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(71) Applicant: **Mitsubishi Heavy Industries, Ltd.**
Tokyo 108-8215 (JP)

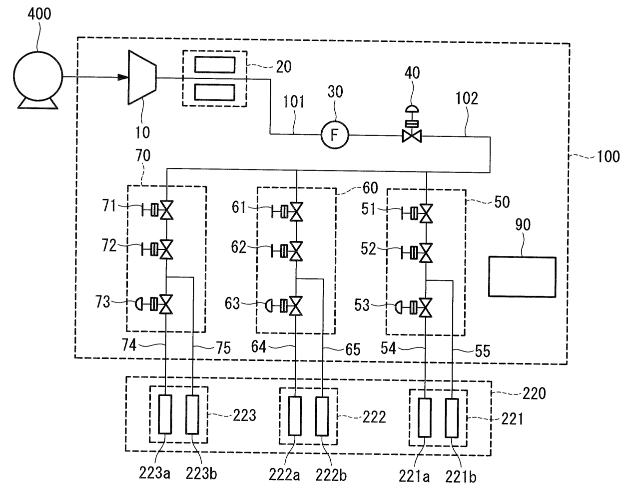
(72) Inventors:
- **NAKAMURA, Ryuta**
Nagasaki-shi
Nagasaki 850-8610 (JP)
- **MATSUSHITA, Koichi**
Nagasaki-shi
Nagasaki 850-8610 (JP)

(74) Representative: **Hoffmann Eitle**
Patent- und Rechtsanwälte PartmbB
Arabellastraße 30
81925 München (DE)

(54) FUEL SUPPLY DEVICE AND MARINE BOILER PROVIDED THEREWITH, AND FUEL SUPPLY DEVICE CONTROL METHOD

(57) Provided is a fuel supply system (100) including a fuel gas supply header (102) through which fuel gas supplied from an LNG tank (400) flows; a main nozzle supply pipe (54); a pilot nozzle supply pipe (55); a control valve (53) provided to the main nozzle supply pipe (54); and a control unit (90) that controls the degree of opening of the control valve (53). The control unit (90) controls the control valve (53) so that when the flow rate of the fuel gas supplied from the fuel gas supply header (102) to the first burner (221) is less than a predetermined flow rate, the control valve (53) is closed, and when the flow rate of the fuel gas supplied from the fuel gas supply header (102) to the first burner (221) is greater than or equal to the predetermined flow rate, the degree of opening of the control valve (53) increases with an increase in the flow rate of the fuel gas.

FIG. 2



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Description

[Technical Field]

[0001] The present invention relates to a fuel supply system and a marine boiler including the same, and a method of controlling the fuel supply system.

[Background Art]

[0002] In recent years, from the viewpoint of environmental protection, regulations on the sulfur content in ship fuel (especially heavy oil) have been stricter. Light oil which has a low sulfur content can be used instead of heavy oil; however, a high price of light oil greatly impairs the operational profit.

[0003] Meanwhile, a liquefied natural gas carrier (an LNG ship) is known which generates steam by combusting liquefied natural gas stored in a liquefied natural gas tank (LNG tank) or boil-off gas generated in the LNG tank, with a burner unit in the boiler, and obtains propulsive force by rotating a propeller through a steam turbine (see, Patent Literature 1, for example). An LNG ship can use fuel gas free from sulfur, such as liquefied natural gas or boil-off gas, as a fuel for obtaining propulsive force, and is therefore advantageous from the viewpoint of environmental protection.

[Citation List]

[Patent Literature]

[0004] [PTL 1]
Japanese Unexamined Patent Application, Publication No. 2014-118047

[Summary of Invention]

[Technical Problem]

[0005] However, the LNG ship described in Patent Literature 1 supplies fuel gas to the boiler at a constant flow rate even when the load on the steam turbine is low so that an amount of steam greater than the amount of steam required by a steam turbine for the main engine can be constantly generated. The LNG ship described in Patent Literature 1 returns excess steam with respect to the load on the steam turbine to a main water condenser from a dump steam pipe. Accordingly, the LNG ship described in Patent Literature 1 wastes the energy of the fuel gas for generation of steam to be returned from the dump steam pipe to the main water condenser. To avoid such a waste, the amount of fuel gas to be supplied should be reduced according to the load on the steam turbine.

[0006] Here, in such an LNG ship described in Patent Literature 1, the turndown ratio (a ratio between the maximum flow rate and controllable minimum flow rate at the rated output power) for fuel gas supplied to the burner unit is generally about 7:1. Further, the square root of the flow rate of fuel gas is proportional to the pressure of fuel gas. Therefore, if the flow rate of fuel gas with a turndown ratio of 7:1 is controlled by a single control valve between the minimum flow rate and maximum flow rate, the pressure of fuel gas for supply at the minimum flow rate becomes 1/49 (the square of 1/7) of the pressure for supply to the burner unit at the maximum flow rate. For this reason, unless the pressure of the fuel gas present upstream from a single control valve is made excessively high, the pressure of fuel gas for supply at the minimum flow rate goes too low and stable combustion cannot be maintained due to accidental fire or the like.

[0007] As described above, when the steam turbine is operated at low load, i.e., when fuel gas is supplied to the burner unit at the minimum flow rate, avoidance a waste of the energy of fuel gas and maintenance of stable combustion using fuel gas only could not be attained.

[0008] An object of the present invention, which has been made in this background, is to provide a fuel supply system that enables maintenance of stable combustion using fuel gas only without wasting the energy of fuel gas, from a low-load region in which a small amount of fuel gas is supplied to a burner unit to a high-load region in which a large amount of fuel gas is supplied to the burner unit; a marine boiler including the fuel supply system; and a method of controlling the fuel supply system.

[Solution to Problem]

[0009] To solve the above-described problem, the present invention employs the following solutions.

[0010] In particular, a fuel supply system of one aspect of the present invention is used for a marine boiler and supplies fuel gas to a burner unit including a main nozzle and a sub-nozzle, the fuel supply system including: a first supply pipe through which the fuel gas supplied from a supply source flows; a second supply pipe that supplies the fuel gas from the first supply pipe to the main nozzle; a third supply pipe that supplies the fuel gas from the first supply pipe to the sub-nozzle; a first adjustment valve that is provided to the second supply pipe and adjusts the flow rate of the fuel gas guided from the first supply pipe to the main nozzle through the second supply pipe; and a control unit that controls the degree of opening of the first adjustment valve. The control unit controls the first adjustment valve so that when the flow rate of the fuel gas supplied from the first supply pipe to the burner unit is less than a predetermined flow rate, the first adjustment valve is closed, and when the flow rate of the fuel gas supplied from the first supply pipe to the burner unit is greater than or equal to the predetermined flow rate, the degree of opening of the first adjustment valve increases with an increase in the flow rate of the fuel gas.

[0011] In the fuel supply system of one aspect of the present invention, in the low-load region in which the flow rate of fuel gas supplied from the first supply pipe to the burner unit is less than a predetermined flow rate, the first adjustment valve is closed and the total amount of fuel gas supplied from the first supply pipe to the burner unit is guided from the third supply pipe to the sub-nozzle. In this low-load region, the first adjustment valve is closed, so that the pressure of fuel gas decreases in proportion to the square root of the flow rate of fuel gas. However, the range of flow rate in the low-load region is limited to a certain range, which can suppress fluctuations in the pressure of fuel gas according to variations in flow rate.

