In a rapid load reduction mode for reducing a flow rate of powder to be supplied to the outside of a feed tank to a predetermined rate after a predetermined period of time, a controller sets an internal pressure control valve to an exhaust state and closes a powder discharge valve to a predetermined aperture, and as soon as the powder flow rate becomes smaller than a scheduled powder flow rate that is expected before elapse of the predetermined period of time, the controller controls at least one of the internal pressure control valve and the powder discharge valve so that the powder flow rate becomes the scheduled powder flow rate.
FIG. 4

<table>
<thead>
<tr>
<th>POWDER FLOW RATE [kg/h]</th>
<th>APERTURE OF POWDER DISCHARGE VALVE [%]</th>
<th>DIFFERENTIAL PRESSURE [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>50</td>
<td>0.01</td>
</tr>
<tr>
<td>5000</td>
<td>60</td>
<td>0.03</td>
</tr>
<tr>
<td>10000</td>
<td>80</td>
<td>0.05</td>
</tr>
<tr>
<td>15000</td>
<td>100</td>
<td>0.06</td>
</tr>
</tbody>
</table>

FIG. 5

<table>
<thead>
<tr>
<th>TIME FROM START OF RAPID LOAD REDUCTION MODE [sec]</th>
<th>SCHEDULED POWDER FLOW RATE [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>91.7</td>
</tr>
<tr>
<td>20</td>
<td>83.3</td>
</tr>
<tr>
<td>30</td>
<td>75.0</td>
</tr>
<tr>
<td>40</td>
<td>66.6</td>
</tr>
<tr>
<td>50</td>
<td>58.3</td>
</tr>
<tr>
<td>60</td>
<td>50.0</td>
</tr>
</tbody>
</table>

FIG. 6

- **STEP 1**: OPERATION BY NORMAL MODE
- **STEP 2**: START OF RAPID LOAD REDUCTION MODE
- **STEP 3**: ADJUSTMENT BY POWDER FLOW RATE OF INTERNAL PRESSURE CONTROL VALVE
FIG. 7

POWDER FLOW RATE

NORMAL MODE

RAPID LOAD REDUCTION MODE

STEP1

STEP2

STEP3

SV

PV

TIME
POWDER SUPPLY DEVICE AND POWDER SUPPLY METHOD

TECHNICAL FIELD

[0001] The present invention relates to a powder supply device and a powder supply method, which can suppress the undershooting of the powder flow rate while reducing the powder flow rate rapidly.

BACKGROUND ART

[0002] Combustion furnaces for burning pulverized fuel such as pulverized coal supplied from powder supply devices are known as combustion furnaces used in blast furnace facilities, thermal power plants, and the like. In such combustion furnaces, the pulverized fuel is burned while the pulverized fuel is jet into the combustion furnace together with air. A method of combustion with the use of the pulverized coal as the pulverized fuel has been widely popular because, for example, the coal itself has high combustibility.

[0003] A gas-carried powder supply device that conveys pulverized fuel with carrier gas is known as a powder supply device for supplying pulverized fuel to a combustion furnace. In this powder supply device, the pulverized fuel in a feed tank is supplied to a powder delivery pipe and is conveyed with carrier gas in the powder delivery pipe. The amount of pulverized fuel (powder flow rate) to be supplied per unit time to the inside of powder delivery pipe may be controlled by, for example, the aperture of a powder discharge valve provided for an outlet at a bottom portion of the feed tank and the differential pressure between the pressure in the feed tank and the pressure in the powder delivery pipe (see Patent Document 1 below). The aperture of the powder discharge valve and the differential pressure between the pressure in the feed tank and the pressure in the powder delivery pipe are generally controlled by the feedback of the information on the powder flow rate that is detected by a powder flowmeter provided for the powder delivery pipe or the like.

[0004] In general, the powder flow rate is determined based on the instruction from, for example, the combustion furnace to which the powder is supplied. When the powder flow rate is reduced, the information on the powder flow rate is also fed back to the control for the aperture of the powder discharge valve or the control for the differential pressure between the pressure in the feed tank and the pressure in the powder delivery pipe so that the value of the powder flow rate becomes the determined target value.

CITATION LIST

Patent Document


SUMMARY OF INVENTION

Objects to be Achieved by the Invention

[0005] In the occurrence of a trouble in the combustion furnace to which the pulverized fuel is supplied, the mode of the powder supply device may become a rapid load reduction mode where the powder flow rate needs to be rapidly reduced. Even in the rapid load reduction mode, however, the instant reduction of the powder flow rate may apply load to the combustion furnace, which may result in the trouble of the combustion furnace. In view of this, in the rapid load reduction mode, the powder flow rate needs to be reduced to a determined flow rate in a determined period of time.

[0006] In this case, the rapid reduction of the powder flow rate may fail if the powder flow rate is reduced under the aforementioned feedback. In view of this, in this rapid load reduction mode, the powder discharge valve is closed to a predetermined aperture and at the same time, the differential pressure between the pressure in the feed tank and the pressure in the powder delivery pipe is reduced instead of the aforementioned feedback control so that the value of the powder flow rate becomes the target value. In this case, however, the undershooting may be caused in which the powder flow rate is reduced further to be lower than the powder flow rate that is finally determined because of the external factor such as the pressure variation at the destination of the powder supply.

[0007] In view of this, an object of the present invention is to provide a powder supply device and a powder supply method capable of suppressing the undershooting of the powder flow rate while reducing the powder flow rate rapidly.

