

DESCRIPTION

TITLE OF INVENTION: HYDROGEN COMBUSTION FURNACE, AND METHOD
FOR OPERATING HYDROGEN COMBUSTION FURNACE

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TECHNICAL FIELD

[0001]

The present invention relates to a hydrogen combustion furnace and an operating method for a hydrogen combustion furnace.

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BACKGROUND ART

[0002]

In order to realize the demand for carbon neutrality, there is growing interest in technological development for reducing CO₂ gas emissions. Industrial furnaces used in the manufacturing process of metals, glass, and the like emit large amounts of CO₂ gas, and reducing this amount is recognized as an important issue.

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[0003]

Oxyfuel combustion is known to be an effective means of reducing CO₂ gas and saving energy. Oxyfuel combustion is a combustion method that uses oxygen or oxygen-enriched air as an oxidant, and is widely used in industrial furnaces. Oxyfuel combustion reduces the amount of nitrogen in the oxidant, which does not contribute to combustion, resulting in benefits such as an increase in flame temperature and a reduction in exhaust gas heat loss. As a result, it is possible to reduce the amount of fuel used by improving thermal efficiency. In other words, the amount of hydrocarbon fuel used can be reduced, which greatly contributes to reducing CO₂ gas emissions.

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[0004]

In addition to conventional energy-saving technologies, the conversion of hydrocarbon fuels to hydrogen energy is expected. Patent Document 1 discloses a technology using a combustion burner (hydrogen burner) that uses hydrogen gas as fuel in an industrial combustion furnace.

PRIOR ART DOCUMENTS

PATENT LITERATURE

10 [0005]

Patent Document 1 Japanese Unexamined Patent Application, First Publication No. 2020-094740

SUMMARY OF INVENTION

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PROBLEM TO BE SOLVED BY THE INVENTION

[0006]

In furnace combustion using a combustion burner and a combustion furnace, the input energy is classified into the amount of heat effectively used in the furnace and the amount of heat lost by being discharged to the outside of the system as exhaust gas. For example, when the oxygen ratio is 1.05 and the exhaust gas temperature is 1300°C, it is known that the higher the oxygen concentration in the oxidizer, the smaller the proportion of exhaust gas heat loss (i.e., the higher the proportion of heat effectively used in the furnace, which means higher heating efficiency) in both cases of using a hydrocarbon fuel (e.g., methane) and using hydrogen as fuel. The higher the heating

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efficiency, the smaller the amount of heat required to heat and maintain the furnace to a specified temperature. Therefore, by applying oxygen combustion to a hydrogen burner that uses hydrogen as fuel, it is expected to reduce fuel costs.

[0007]

5 However, it is generally believed that hydrogen combustion has a higher flame temperature than hydrocarbon fuel combustion, which leads to increased NO_x emissions, mainly thermal NO_x. Similarly, oxygen combustion is known to increase NO_x emissions, especially in oxygen-rich conditions, due to the high flame temperature. Therefore, there is concern that the combination of hydrogen combustion and oxygen
10 combustion will further increase NO_x emissions.

[0008]

 The present invention has been made in view of the above circumstances, and an object of the present invention is to provide a hydrogen combustion furnace that is capable of reducing NO_x emissions, and an operation method for a hydrogen combustion
15 furnace.

MEANS FOR SOLVING THE PROBLEM

[0009]

 In order to solve the above problems, the present invention has the following
20 configurations.

[1] A hydrogen combustion furnace, including:

 a combustion furnace main body having a burner;

 a first path which supplies hydrogen into the burner;

 a second path which supplies a combustion-supporting gas containing oxygen

25 into the burner;

a third path which leads out an exhaust gas from the combustion furnace main body;

a first control device which is located on the first path and adjusts an amount of hydrogen supplied;

5 a second control device which is located on the second path and adjusts an amount of the combustion-supporting gas supplied;

a gas analyzer which is located on the third path and analyzes components in the exhaust gas; and

a control device which transmits and receives electric signals between the first
10 control device, the second control device, and the gas analyzer,

wherein the control device controls the first control device and the second control device based on an analysis value obtained by the gas analyzer so that the hydrogen in the combustion furnace main body is incompletely combusted.