[0012] In addition, in the fuel supply system of one aspect of the present invention, in the high-load region in which the flow rate of fuel gas supplied from the first supply pipe to the burner unit is greater than or equal to a predetermined flow rate, the degree of opening of the first adjustment valve increases with an increase in the flow rate of fuel gas. Increasing the cross-sectional area of the flow path of the burner unit by increasing the degree of opening of the first adjustment valve makes it possible to decrease the pressure of fuel gas required for supplying fuel gas to the burner unit at a desired flow rate.

[0013] In this manner, in the fuel supply system of one aspect of the present invention, from the low-load region in which the burner unit is supplied with a small amount of fuel gas, to the high-load region in which the burner unit is supplied with a large amount of fuel gas, maintenance of stable combustion using fuel gas only can be achieved without wasting the energy of fuel gas. In this case, it is unnecessary to set the pressure of fuel gas on the supply source side to an excessively high value.

[0014] A fuel supply system of one aspect of the present invention may include a second adjustment valve that adjusts the flow rate of the fuel gas supplied from the supply source to the first supply pipe, and the control unit may control the degree of opening of the second adjustment valve. In this configuration, the second adjustment valve can adjust the flow rate of the fuel gas supplied from the supply source to the first supply pipe to an appropriate value.

[0015] In the fuel supply system with the above-described configuration, the control unit may control the first adjustment valve so that when the flow rate of the fuel gas supplied from the first supply pipe to the burner unit is greater than or equal to the predetermined flow rate, the degree of opening of the first adjustment valve increases with an increase in the degree of opening of the second adjustment valve.

[0016] Hence, in the high-load region in which the flow rate of fuel gas supplied from the first supply pipe to the burner unit is greater than or equal to a predetermined flow rate, the cross-sectional area of the flow path of the burner unit is increased with an increase in the amount of fuel gas supplied to the burner unit, thereby making it possible to decrease the pressure of fuel gas required for supplying fuel gas to the burner unit at a desired flow rate.

[0017] A marine boiler of one aspect of the present invention includes the burner unit and the above-described fuel supply system.

[0018] Since the above-described fuel supply system is provided, from the low-load region in which the burner unit is supplied with a small amount of fuel gas, to the high-load region in which the burner unit is supplied with a large amount of fuel gas, maintenance of stable combustion using fuel gas only can be achieved without wasting the energy of fuel gas.

[0019] A method of controlling a fuel supply system of one aspect of the present invention is a method of controlling a fuel supply system that is used for a marine boiler and supplies fuel gas to a burner unit including a main nozzle and a sub-nozzle, the fuel supply system including: an adjustment valve that adjusts a ratio between the flow rate of the fuel gas guided to the main nozzle and the flow rate of the fuel gas guided to the sub-nozzle, the method including: a first control step of controlling the adjustment valve so that when the flow rate of the fuel gas supplied to the burner unit is less than a predetermined flow rate, the adjustment valve is closed; and a second control step of controlling the adjustment valve so that when the flow rate of the fuel gas supplied to the burner unit is greater than or equal to the predetermined flow rate, the degree of opening of the adjustment valve increases with an increase in the flow rate of the fuel gas.

[0020] In the method of controlling a fuel supply system of one aspect of the present invention, from the low-load region in which the burner unit is supplied with a small amount of fuel gas, to the high-load region in which the burner unit is supplied with a large amount of fuel gas, maintenance of stable combustion using fuel gas only can be achieved without wasting the energy of fuel gas. In this case, it is unnecessary to set the pressure of fuel gas on the supply source side to an excessively high value.

[Advantageous Effects of Invention]

[0021] The present invention can provide a fuel supply system that enables maintenance of stable combustion using fuel gas only without wasting the energy of fuel gas, from a low-load region in which a small amount of fuel gas is supplied to a burner unit to the high-load region in which a large amount of fuel gas is supplied to the burner unit; a marine boiler including the fuel supply system; and a method of controlling the fuel supply system.

[Brief Description of Drawings]

[0022]

[Fig. 1] Fig. 1 is a configuration diagram showing a marine propulsion plant with a marine boiler.
[Fig. 2] Fig. 2 is a configuration diagram of a fuel supply system shown in Fig. 1.
[Fig. 3] Fig. 3 is a diagram showing a relationship between the flow rate of fuel gas and the degrees of opening of a control valve and a flow rate adjustment valve.
[Fig. 4] Fig. 4 is a diagram showing a relationship between the flow rate of fuel gas and the loads on a main nozzle and a pilot nozzle.
[Fig. 5] Fig. 5 is a diagram showing a relationship between the flow rate of fuel gas and the pressure of fuel gas.

[Description of Embodiments]

[0023] A marine propulsion plant 300 with a marine boiler of one embodiment of the present invention will now be described with reference to the accompanying drawings.

[0024] The marine propulsion plant 300 installed in the ship shown in Fig. 1 includes a marine boiler 200 generating steam, a propulsion turbine unit 310 driven by steam generated by the marine boiler 200, and a propulsive force generating unit 320 that is coupled to the propulsion turbine unit 310 and obtains propulsive force for the propulsion of the ship.

[0025] The components of the marine propulsion plant 300 will now be described.

[0026] First, the marine boiler 200 will be described in detail.

[0027] The marine boiler 200 includes a main furnace 210, a burner unit 220, a reheat furnace 230, a reheater 240, and a fuel supply system 100.

[0028] The main furnace 210 of the marine boiler 200 includes a furnace 211 having a hollow generally rectangular parallelepiped shape, a front bank tube 212 through which water flows, a superheater 213 including a primary superheater pipe 213a and a secondary superheater pipe 213b, an evaporation tube group 214, a water drum 215, and a steam drum 216.

[0029] The primary superheater pipe 213a is disposed adjacent to the furnace 211, and the secondary superheater pipe 213b is disposed adjacent to the evaporation tube group 214. The primary superheater pipe 213a and the secondary superheater pipe 213b are coupled to each other so that a path for superheated steam can be formed within them.

[0030] An end of the primary superheater pipe 213a adjacent to the furnace 211 is designed to receive saturated steam generated in the steam drum 216. An end of the secondary superheater pipe 213b adjacent to the evaporation tube group 214 is connected to one end of a superheater outlet pipe L1. Meanwhile, the other hand of the superheater outlet pipe L1 is connected to a branching pipe L2 and a branching pipe L3 of the propulsion turbine unit 310, at a branching position P1.

[0031] The burner unit 220 is a device for combustion of fuel gas supplied from the fuel supply system 100. Combustion of fuel gas in the burner unit 220 is performed within the furnace 211. Exhaust gas caused by combustion of fuel gas is guided from the furnace 211 to the reheat furnace 230 through the superheater 213 and the evaporation tube group 214. The details of the fuel supply system 100 will be described later.

[0032] The reheat furnace 230 is a device provided downstream from the evaporation tube group 214 of the main furnace 210 with respect to the direction of a flow of the exhaust gas, and has a vertically (in the up-and-down direction) extending hollow cylindrical shape. The reheat furnace 230 includes a reheat burner 231 for reheating exhaust gas guided from the furnace 211. The reheat burner 231 is supplied with boil-off gas (fuel gas) from an LNG tank 400, which will be described later, through a fuel pipe L4. The amount of fuel supplied to the reheat burner 231 is adjusted through the flow rate adjustment valve 232. Exhaust gas generated through fuel combustion in the reheat burner 231 and exhaust gas from the furnace 211 generated through reheat in the reheat burner 231 are guided to the reheater 240.

