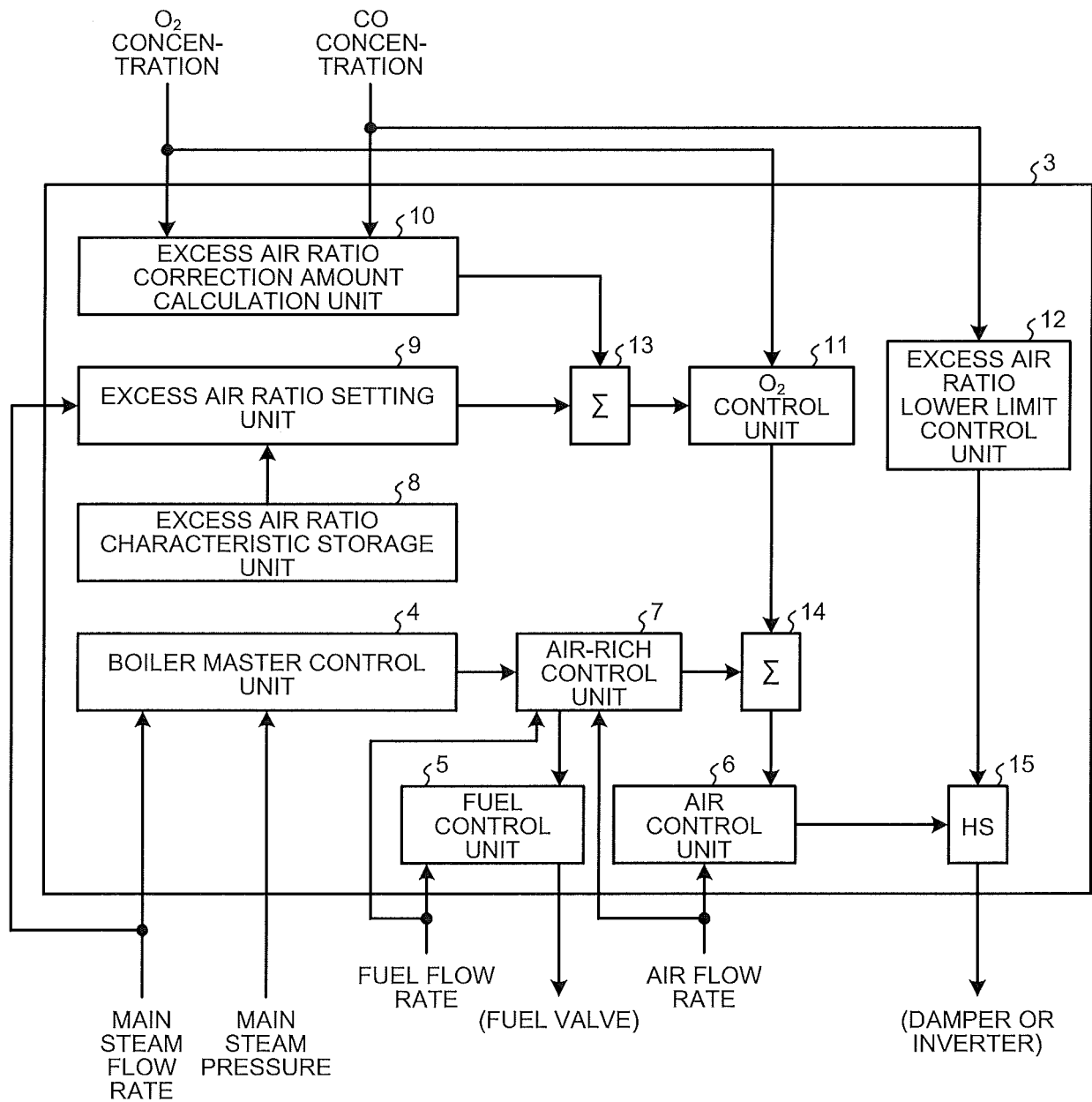


FIG.3

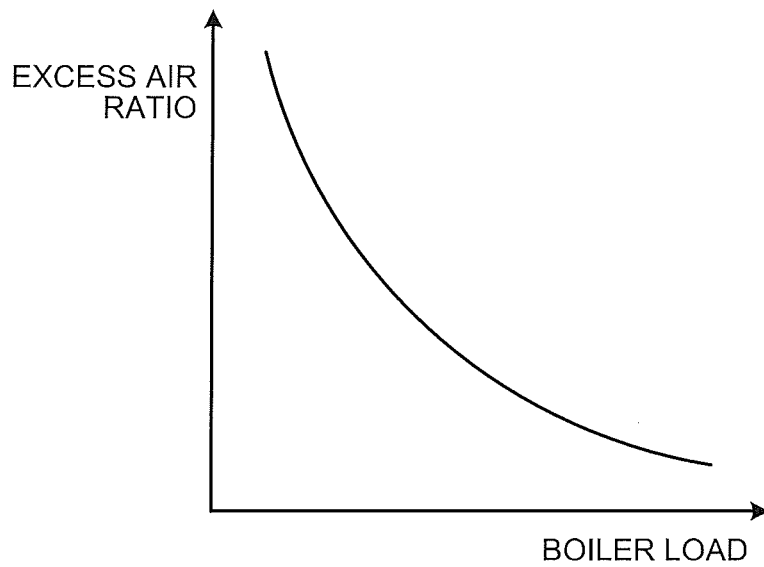


