

DESCRIPTION

Title of Invention

COMBUSTION DEVICE, COMBUSTION METHOD, AND COMBUSTION  
PROGRAM

Technical Field

[0001]

The present invention relates to a combustion device and the like.

Background Art

[0002]

A bubbling fluidized bed (BFB) boiler or a circulating fluidized bed (CFB) boiler that combusts a fuel with a fluidized bed or a fluidized layer formed by a fluid material such as silica sand flowing in a combustion chamber as a medium is known as a boiler that generates steam from water with heat generated by the combustion of the fuel. PTL 1 discloses a CFB boiler.

Citation List

Patent Literature

[0003]

[PTL 1] Japanese Unexamined Patent Publication No.

2012-255612

## Summary of Invention

### Technical Problem

[0004]

As disclosed in PTL 1, in order to suppress agglomeration in a CFB boiler, additives such as calcium carbonate and dolomite have been supplied to the combustion chamber. However, the mechanism and conditions under which agglomeration occurs in the CFB boiler have not been fully elucidated, and it has been difficult to appropriately determine the supply timing, the supply amount, the supply manner, and the like of additives.

[0005]

The present invention has been made in view of the above circumstances, and an object of the present invention is to provide a combustion device and the like that can effectively suppress the occurrence of agglomeration.

### Solution to Problem

[0006]

In order to solve the above problem, according to an aspect of the present invention, there is provided a combustion device that supplies a fuel into a combustion chamber in which a fluid material containing silica flows

and that combusts the fuel, the combustion device including: a fuel supply unit that supplies the fuel to which an alkaline earth metal and/or an earth metal has been added into the combustion chamber such that a ratio of the alkaline earth metal and/or the earth metal to an alkali metal in the combustion chamber exceeds a predetermined lower limit.

[0007]

As will be described later, as a result of tests in an actual CFB boiler, it was found that the occurrence of agglomeration may be related to a ratio (hereinafter also referred to as a metal ratio) of alkaline earth metals (magnesium, calcium, and the like) and/or earth metals (aluminum and the like) to alkali metals (sodium, potassium, and the like) in the combustion chamber. In the present aspect, therefore, the occurrence of agglomeration is effectively suppressed by supplying alkaline earth metals and/or earth metals such that the metal ratio in the combustion chamber exceeds a predetermined lower limit.

[0008]

According to another aspect of the present invention, there is provided a combustion method. The method is executed in a combustion device that supplies a fuel into a combustion chamber in which a fluid material containing silica flows and that combusts the fuel, and includes: a

fuel supply step of supplying the fuel to which an alkaline earth metal and/or an earth metal has been added into the combustion chamber such that a ratio of the alkaline earth metal and/or the earth metal to an alkali metal in the combustion chamber exceeds a predetermined lower limit.

[0009]

Any combination of the above components, or any expression of these components converted into methods, devices, systems, recording media, computer programs, or the like, are also included in the present invention.

#### Advantageous Effects of Invention

[0010]

According to the present invention, the occurrence of agglomeration can be effectively suppressed.

#### Brief Description of Drawings

[0011]

Fig. 1 schematically illustrates a CFB boiler.

Fig. 2 is a state diagram of a eutectic system consisting of three types of components including silica derived from a fluid material, an alkali metal oxide ( $K_2O$ ) derived from a highly alkaline fuel, and an alkaline earth metal oxide ( $CaO$ ).

Fig. 3 illustrates results of tests carried out in an actual CFB boiler to set a lower limit of a metal ratio.

#### Description of Embodiments

[0012]

Hereinafter, a mode for carrying out the present invention (hereinafter also referred to as an embodiment) will be described in detail with reference to the drawings. In the description and/or the drawings, identical or equivalent components, members, processing, and the like are denoted by the same reference numerals, and overlapping description thereof will be omitted. The scales or shapes of each part shown in the drawings are conveniently set to simplify the description, and should not be interpreted as being limited unless otherwise stated. The embodiment is exemplary and does not limit the scope of the present invention. All features or combinations thereof described in the embodiments are not necessarily essential to the present invention.

[0013]

Fig. 1 schematically illustrates a circulating fluidized bed (CFB) boiler as a combustion device according to the present embodiment. Instead of the CFB boiler, any other combustion device such as a bubbling fluidized bed (BFB) boiler or a rotary kiln may be used.