[0033] The reheater 240 is a device for reheating, using the heat of exhaust gas, steam that has been used in the high pressure turbine 311 of the propulsion turbine unit 310, and supplying it to the medium pressure turbine 312 of the propulsion turbine unit 310. The reheater 240 reheats steam guided from the propulsion turbine unit 310, using the heat of exhaust gas guided to the reheater 240. Exhaust gas exchanging heat with steam in the reheater 240 is exhausted to the atmosphere.

[0034] The propulsion turbine unit 310 will now be described in detail.

[0035] The propulsion turbine unit 310 includes a high pressure turbine 311, a medium pressure turbine 312, a low pressure turbine 313, a reverse turbine 314, a water condenser 315, an on/off valve 316 on the branching pipe L2, and an on/off valve 317 on the branching pipe L3.

[0036] The high pressure turbine 311 obtains rotational power through superheated steam supplied from the superheater outlet pipe L1 through the branching pipe L2. Steam that has been used in the high pressure turbine 311 is guided to the top end of the reheater 240.

[0037] The medium pressure turbine 312 obtains rotational power through reheated steam that has been reheated in the reheater 240. Steam that has been used in the medium pressure turbine 312 is guided to the low pressure turbine 313.

[0038] The rotational power that the high pressure turbine 311 and the medium pressure turbine 312 obtain is transferred to the propulsive force generating unit 320 coupled to these turbines.

[0039] The low pressure turbine 313 obtains rotational power through steam guided from the medium pressure turbine 312. The rotational power that the medium pressure turbine 312 obtains is transferred to the propulsive force generating unit 320 coupled to the medium pressure turbine 312. The steam that has been used in the low pressure turbine 313 is guided to the water condenser 315.

[0040] The reverse turbine 314 obtains rotational power through superheated steam supplied from the superheater outlet pipe L1 through the branching pipe L3. The steam that has been used in the reverse turbine 314 is guided to the water condenser 315.

[0041] The water condenser 315 condenses steam guided from the low pressure turbine 313 and the reverse turbine 314 into water, and supplies the water to the steam drum 216 of the main furnace 210.

[0042] The direction of the rotational power that the reverse turbine 314 obtains is the reverse of that of the rotational power that the high pressure turbine 311, the medium pressure turbine 312, and the low pressure turbine 313 obtain.

[0043] The high pressure turbine 311, the medium pressure turbine 312, and the low pressure turbine 313 transfer rotational power for moving the ship forward, to the propulsive force generating unit 320. On the other hand, the reverse turbine 314 transfers rotational power for moving the ship backward, to the propulsive force generating unit 320.

[0044] The on/off valve 316 and the on/off valve 317 are valves that can be opened and closed according to a control device (not shown in the drawing) for the marine propulsion plant 300. The control device for the marine propulsion plant 300 guides superheated steam from the superheater outlet pipe L1 to the high pressure turbine 311 through the branching pipe L2 by opening the on/off valve 316 and closing the on/off valve 317. On the other hand, the control device for the marine propulsion plant 300 guides superheated steam from the superheater outlet pipe L1 to the reverse turbine 314 through the branching pipe L3 by closing the on/off valve 316 and opening the on/off valve 317.

[0045] The propulsive force generating unit 320 will now be described in detail.

[0046] The propulsive force generating unit 320 includes a decelerator 321 for reducing the number of revolutions attained through rotational power transferred from the propulsion turbine unit 310, a propeller shaft 322 coupled to the decelerator 321, and a propeller 323 coupled to the propeller shaft 322. The propulsive force generating unit 320 rotates the propeller 323 through rotational power transferred from the high pressure turbine 311, the medium pressure turbine 312, and the low pressure turbine 313, thereby generating propulsive force for moving the ship forward. Further, the propulsive force generating unit 320 rotates the propeller 323 through rotational power transferred from the reverse turbine 314, thereby generating propulsive force for moving the ship backward.

[0047] Next, the details of the fuel supply system 100 included in the marine boiler 200 of this embodiment will be described with reference to the drawings.

[0048] As shown in Fig. 2, the fuel supply system 100 includes a compressor 10 that compresses fuel gas supplied from the LNG tank (supply source) 400, a heater 20 that heats fuel gas pressurized in the compressor 10, a flowmeter 30 that measures the flow rate of fuel gas flowing along a fuel gas supply path 101, a flow rate adjustment valve (second adjustment valve) 40 that adjusts the flow rate of fuel gas guided from the fuel gas supply path 101 to the fuel gas supply header 102, a first fuel supply unit 50, a second fuel supply unit 60, a third fuel supply unit 70, and a control unit 90.

[0049] In addition, the fuel supply system 100 includes, as a supply system for fuel gas supplied from the LNG tank 400, the fuel gas supply path 101 connected to the LNG tank 400, and the fuel gas supply header 102 (the first supply pipe) that is connected to the fuel gas supply path 101 and through which fuel gas supplied from the LNG tank 400 flows.

[0050] Although the total amount of fuel gas supplied to the fuel gas supply path 101 is supposed to be supplied to the fuel gas supply header 102 in the configuration shown in Fig. 2, another aspect may be employed. For example, when the marine propulsion plant 300 includes a plurality of marine boilers 200, a fuel supply path for distributing fuel gas supplied to the fuel gas supply path 101 among a plurality of marine boilers 200 may be separately provided.

[0051] In addition, the fuel supply system 100 includes a main nozzle supply pipe (the second supply pipe) 54, a main nozzle supply pipe (the second supply pipe) 64, and a main nozzle supply pipe (the second supply pipe) 74 each connected to the fuel gas supply path 101.

[0052] Further, the fuel supply system 100 includes a pilot nozzle supply pipe (the third supply pipe) 55, a pilot nozzle supply pipe (the third supply pipe) 65, and a pilot nozzle supply pipe (the third supply pipe) 75 each connected to the fuel gas supply path 101.

[0053] As shown in Fig. 2, the burner unit 220 of the marine boiler 200 includes a first burner 221, a second burner 222, and a third burner 223. The first burner 221 includes a main nozzle 221a connected to the main nozzle supply pipe 54, and a pilot nozzle 221b connected to the pilot nozzle supply pipe 55. The second burner 222 includes a main nozzle 222a connected to the main nozzle supply pipe 64, and a pilot nozzle 222b connected to the pilot nozzle supply pipe 65. The third burner 223 includes a main nozzle 223a connected to the main nozzle supply pipe 74, and a pilot nozzle 223b connected to the pilot nozzle supply pipe 75.

[0054] Here, the fuel gas supplied to the compressor 10 is boil-off gas generated in the LNG tank 400 that stores a natural gas, which is a hydrocarbon-based flammable gas, in a liquefied state. Boil-off gas refers to gas generated by vaporizing a liquefied natural gas stored in the LNG tank 400, using heat input from the exterior, for example.

[0055] Alternatively, fuel gas supplied to the compressor 10 may be gas generated by forcibly vaporizing a liquefied natural gas through a heat source (not shown in the drawing).