Means for Achieving the Objects

[0008] For achieving the above object, the present invention provides a powder supply device that supplies powder in a feed tank to the outside of the feed tank through a powder delivery pipe connected to the feed tank, the device including: an internal pressure control valve that is connected to the feed tank and that adjusts the pressure in the feed tank; a powder discharge valve connected to the powder delivery pipe; and a controller that controls the internal pressure control valve and the powder discharge valve, wherein: in a rapid load reduction mode for reducing a flow rate of powder to be supplied to the outside of the feed tank to a predetermined rate after a predetermined period of time, the controller sets the internal pressure control valve to an exhaust state of reducing the pressure in the feed tank and closes the powder discharge valve to a predetermined aperture so that the powder flow rate becomes smaller than the predetermined rate after the predetermined period of time; and as soon as the powder flow rate becomes smaller than a scheduled powder flow rate that is expected before elapse of the predetermined period of time for reducing the powder flow rate to the predetermined rate after the predetermined period of time, the controller controls at least one of the internal pressure control valve and the powder discharge valve on the basis of information of the powder flow rate so that the powder flow rate becomes the scheduled powder flow rate.

[0009] In addition, for achieving the above object, the present invention provides a powder supply method for supplying powder in a feed tank to the outside of the feed tank through a powder delivery pipe connected to the feed tank, the method including: in a rapid load reduction mode for reducing a flow rate of powder to be supplied to the outside of the feed tank to a predetermined rate after a predetermined period of time, setting an internal pressure control valve connected to the feed tank to an exhaust state of reducing the pressure in the feed tank and closing a powder discharge valve connected to the powder delivery pipe to a predetermined aperture so that the powder flow rate becomes smaller than the predetermined rate after the predetermined period of time; and as soon as the powder flow rate becomes smaller than a scheduled powder flow rate that is expected before elapse of the predetermined period of time for reducing the powder flow rate to the pre-
determined rate after the predetermined period of time, adjusting at least one of the internal pressure control valve and the powder discharge valve on the basis of information of the powder flow rate so that the powder flow rate becomes the scheduled powder flow rate.

[0010] In general, in the rapid load reduction mode of the powder supply device, even when the internal pressure control valve is set to the exhaust state and the powder discharge valve is closed to a predetermined aperture, it is difficult to reduce the powder flow rate just after the start of the rapid load reduction mode because of the operation time of the device or the primary time lag. Therefore, it is likely that the actual powder flow rate is larger than the scheduled powder flow rate (powder flow rate that is determined as an index according to the time in the middle of the rapid pressure reduction mode for reducing the powder flow rate to a predetermined rate after a predetermined period of time). Thus, in the powder supply device and the powder supply method according to the present invention, the pressure in the feed tank is reduced by having the internal pressure control valve in the exhaust state to thereby reduce the differential pressure between the pressure in the feed tank and the pressure in the powder delivery pipe and moreover the powder discharge valve is closed to a predetermined aperture so that the powder flow rate becomes smaller than the predetermined rate after the predetermined period of time in the rapid load reduction mode. Therefore, the flow rate of the powder to be supplied from the feed tank can be reduced rapidly. On the other hand, after the flow rate of the powder to be supplied from the feed tank is reduced to be less than the scheduled powder flow rate for reducing the powder flow rate to the predetermined rate after the predetermined period of time, at least one of the internal pressure control valve and the powder discharge valve is controlled based on the actual powder flow rate so that the powder flow rate becomes the scheduled powder flow rate. In other words, after the powder flow rate has become the scheduled powder flow rate, at least one of the internal pressure control valve and the powder discharge valve is subjected to the feedback control. Therefore, the undershooting of the powder flow rate at the end of the rapid load reduction mode can be suppressed. In this manner, in the powder supply device according to the present invention, the undershooting of the powder flow rate is suppressed while the powder flow rate is reduced rapidly.

[0011] In this specification, when “the powder flow rate” is simply referred to, this term means the flow rate of the powder that is supplied from the feed tank and flows through the powder delivery pipe.

[0012] The scheduled powder flow rate is preferably determined based on the powder flow rate that is just before the rapid load reduction mode is set. Since the appropriate scheduled powder flow rate according to the circumstance of the powder supply before the rapid load reduction mode can be set by determining the scheduled powder flow rate as above, the smooth reduction of the powder flow rate can be achieved.

[0013] In the above powder supply device, the powder flowmeter is connected to the powder delivery pipe, and the controller preferably controls the internal pressure control valve and the powder discharge valve on the basis of the information from the powder flowmeter. In the above powder supply method, the internal pressure control valve and the powder discharge valve are preferably adjusted on the basis of the information from the powder flowmeter connected to the powder delivery pipe.

[0014] By adjusting the pressure in the feed tank and the powder discharge valve on the basis of the information from the powder flowmeter, the powder flow rate can be adjusted minutely following the slight variation in powder flow rate. Thus, the undershooting can be suppressed further.

[0015] In the above powder supply device, the controller preferably sets the internal pressure control valve in the exhaust state before the powder discharge valve is closed to the predetermined aperture and in the above powder supply method, the internal pressure control valve is preferably set to the exhaust state before the powder discharge valve is closed to the predetermined aperture.

[0016] When the powder discharge valve that discharges the powder out of the feed tank is closed to the predetermined aperture, the pressure in the feed tank tends to increase temporally. Even if the timing at which the internal pressure control valve is set to the exhaust state and the timing at which the powder discharge valve is closed to the predetermined aperture are simultaneous, this tendency is caused due to the temporal delay of the exhaustion or the like. Therefore, in the initial stage of the rapid load reduction mode, the powder flow rate may not be reduced that much though the powder discharge valve is closed to the predetermined aperture for rapidly reducing the powder flow rate. In view of this, the gas in the feed tank is exhausted before the powder discharge valve is closed to the predetermined aperture. This makes it possible to prevent the pressure in the feed tank from becoming higher than the pressure before the exhaustion even though the powder discharge valve is closed to the predetermined aperture. Thus, the powder flow rate can be rapidly reduced.

Effect of Invention

[0017] As described above, according to the present invention, the powder supply device and the powder supply method that can suppress the undershooting of the powder flow rate while rapidly reducing the powder flow rate are provided.

BRIEF DESCRIPTION OF DRAWINGS

[0018] FIG. 1 is a diagram showing a powder supply device according to an embodiment of the present invention.

[0019] FIG. 2 is a diagram showing a powder discharge valve.

[0020] FIG. 3 is a diagram showing a structure of a section of the powder discharge valve.