[0014]

The CFB boiler includes a combustion section 1 in which a fuel such as a biomass fuel or a fossil fuel such as coal is supplied into and combusted in a furnace 11 in which a fluid material such as silica sand flows, a steam generation section 2 that generates steam from water by heat generated in the combustion section 1, a fluid material circulation section 3 as a circulation section that collects a fluid material flowing out of the furnace 11 and returns the fluid material into the furnace 11, a heat transfer section 4 that heats the water which is supplied to the steam generation section 2 or the steam which is generated in the steam generation section 2 with a high-temperature exhaust gas of the combustion section 1, an exhaust treatment device 5 that separates and collects soot or dust in the exhaust gas from the heat transfer section 4, and a chimney 6 that releases the exhaust gas purified by the exhaust treatment device 5 into the atmosphere. Also, the CFB boiler includes an agglomeration suppression device 8 that suppresses agglomeration in the furnace 11.

[0015]

The combustion section 1 includes the furnace 11 as a combustion chamber. The furnace 11 has a long tubular shape in a vertical direction, and a bottom portion thereof has a

tapered shape to increase the density of a solid fuel such as a biomass fuel or coal or a fluid material and to enable efficient combustion. The bottom portion of the furnace 11 does not need to have a tapered shape, and the furnace 11 may be formed in a tubular shape to have a substantially constant cross-sectional shape from a top portion to the bottom portion. A region, which is denoted by "A", of the bottom portion of the furnace 11 indicates a fluidized bed (also called a fluidized layer or a sand layer) made of a high-density fluid material. In the fluidized bed A, a fluid material such as silica sand in a powder form, a particle form, or a lump form is fluidized by a fluidizing fluid which is supplied from the bottom portion of the furnace 11. The solid fuel such as the biomass fuel or the coal input into the fluidized bed A is efficiently combusted by being repeatedly brought into contact with a high-temperature fluid material to be stirred in the fluidized bed A.

[0016]

Since the fluid material rises in the furnace 11 due to ascending air current caused by combustion, the fluid material is also present in a free board B, which is a space above the fluidized bed A. The density of the fluid material in the free board B is lower than the density of the fluid material in the fluidized bed A, and is reduced

toward an upper side of the furnace 11. In the free board B, the fuel that has not been completely combusted in the fluidized bed A is combusted while coming into contact with a floating fluid material. Although silica sand has been exemplified as the fluid material, any fluid material that can function as a medium for transferring heat to the fuel while remaining in a solid state and flowing without being combusted even in the high-temperature furnace 11 may be used, for example, other types of sand, stones such as limestone, or ash.

[0017]

The bottom portion of the furnace 11 is provided with a porous plate (also called a dispersion plate) 121 as a fluid permeable portion that is made of a porous material allowing a fluidizing fluid such as air to permeate. An air box 122, which is the space immediately below the porous plate 121, constitutes a fluidizing fluid supply unit that supplies pressurized air or the like as the fluidizing fluid, which is supplied via a first flow rate control valve 71A from a first blower 71 as a blower, into the furnace 11 via the porous plate 121. The fluidizing fluid supplied to the bottom portion of the furnace 11 by the air box 122 fluidizes the fluid material to form the fluidized bed A and is used for the combustion of the fuel in the fluidized bed A or the free board B. In Fig. 1, the fluid

permeable portion has been described using the porous plate 121 as an example. However, the fluid permeable portion may be any portion capable of causing the fluid material to flow in the fluidized bed A, and may be formed of, for example, many plates in which slits for supplying the fluidizing fluid into the furnace 11 are formed.

[0018]

A second blower 72 which is provided in addition to the first blower 71 supplies pressurized air or the like into the free board B via a second flow rate control valve 72A in order to promote the combustion of the fuel in the free board B and suppress the generation of harmful substances such as dioxin or carbon monoxide due to incomplete combustion.

[0019]

In order to circulate the fluid material in the fluidized bed A, an external circulation mechanism 13 having a circulation path outside the furnace 11 is provided. The external circulation mechanism 13 includes an extraction pipe 131 that communicates with the bottom portion of the furnace 11 to be capable of extracting a part of the fluid material in the fluidized bed A, an on-off valve 132 that controls the opening and closing of the extraction pipe 131 to be capable of adjusting the flow rate of the fluid material, that is, the amount of the

fluid material to be extracted via the extraction pipe 131, a fluid material conveyor 133 such as a bucket conveyor that transports the fluid material extracted via the extraction pipe 131 upward, a fluid material silo 134 that is provided on the outer periphery of the furnace 11 corresponding to an upper portion of the fluidized bed A and receives the fluid material transported by the fluid material conveyor 133, and a fluid material re-input part 135 that inputs the fluid material stored in the fluid material silo 134 into the furnace 11 again.