FIG.4

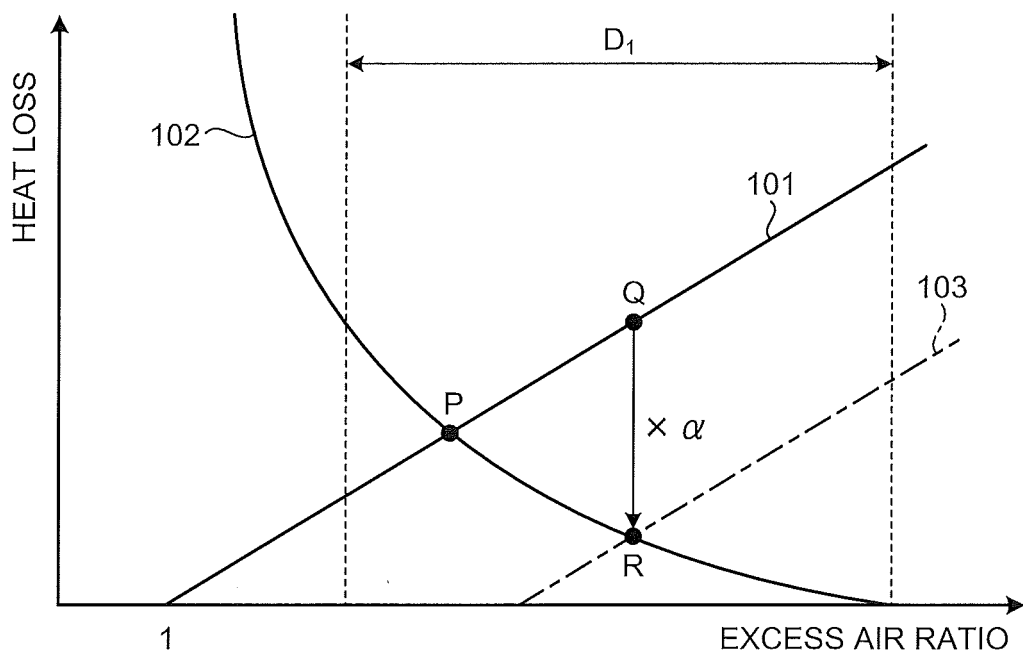


FIG.5