[0021] FIG. 4 is a diagram showing a table 1.

[0022] FIG. 5 is a diagram showing a table 2.

[0023] FIG. 6 is a flowchart showing a method of adjusting the powder flow rate in a rapid load reduction mode.

[0024] FIG. 7 is a diagram showing the scheduled powder flow rate in the rapid load reduction mode and the change of the powder flow rate over time.

DESCRIPTION OF EMBODIMENTS

[0025] A preferred embodiment of a powder supply device and a powder supply method according to the present invention will be described in detail below with reference to the drawings.

[0026] FIG. 1 is a diagram showing the powder supply device according to the embodiment of the present invention.

[0027] As illustrated in FIG. 1, a powder supply device 1 mainly includes: a feed tank 11 that supplies a predetermined amount of pulverized fuel such as pulverized coal; a pressure equalizing tank 12 that stores the pulverized fuel to be sup-
plied to the feed tank 11; an internal pressure gas supply pipe 32 that is connected to the feed tank 11 and conveys the internal pressure gas to be supplied to the feed tank 11; an internal pressure control valve 22 that is connected to the internal pressure gas supply pipe 32 and adjusts the pressure in the feed tank 11; a powder delivery pipe 31 that conveys the pulverized fuel supplied from the feed tank 11; a powder discharge valve 21 that is connected to the powder delivery pipe 31 and adjusts the amount of pulverized fuel supplied from the feed tank 11; a carrier gas main pipe 33 that is connected to the powder delivery pipe 31 and introduces the carrier gas to the powder delivery pipe 31; and a powder flowmeter 40 that detects the flow rate of the pulverized fuel conveyed through the powder delivery pipe 31.

[0028] The feed tank 11 and the pressure equalizing tank 12 are metal tanks. The feed tank 11 is disposed below the pressure equalizing tank 12, and the powder supply pipe 35 connected to a bottom portion of the pressure equalizing tank 12 is connected to a top portion of the feed tank 11. The pulverized fuel is supplied from the pressure equalizing tank 12 to the feed tank 11 through this powder supply pipe 35. A powder supply valve 25 is provided in the middle of the powder supply pipe 35, and the start or stop of the supply of the pulverized fuel from the pressure equalizing tank 12 to the feed tank 11 is controlled by opening or closing the powder supply valve 25.

[0029] The feed tank 11 has a load cell 45 connected thereto, and the weight applied from the feed tank 11 to the load cell 45 is continuously detected by this load cell 45. The load cell 45 has a weight indicator/controller 46 connected thereto. The weight indicator/controller 46 measures the weight of the pulverized fuel in the feed tank 11 continuously based on a detection signal output from the load cell, and outputs a signal including the information based on the weight of the pulverized fuel.

[0030] The feed tank 11 has a pressure indicator 48 connected thereto. The pressure indicator 48 detects the pressure in the feed tank 11 and outputs a signal including the information based on the pressure in the feed tank 11.

[0031] In addition, the powder delivery pipe 31 is connected to a bottom portion of the feed tank 11. The pulverized fuel supplied from the feed tank 11 is introduced into the powder delivery pipe 31 from the feed tank 11 and conveyed by the powder delivery pipe 31 as described above.

[0032] The powder discharge valve 21 is connected in the middle of the powder delivery pipe 31 below the feed tank 11. Therefore, the pulverized fuel supplied from the feed tank 11 is conveyed by the powder delivery pipe 31 through the powder discharge valve 21.

[0033] FIG. 2 is a diagram showing a part of the structure of the powder discharge valve 21 according to this embodiment, and FIG. 3 is a diagram showing the structure of the section of the powder discharge valve 21. As shown in FIG. 2 and FIG. 3, the powder discharge valve 21 mainly includes a valve box 76, a set of valve bodies 71 each housed in the valve box 76 and having an approximately cylindrical shape, and an axial center 73 penetrating along the axis of the valve body 71. In FIG. 3, the illustration of the valve, valve box 76 is omitted for helping the understanding.

[0034] Each valve body 71 has an approximately cylindrical shape, and a side surface 72 of each valve body 71 is provided with a cutout 75. The axial center 73 is provided along the axis of each valve body 71. The valve bodies 71 are disposed rotatably about the axis with the side surfaces 72 thereof in contact with each other in a manner that the longitudinal directions of the valve bodies 71 are in parallel to each other. This enables the portion of the side surfaces 72 with the cutouts 75 to face each other when the valve bodies 71 are rotated about their axes. Therefore, in the state that their cutouts 75 face each other, the cutouts 75 form a passage H between the valve bodies 71 as shown in FIG. 2 and FIG. 3. By the rotation of the valve bodies 71 about their axes, the hole diameter of the passage H can be changed steplessly (the area of the passage H on a plane along the axial center 73 can be changed). This passage H is a hole continuing from the feed tank 11, and by adjusting the hole diameter of the passage H, the amount of the pulverized fuel supplied from the feed tank 11 is adjusted steplessly.

[0035] The powder discharge valve 21 has a powder discharge valve indicator 41, and this powder discharge valve indicator 41 is adapted to adjust the aperture of the powder discharge valve 21.

[0036] As aforementioned, the feed tank 11 is connected to the internal pressure gas supply pipe 32 for supplying the internal pressure gas for adjusting the pressure in the feed tank 11, and the internal pressure gas supply pipe 32 has the internal pressure control valve 22 connected thereto. By the aperture of the valve connecting between the feed tank 11 and the internal pressure gas supply pipe 32 of the internal pressure control valve 22, the amount of the internal pressure gas to be supplied to the feed tank 11 is adjusted. In this embodiment, the internal pressure control valve 22 has a function as the exhaust valve for reducing the pressure in the feed tank by exhausting the gas out of the feed tank 11. As the internal pressure control valve 22 has such a function, a three-way valve can be given. Although not shown in this embodiment, the internal pressure control valve 22 may include a valve dedicated to pressure application, which is connected to the internal pressure gas supply pipe 32 and performs only the supply of the internal pressure gas into the feed tank 11, and a valve dedicated to exhaustion, which is connected to the feed tank 11 and exhausts the gas out of the feed tank 11. The internal pressure control valve 22 has an internal pressure control valve indicator 42 connected thereto. The internal pressure control valve indicator 42 is adapted to adjust the aperture of the valve for exhaustion or the valve connecting between the feed tank 11 and the internal pressure gas supply pipe 32 of the internal pressure control valve 22.