[0020]

The extraction pipe 131, the on-off valve 132, the fluid material conveyor 133, the fluid material silo 134, and the fluid material re-input part 135 constitute a fluid material circulation path that connects a bottom surface and a side surface of the furnace 11 on the outside of the furnace 11. That is, the fluid material extracted from the bottom surface of the furnace 11 via the extraction pipe 131 is input from the side surface of the furnace 11 into the fluidized bed A again by the fluid material re-input part 135 via the on-off valve 132, the fluid material conveyor 133, and the fluid material silo 134. The fluid material passing through the external circulation mechanism 13 may be mixed with combustion ash such as a biomass fuel combusted in the furnace 11. Therefore, a combustion ash

separation section may be provided that separates combustion ash from the fluid material passing through the external circulation mechanism 13 based on differences in particle size or the like. The combustion ash separated by the combustion ash separation section may be provided to a combustion ash measurement unit 81 to be described later.

[0021]

A furnace wall, which is the side wall of the furnace 11, is provided with a fuel supply unit 14 that supplies fuel into the furnace 11, a fluid material supply unit 15 that supplies fluid material for forming the fluidized bed A into the furnace 11, and a startup unit 16 that starts up the CFB boiler. The fuel supply unit 14 includes a funnel-shaped hopper 141 that stores fuel, a crushing section 142 that crushes the fuel discharged from a bottom portion of the hopper 141 in a granular shape, and a feeder 143 that supplies the fuel crushed in the crushing section 142 into the furnace 11. Hereinafter, the fuel supply unit 14 will be described as supplying solid fuel, but it may also supply liquid or gaseous biomass fuel, oil, ammonia, hydrogen, or other fluid fuel in addition to or instead of the solid fuel.

[0022]

The fuel supply unit 14 supplies any fuel, such as fossil fuels such as coal, biomass fuels, sludge, waste

materials, and the like, into the furnace 11. As a result of combustion of these fuels in the furnace 11, combustion ash containing various components mainly derived from the fuel is generated. In particular, some biomass fuels contain large amounts of alkali metals such as sodium and potassium, and when combusted, highly alkaline combustion ash containing a large amount of alkali metals is generated. The biomass fuel is carbon neutral fuel having a small or zero net carbon dioxide emission. In order to reduce the amount of generated carbon dioxide in the furnace 11, the fuel supply unit 14 may supply carbon-free fuel that does not contain carbon to the furnace 11 in addition to a carbon-containing fuel such as a biomass fuel.

[0023]

The crushing section 142 in the fuel supply unit 14 crushes the fuel, which is not yet supplied to the furnace 11, in a granular shape. Since the size of the fuel suitable for the transport of the fuel to the CFB boiler or the hopper 141 and the size of the fuel suitable for the combustion of the material in the furnace 11 may be different from each other, the fuel is crushed into particles having a particle size suitable for the latter by the crushing section 142. In addition, in a case where the suitable particle size differs for each fuel, the crushing

section 142 may be provided for each fuel, or the particle size when crushing each fuel in sequence in one crushing section 142 may be changed for each fuel. In a case where a problem does not occur even though the fuel having a particle size stored in the hopper 141 is supplied to the furnace 11 as it is, the crushing section 142 may not be provided. Here, the terms "particle", "granular shape", and "particle size" do not refer to a specific size or dimension, and the size or dimension of the fuel supplied into the furnace 11 is not important as long as it achieves the intended effect. For example, the terms "lump", "lump-like", and "lump diameter" used for relatively large particles and the terms "powder", "powder form", and "powder size" used for relatively small particles are included in "particle", "granular shape", and "particle size" of the present embodiment. A required amount of the granular fuel crushed by the crushing section 142 is input to the furnace 11 by the feeder 143 whose rotation speed can be controlled.

[0024]

The fluid material supply unit 15, which supplies a fluid material for forming the fluidized bed A, includes a funnel-shaped fluid material hopper 151 that stores a fluid material, and a fluid material feeder 152 that supplies a fluid material discharged from a bottom portion of the

fluid material hopper 151 into the furnace 11. The rotation speed of the fluid material feeder 152 is controlled, so that a required amount of fluid material is input to the furnace 11.

[0025]

The startup unit 16 that starts up the CFB boiler includes a startup fuel storage section 161, a startup fuel control valve 162, and a startup burner 163. The startup fuel storage section 161 stores heavy oil as a carbon-containing fuel. The startup fuel control valve 162 controls the amount of heavy oil to be supplied from the startup fuel storage section 161 to the startup burner 163. Specifically, when the CFB boiler is started up, the startup fuel control valve 162 is brought into an opened state and supplies the heavy oil stored in the startup fuel storage section 161 to the startup burner 163. The startup burner 163 heats the fluid material in the fluidized bed A with flame that is caused by the combustion of the heavy oil supplied from the startup fuel control valve 162. Since the startup burner 163 is provided to be inclined downward, the surface of the fluidized bed A formed by the fluid material is directly heated. As a result, the temperatures in the fluidized bed A and the furnace 11 efficiently rise. As such, the startup burner 163 is also referred to as a

sand-top burner as it heats the sand-like fluidized bed A from above.