[2] The hydrogen combustion furnace according to [1],

15 wherein the hydrogen combustion furnace further includes a moisture removal device which is located on the third path and removes moisture from the exhaust gas.

[3] The hydrogen combustion furnace according to [1] or [2],

wherein the moisture removal device is located on the primary side of the gas analyzer.

20 [4] The hydrogen combustion furnace according to any one of [1] to [3],

wherein the hydrogen combustion furnace further includes a combustion device which is connected to the third path and uses the exhaust gas as at least a part of fuel.

[5] The hydrogen combustion furnace according to any one of [1] to [4],

wherein the combustion device is a heat exchanger provided across one or both of
25 the first path and the second path.

[6] The hydrogen combustion furnace according to any one of [1] to [5], wherein the combustion furnace main body is a heating furnace that heats an object to be heated accommodated in an inner space.

[7] An operation method for a hydrogen combustion furnace, including a combustion furnace body having a burner which combusts hydrogen and a combustion-supporting gas containing oxygen, wherein the hydrogen is incompletely combusted in the combustion furnace body.

[8] The operation method for a hydrogen combustion furnace according to [7], wherein hydrogen is incompletely combusted in the combustion furnace body with an oxygen ratio of 0.98 or less.

[9] The operation method for a hydrogen combustion furnace according to [7] or [8], wherein the combustion-supporting gas having an oxygen concentration of 90% by volume or more is used.

EFFECTS OF THE INVENTION

[0010]

According to the hydrogen combustion furnace and the operation method for a hydrogen combustion furnace of the present invention, it is possible to reduce NO_x emissions.

BRIEF DESCRIPTION OF DRAWINGS

[0011]

[FIG. 1] FIG. 1 is a system diagram showing the configuration of a

hydrogen combustion furnace of one embodiment according to the present invention.

[FIG. 2] FIG. 2 is a system diagram showing the configuration of a hydrogen combustion furnace of another embodiment according to the present invention.

[FIG. 3] FIG. 3 is a diagram showing the results of a verification test of the present invention.

[FIG. 4] FIG. 4 is a diagram showing the results of a verification test of the present invention.

[FIG. 5] FIG. 5 is a diagram showing the results of a verification test of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012]

Hereinafter, a hydrogen combustion furnace and an operation method for a hydrogen combustion furnace, which are one embodiment according to the present invention, will be described in detail with reference to the figures. Note that the figures used in the following description may show characteristic parts in an enlarged scale for the sake of convenience in order to make the characteristics easier to understand, and the dimensional ratios of each component may not necessarily be the same in reality.

[0013]

The meanings and definitions of the terms used in the present description are as follows.

"Heating efficiency" is the ratio of energy used to heat the furnace with respect to the energy input. The energy used to heat the furnace is calculated by calculating the amount of heat carried away by the exhaust gas (exhaust gas heat loss) and subtracting the exhaust gas loss from the energy input.

"Oxygen ratio" refers to the ratio of the amount of oxygen contained in the combustion-supporting gas with respect to the amount of oxygen required for complete combustion of fuel.

A numerical range expressed as "~" means a numerical range with the numbers before and after ~ as the lower and upper limits.

[0014]

<Hydrogen combustion furnace>

First, the configuration of a hydrogen combustion furnace, which is an embodiment according to the present invention, will be described. FIG. 1 is a system diagram showing the configuration of a hydrogen combustion furnace of the present embodiment. Note that the solid arrows in FIG. 1 indicate the direction of gas flow, and the dotted arrows indicate the direction of transmission of electrical signals.

As shown in FIG. 1, a hydrogen combustion furnace 1 of the present embodiment is configured to include a combustion furnace body 2, a burner 3, a moisture removal device 4, a gas analyzer 5, a control device 6, a flow rate control valve (first control device) 7, a flow rate control valve (second control device) 8, a combustor (combustion device) 9, and paths L1 to L6.