[0056] Although the fuel gas is a natural gas mainly composed of methane here, another aspect may be employed. For example, another hydrocarbon-based flammable gas, such as ethylene, can be used. Thus, in this embodiment, a hydrocarbon-based fuel gas free from sulfur is supplied to the burner unit 220 from the viewpoint of environmental protection.

[0057] The compressor 10 is a device for pressurizing fuel gas supplied from the LNG tank 400. The compressor 10 supplies fuel gas, the pressure of which is increased to about 80 kPa, to the fuel gas supply path 101. In addition, the temperature of fuel gas increases due to the compression through the compressor 10. The temperature of fuel gas is, for example, about -90°C before compression through the compressor 10, and in the range of -80°C to -70°C after the compression.

[0058] The heater 20 is a device for heating fuel gas pressurized in the compressor 10. The heater 20 operates according to control commands from a control device (not shown in the drawing) different from the control unit 90 so that the temperature of fuel gas detected by a temperature sensor (not shown in the drawing) provided downstream from the heater 20 becomes a predetermined temperature (e.g., 30°C).

[0059] The flowmeter 30 is a device for measuring the flow rate of fuel gas supplied from the fuel gas supply path 101 to the fuel gas supply header 102. The flowmeter 30 outputs a measurement signal indicating a measured flow rate of fuel gas to the control unit 90 through a signal line (not shown in the drawing).

[0060] The flow rate adjustment valve 40 is a valve for adjusting the flow rate of fuel gas supplied from the LNG tank 400 to the fuel gas supply header 102. The degree of opening of the flow rate adjustment valve 40 is controlled according to a control signal transferred from the control unit 90 through a signal line (not shown in the drawing) so that a flow rate measured by the flowmeter 30 matches a flow rate set by the control unit 90.

[0061] The first fuel supply unit 50, the second fuel supply unit 60, and the third fuel supply unit 70 are provided to the fuel gas supply header 102.

[0062] The first fuel supply unit 50 is a device for adjusting the ratio between the flow rate of fuel gas supplied from the fuel gas supply header 102 to the main nozzle 221a through the main nozzle supply pipe 54, and the flow rate of fuel gas supplied from the fuel gas supply header 102 to the pilot nozzle 221b through the pilot nozzle supply pipe 55. Similarly, the second fuel supply unit 60 is a device for adjusting the ratio between the flow rate of fuel gas supplied from the fuel gas supply header 102 to the main nozzle 222a through the main nozzle supply pipe 64, and the flow rate of fuel gas supplied from the fuel gas supply header 102 to the pilot nozzle 222b through the pilot nozzle supply pipe 65. Similarly, the third fuel supply unit 70 is a device for adjusting the ratio between the flow rate of fuel gas supplied from the fuel gas supply header 102 to the main nozzle 223a through the main nozzle supply pipe 74, and the flow rate of fuel gas supplied from the fuel gas supply header 102 to the pilot nozzle 223b through the pilot nozzle supply pipe 75.

[0063] The first fuel supply unit 50 includes a shutoff valve 51 and a shutoff valve 52 each provided to the fuel gas supply header 102, and a control valve (the first adjustment valve) 53 for adjusting the flow rate of fuel gas guided from the fuel gas supply header 102, which is provided to the main nozzle supply pipe 54, to the main nozzle 221a through the main nozzle supply pipe 54.

[0064] The shutoff valve 51 and the shutoff valve 52 are opened by the control unit 90 when the burner unit 220 performs combustion of fuel gas, and is closed by the control unit 90 when the burner unit 220 does not perform combustion of fuel gas.

[0065] It should be noted that the detailed description of the shutoff valve 61, the shutoff valve 62, and the control valve 63 in the second fuel supply unit 60, which are similar to the shutoff valve 51, the shutoff valve 52, and the control valve 53 in the first fuel supply unit 50, respectively, will be omitted. Similarly, the detailed description of the shutoff valve 71, the shutoff valve 72, and the control valve 73 in the third fuel supply unit 70, which are similar to the shutoff valve 51, the shutoff valve 52, and the control valve 53 in the first fuel supply unit 50, respectively, will be omitted.

[0066] The control unit 90 is a device for controlling the components of the fuel supply system 100. The control unit 90 controls the degrees of opening of the control valve 53, the control valve 63, and the control valve 73, and the degree of opening of the flow rate adjustment valve 40. The control unit 90 controls the opening/closing states of the shutoff valve 51, the shutoff valve 52, the shutoff valve 61, the shutoff valve 62, the shutoff valve 71, and the shutoff valve 72.

[0067] It should be noted that the control unit 90 is composed of, for example, a central processing unit (CPU), a random access memory (RAM), a read only memory (ROM), or a computer-readable storage medium. A sequence of processing for implementing each function is stored in a storage medium in the form of, for example, a program, and this program is read by a CPU into a RAM or the like so that information is subjected to processing and operations, thereby implementing each function.

[0068] Next, the control over the degree of opening of the control valve 53 and the degree of opening of the flow rate adjustment valve 40 performed by the control unit 90 will be described with reference to Fig s. 3 to 5.

[0069] Although only the first fuel supply unit 50 will be described below, the second fuel supply unit 60 and the third fuel supply unit 70 are similar to the first fuel supply unit 50. Accordingly, the description of the second fuel supply unit 60 and the third fuel supply unit 70 will be omitted below.

[0070] In Figs. 3 to 5, the flow rate [%] of fuel gas represented by the horizontal axis is based on the premise that the flow rate of fuel gas supplied from the first fuel supply unit 50 to the first burner 221 is 100% when the control valve 53 and the flow rate adjustment valve 40 of this embodiment are maintained at the respective maximum degrees of opening, and shows an actual percentage with respect to 100% flow rate of fuel gas.

[0071] The lower limit Fr1 of the flow rate of fuel gas is set to about 15% in Figs. 3 to 5 because the turndown ratio (a ratio between the maximum flow rate and controllable minimum flow rate at the rated output power) of fuel gas of this embodiment is about 7:1.

[0072] It should be noted that the fuel supply system 100 of this embodiment approximately equally supplies fuel gas to the first fuel supply unit 50, the second fuel supply unit 60, and the third fuel supply unit 70, through the fuel gas supply header 102. Accordingly, the flow rates of fuel gas supplied to the first fuel supply unit 50, the second fuel supply unit 60, and the third fuel supply unit 70, respectively are 1/3 of the flow rate of fuel gas measured by the flowmeter 30.

[0073] In addition, when the shutoff valves of any one of the first fuel supply unit 50, the second fuel supply unit 60, and the third fuel supply unit 70 are closed and the shutoff valves of the other fuel supply units are opened, the flow rates of fuel gas supplied to the opened fuel supply units are 1/2 of the flow rate of fuel gas measured by the flowmeter 30.

[0074] In addition, when the shutoff valves of any one of the first fuel supply unit 50, the second fuel supply unit 60, and the third fuel supply unit 70 are opened and the shutoff valves of the other fuel supply units are closed, the flow rate of fuel gas supplied to the opened fuel supply unit is equal to the flow rate of fuel gas measured by the flowmeter 30.

[0075] As indicated by the dashed line in Fig. 3, the control unit 90 controls the degree of opening of the flow rate adjustment valve 40. As shown in Fig. 3, when the control unit 90 gradually increases the degree of opening of the flow rate adjustment valve 40, the flow rate of fuel gas accordingly gradually increases from the lower limit Fr1 to the upper limit Fr3 (the flow rate of 100%).