[0026]

After the CFB boiler in which the fluidized bed A and the inside of the furnace 11 are sufficiently heated is started up, specifically, after the fuel supplied from the fuel supply unit 14 can be combusted in the fluidized bed A, the startup fuel control valve 162 is brought into a closed state to stop the supply of the heavy oil to the startup burner 163. In a subsequent normal operation state, the fuel supplied from the fuel supply unit 14 is combusted in the high-temperature furnace 11.

[0027]

The combustion section 1 of the CFB boiler has been described in detail above. Subsequently, the configurations of the CFB boiler other than the combustion section 1 will be described. The steam generation section 2 includes a drum 21 that stores water to be used to generate steam, a water supply pipe 22 through which water is supplied to the drum 21, a water pipe 23 through which the water in the drum 21 is guided into the high-temperature furnace 11 and is heated, and a steam pipe 24 through which steam generated from the water heated in the water pipe 23 is discharged from the drum 21 as an output of the CFB boiler. A steam turbine of a generator 25 is rotated by the steam

output from the steam pipe 24 to generate electricity. The water supply pipe 22 constitutes a coal economizer that meanders in the heat transfer section 4 through which the high-temperature exhaust gas of the combustion section 1 passes and preheats supplied water, and the steam pipe 24 constitutes a superheater that meanders in the heat transfer section 4 through which the high-temperature exhaust gas of the combustion section 1 passes, and that superheats steam. Similarly, the pressurized air or the like which is supplied into the furnace 11 by the first blower 71 and the second blower 72 is also preheated with the high-temperature exhaust gas in the heat transfer section 4.

[0028]

The fluid material circulation section 3 includes a cyclone 31 that separates and collects the granular fluid material from the exhaust gas discharged from the upper portion of the furnace 11, and a circulation seal 32 (also called a wall seal or a seal pot) that returns the fluid material collected by the cyclone 31 into the furnace 11. The cyclone 31 is a cyclone-type powder separator whose upper portion is formed in a substantially cylindrical shape and lower portion is formed in a substantially conical shape, and generates air current that spirally descends along the inner wall. When spirally descending

along the air current, the granular fluid material contained in the exhaust gas discharged from the furnace 11 comes into contact with the inner wall of the cyclone 31, falls, and is then collected.

[0029]

Since the circulation seal 32 provided below the cyclone 31 is filled with a fluid material, the backflow of unburned gas or the like from the furnace 11 to the cyclone 31 is prevented. The granular fluid material filled in the circulation seal 32 gradually returns into the furnace 11 in the form of being pushed out by the weight of a fluid material newly collected by the cyclone 31. The fluid material passing through the circulation seal 32 may be mixed with combustion ash such as a biomass fuel combusted in the furnace 11. Therefore, a combustion ash separation section may be provided that separates combustion ash from the fluid material passing through the circulation seal 32 based on differences in particle size or the like. The combustion ash separated by the combustion ash separation section may be provided to a combustion ash measurement unit 81 to be described later.

[0030]

The exhaust treatment device 5 separates and collects the combustion ash or the like in the exhaust gas from the heat transfer section 4, and recovers the combustion ash or

the like. The combustion ash separated and recovered by the exhaust treatment device 5 may be provided to a combustion ash measurement unit 81 to be described later.

[0031]

The agglomeration suppression device 8 is a device that predicts and/or suppresses the occurrence of agglomeration in the furnace 11 of the CFB boiler as described above. The agglomeration suppression device 8 includes a combustion ash measurement unit 81, a fuel component information acquisition unit 82, a metal ratio estimation unit 83, a shortage detection unit 84, and an earth metal supply unit 85.

[0032]

Agglomeration, also referred to as coagulation, is the gathering together of particles into a lump. In a CFB boiler in which a fuel such as a biomass fuel is supplied and combusted in the furnace 11 in which a fluid material such as silica sand flows, as in the present embodiment, components such as silica contained in the fluid material and various components contained in the fuel are involved in the occurrence of agglomeration.

[0033]

As a result of an actual test using a CFB boiler, it was confirmed that agglomeration occurs frequently in a case where a highly alkaline fuel such as a biomass fuel

containing a large amount of an alkali metal such as sodium or potassium is combusted in the furnace 11. As a result of their own investigations and/or analyses, it was confirmed that silica derived from the fluid material combines with an alkali metal oxide and the like derived from the highly alkaline fuel to generate a low melting point compound. This low melting point compound is easily liquefied in the high-temperature furnace 11, and a large amount of sand-like fluid material (such as silica sand) and solid combustion ash are adsorbed thereto, thereby causing agglomeration.