[0015]

In the hydrogen combustion furnace 1 of the present embodiment, when hydrogen as fuel and oxygen contained in a combustion-supporting gas are supplied into the burner 3 and combusted in the combustion furnace main body 2 (in-furnace combustion), hydrogen is combusted at a low oxygen ratio (i.e., incomplete combustion), thereby reducing NOx emissions.

[0016]

The combustion furnace body 2 is not particularly limited as long as it has a space

inside and can combust the flame of the burner 3 inside the furnace. As the combustion furnace body 2, a heating furnace that heats a heated object (not shown) contained in the inner space can be used. As a specific configuration, a conventionally known configuration (for example, a configuration described in patent documents such as

5 Japanese Unexamined Patent Application, First Publication No. 2020-148426 and Japanese Unexamined Patent Application, First Publication No. 2021-042102) can be used.

[0017]

When the hydrogen combustion furnace 1 of the present embodiment is used as a

10 heating furnace, examples of the objects to be heated include steel, molten metal, and glass. Since the hydrogen combustion furnace 1 of the present embodiment uses hydrogen gas as fuel, the main components of the exhaust gas during incomplete combustion are H_2 , H_2O , and N_2 , and carbon monoxide (CO), carbon dioxide (CO_2), and soot that are generated when a hydrocarbon fuel is used are not emitted. Therefore, this

15 is preferable because there is no risk of adversely affecting the quality of the objects to be heated.

[0018]

The burner 3 is connected to the combustion furnace main body 2 so that the flame nozzle communicates with the space inside the combustion furnace main body 2.

20 The burner 3 is not particularly limited as long as it causes hydrogen, which is fuel, and oxygen contained in the combustion-supporting gas to combust (in-furnace combustion) in the combustion furnace main body 2. As a specific configuration, a conventionally known configuration (for example, a configuration described in patent documents such as Japanese Unexamined Patent Application, First Publication No. Hei 09-243028, Japanese

25 Unexamined Patent Application, First Publication No. 2013-079753, and Japanese

Unexamined Patent Application, First Publication No. 2021-124212) can be used.

[0019]

The path (first path) L1 is located between a hydrogen gas supply source (not shown) and the burner 3. The path L1 is a gas supply line that supplies hydrogen gas (H₂) as fuel from the hydrogen gas supply source into the burner 3. The flow rate control valve (first control device) 7 is provided on the path L1.

[0020]

The path (second path) L2 is located between a combustion-supporting gas supply source (not shown) and the burner 3. The path L2 is a gas supply line that supplies the combustion-supporting gas from the combustion-supporting gas supply source into the burner 3. The flow rate control valve (second control device) 8 is provided on the path L2.

[0021]

The flow rate control valves 7 and 8 are control devices that adjust the supply amount of gas flowing through the gas supply line by a control signal from the control device 6 or manually. Examples of the flow rate control valves 7 and 8 include a control valve, a mass flow controller, and a manual needle valve.

[0022]

The combustion-supporting gas is a gas (oxidizer) containing oxygen, and oxygen gas (O₂), oxygen-enriched air obtained by enriching air with oxygen, or air can be used.

The oxygen concentration in the combustion-supporting gas (oxidizer) is preferably 21% by volume or more, more preferably 40% by volume or more, and even more preferably 90% by volume or more. The higher the oxygen concentration in the combustion-supporting gas, the lower the nitrogen concentration in the combustion-supporting gas, so that NO_x emissions can be reduced when incomplete combustion is performed in the

hydrogen combustion furnace 1. In addition, when the oxygen concentration in the combustion-supporting gas is 90% by volume or more, the hydrogen concentration in the exhaust gas increases, so that unreacted hydrogen gas contained in the exhaust gas can be effectively used as fuel.

5 [0023]

The path (third path) L3 is located between the combustion furnace main body 2 and the combustor 9. The path L3 is a gas supply line that supplies hydrogen gas in the exhaust gas discharged from the combustion furnace main body 2 into the combustor 9 as a part of fuel. The moisture removal device 4 and the gas analyzer 5 are provided in

10 this order from the primary side on the path L3.