[0037] A gas generator 30 is connected to one end of the internal pressure gas supply pipe 32 opposite to the end thereof on the side of the feed tank 11. Part of gas output from the gas generator 30 is introduced into the internal pressure gas supply pipe 32 and used as internal pressure gas.

[0038] The carrier gas main pipe 33 is also connected to the gas generator 30. The carrier gas main pipe 33 is a pipe for introducing carrier gas for conveying the pulverized fuel into the powder delivery pipe 31. Therefore, one end of the carrier gas main pipe 33 is connected to one end of the aforementioned powder delivery pipe 31, opposite to the end thereof on the side of the gas generator 30 is connected to one end of the aforementioned powder delivery pipe 31 opposite to the end thereof on the side of the feed tank 11 based on the powder discharge valve 21. With the carrier gas introduced from the carrier gas main pipe 33 to the powder delivery pipe 31, the pulverized fuel introduced from the feed tank 11 to the powder delivery pipe 31 through the powder discharge valve 21 is conveyed. Furthermore, a pressure indicator 43 is connected to the car-
rier gas main pipe 33 to detect the pressure in the carrier gas main pipe 33 and output a signal based on the pressure in the carrier gas main pipe 33.

[0039] Another part of the gas output from the gas generator 30 is introduced into the carrier gas main pipe 33. Thus, the internal pressure gas and the carrier gas are the same gas species in the present embodiment.

[0040] Furthermore, a fluidizing gas pipe 34 is branched off from the carrier gas main pipe 33, and an end of the fluidizing gas pipe 34 is connected to the powder delivery pipe 31. The portion of the fluidizing gas pipe 34 is connected to the feed tank 11. In the present embodiment, the portion of the fluidizing gas pipe 34 is connected to the feed tank 11. Part of the carrier gas flowing through the carrier gas main pipe 33 is introduced as fluidizing gas into the fluidizing gas pipe 34, and the fluidizing gas is introduced into the feed tank 11 from below via the powder fluidizing portion 54. Since part of the carrier gas is used as the fluidizing gas as described above, the fluidizing gas and the carrier gas are the same gas species in the present embodiment. Furthermore, the fluidizing gas pipe 34 is provided with a fluidizing gas valve 24 in the middle portion thereof. The amount of the fluidizing gas introduced into the feed tank 11 is adjusted by adjusting the aperture of the fluidizing gas valve 24. Furthermore, a fluidizing gas valve indicator 44 is connected to the fluidizing gas valve 24, and is adapted to adjust the aperture of the fluidizing gas valve 24.

[0041] In addition, a fluidizing gas pipe 37 is branched off from the carrier gas main pipe 33 at the portion of the fluidizing gas pipe 34, and one end of the fluidizing gas pipe 37 is connected to the powder delivery pipe 31. The portion of the fluidizing gas pipe 37 is connected to the powder delivery pipe 31. In this embodiment, the portion of the fluidizing gas pipe 37 is connected between the powder fluidizing portion 54 and the powder discharge valve 21 in the powder delivery pipe 31. In this embodiment, the portion of the fluidizing gas pipe 37 is connected between the powder fluidizing portion 54 and the powder discharge valve 21. The fluidizing gas is introduced from the powder fluidizing portion 57 to the powder delivery pipe 31. In FIG. 1, the powder delivery pipe 31 connects between the powder fluidizing portion 57 and the powder discharge valve 21; however, the powder fluidizing portion 57 is preferably connected to the powder fluidizing portion 57 directly. In this manner, part of the carrier gas flowing through the carrier gas main pipe 33 is introduced into the fluidizing gas pipe 37 as the fluidizing gas, and the fluidizing gas is introduced from between the powder fluidizing portion 54 and the powder fluidizing portion 57. As described above, the fluidizing gas pipe 37 is branched off from the carrier gas main pipe 33, and the fluidizing gas and the carrier gas are the same gas species in the present embodiment. Thus, all of the fluidizing gas, the fluidizing gas, and the carrier gas are the same gas species. Furthermore, the fluidizing gas valve 27 is provided in a middle portion of the fluidizing gas pipe 37, and the amount of the introduced fluidizing gas is adjusted by adjusting the aperture of the fluidizing gas valve 27. Furthermore, a fluidizing gas valve indicator 47 is connected to the fluidizing gas valve 27, and is adapted to adjust the aperture of the fluidizing gas valve 27.

[0042] In addition, a pressure indicator 49 is connected to a portion of the powder delivery pipe 31 where the pulverized fuel is conveyed by the carrier gas, that is, a portion downstream of the position at the powder delivery pipe 31 to which the carrier gas main pipe 33 is connected, and is configured to detect the pressure in the powder delivery pipe 31 and output a signal containing information based on the pressure in the powder delivery pipe 31. A powder flowmeter 40 is further provided in the portion of the powder delivery pipe 31 where the pulverized fuel is conveyed by the carrier gas, and is adapted to detect the powder flow rate flowing through the powder delivery pipe 31 and output a signal containing the detected information.

[0043] In such a powder supply device, the pressure in the feed tank 11 is higher than the pressure in the carrier gas main pipe 33, and the pressure in the carrier gas main pipe 33 is higher than the pressure in the powder delivery pipe 31. The powder supply device 1 is adapted to convey the pulverized fuel by utilizing the differential pressures between these pressures. These pressures are not particularly limited, but may be in a range of 2 MPa to 4 MPa, for example.