[0034]

In order to predict and/or suppress agglomeration, which is considered to be primarily caused by highly alkaline fuels such as a biomass fuel, in the present embodiment, attention is focused on alkaline earth metals such as magnesium and calcium and/or earth metals such as aluminum. Specifically, attention is focused on a eutectic system consisting of three types of components including silica derived from a fluid material such as silica sand, an alkali metal oxide derived from a highly alkaline fuel such as a biomass fuel, and an alkaline earth metal oxide and/or an earth metal oxide.

[0035]

Fig. 2 is a state diagram or a phase diagram of a eutectic system consisting of three types of components including silica ( $\text{SiO}_2$ ) derived from a fluid material such as silica sand, potassium oxide ( $\text{K}_2\text{O}$ ) as an alkali metal oxide derived from a highly alkaline fuel such as a biomass fuel, and calcium oxide ( $\text{CaO}$ ) as an alkaline earth metal oxide. This state diagram illustrates a schematic representation of the states (phases) that are realized in a case where the component ratio (molar ratio) of  $\text{SiO}_2$ ,  $\text{K}_2\text{O}$ , and  $\text{CaO}$  in a eutectic system is changed. The example of Fig. 2 corresponds to a case of  $1000^\circ\text{C}$ , which is a typical temperature that can be achieved in the furnace 11.

[0036]

In this state diagram, for example, in a case where no  $\text{CaO}$  is present,  $\text{SiO}_2$  and  $\text{K}_2\text{O}$  are almost completely liquefied, causing agglomeration, as shown by "Liquid" in the region covering almost the entire base of the triangle. When the amount of  $\text{CaO}$  is increased from this state, the eutectic system transitions to the solid phase region above the triangle (the hatched region). In other words, by increasing the amount of  $\text{CaO}$ , the melting point of the eutectic system increases.

[0037]

In the typical CFB boiler, the amount of silica ( $\text{SiO}_2$ ) contained in the fluid material such as silica sand is

considered to be approximately constant. Therefore, in the present embodiment, attention is focused on the other two components in the eutectic system, that is, alkali metals such as potassium (K) in  $K_2O$  and sodium (Na) in  $Na_2O$ , and alkaline earth metals such as calcium (Ca) in  $CaO$  and magnesium (Mg) in  $MgO$ , and/or earth metals such as aluminum (Al) in  $Al_2O_3$ . Specifically, attention is focused on the metal ratio of an alkaline earth metal and/or an earth metal to an alkali metal, for example, the molar ratio of calcium (Ca) in  $CaO$  to potassium (K) in  $K_2O$ , "Ca/K". Here, in the present invention, in addition to such metal ratios, the component amount and component ratio of silica or silicon (Si), which is the remaining component of the eutectic system, may be taken into consideration with respect to a state diagram such as that shown in Fig. 2.

[0038]

As the metal ratio "Ca/K" decreases, the melting point of the eutectic system decreases, entering the lower liquid phase region in the state diagram of Fig. 2, making agglomeration more likely to occur. As the metal ratio "Ca/K" increases, the melting point of the eutectic system increases, entering the upper solid phase region in the state diagram of Fig. 2, making it difficult for agglomeration to occur.

[0039]

Based on the above considerations and/or hypotheses, the agglomeration suppression device 8 in Fig. 1 includes a metal ratio estimation unit 83 that estimates the metal ratio ( $[Mg, Ca, Al]/[Na, K]$  and the like) of alkaline earth metals (Mg, Ca, and the like) and/or earth metals (Al, and the like) to alkali metals (Na, K, and the like) in the furnace 11.

[0040]

The metal ratio estimation unit 83 may directly measure a metal ratio such as "Ca/K" in the furnace 11, but it is practically difficult to measure in the high-temperature furnace 11. Therefore, the metal ratio estimation unit 83 estimates a metal ratio such as "Ca/K" based on the measurement results of the combustion ash measurement unit 81 and/or the fuel component information acquisition unit 82.