[0024]

The moisture removal device 4 is located on the primary side of the gas analyzer 5 on the path L3. The moisture removal device 4 removes moisture (H_2O) from the exhaust gas flowing through the path L3. The moisture removal device 4 is also

15 connected to the path L4, and discharges the moisture removed from the exhaust gas to the outside of the system. The moisture removal device 4 is not particularly limited as long as it can remove moisture from a mixed gas. Examples of the moisture removal device 4 include a mist separator, a water wash bubbler, and a chiller.

[0025]

20 The gas analyzer 5 is located on the secondary side of the moisture removal device 4 on the path L3. The gas analyzer 5 is a device having an analyzer that analyzes components in the exhaust gas that is led out from the combustion furnace main body 2 to the path L3 and from which moisture has been removed by the moisture removal device 4. The gas analyzer 5 has one or more analyzers that can confirm that the
25 combustion furnace main body 2 is incompletely combusted. That is, the gas analyzer 5

has at least one of a hydrogen analyzer for confirming whether or not hydrogen is contained in the exhaust gas and an oxygen analyzer for confirming whether or not oxygen is contained in the exhaust gas. The gas analyzer 5 may also have one or more analyzers that can detect nitrogen, NO_x, and moisture among the components in the exhaust gas led out into the path L3.

[0026]

The combustor 9 is a combustion device that uses unreacted hydrogen gas contained in the exhaust gas discharged from the combustion furnace main body 2 as at least a part of fuel. The combustor 9 is not particularly limited as long as it can use the hydrogen gas contained in the exhaust gas as fuel. Examples of the combustor 9 include a boiler and other combustion furnaces. In addition, it is more preferable that the combustor 9 not increase the amount of NO_x contained in the exhaust gas discharged from the combustion furnace main body 2.

[0027]

The paths L3, L5, and L6 are connected to the combustor 9. The path L5 is a gas supply line that supplies fuel and combustion-supporting gas into the combustor 9. The path L6 is a gas discharge line that discharges the exhaust gas led out from the combustor 9 to the outside of the system.

[0028]

The control device 6 transmits and receives electric signals by wire or wirelessly between the flow rate control valve (first control device) 7, the flow rate control valve (second control device) 8, and the gas analyzer 5. The control device 6 has a function of controlling the flow rate control valves 7 and 8 based on the gas analysis values obtained from the gas analyzer 5 so that hydrogen in the combustion furnace main body 2 is incompletely combusted.

[0029]

The control device 6 is not particularly limited as long as it has the above-mentioned functions. The control device 6 may be configured to include a central processing unit (CPU), a memory, and a hard disk drive. The control device 6 may be provided independently of (as a separate entity from) the flow rate control valve 7, the flow rate control valve 8, and the gas analyzer 5, or may be provided as an attachment to any of the flow rate control valve 7, the flow rate control valve 8, and the gas analyzer 5.

[0030]

<Operation method for hydrogen combustion furnace>

Next, an operation method for a hydrogen combustion furnace, which is one embodiment of the presented invention, will be explained.

The operation method for a hydrogen combustion furnace of the present embodiment is a method for operating the hydrogen combustion furnace 1 including the combustion furnace main body 2 having the burner 3 that combusts hydrogen and the combustion-supporting gas containing oxygen.

Below, as an example of an operation method for a hydrogen combustion furnace according to one embodiment of the present invention, a specific description will be given of the above-mentioned hydrogen combustion furnace 1 using oxygen-enriched air as the combustion-supporting gas.

[0031]

First, in the hydrogen combustion furnace 1 shown in FIG. 1, hydrogen gas (H_2) is supplied from the path L1, and oxygen-enriched air (N_2 , O_2) is supplied from the path L2 as a combustion-supporting gas into the burner 3, and they are combusted in the furnace in the combustion furnace main body 2. In the present embodiment, hydrogen is incompletely combusted in the combustion furnace main body 2.

From the combustion furnace main body 2, a mixed gas containing unreacted hydrogen gas (H_2), nitrogen gas (N_2), water (H_2O), and NO_x is discharged as exhaust gas into the path L3.