[0076] Further, the control unit 90 controls the degree of opening of the control valve 53 as indicated by the solid line in Fig. 3. As shown in Fig. 3, when the flow rate of fuel gas supplied from the fuel gas supply header 102 to the first burner 221 is in a low-load region in which it is greater than or equal to Fr1 and less than Fr2 (a predetermined flow rate), the control unit 90 controls the degree of opening of the control valve 53 so that the control valve 53 is closed. Further, when the flow rate of fuel gas supplied from the fuel gas supply header 102 to the first burner 221 is in a high-load region in which it is greater than or equal to Fr2, the control unit 90 controls the control valve 53 so that its degree of opening increases with an increase in the flow rate of fuel gas.

[0077] Next, referring to Fig. 4, adjustment of the ratio between the loads on the main nozzle 221a and the pilot nozzle 221b achieved by adjustment of the degrees of opening of the flow rate adjustment valve 40 and the control valve 53 through the control unit 90 will be described.

[0078] Load [%] represented by the vertical axis in Fig. 4 is based on the premise that the load (output power) on the first burner 221 is 100% when the control valve 53 and the flow rate adjustment valve 40 are maintained at the maximum degree of opening (the maximum load), and shows the actual percentage of the loads on the main nozzle 221a and the pilot nozzle 221b with respect to 100% load.

[0079] As shown in Fig. 4, when the flow rate of fuel gas is in the low-load region in which it is greater than or equal to Fr1 and less than Fr2 (a predetermined flow rate), the control valve 53 is closed, so that the load on the main nozzle 221a is maintained at 0%. In this low-load region, the load on the pilot nozzle 221b gradually increases with an increase in the flow rate of fuel gas.

[0080] Further, as shown in Fig. 4, when the flow rate of fuel gas is in the high-load region in which it is greater than or equal to Fr2, the control valve 53 gradually increases the degree of opening of the control valve 53 with an increase in the flow rate of fuel gas, so that the load on the main nozzle 221a gradually increases. In this high-load region, the load on the pilot nozzle 221b gradually increases with an increase in the flow rate of fuel gas. On the other hand, in the high-load region, the amount of increase in the load on the pilot nozzle 221b with respect to the amount of increase in the flow rate of fuel gas is less than that in the low-load region.

[0081] This is because, in the high-load region, the control unit 90 controls the control valve 53 so that the degree of opening of the control valve 53 increases with an increase in the degree of opening of the flow rate adjustment valve

40. With an increase in the degree of opening of the control valve 53, the ratio of the load on the main nozzle 221a to the load on the pilot nozzle 221b gradually increases. When the flow rate of fuel gas is about 60%, the percentage of the load on the pilot nozzle 221b equals to that of the load on the main nozzle 221a.

[0082] When the flow rate of fuel gas is 100%, the load on the pilot nozzle 221b is about 35%, while the load on the main nozzle 221a is about 65%. Thus, when the flow rate of fuel gas is 100%, the ratio between the flow rates of fuel gas to the pilot nozzle 221b and the main nozzle 221a is 65:35, and the sum of the load on the pilot nozzle 221b and the load on the main nozzle 221a is 100%.

[0083] Next, referring to Fig. 5, a relationship between the flow rate of fuel gas and the pressure of fuel gas will be described.

[0084] The pressure [kPa] of fuel gas represented by the vertical axis in Fig. 5 is the pressure of fuel gas in the fuel gas supply header 102. The pressure of fuel gas supplied to the fuel gas supply header 102 is decreased in the way from the fuel gas supply path 101 to the flow rate adjustment valve 40.

[0085] As indicated by the solid line in Fig. 5, either in the low-load region in which the flow rate of fuel gas is greater than or equal to Fr1 and less than Fr2 (a predetermined flow rate) or in the high-load region in which the flow rate of fuel gas is greater than or equal to Fr2, the pressure of fuel gas of this embodiment gradually increases with an increase in the flow rate of fuel gas.

[0086] On the other hand, in the high-load region, the amount of increase in the pressure of fuel gas with respect to the amount of increase in the flow rate of fuel gas is less than that in the low-load region.

[0087] This is because, in the high-load region, the control unit 90 controls the control valve 53 so that the degree of opening of the control valve 53 increases with an increase in the degree of opening of the flow rate adjustment valve 40. With an increase in the degree of opening of the control valve 53, the amount of increase in the pressure of fuel gas required for increasing a unit flow rate is suppressed.

[0088] Meanwhile, the comparative example represented by the dashed line in Fig. 5 shows the case where the control unit 90 closes the control valve 53 even in the high-load region. In this comparative example, even in the high-load region, the amount of increase in the pressure of fuel gas with respect to the amount of increase in the flow rate of fuel gas is equal to that in the low-load region.

[0089] Accordingly, as indicated by the dashed line in Fig. 5, in the comparative example, a pressure of fuel gas required for obtaining a desired flow rate of fuel gas in the high-load region is excessively higher than in this embodiment. This means that, in order that the pressure of fuel gas Pmin which is required when the flow rate of fuel gas is at the lower limit Fr1 may be equal between this embodiment and the comparative example, the pressure of fuel gas supplied to the fuel gas supply path 101 in the comparative example needs to be made excessively high. In other words, in the comparative example, in order that the pressure of fuel gas supplied to the fuel gas supply path 101 may be made excessively high, the compressor 10 needs to have high pressurizing performance.

[0090] A pressure of fuel gas required in this embodiment and a pressure of fuel gas required in the comparative example will now be described with specific examples.

[0091] In this embodiment, when the flow rate of fuel gas is 100%, the flow rates of fuel gas to the pilot nozzle 221b and the main nozzle 221a are 300kg/h and 700kg/h, respectively, and the total flow rate is 1000kg/h. In this case, the ratio between the flow rates of fuel gas to the pilot nozzle 221b and the main nozzle 221a is 30:70.

[0092] In this case, assuming that the lower limit Fr1 of flow rate of fuel gas is 100kg/h, in order that the flow rate of fuel gas to the pilot nozzle 221b may be adjustable in the range of 100kg/h to 300kg/h, the pressure of fuel gas supplied to the fuel gas supply header 102 needs to be at least the pressure Pr1 [kPa] expressed by Equation (1).

$$Pr1 = 1.5 \cdot (300/100)^2 = 13.50 \qquad (1)$$

[0093] Here, 1.5 [kPa] is a minimum pressure of combustion gas required for keeping combustion of fuel gas without causing accidental fire in the first burner 221.

[0094] In addition, because the flow rate of fuel gas to the main nozzle 221a is 700kg/h when the flow rate of fuel gas is 100%, the flow rate of fuel gas to the main nozzle 221a is adjusted in the range of 300kg/h (the maximum flow rate at the pilot nozzle 221b) to 700kg/h. In order that the flow rate of fuel gas to the main nozzle 221a may be adjustable in the range of 300kg/h to 700kg/h, the pressure of fuel gas supplied to the fuel gas supply header 102 needs to be at least the pressure Pr2 [kPa] expressed by Equation (2).

$$Pr2 = 1.5 \cdot (700/300)^2 = 8.17 \qquad (2)$$

[0095] In this manner, Pr1 is greater than Pr2 when the ratio between the flow rates of fuel gas to the pilot nozzle 221b and the main nozzle 221a is 30:70. Accordingly, setting the pressure of fuel gas supplied to the fuel gas supply header 102 to at least P1 makes the flow rate of fuel gas adjustable in the range of a minimum flow rate of 100kg/h to a maximum flow rate of 1000Kg/h.