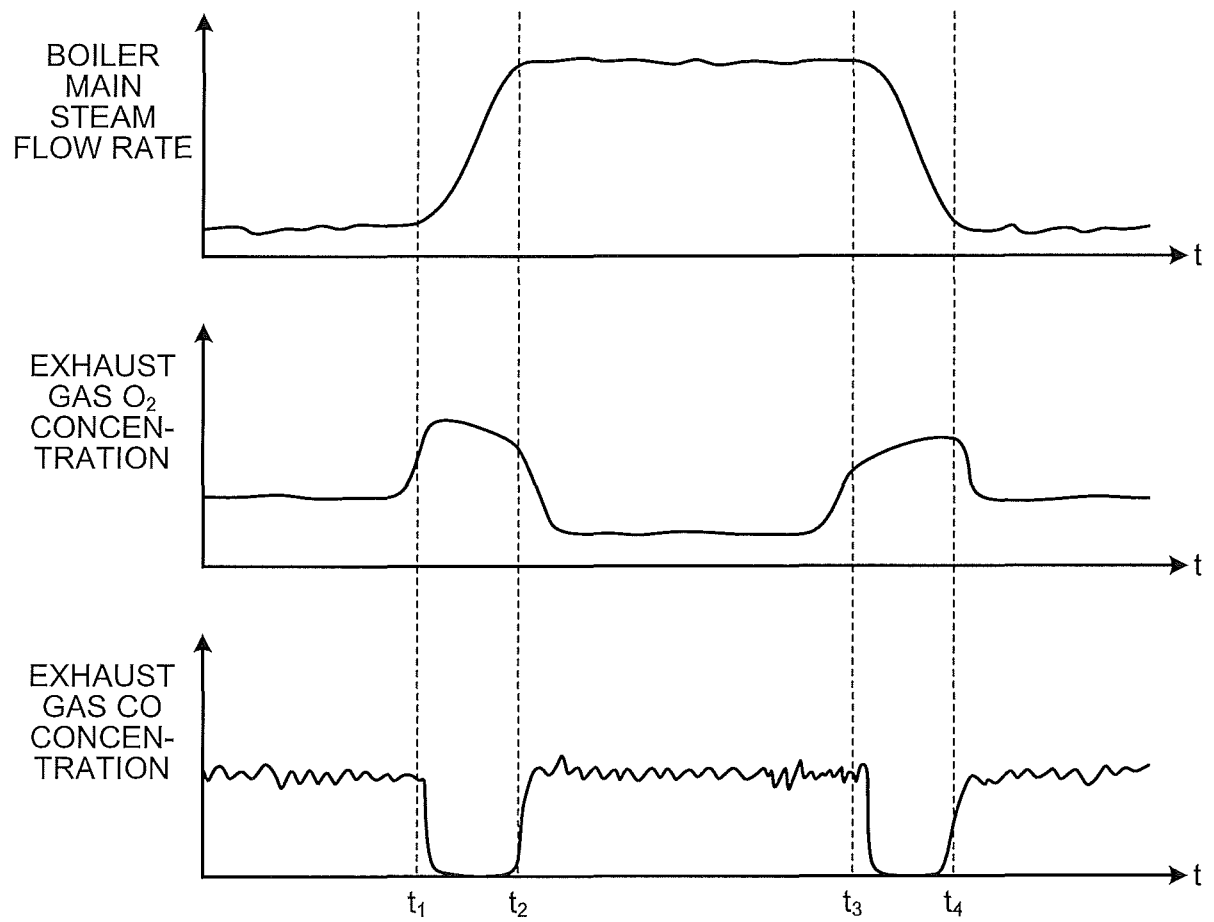


FIG.6

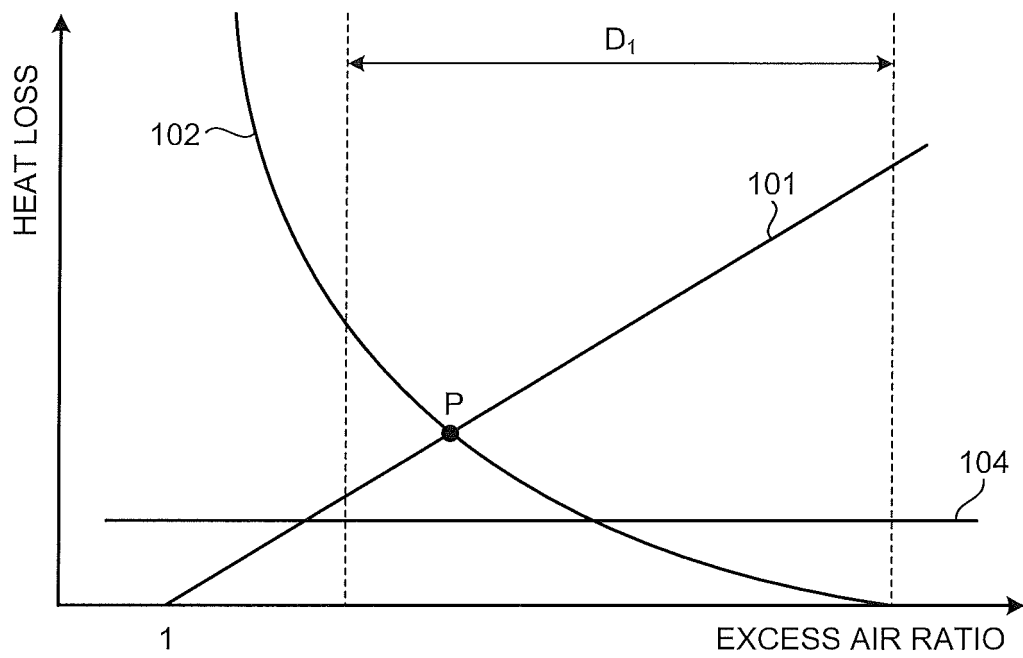


FIG.7