[0032]

5 Next, water is removed from the exhaust gas discharged into the path L3 in the moisture removing device 4. Thereby, a mixed gas containing hydrogen gas (H_2), nitrogen gas (N_2), and NO_x flows through the path L3 on the secondary side of the moisture removing device 4.

[0033]

10 Then, the gas components in the mixed gas flowing through the path L3 are analyzed by the gas analyzer 5. Specifically, the gas analyzer 5 confirms that hydrogen is incompletely combusted in the combustion furnace main body 2, that is, that hydrogen gas is contained in the mixed gas, and that oxygen gas is not contained in the mixed gas.

[0034]

15 The analysis results from the gas analyzer 5 are transmitted to the control device 6 through electric signals. If hydrogen gas is not contained in the mixed gas, the control device 6 transmits a control signal to the flow rate control valve (first control device) 7 to increase the opening degree. This increases the amount of hydrogen gas supplied into the burner 3 through the path L1.

20 [0035]

On the other hand, when oxygen gas is contained in the mixed gas, the control device 6 transmits a control signal to the flow rate control valve (second control device) 8 to reduce the opening degree. As a result, the combustion-supporting gas supplied into the burner 3 through the path L2 is reduced.

25 [0036]

In the operation method for a hydrogen combustion furnace of the present embodiment, the control device 6 controls the oxygen ratio in the combustion furnace main body 2 to be less than 1. By setting the upper limit of the oxygen ratio to less than 1, an incomplete combustion state is obtained, and the amount of NO_x in the exhaust gas can be suppressed. The upper limit of the oxygen ratio is preferably 0.98 or less, and more preferably 0.97 or less. By setting the oxygen ratio to 0.98 or less, a further reduction in NO_x emissions can be obtained. The lower limit of the oxygen ratio is preferably 0.90 or more, and more preferably 0.95 or more. By setting the oxygen ratio to 0.90 or more, NO_x emissions can be effectively reduced while suppressing a decrease in heating efficiency.

[0037]

Next, after the gas components are analyzed by the gas analyzer 5, the mixed gas flowing through the path L3 is introduced into the combustor 9.

In the combustor 9, hydrogen contained in the mixed gas is used as part of fuel due to incomplete combustion in the combustion furnace main body 2. As a result, according to the operation method for the hydrogen combustion furnace 1 of the present embodiment, it is possible to suppress a decrease in the heating efficiency of the entire hydrogen combustion furnace 1 including the combustor 9.

[0038]

When combusting in the combustor 9 by supplying normal fuel and the combustion-supporting gas through the path L5, if a small amount of hydrogen is supplied and mixed with the existing fuel, the combustion conditions do not change significantly. Therefore, the mixed gas containing a small amount of NO_x is discharged through the path L6.

According to the operating method for the hydrogen combustion furnace 1 of the

present embodiment, the exhaust gas led out from the combustion furnace main body 2 can be reused without increasing NOx emissions.

[0039]

As described above, according to the hydrogen combustion furnace 1 and the operation method thereof of the present embodiment, when hydrogen gas is used as fuel for the burner 3 and in-furnace combustion is performed in the combustion furnace main body 2, hydrogen is combusted at a low oxygen ratio (i.e., incomplete combustion), so that it is possible to reduce the amount of NOx in the exhaust gas discharged from the combustion furnace main body 2.

10 [0040]

Moreover, according to the hydrogen combustion furnace 1 and the operation method thereof of the present embodiment, hydrogen contained in the mixed gas which is generated due to incomplete combustion of the hydrogen gas in the combustion furnace main body 2 is used as part of the fuel for the combustor 9, so that a decrease in heating efficiency of the entire hydrogen combustion furnace 1 including the combustor 9 can be suppressed.

[0041]

The technical scope of the present invention is not limited to the above-described embodiments, and various modifications can be made without departing from the spirit of the present invention. According to the above-described hydrogen combustion furnace 1 and the operating method thereof, the configuration in which the combustor 9 is used as the combustion device has been described as an example, but the present invention is not limited to this embodiment. For example, the present invention may be configured to use a heat exchanger 29 (see the following embodiment) instead of the combustor 9 as the combustion device.