[0096] The comparative example will now be described. The comparative example indicates the case where the control valve 53 is closed. In this case, the flow rate of fuel gas needs to be adjusted in the range of a minimum flow rate of 100kg/h to 1000kg/h with the pilot nozzle 221b only. In order that the flow rate of fuel gas to the pilot nozzle 221b may be adjustable in the range of 100kg/h to 1000kg/h, the pressure of fuel gas supplied to the fuel gas supply header 102 needs to be at least the pressure Pr3 [kPa] expressed by Equation (3) .

$$Pr3 = 1.5 \cdot (1000/100)^2 = 150.00 \quad (3)$$

[0097] In other words, in the case of the comparative example, the pressure of fuel gas supplied to the fuel gas supply header 102 needs to be set to a value more than 10 times higher than that in this embodiment.

[0098] As described above, in this embodiment, it is unnecessary to set the pressure of fuel gas supplied to the fuel gas supply header 102 to an excessively high value.

[0099] In other words, in this embodiment, the turndown ratio (a ratio between the maximum flow rate and controllable minimum flow rate at the rated output power) to the pressure of fuel gas supplied to the fuel gas supply header 102 can be set to a high value. In particular, the minimum flow rate with respect to the maximum flow rate at the rated output power can be set to a low value.

[0100] The acts and effects of the above-described embodiment will now be described.

[0101] In the fuel supply system 100 of this embodiment, in the low-load region in which the flow rate of fuel gas supplied from the fuel gas supply header 102 to the first burner 221 is less than Fr2 (a predetermined flow rate), the control valve 53 is closed and the total amount of fuel gas supplied from the fuel gas supply header 102 to the first burner 221 is guided from the pilot nozzle supply pipe 55 to the pilot nozzle 221b. In this low-load region, the control valve 53 is closed, so that the pressure of fuel gas decreases in proportion to the square root of the flow rate of fuel gas. However, the range of flow rate in the low-load region is limited to a certain range of greater than or equal to the lower limit Fr1 and less than Fr2, which can suppress fluctuations in the pressure of fuel gas according to variations in flow rate.

[0102] In addition, in the fuel supply system 100 of this embodiment, in the high-load region in which the flow rate of fuel gas supplied from the fuel gas supply header 102 to the first burner 221 is greater than or equal to Fr2 (a predetermined flow rate), the degree of opening of the control valve 53 increases with an increase in the flow rate of fuel gas. Increasing the cross-sectional area of the flow path of the first burner 221 (the opening area to the furnace 211) by increasing the degree of opening of the control valve 53 makes it possible to decrease in the pressure of fuel gas required for supplying fuel gas to the first burner 221 at a desired flow rate.

[0103] In this manner, in the fuel supply system 100 of this embodiment, from the low-load region in which the first burner 221 is supplied with a small amount of fuel gas, to the high-load region in which the first burner 221 is supplied with a large amount of fuel gas, maintenance of stable combustion using fuel gas only can be achieved without wasting the energy of fuel gas. In this case, it is unnecessary to set the pressure of fuel gas on the LNG tank 400 side to an excessively high value.

[0104] In other words, in this embodiment, the turndown ratio to the pressure of supplied fuel gas can be set to a high value, and the minimum flow rate with respect to the maximum flow rate at the rated output power can be set to a lower value.

[0105] The fuel supply system 100 of this embodiment includes the flow rate adjustment valve 40 for adjusting the flow rate of fuel gas supplied from the LNG tank 400 to the fuel gas supply header 102, and the control unit 90 controls the degree of opening of the flow rate adjustment valve 40.

[0106] Hence, the flow rate adjustment valve 40 can adjust the flow rate of fuel gas supplied from the LNG tank 400 to the fuel gas supply header 102 to an appropriate value.

[0107] Further, when the flow rate of fuel gas supplied from the fuel gas supply header 102 to the first burner 221 is greater than or equal to Fr2 (a predetermined flow rate), the control unit 90 controls the control valve 53 so that the degree of opening of the control valve 53 increases with an increase in the degree of opening of the flow rate adjustment valve 40.

[0108] Hence, in the high-load region in which the flow rate of fuel gas supplied from the fuel gas supply header 102 to the first burner 221 is greater than or equal to Fr2 (a predetermined flow rate), the cross-sectional area of the flow path of the first burner 221 is increased with an increase in the amount of fuel gas supplied to the first burner 221, thereby making it possible to decrease the pressure of fuel gas required for supplying fuel gas to the first burner 221 at a desired flow rate.

[0109] The fuel supply system 100 of this embodiment includes the compressor 10 for pressurizing fuel gas supplied from the LNG tank 400, and the heater 20 for heating fuel gas pressurized by the compressor 10.

[0110] Accordingly, fuel gas supplied from the LNG tank 400 can be pressurized and heated properly and supplied to the first burner 221.

[0111] A method of controlling the fuel supply system 100 of this embodiment includes a first control step of closing the control valve 53 when the flow rate of fuel gas supplied from the fuel gas supply header 102 to the first burner 221 is less than Fr2 (a predetermined flow rate), and a second control step of controlling the control valve 53 so that the degree of opening increases with an increase in the flow rate of fuel gas, when the flow rate of fuel gas supplied from the fuel gas supply header 102 to the first burner 221 is greater than or equal to Fr2 (a predetermined flow rate).

[0112] In the method of controlling the fuel supply system 100 of this embodiment, from the low-load region in which the first burner 221 is supplied with a small amount of fuel gas, to the high-load region in which the first burner 221 is supplied with a large amount of fuel gas, maintenance of stable combustion using fuel gas only can be achieved without wasting the energy of fuel gas. In this case, it is unnecessary to set the pressure of fuel gas on the LNG tank 400 side to an excessively high value.

Another embodiment

[0113] Although, in the above description, the burner unit 220 includes three burners: the first burner 221, the second burner 222, and the third burner 223, and the fuel supply system 100 includes three fuel supply units: the first fuel supply unit 50, the second fuel supply unit 60, and the third fuel supply unit 70, another aspect can be employed.

[0114] For example, an aspect may be employed in which the burner unit 220 includes the first burner 221 only, and the fuel supply system 100 includes the first fuel supply unit 50 only.

[0115] Alternatively, for example, the burner unit 220 may include four or more burners, and the fuel supply system 100 may include the same number of fuel supply units as the burners.

[0116] Further, although, in the above description, the marine boiler 200 includes the reheat furnace 230 and the reheater 240, the marine boiler does not necessarily include them. The above-described fuel supply system 100 is applicable to a marine boiler that does not include the reheat furnace 230 and the reheater 240.