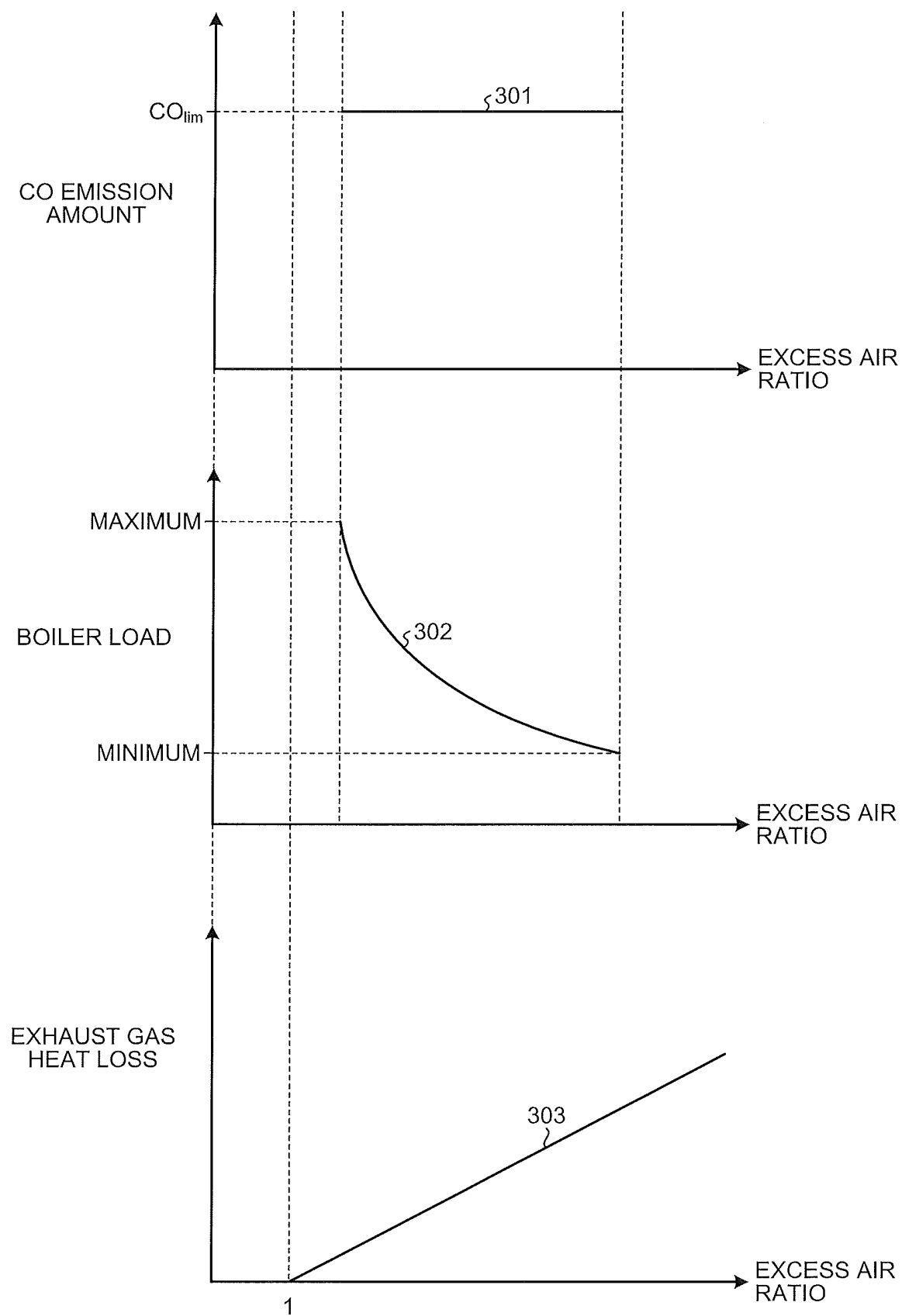
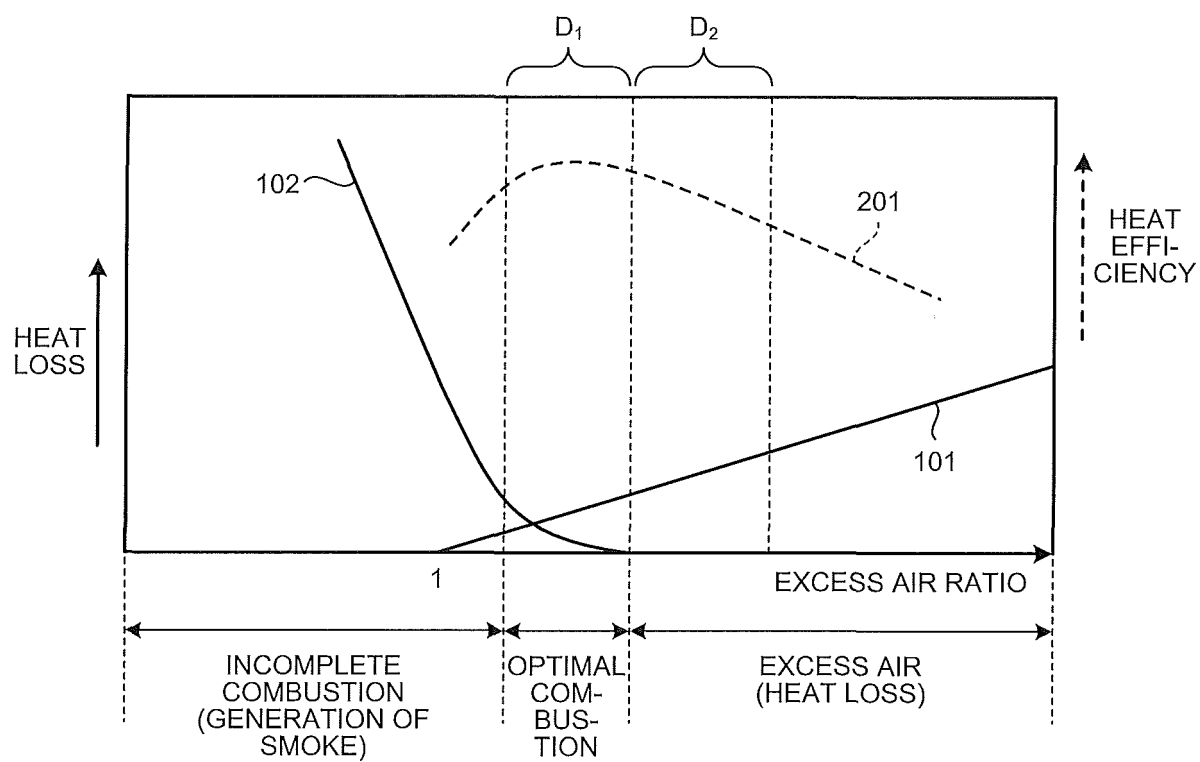