[0042]

FIG. 2 is a system diagram showing the configuration of a hydrogen combustion furnace of another embodiment according to the present invention.

As shown in FIG. 2, a hydrogen combustion furnace 21 of the present
5 embodiment differs in the hydrogen combustion furnace 1 above in that it uses the heat exchanger 29 instead of the combustor 9 as the combustion device, and uses paths L25 and L26 instead of paths L5 and L6. Therefore, in the hydrogen combustion furnace 21, the same components as those of the hydrogen combustion furnace 1 are denoted by the same reference numerals, and their description will be omitted.

10 [0043]

The heat exchanger (combustion device) 29 is provided across the path L1 and the path L2, and uses unreacted hydrogen gas contained in the exhaust gas discharged from the combustion furnace main body 2 as at least a part of the fuel.

[0044]

15 The paths L3, L25, and L26 are connected to the heat exchanger 29. The path L25 is a gas supply line that supplies a combustion-supporting gas (oxygen gas (O_2) is exemplified in the figure) into the heat exchanger 29. The path L26 is a gas discharge line that discharges the exhaust gas led out from the heat exchanger 29 to the outside of the system.

20 [0045]

In addition, in the operating method for the hydrogen combustion furnace 21, after the gas components are analyzed by the gas analyzer 5, the mixed gas flowing through path L3 is introduced into the heat exchanger 29.

The heat exchanger 29 uses hydrogen contained in the mixed gas which is
25 generated due to incomplete combustion in the combustion furnace main body 2 as fuel.

As a result, the hydrogen gas flowing through the path L1 and the combustion-supporting gas flowing through the path L2 can be heated (preheated) by heat generated by combusting the hydrogen gas by the heat exchanger 29.

[0046]

5 As described above, the hydrogen combustion furnace 21 and the operating method thereof make it possible to recover heat in proportion to the efficiency of the heat exchanger 29. By controlling the temperature of the heat exchanger 29 to be, for example, 1000°C or lower, it is possible to improve the heating efficiency of the entire hydrogen combustion furnace 21 including the heat exchanger 29 without increasing the
10 amount of NO_x in the exhaust gas.

[0047]

In the above-described hydrogen combustion furnace 21, the heat exchanger 29 is provided across the path L1 and the path L2 as an example, but is not limited thereto. The heat exchanger 29 may be provided across at least one of the path L1 and the path
15 L2.

EXAMPLES

[0048]

The effects of the present invention will be described below with reference to
20 verification tests. Note that the present invention is not limited to the contents of the following verification tests.

[0049]

<Verification Test 1>

In verification test 1, the hydrogen combustion furnace 1 shown in FIG. 1 was
25 used to verify the relationship between the oxygen ratio and NO_x emission concentration

when hydrogen gas was used as fuel for the burner 3, that is, during hydrogen combustion.

[Simulation conditions]

(1) Simulation software (calculation software): Chemikin Pro: manufactured by

5 Ansys

(2) Fuel gas: Hydrogen

(3) Combustion-supporting gas: Oxygen or oxygen-enriched air

(4) Reaction model: GRI Mech 3.0 http://www.me.berkeley.edu/gri_mech

[0050]

10 FIG. 3 shows the relationship between the oxygen ratio and the NO_x emission concentration during hydrogen combustion. FIG.3 (A) shows the case where the oxygen concentration in the combustion-supporting gas was 90% by volume, FIG. 3(B) shows the case where the oxygen concentration in the combustion-supporting gas was 40% by volume, and FIG. 3 (C) shows the case where the oxygen concentration in the
15 combustion-supporting gas was 21% by volume.

In FIGS. 3(A) to 3(C), the horizontal axis shows the oxygen ratio (Oxygen ratio [-]) and the vertical axis shows the NO_x emission concentration (NO_x [ppm-wet]). In FIGS. 3(A) to 3(C), the furnace temperatures in the combustion furnace main body 2 were 1300°C, 1400°C, 1500°C, and 1600°C.

20 The NO_x emission concentration is the NO_x concentration in the exhaust gas containing water vapor (H₂O) led out from the combustion furnace main body 2.