[0041]

The combustion ash measurement unit 81 measures the combustion ash generated by combustion in the furnace 11 continuously or intermittently (for example, several times a day or an hour). The combustion ash to be measured by the combustion ash measurement unit 81 can be acquired from each part of the CFB boiler. Specifically, the combustion ash measurement unit 81 measures at least one of the following: combustion ash (so-called bottom ash) separated

from the fluid material that is extracted from the bottom surface of the furnace 11 and passes through the external circulation mechanism 13; combustion ash separated from the fluid material that fills the circulation seal 32 in the fluid material circulation section 3 that returns the fluid material discharged from the furnace 11 to the furnace 11; and combustion ash separated and recovered by the exhaust treatment device 5. The purpose of the measurement by the combustion ash measurement unit 81 is to measure the composition of (highly alkaline) combustion ash that may cause agglomeration in the furnace 11. Therefore, it is preferable that combustion ash having a composition similar to that of the combustion ash in the furnace 11 is measured by the combustion ash measurement unit 81.

[0042]

The preferred combustion ash from this viewpoint is the bottom ash in the external circulation mechanism 13 and the combustion ash in the circulation seal 32, both of which are circulated within the furnace 11. However, since it takes a long time for the bottom ash to reach an equilibrium state in which it can be considered to be approximately the same quality as the combustion ash in the furnace 11, the combustion ash in the circulation seal 32 is optimal for the purpose of quickly estimating a metal ratio such as "Ca/K" in the combustion ash in the furnace

11. In addition, since agglomeration is likely to occur in a location where the flow rate of the combustion ash and/or the fluid material is slow, by the combustion ash measurement unit 81 measuring the combustion ash and/or the fluid material that is substantially retained in the circulation seal 32, not only the components but also the actual occurrence and signs of agglomeration can be detected.

[0043]

The fuel component information acquisition unit 82 acquires component information of the fuel such as the biomass fuel supplied into the furnace 11 by the fuel supply unit 14, as information useful for the metal ratio estimation unit 83 to estimate a metal ratio such as "Ca/K". The fuel component information acquisition unit 82 may, for example, directly measure the component of the fuel in the hopper 141, or electronically acquire component information provided by a fuel supplier. As described above, component information on alkali metals, which are mainly derived from the fuel and are considered to contribute to the occurrence of agglomeration in the furnace 11, can be acquired through measurement of combustion ash by the combustion ash measurement unit 81, but may also be acquired directly by the fuel component information acquisition unit 82. Here, the component

information acquired by the fuel component information acquisition unit 82 merely represents the components before combustion, and does not directly represent the amount of alkali metals that actually remain in the furnace 11 and cause agglomeration (it is merely an indirect index). For example, it is considered that about half of the alkali metals contained in highly alkaline fuels such as the biomass fuel do not remain in the furnace 11 but are exhausted.

[0044]

The metal ratio estimation unit 83 estimates the metal ratio (Ca/K, and the like) of alkaline earth metals (Mg, Ca, and the like) and/or earth metals (Al, and the like) to alkali metals (Na, K, and the like) in the furnace 11 based on the combustion ash measurement results by the combustion ash measurement unit 81 and/or the fuel component information acquired by the fuel component information acquisition unit 82.

[0045]

The shortage detection unit 84 detects a shortage of alkaline earth metals (Mg, Ca, and the like) and/or earth metals (Al, and the like) in the furnace 11 in a case where a metal ratio such as "Ca/K" estimated by the metal ratio estimation unit 83 falls below a predetermined lower limit.

[0046]

Fig. 3 illustrates results of tests carried out in an actual CFB boiler to set a lower limit of a metal ratio such as "Ca/K". The points indicated by triangles in this diagram correspond to the cases where "Ca/K" is approximately zero, that is, where there is almost no calcium (Ca) present in the furnace 11. As described above with reference to Fig. 2, the melting point of the eutectic system in this case is low and it is easily liquefied. As a result, agglomeration occurs and the CFB boiler is likely to stop flowing. Therefore, the flow stop temperature is low, at 800°C or lower.

[0047]

When calcium (Ca) is added from this state to increase the "Ca/K" in the furnace 11 to between 0.6 and 2.3, an effect of increasing the flow stop temperature to approximately 1000°C has been confirmed, as shown by the three circles in Fig. 3. As described above with reference to Fig. 2, as the "Ca/K" increases, the melting point of the eutectic system increases, making it difficult to liquefy, and as a result, agglomeration does not occur and the CFB boiler is less likely to stop flowing. As shown in Fig. 3, such an effect has been confirmed in the region where the "Ca/K" is 0.6 or more. Therefore, it is preferable that the lower limit of a metal ratio such as "Ca/K" for the shortage detection unit 84 to detect a

shortage of alkaline earth metals (Mg, Ca, and the like) and/or earth metals (Al, and the like) in the furnace 11 is at least 0.6.