[0044] By adjusting the pressure in the feed tank 11, the differential pressure between the pressure in the feed tank 11 and the pressure in the powder delivery pipe 31 can be adjusted. As described above, the pulverized fuel is conveyed using the differential pressure in the powder supply device 1; therefore, the flow rate of the pulverized fuel to be supplied from the feed tank 11 can be adjusted by the differential pressure in addition to the aperture of the powder discharge valve 21. In the case of adjusting the flow rate of the pulverized fuel by controlling the differential pressure as above, the minute control of the powder flow rate is possible as compared to the case where the flow rate of the pulverized fuel is adjusted by controlling the aperture of the powder discharge valve 21.

[0045] The powder supply device 1 further includes a controller 60 and a memory 61 connected to the controller 60. The controller 60 is connected to the powder flowmeter 40, the pressure indicators 43, 48, and 49, and the weight indicator/controller 46. The controller 60 accepts the input of a signal including the information related to the powder flow rate output from the powder flowmeter 40, a signal including the information related to the pressure in the carrier gas main pipe 33 output from the pressure indicator 43, a signal including the information related to the pressure in the feed tank 11 output from the pressure indicator 48, a signal including the information related to the pressure in the powder delivery pipe 31 output from the pressure indicator 49, a signal including the information related to the weight of the pulverized fuel in the feed tank 11 output from the weight indicator/controller 46, and the like. Then, the controller 60 generates a control signal based on the information of the memory 61 and the information from the powder flowmeter 40. On this occasion, the controller 60 uses the signals from the pressure indicators 43, 48, and 49, and the signal output from the weight indicator/controller 46 as necessary. The controller 60 is connected to the powder discharge valve indicator 41, the internal pressure control valve indicator 42, the fluidizing gas valve indicator 44, and the fluidizing gas valve indicator 47, and inputs the generated control signals to those indicators.

[0046] The powder discharge valve indicator 41 is adapted to adjust the aperture of the powder discharge valve 21 based on the control signal from the controller 60. Therefore, in the case where the controller 60 outputs the control signal based on the signal from the powder flowmeter 40, the powder discharge valve indicator 41 adjusts the aperture of the powder discharge valve 21 based on the information from the powder flowmeter 40. On the other hand, in the case where the
controller 60 outputs the control signal based on the information of the memory 61, the powder discharge valve indicator 41 adjusts the aperture of the powder discharge valve 21 based on the information of the memory 61.

Moreover, the internal pressure control valve indicator 42 is adapted to adjust the aperture of the exhaust valve or the aperture of the valve connecting between the feed tank 11 and the internal pressure gas supply pipe 32 of the internal pressure control valve 22 based on the signal from the controller 60. As a result, in the case where the controller 60 outputs the control signal based on the signal from the powder flowmeter 40, the internal pressure control valve indicator 42 adjusts the aperture of the internal pressure control valve 22 based on the information from the powder flowmeter 40. On the other hand, in the case where the controller 60 outputs the control signal based on the information of the memory 61, the internal pressure control valve indicator 42 adjusts the aperture of the internal pressure control valve 22 based on the information of the memory 61. Note that the controller 60 uses the signals from the pressure indicators 43, 48, and 49 as necessary when generating the control signal that controls the internal pressure control valve 22.

Furthermore, the fluidizing gas valve indicator 44 is configured to adjust the aperture of the fluidizing gas valve 24 on the basis of a control signal from the controller 60. Therefore, when the controller 60 outputs the control signal based on the signal from the powder flowmeter 40, the fluidizing gas valve indicator 44 adjusts the aperture of the fluidizing gas valve 24 based on the information from the powder flowmeter 40. On the other hand, when the controller 60 outputs the control signal based on the information of the memory 61, the fluidizing gas valve indicator 44 adjusts the aperture of the fluidizing gas valve 24 based on the information of the memory 61.

Furthermore, the refueling gas valve indicator 47 is configured to adjust the aperture of the refueling gas valve 27 on the basis of a control signal from the controller 60. Therefore, when the controller 60 outputs the control signal based on the aperture of the powder discharge valve 21, the refueling gas valve indicator 47 adjusts the aperture of the refueling gas valve 27 based on the aperture of the powder discharge valve 21. In this case, the control signal based on the aperture of the powder discharge valve 21 to be output from the controller may be generated based on the control signal to be output from the controller 60 to the powder discharge valve indicator 41. On the other hand, when the controller 60 outputs the control signal based on the information of the memory 61, the refueling gas valve indicator 47 adjusts the aperture of the refueling gas valve 27 based on the information of the memory 61.

FIG. 4 is a diagram schematically showing part of the information of the memory 61. In particular, the diagram schematically shows a table representing the relation of the powder flow rate, the aperture of the powder discharge valve 21, and the differential pressure between the pressure in the feed tank 11 and the pressure in the powder delivery pipe 31. This table is referred to as a table 1. As shown in FIG. 4, when the powder flow rate [kg/h] has been specified, the relation between the differential pressure [MPa] and the aperture [%] of the powder discharge valve 21 relative to the powder flow rate is specified. For example, when the powder flow rate is 500 [kg/h], the aperture of the powder discharge valve 21 is 60% and the differential pressure is 0.05 [MPa]. Then, the controller controls the aperture of the powder discharge valve 21 or the aperture of the internal pressure control valve 22 on the basis of the information of the memory 61 representing the aperture of the powder discharge valve 21 as necessary. Note that such a table in the memory 61 is obtained in advance through experiments or the like and recorded in the memory 61.

FIG. 5 is a diagram schematically showing the information different from the information in the table 1 in the memory 61. Specifically, FIG. 5 is a diagram schematically showing a table representing, in the case where the mode of the controller 60 becomes the rapid load reduction mode, the relation between the time elapsed from the start of the rapid load reduction mode and the scheduled powder flow rate at that time. This table is referred to as a table 2. This scheduled powder flow rate refers to the flow rate of the pulverized fuel to be supplied from the feed tank 11 at that time. In other words, the scheduled powder flow rate refers to the powder flow rate to be the index in the middle of the rapid load mode for reducing the powder flow rate to the predetermined rate in the predetermined period of time after the start of the rapid load reduction mode. As shown in FIG. 5, when the elapsed time [sec] from the start of the rapid load reduction mode has been specified, the ratio [%] of the scheduled powder flow rate relative to the powder flow rate that is just before the rapid load reduction mode is set is specified. For example, when the elapsed time from the start of the rapid load reduction mode is 20 [sec], the scheduled powder flow rate at that time is 83.3 [%] of the powder flow rate that is just before the rapid load reduction mode is set.