[Reference Signs List]

[0117]

40	flow rate adjustment valve (second adjustment valve)
50	first fuel supply unit
53	control valve (first adjustment valve)
54	main nozzle supply pipe (second supply pipe)
55	pilot nozzle supply pipe (third supply pipe)
60	second fuel supply unit
70	third fuel supply unit
90	control unit
100	fuel supply system
101	fuel gas supply path
102	fuel gas supply header (first supply pipe)
200	marine boiler
220	burner unit
221	first burner
221a	main nozzle
221b	pilot nozzle (sub-nozzle)
222	second burner
222a	main nozzle
222b	pilot nozzle (sub-nozzle)
223	third burner
223a	main nozzle
223b	pilot nozzle (sub-nozzle)
400	LNG tank (supply source)

Claims

1. A fuel supply system that is used for a marine boiler and supplies fuel gas to a burner unit including a main nozzle and a sub-nozzle, the fuel supply system comprising:

   a first supply pipe through which the fuel gas supplied from a supply source flows;
   a second supply pipe that supplies the fuel gas from the first supply pipe to the main nozzle;
   a third supply pipe that supplies the fuel gas from the first supply pipe to the sub-nozzle;
   a first adjustment valve that is provided to the second supply pipe and adjusts a flow rate of the fuel gas guided from the first supply pipe to the main nozzle through the second supply pipe; and
   a control unit that controls the degree of opening of the first adjustment valve, wherein
   the control unit controls the first adjustment valve so that when a flow rate of the fuel gas supplied from the first supply pipe to the burner unit is less than a predetermined flow rate, the first adjustment valve is closed, and when the flow rate of the fuel gas supplied from the first supply pipe to the burner unit is greater than or equal to the predetermined flow rate, the degree of opening of the first adjustment valve increases with an increase in the flow rate of the fuel gas.

2. The fuel supply system according to Claim 1, further comprising:

   a second adjustment valve that adjusts a flow rate of the fuel gas supplied from the supply source to the first supply pipe, wherein
   the control unit controls the degree of opening of the second adjustment valve.

3. The fuel supply system according to Claim 2, wherein
   the control unit controls the first adjustment valve so that when the flow rate of the fuel gas supplied from the first supply pipe to the burner unit is greater than or equal to the predetermined flow rate, the degree of opening of the first adjustment valve increases with an increase in the degree of opening of the second adjustment valve.

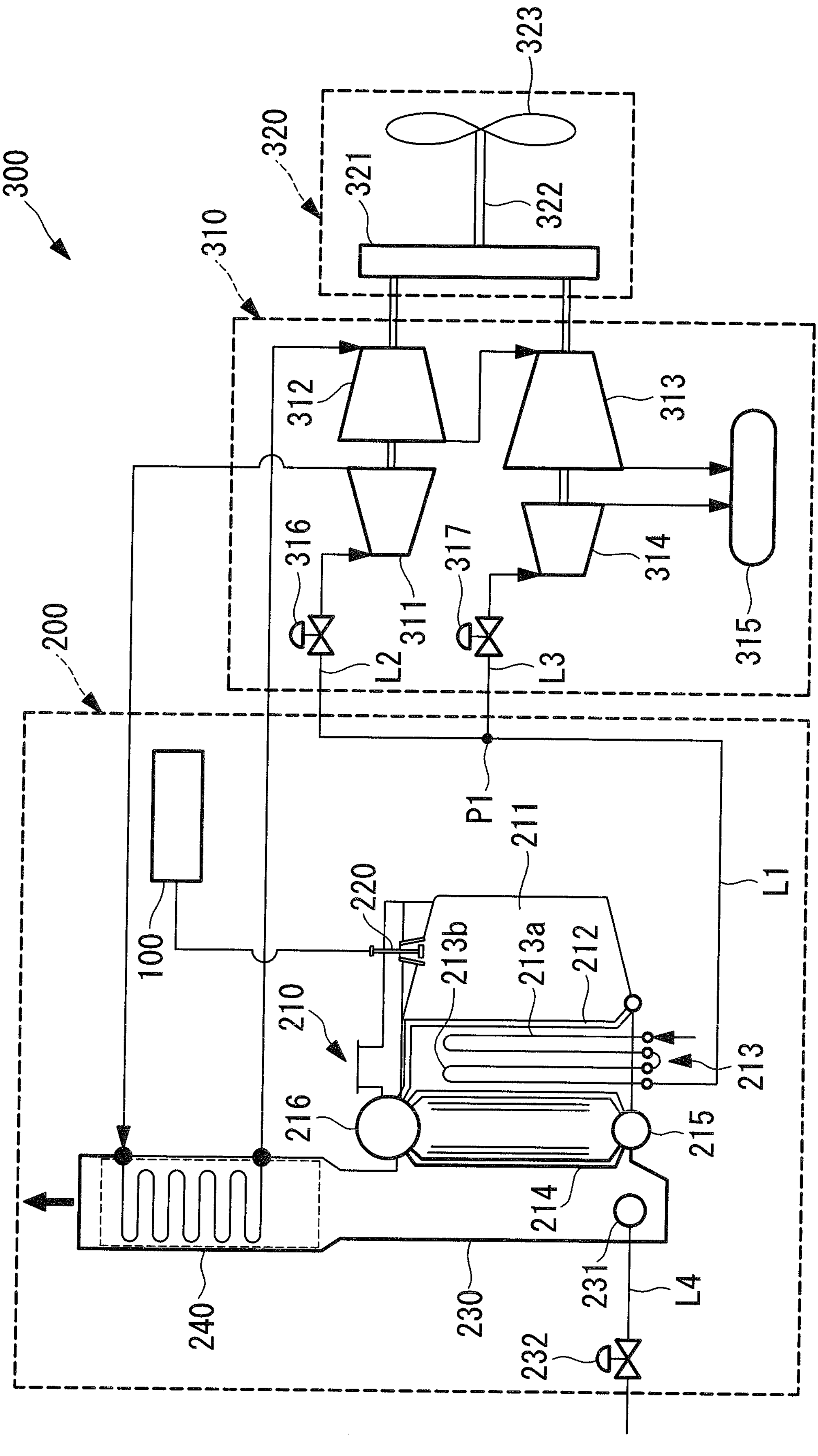
4. A marine boiler comprising:

   the burner unit; and
   the fuel supply system according to any one of Claims 1 to 3.

5. A method of controlling a fuel supply system that is used for a marine boiler and supplies fuel gas to a burner unit including a main nozzle and a sub-nozzle, the fuel supply system comprising:
   an adjustment valve that adjusts a ratio between a flow rate of the fuel gas guided to the main nozzle and a flow rate of the fuel gas guided to the sub-nozzle, the method comprising:

   a first control step of controlling the adjustment valve so that when a flow rate of the fuel gas supplied to the burner unit is less than a predetermined flow rate, the adjustment valve is closed; and
   a second control step of controlling the adjustment valve so that when the flow rate of the fuel gas supplied to the burner unit is greater than or equal to the predetermined flow rate, the degree of opening of the adjustment valve increases with an increase in the flow rate of the fuel gas.