[0048]

The earth metal supply unit 85 supplies alkaline earth metals (Mg, Ca, and the like) and/or earth metals (Al, and the like) into the furnace 11 in response to a shortage of alkaline earth metals (Mg, Ca, and the like) and/or earth metals (Al, and the like) in the furnace 11 detected by the shortage detection unit 84. For example, the earth metal supply unit 85 supplies at least one of limestone ( $\text{CaCO}_3$ ), quicklime ( $\text{CaO}$ ), dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ), and alumina ( $\text{Al}_2\text{O}_3$ ) into the furnace 11. In the high-temperature furnace 11, these generate alkaline earth metal oxides and/or earth metal oxides that constitute a eutectic system with silica ( $\text{SiO}_2$ ) and alkali metal oxides ( $\text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}$ , and the like). Specifically, limestone ( $\text{CaCO}_3$ ) and quicklime ( $\text{CaO}$ ) generate calcium oxide ( $\text{CaO}$ ) as alkaline earth metal oxides, dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ) generates magnesium oxide ( $\text{MgO}$ ) and calcium oxide ( $\text{CaO}$ ) as alkaline earth metal oxides, and alumina ( $\text{Al}_2\text{O}_3$ ) generates aluminum oxide ( $\text{Al}_2\text{O}_3$ ) as an earth metal oxide.

[0049]

As described above, the alkaline earth metal and/or the earth metal supplied by the earth metal supply unit 85

effectively suppresses the occurrence of agglomeration in the furnace 11 by increasing the melting point of the eutectic system consisting of three types of components including silica, an alkali metal oxide, and an alkaline earth metal oxide and/or an earth metal oxide. Furthermore, as a result of the alkaline earth metal and/or the earth metal being supplied into the furnace 11 by the earth metal supply unit 85, the metal ratio such as "Ca/K" in the furnace 11 exceeds the above-described lower limit (at least 0.6).

[0050]

In this way, the earth metal supply unit 85 supplies alkaline earth metals and/or earth metals such that the metal ratio ( $[Mg, Ca, Al]/[Na, K]$  and the like) of alkaline earth metals (Mg, Ca, and the like) and/or earth metals (Al, and the like) to alkali metals (Na, K, and the like) in the furnace 11 exceeds a predetermined lower limit (at least 0.6).

[0051]

The earth metal supply unit 85 may supply alkaline earth metals and/or earth metals directly into the furnace 11, or supply alkaline earth metals and/or earth metals indirectly into the furnace 11 via the fuel supply unit 14 and/or the fluid material supply unit 15. That is, the fuel supply unit 14 may supply a fuel such as a biomass fuel to

which alkaline earth metals and/or earth metals (limestone, quicklime, dolomite, alumina, and the like) supplied by the earth metal supply unit 85 have been added into the furnace 11. In addition, the fluid material supply unit 15 may supply a fluid material such as silica sand to which alkaline earth metals and/or earth metals (limestone, quicklime, dolomite, alumina, and the like) supplied by the earth metal supply unit 85 have been added into the furnace 11.

[0052]

The earth metal supply unit 85 may supply alkaline earth metals and/or earth metals into the furnace 11 without being based on a metal ratio such as "Ca/K" estimated in real time by the metal ratio estimation unit 83. For example, based on the past operating results of CFB boilers, measurement data on combustion ash and the like, and the occurrence history of agglomeration, it is possible to accumulate knowledge and know-how regarding cases and conditions in which the metal ratio ( $[Mg, Ca, Al]/[Na, K]$  or the like) falls below the lower limit (at least 0.6). The earth metal supply unit 85 can utilize such knowledge and know-how to appropriately supply alkaline earth metals and/or earth metals such that the metal ratio ( $[Mg, Ca, Al]/[Na, K]$  and the like) of alkaline earth metals (Mg, Ca, and the like) and/or earth metals (Al, and the like) to

alkali metals (Na, K, and the like) in the furnace 11 exceeds a predetermined lower limit (at least 0.6).

[0053]

According to the present embodiment as described above, it is possible to effectively predict and/or suppress the occurrence of agglomeration in the furnace 11 of a CFB boiler, based on the metal ratio ( $[Mg, Ca, Al]/[Na, K]$  and the like) of alkaline earth metals (Mg, Ca, and the like) and/or earth metals (Al, and the like) to alkali metals (Na, K, and the like) in the furnace 11.

[0054]

Furthermore, even in a case where a highly alkaline fuel such as a biomass fuel is used, the metal ratio in the furnace 11 can be maintained higher than a predetermined lower limit (at least 0.6) by supplying alkaline earth metals and/or earth metals (limestone, quicklime, dolomite, alumina, and the like) by the earth metal supply unit 85, thereby effectively suppressing the occurrence of agglomeration. In other words, even highly alkaline fuels that have been known to cause agglomeration can be used, thereby dramatically increasing the freedom of fuel selection for CFB boilers. In particular, since biomass fuels or the like, which have a low environmental load, can be actively employed, the present invention can also contribute to protecting the natural environment.