In the powder supply device 1, the powder delivery pipe 31 is directly or indirectly connected to a combustion furnace 100 for burning the pulverized fuel to extract energy.

Next, description is made of the operation of the powder supply device 1 and a method of adjusting the powder flow rate of the pulverized fuel by the powder supply device 1.

FIG. 6 is a flowchart of a method of adjusting the powder flow rate in the rapid load reduction mode.

As shown in FIG. 6, the method of supplying the powder flow rate by the powder supply device 1 includes STEP1 of operating the device in a normal operation mode, STEP2 of changing the mode from the normal operation mode to the rapid load reduction mode in which the internal pressure control valve 22 is set to the exhaust state and the powder discharge valve is closed to the predetermined aperture, and STEP3 of controlling at least one of the internal pressure control valve and the powder discharge valve on the basis of the information of the powder flow rate.

First, the powder supply device 1 is operated in the normal operation mode. On this occasion, the feed tank 11 is already filled with the pulverized fuel supplied from the pressure equalizing tank 12. The fluidizing gas is introduced into the feed tank 11 from the fluidizing gas pipe 34 through the powder fluidizing portion 54, thereby fluidizing the pulverized fuel in the feed tank 11.

When the flow rate of the powder to be supplied from the feed tank 11 has been determined, the controller 60 determines the aperture of the powder discharge valve 21 and the differential pressure between the pressure in the feed tank 11 and the pressure in the carrier gas main pipe 33 for the determined powder flow rate with reference to the table 1 in the memory 61. Next, the controller 60 transmits the control
signal that determines the aperture of the powder discharge valve 21 generated based on the information of the memory 61 to the powder discharge valve indicator 41, and the powder discharge valve indicator 41 adjusts the aperture of the powder discharge valve 21 based on the control signal. Thus, the aperture of the powder discharge valve 21 is controlled based on the information of the memory 61. Furthermore, the controller 60 generates the control signal that determines the aperture of the valve, which connects between the feed tank 11 and the internal pressure gas supply pipe 32 of the internal pressure control valve 22, based on the data of the memory 61 and the information from the pressure indicators 49 and 46, and transmits this control signal to the internal pressure control valve indicator 42. The internal pressure control valve indicator 42 adjusts the aperture of the internal pressure control valve 22 based on this control signal. When the aperture of the internal pressure control valve 22 has been adjusted, the differential pressure between the pressure in the feed tank 11 and the pressure in the powder delivery pipe 31 is in the predetermined range. Thus, the powder is supplied from the feed tank 11.

In the case where the amount of the refluidizing gas to be introduced is determined based on the aperture of the powder discharge valve 21 as described above, the aperture of the refluidizing gas valve 27 is decreased as the aperture of the powder discharge valve 21 is increased, in which case the amount of the refluidizing gas to be introduced becomes smaller. In other words, the amount of the refluidizing gas to be introduced is controlled to be inversely proportional to the aperture of the powder discharge valve 21.

Next, in the case where the signal including the information of the powder flow rate from the powder flowmeter 40 indicates that there is a difference between the determined powder flow rate and the powder flow rate in the powder delivery pipe 31 and this difference is in the predetermined range, the controller 60 controls the internal pressure control valve 22 to adjust the differential pressure between the pressure in the feed tank 11 and the pressure in the carrier gas main pipe 33. This is because the more precise control for the powder flow rate is possible when the differential pressure between the pressure in the feed tank 11 and the pressure in the carrier gas main pipe 33 is adjusted by controlling the internal pressure control valve 22 than when the aperture of the powder discharge valve 21 is adjusted. On the other hand, when this difference is out of the predetermined range, the controller 60 controls the aperture of the powder discharge valve 21 again to adjust the differential pressure between the pressure in the feed tank 11 and the pressure in the carrier gas main pipe 33. In this manner, in the normal operation mode, the feedback control is made by the signal including the information of the powder flow rate from the powder flowmeter 40 to enable the correct adjustment of the powder flow rate.

FIG. 7 is a diagram showing the change over time of the scheduled powder flow rate SV in the rapid load reduction mode and the powder flow rate PV from the feed tank 11. In this embodiment, as shown in FIG. 7, t1 represents the time at which the mode becomes the rapid load reduction mode and t3 represents the time after a predetermined period of time from the time t1, and the powder flow rate to be the predetermined flow rate at the time t3 is 50% of the powder flow rate that is before the rapid load reduction mode.

As shown in FIG. 7, upon the reception of an abnormality signal of the combustion furnace 100 or the input of the signal notifying the abnormality from an operator in the controller 60 at the time t1, the mode of the controller 60 becomes the rapid load reduction mode.