[0051]

As shown in FIGS. 3(A) to 3(C), when the oxygen ratio on the horizontal axis was less than 1, the state was incomplete combustion. During incomplete combustion,
25 the NO_x emission concentration dramatically decreased and approached zero.

[0052]

Therefore, from the viewpoint of reducing the concentration of NO_x emissions, it was confirmed that, regardless of the oxygen concentration in the combustion-supporting gas, the upper limit of the oxygen ratio is preferably 0.98 or less, and more preferably 0.97 or less.

[0053]

<Verification Test 2>

In verification test 2, the hydrogen combustion furnace 1 shown in FIG. 1 was used to verify the relationship between the oxygen ratio and the heating efficiency during hydrogen combustion using hydrogen gas as fuel for the burner 3.

[0054]

FIG. 4 shows the relationship between the oxygen ratio and the heating efficiency during hydrogen combustion. FIG. 4(A) shows the case where the oxygen concentration in the combustion-supporting gas was 90% by volume, FIG. 4(B) shows the case where the oxygen concentration in the combustion-supporting gas was 40% by volume, and FIG. (C) shows the case where the oxygen concentration in the combustion-supporting gas was 21% by volume.

In FIGS. 4(A) to 4(C), the horizontal axis shows the oxygen ratio (Oxygen ratio [-]) and the vertical axis shows the heating efficiency (Heat Efficiency [%]). In FIGS. 4(A) to 4(C), the furnace temperatures in the combustion furnace main body 2 were confirmed to be 1300°C, 1400°C, 1500°C, and 1600°C.

Note that the "heating efficiency" is the ratio of the energy used for heating the furnace with respect to the energy input. The energy used for heating the furnace is calculated by calculating the amount of heat carried away by the exhaust gas outside the furnace (exhaust gas heat loss) and subtracting the exhaust gas loss from the energy

input.

[0055]

As shown in FIGS 4 (A) to 4(C), it was confirmed that, regardless of the oxygen concentration in the combustion-supporting gas, the heating efficiency was maximized when the oxygen ratio was 1, and that the heating efficiency decreased as the difference from 1 increased.

Normally, burner combustion is operated so that the oxygen ratio is 1 or above to prevent incomplete combustion, and excess oxygen is supplied to the burner. However, when the oxygen ratio was significantly lowered to cause incomplete combustion, it was confirmed that the heating efficiency was clearly lower than in the case where the oxygen ratio was 1 or above.

[0056]

Therefore, from the viewpoint of maintaining heating efficiency, it was confirmed that it is preferable to set the lower limit of the oxygen ratio to 0.95 or more, regardless of the oxygen concentration in the combustion-supporting gas.

[0057]

<Verification Test 3>

In verification test 3, the hydrogen combustion furnace 1 shown in FIG. 1 was used to verify the relationship between the oxygen ratio and the hydrogen concentration in the exhaust gas during hydrogen combustion using hydrogen gas as fuel for the burner 3.

[0058]

FIG. 5 shows the relationship between the oxygen ratio and the hydrogen concentration in the exhaust gas during hydrogen combustion. FIG. 5(A) shows the case where the oxygen concentration in the combustion-supporting gas was 90% by

volume, FIG. 5(B) shows the case where the oxygen concentration in the combustion-supporting gas was 40% by volume, and FIG. 5(C) shows the case where the oxygen concentration in the combustion-supporting gas was 21% by volume.

In FIGS. 5 (A) to 5(C), the horizontal axis shows the oxygen ratio (Oxygen ratio [-]) and the vertical axis shows the hydrogen concentration (H_2 [vol% dry]). In FIGS. 5 (A) to 5(C), the furnace temperatures in the combustion furnace main body 2 were 1300°C, 1400°C, 1500°C, and 1600°C.

The hydrogen concentration is the hydrogen concentration in the dry gas obtained by removing the water vapor (H_2O) led out from the combustion furnace main body 2 by the moisture remover 4.