FIG.8



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/085575

A. CLASSIFICATION OF SUBJECT MATTER

F23N5/00(2006.01)i, F23N1/02(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F23N5/00, F23N1/02, F22B35/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2016
 Kokai Jitsuyo Shinan Koho 1971-2016 Toroku Jitsuyo Shinan Koho 1994-2016

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4531905 A (GENERAL SIGNAL CORP.),	1-2, 9-11
Y	30 July 1985 (30.07.1985),	7-8
A	column 2, line 59 to column 7, line 57; fig. 1 to 4B (Family: none)	3-6
Y	JP 59-208320 A (Toshiba Corp.), 26 November 1984 (26.11.1984), page 3, lower left column, line 8 to page 4, lower right column, line 11; fig. 1, 3 to 4 (Family: none)	7-8
A	JP 2011-99608 A (Mitsubishi Electric Corp.), 19 May 2011 (19.05.2011), entire text; all drawings (Family: none)	1-11

☒ Further documents are listed in the continuation of Box C.☐ See patent family annex.

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Date of the actual completion of the international search
02 March 2016 (02.03.16)Date of mailing of the international search report
15 March 2016 (15.03.16)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

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Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/085575

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 6-180116 A (Toshiba Corp.), 28 June 1994 (28.06.1994), entire text; all drawings (Family: none)	1-11
A	JP 62-166219 A (Yokogawa Electric Corp.), 22 July 1987 (22.07.1987), entire text; all drawings (Family: none)	1-11
A	JP 57-174620 A (Sumitomo Metal Industries, Ltd.), 27 October 1982 (27.10.1982), entire text; all drawings (Family: none)	1-11
A	US 3723047 A (CONTROLE BAILEY (S.A.)), 27 March 1973 (27.03.1973), entire text; all drawings & FR 2093025 A	1-11

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REFERENCES CITED IN THE DESCRIPTION

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