When the mode has become the rapid load reduction mode, the controller 60 first sets the internal pressure control valve 22 to the exhaust state. In other words, in this embodiment, the aperture of the valve connecting between the feed tank 11 and the internal pressure gas supply pipe 32 of the internal pressure control valve 22 is decreased to set the exhaust valve for reducing the pressure in the feed tank by exhausting the gas in the feed tank 11 to have the predetermined aperture, thereby exhausting the gas in the feed tank 11. This reduces the differential pressure between the pressure in the feed tank and the pressure in the powder delivery pipe 31 to reduce the pressure that extrudes the powder. After that, the controller 60 controls to close the powder discharge valve 21 to the predetermined aperture. The period after the internal pressure control valve 22 is set to the exhaust state and before the powder discharge valve 21 is closed to the predetermined aperture is not particularly limited but is 3 seconds, for example. By setting the internal pressure control valve 22 to the exhaust state and closing the powder discharge valve 21 to the predetermined aperture, the flow rate of the powder supplied from the feed tank 11 is reduced. On this occasion, the internal pressure control valve 22 and the powder discharge valve 21 are controlled without the feedback of the information related to the powder flow rate from the powder flowmeter so that the average of the inclination of the powder flow rate PV after the powder flow rate PV starts to drop is increased in the negative direction as compared with the average of the inclination of the scheduled powder flow rate SV. In other words, the internal pressure control valve 22 is set to the exhaust state and the powder discharge valve 21 is closed to the predetermined aperture so that the powder flow rate becomes smaller than the predetermined flow rate (50% of the powder flow rate that is before the mode becomes the rapid load reduction mode) after the predetermined period of time (at the time t3). The control of the internal pressure control valve 22 and the powder discharge valve 21 is obtained by experiments in advance. As described above, the powder discharge valve 21 in this embodiment has a hole diameter of the passage H changeable steplessly, whereby the amount of the pulverized fuel to be supplied from the feed tank 11 can be adjusted steplessly. Therefore, when the mode is the urgent load reduction mode, the pressure reduction in the feed tank 11 by the internal pressure control valve 22 and the aperture of the powder discharge valve 21 can be balanced.

Moreover, the reason why the internal pressure control valve 22 is set to the exhaust state before the powder discharge valve 21 is closed to the predetermined aperture when the mode is the rapid load reduction mode is as follows. When the powder discharge valve 21 is closed to the predetermined aperture, the pressure in the feed tank 11 tends to increase temporarily. Even if the timing at which the internal pressure control valve 22 is set to the exhaust state and the timing at which the powder discharge valve 21 is closed to the predetermined aperture are simultaneous, this tendency is caused due to the temporal delay of the exhaustion or the like. Therefore, in the initial stage of the rapid load reduction
mode, the powder flow rate may not be reduced as much as expected even though the powder discharge valve is closed to the predetermined aperture for rapidly reducing the powder flow rate. In view of this, the gas in the feed tank 11 is exhausted before the powder discharge valve 21 is closed to the predetermined aperture. As a result, even though the powder discharge valve 21 is closed to the predetermined aperture, the pressure in the feed tank 11 is prevented from becoming higher than the pressure before the exhaustion. Thus, the powder flow rate can be rapidly reduced by controlling the internal pressure control valve 22 and the powder discharge valve 21 in this manner.

[0064] In the rapid load reduction mode, the controller 60 compares the scheduled powder flow rate SV and the actual powder flow rate PV. The scheduled powder flow rate SV in FIG. 7 is obtained so that the decrease in powder flow rate is constant in the case where the powder flow rate is decreased to the predetermined flow rate after the predetermined period of time. The information in the decrease in powder flow rate is set constant so that the scheduled powder flow rate SV of this embodiment after 60 seconds becomes 50.0% of the powder flow rate that is before the rapid load reduction mode is represented based on the table 2 of the memory 61 of FIG. 5. The actual powder flow rate PV is represented based on the information from the powder flowmeter 40.

[0065] As described above, the flow rate of the powder supplied from the feed tank 11 is reduced in the rapid load reduction mode. As shown in FIG. 7, however, the powder flow rate PV does not start to decrease just after the mode has become the rapid load reduction mode but starts to decrease after a predetermined period of time because of the time required for operating the internal pressure control valve 22 or the powder discharge valve 21 or the temporal delay after the start of the operation of the internal pressure control valve 22 or the powder discharge valve 21. Therefore, for a while after the mode becomes the rapid load reduction mode, the powder flow rate PV from the feed tank 11 transits more than the scheduled powder flow rate SV.

[0066] As the time elapses, the difference between the powder flow rate PV and the scheduled powder flow rate SV is reduced and at the time t2, the difference between the powder flow rate PV and the scheduled powder flow rate SV no longer exists.

<STEP3>

[0067] As soon as the powder flow rate PV becomes smaller than the scheduled powder SV, the controller 60 controls at least one of the internal pressure control valve 22 and the powder discharge valve 21 on the basis of the information related to the powder flow rate from the powder flowmeter 40 so that the powder flow rate PV becomes the scheduled powder flow rate SV. In other words, the controller 60 performs the feedback control on at least one of the internal pressure control valve 22 and the powder discharge valve 21 by using the information related to the powder flow rate from the powder flowmeter 40 so that the powder flow rate PV gets closer to the scheduled powder SV. The powder flow rate PV from the feed tank 11 is smaller than the scheduled powder flow rate SV just after the elapse of the time t2; therefore, in the case of controlling the internal pressure control valve 22 at this time, the controller 60 controls to reduce the exhaustion from the feed tank 11 and in the case of controlling the powder discharge valve 21 at this time, the controller 60 controls the aperture to open the powder discharge valve 21. Note that the more precise control for the powder flow rate is possible when the differential pressure between the pressure in the feed tank 11 and the pressure in the carrier gas main pipe 33 is adjusted than when the aperture of the powder discharge valve 21 is fixed.

[0068] At the time t3, the amount of powder becomes the predetermined amount and the rapid load reduction mode ends.

[0069] Thus, the flow rate of the powder to be supplied to the combustion furnace 100 is rapidly decreased. Just after the end of the rapid load reduction mode, the control for increasing the powder flow rate is not made again and the normal control to make the powder flow rate of the predetermined flow rate is continued until another instruction is made.

[0070] As described above, in the powder supply device 1 according to this embodiment, the pressure in the feed tank 11 is reduced by having the internal pressure control valve 22 in the exhaust state in the rapid load reduction mode, whereby the differential pressure between the pressure in the feed tank 11 and the pressure in the powder delivery pipe is reduced and in addition, the powder discharge valve 21 is closed to the predetermined aperture. Thus, the flow rate of the powder to be supplied from the feed tank 11 can be reduced rapidly. After the flow rate of the powder supplied from the feed tank 11 is reduced to be smaller than the scheduled powder flow rate for reducing the powder flow rate to the predetermined flow rate after the predetermined period of time, at least one of the internal pressure control valve 22 and the powder discharge valve 21 is subjected to the feedback control by the information from the powder flowmeter 40. Therefore, the undershooting of the powder flow rate at the end of the rapid load reduction mode can be suppressed. In this manner, in the powder supply device 1 of the present invention, the undershooting of the powder flow rate is suppressed while the powder flow rate is rapidly reduced.