[0059]

As shown in FIGS 5(A) to 5(C), it was confirmed that the oxygen ratio on the horizontal axis was less than 1, and the smaller the oxygen ratio value, the more hydrogen was discharged uncombusted, and therefore the hydrogen concentration in the exhaust gas also increased.

[0060]

Therefore, from the viewpoint of reusing hydrogen in exhaust gas, regardless of the oxygen concentration in the combustion-supporting gas, the smaller the oxygen ratio, the higher the hydrogen concentration in the exhaust gas and the easier it is to combust, suggesting that it may be possible to reuse it as fuel in other combustion devices.

[0061]

As shown in FIGS. 5(A) to 5(C), it was confirmed that when the oxygen ratio was less than 1 and the oxygen concentration in the combustion-supporting gas was higher, the amount of uncombusted hydrogen discharged increased, and therefore the hydrogen concentration in the exhaust gas also increased.

[0062]

Therefore, from the viewpoint of reusing hydrogen in exhaust gas, the higher the oxygen concentration in the combustion-supporting gas, the higher the hydrogen concentration in the exhaust gas when the oxygen ratio is less than 1, making it easier to combust, and it was suggested that the hydrogen could be reused as fuel in other combustion devices.

EXPLANATION OF REFERENCE NUMERAL

[0063]

- | | | |
|----|-------|---|
| 10 | 1, 21 | Hydrogen combustion furnace |
| | 2 | Combustion furnace body |
| | 3 | Burner |
| | 4 | Moisture removal device |
| | 5 | Gas analyzer |
| 15 | 6 | Control device |
| | 7 | Flow rate control valve (first control device) |
| | 8 | Flow rate control valve (second control device) |
| | 9 | Combustor (combustion device) |
| | 29 | Heat exchanger (combustion device) |
| 20 | L1 | Path (first path) |
| | L2 | Path (second path) |
| | L3 | Path (third path) |

CLAIMS

[Claim 1] A hydrogen combustion furnace comprising:

a combustion furnace main body having a burner;

a first path which supplies hydrogen into the burner;

5 a second path which supplies a combustion-supporting gas containing oxygen into the burner;

a third path which leads out an exhaust gas from the combustion furnace main body;

a first control device which is located on the first path and adjusts an amount of
10 hydrogen supplied;

a second control device which is located on the second path and adjusts an amount of the combustion-supporting gas supplied;

a gas analyzer which is located on the third path and analyzes components in the exhaust gas; and

15 a control device which transmits and receives electric signals between the first control device, the second control device, and the gas analyzer,

wherein the control device controls the first control device and the second control device based on an analysis value obtained by the gas analyzer so that the hydrogen in the combustion furnace main body is incompletely combusted.

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[Claim 2] The hydrogen combustion furnace according to Claim 1,

wherein the hydrogen combustion furnace further comprises a moisture removal device which is located on the third path and removes moisture from the exhaust gas.

25 [Claim 3] The hydrogen combustion furnace according to Claim 2,

wherein the moisture removal device is located on the primary side of the gas analyzer.

[Claim 4] The hydrogen combustion furnace according to Claim 1,

5 wherein the hydrogen combustion furnace further comprises a combustion device which is connected to the third path and uses the exhaust gas as at least a part of fuel.

[Claim 5] The hydrogen combustion furnace according to Claim 4,

10 wherein the combustion device is a heat exchanger provided across one or both of the first path and the second path.

[Claim 6] The hydrogen combustion furnace according to any one of Claims 1 to 5,

wherein the combustion furnace main body is a heating furnace that heats a heated object accommodated in an inner space.

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[Claim 7] An operation method for a hydrogen combustion furnace, comprising a combustion furnace body having a burner which combusts hydrogen and a combustion-supporting gas containing oxygen,

wherein the hydrogen is incompletely combusted in the combustion furnace body.

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[Claim 8] The operation method for a hydrogen combustion furnace according to Claim 7,

wherein hydrogen is incompletely combusted in the combustion furnace body with an oxygen ratio of 0.98 or less.

25

[Claim 9] The operation method for a hydrogen combustion furnace according to Claim 7 or 8,

wherein the combustion-supporting gas having an oxygen concentration of 90% by volume or more is used.