[0055]

The present invention has been described above based on the embodiment. Various modification examples are possible in the combinations of each component and each process in the embodiment provided as an example, and it is obvious to those skilled in the art that such modification examples are included in the scope of the present invention.

[0056]

The configuration, operation, and function of each device or each method described in the embodiment can be realized by hardware resources or software resources, or by cooperation of hardware resources and software resources. As the hardware resources, for example, a processor, a ROM, a RAM, and various integrated circuits can be used. As the software resources, for example, programs such as an operating system and an application can be used.

#### Industrial Applicability

[0057]

The present invention relates to a combustion device and the like.

#### Reference Signs List

[0058]

- 1 combustion section
- 3 fluid material circulation section
- 8 agglomeration suppression device
- 11 furnace
- 13 external circulation mechanism
- 14 fuel supply unit
- 15 fluid material supply unit
- 32 circulation seal
- 81 combustion ash measurement unit
- 82 fuel component information acquisition unit
- 83 metal ratio estimation unit
- 84 shortage detection unit
- 85 earth metal supply unit

## CLAIMS

1. A combustion device that supplies a fuel into a combustion chamber in which a fluid material containing silica flows and that combusts the fuel, the combustion device comprising:

a fuel supply unit that supplies the fuel to which an alkaline earth metal and/or an earth metal has been added into the combustion chamber such that a ratio of the alkaline earth metal and/or the earth metal to an alkali metal in the combustion chamber exceeds a predetermined lower limit.

2. The combustion device according to claim 1, further comprising:

an earth metal supply unit that supplies the alkaline earth metal and/or the earth metal,

wherein the fuel supply unit supplies the fuel to which the alkaline earth metal and/or the earth metal supplied by the earth metal supply unit has been added into the combustion chamber.

3. The combustion device according to claim 2, wherein the earth metal supply unit supplies at least one

of limestone, quicklime, dolomite, and alumina into the fuel supply unit.

4. The combustion device according to claim 2 or 3, wherein the alkaline earth metal and/or the earth metal supplied by the earth metal supply unit increases a melting point of a eutectic system consisting of three types of components including silica, an alkali metal oxide, and an alkaline earth metal oxide and/or an earth metal oxide.

5. The combustion device according to claim 2 or 3, further comprising:

a combustion ash measurement unit that measures combustion ash generated by combustion in the combustion chamber; and

a metal ratio estimation unit that estimates the ratio of the alkaline earth metal and/or the earth metal to the alkali metal in the combustion chamber based on a measurement result of the combustion ash measurement unit,

wherein the earth metal supply unit supplies the alkaline earth metal and/or the earth metal such that the ratio estimated by the metal ratio estimation unit exceeds the lower limit.

6. The combustion device according to claim 5, wherein the combustion ash measurement unit measures the combustion ash at a circulation seal, which is filled with the fluid material, in a fluid material circulation section that returns the fluid material discharged from the combustion chamber to the combustion chamber.

7. The combustion device according to claim 5, further comprising:

a fuel component information acquisition unit that acquires component information of the fuel,

wherein the metal ratio estimation unit estimates the ratio of the alkaline earth metal and/or the earth metal to the alkali metal in the combustion chamber based on the measurement result of the combustion ash measurement unit and the component information.

8. The combustion device according to any one of claims 1 to 3, wherein the lower limit is at least 0.6.

9. The combustion device according to any one of claims 1 to 3, wherein the alkali metal includes at least one of sodium and potassium.

10. The combustion device according to any one of claims 1 to 3, wherein the alkaline earth metal includes at least one of magnesium and calcium.

11. The combustion device according to any one of claims 1 to 3, wherein the earth metal includes at least aluminum.

12. A combustion method executed in a combustion device that supplies a fuel into a combustion chamber in which a fluid material containing silica flows and that combusts the fuel, the combustion method comprising:

a fuel supply step of supplying the fuel to which an alkaline earth metal and/or an earth metal has been added into the combustion chamber such that a ratio of the alkaline earth metal and/or the earth metal to an alkali metal in the combustion chamber exceeds a predetermined lower limit.

13. A combustion program causing a computer to execute the following step in a combustion device that supplies a fuel into a combustion chamber in which a fluid material containing silica flows and that combusts the fuel, the step comprising:

a fuel supply step of supplying the fuel to which an alkaline earth metal and/or an earth metal has been added into the combustion chamber such that a ratio of the alkaline earth metal and/or the earth metal to an alkali metal in the combustion chamber exceeds a predetermined lower limit.