[0071] Moreover, in this embodiment, the scheduled powder flow rate is determined based on the powder flow rate that is just before the rapid load reduction mode is set. Therefore, the flow rate can be set to the scheduled powder flow rate that is appropriate in accordance with the circumstance of the powder supply, and the rapid reduction of the powder flow rate can be performed smoothly.

[0072] While the present invention has been described above by reference to the embodiment as an example, the present invention is not limited thereto.

[0073] For example, in the above embodiment, as soon as the powder flow rate PV becomes smaller than the scheduled powder flow rate SV in STEP3, the controller 60 may control only the powder discharge valve 21 or may control both the internal pressure control valve 22 and the powder discharge valve 21.

[0074] In the above embodiment, the internal pressure control valve 22 and the powder discharge valve 21 are controlled based on the information of the powder flow rate from the powder flowmeter 40. The present invention is not limited thereto, however, and the controller 60 may calculate the powder flow rate based on the information from the weight indicator/controller 46 and control the internal pressure control valve 22 and the powder discharge valve 21.

[0075] In the above embodiment, other kinds of valve may be employed as the powder discharge valve 21. For example,
a ball valve having a penetration hole with a predetermined inner diameter in a sphere may be used.

[0076] In the above embodiment, the scheduled powder flow rate is determined based on the powder flow rate that is just before the rapid load reduction mode is set; however, the present invention is not limited thereto. For example, the scheduled powder flow rate in the rapid load reduction mode may be the flow rate not based on the powder flow rate that is just before the rapid load reduction mode is set. In this case, for example, the scheduled powder flow rate in the table 2 in the memory 61 corresponds to the absolute flow rate represented by [kg/h].

[0077] Furthermore, the pulverized fuel in the feed tank is fluidized by the fluidizing gas and further refluidized in the powder delivery pipe 31 in the embodiment described above, the fluidizing and refluidizing of the pulverized fuel are not essential.

[0078] Furthermore, although the powder supply device for supplying powder that is pulverized fuel, such as pulverized coal, has been described in the embodiment described above, the present invention is not limited thereto and can be applied to a powder supply device for supplying powder other than the pulverized fuel.

INDUSTRIAL APPLICABILITY

[0079] As described above, the present invention provides the powder supply device and the powder supply method capable of suppressing the undershooting of the powder flow rate while rapidly reducing the powder flow rate, and the present invention can be applied to a powder supply device for supplying the pulverized fuel to the combustion furnace that is used in blast furnace facilities or thermal power plants or other powder supply devices.

REFERENCE SIGNS LIST

[0108] 61...memory
[0109] 100...combustion furnace
1. A powder supply device that supplies powder in a feed tank to the outside of the feed tank through a powder delivery pipe connected to the feed tank, the device comprising:
   an internal pressure control valve that is connected to the feed tank and that adjusts pressure in the feed tank;
   a powder discharge valve that is connected to the powder delivery pipe; and
   a controller that controls the internal pressure control valve and the powder discharge valve, wherein:
in a rapid load reduction mode for reducing a flow rate of powder to be supplied to the outside of the feed tank to a predetermined rate after a predetermined period of time, the controller sets the internal pressure control valve to an exhaust state of reducing the pressure in the feed tank and closes the powder discharge valve to a predetermined aperture so that the powder flow rate becomes smaller than the predetermined rate after the predetermined period of time; and
as soon as the powder flow rate becomes smaller than a scheduled powder flow rate that is expected before elapse of the predetermined period of time for reducing the powder flow rate to the predetermined rate after the predetermined period of time, the controller controls at least one of the internal pressure control valve and the powder discharge valve on the basis of information of the powder flow rate so that the powder flow rate becomes the scheduled powder flow rate.

2. The powder supply device according to claim 1, wherein the scheduled powder flow rate is determined based on the powder flow rate that is just before the rapid load reduction mode is set.

3. The powder supply device according to claim 1, wherein:
   the powder delivery pipe has a powder flowmeter connected thereto; and
   as soon as the powder flow rate becomes smaller than the scheduled powder flow rate, the controller controls the internal pressure control valve and the powder discharge valve on the basis of information from the powder flowmeter.

4. The powder supply device according to claim 1, wherein the controller sets the internal pressure control valve to the exhaust state before the powder discharge valve is closed to the predetermined aperture.

5. A powder supply method for supplying powder in a feed tank to the outside of the feed tank through a powder delivery pipe connected to the feed tank, the method comprising:
in a rapid load reduction mode for reducing a flow rate of powder to be supplied to the outside of the feed tank to a predetermined rate after a predetermined period of time, setting an internal pressure control valve connected to the feed tank to an exhaust state of reducing pressure in the feed tank and closing a powder discharge valve connected to the powder delivery pipe to a predetermined aperture so that the powder flow rate becomes smaller than the predetermined rate after the predetermined period of time; and
as soon as the powder flow rate becomes smaller than a scheduled powder flow rate that is expected before elapse of the predetermined period of time for reducing the powder flow rate to the predetermined rate after the predetermined period of time, adjusting at least one of
the internal pressure control valve and the powder discharge valve on the basis of information of the powder flow rate so that the powder flow rate becomes the scheduled powder flow rate.

6. The powder supply method according to claim 5, wherein the scheduled powder flow rate is determined based on the powder flow rate that is just before the rapid load reduction mode is set.

7. The powder supply method according to claim 5, wherein as soon as the powder flow rate becomes smaller than the scheduled powder flow rate, the internal pressure control valve and the powder discharge valve are adjusted based on information from a powder flowmeter connected to the powder delivery pipe.

8. The powder supply method according to claim 5, wherein the internal pressure control valve is set to the exhaust state before the powder discharge valve is closed to the predetermined aperture.

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