FIG. 1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L1

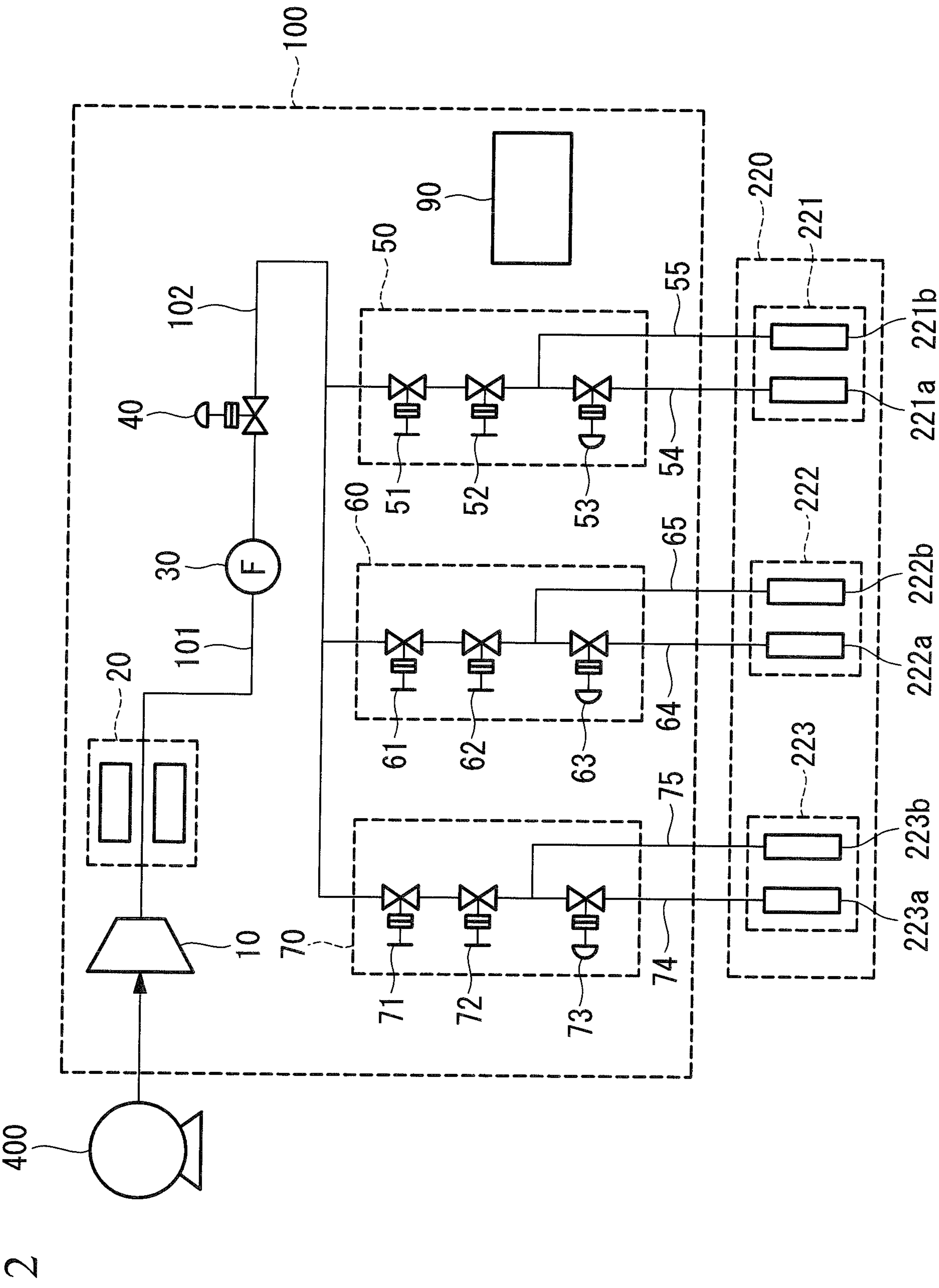
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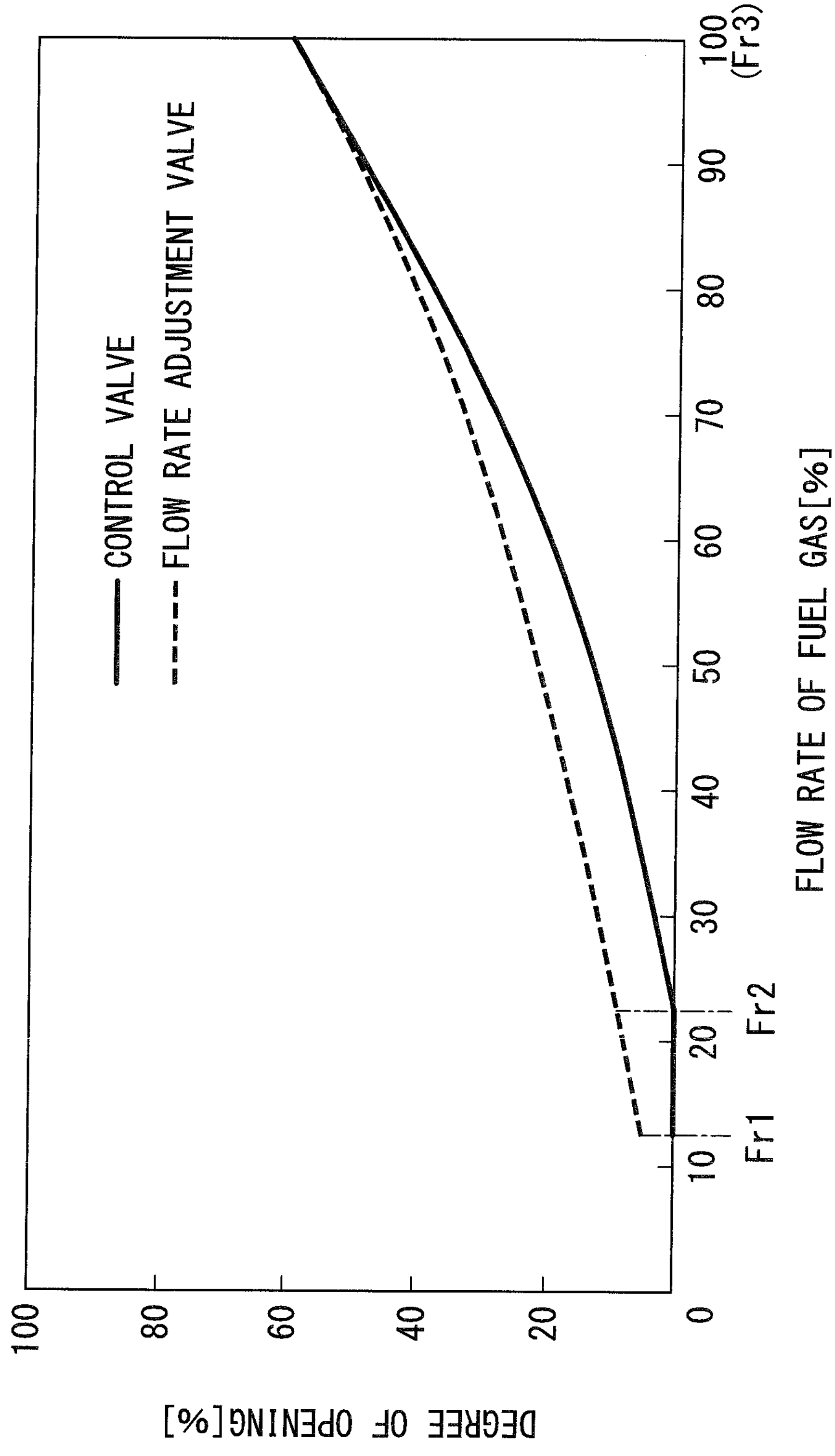
FIG. 2

FIG. 3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FLOW RATE OF FUEL GAS[%]
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10
20
30
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50
60
70
80
90
100
(Fr3)
Fr1
Fr2

FIG. 4

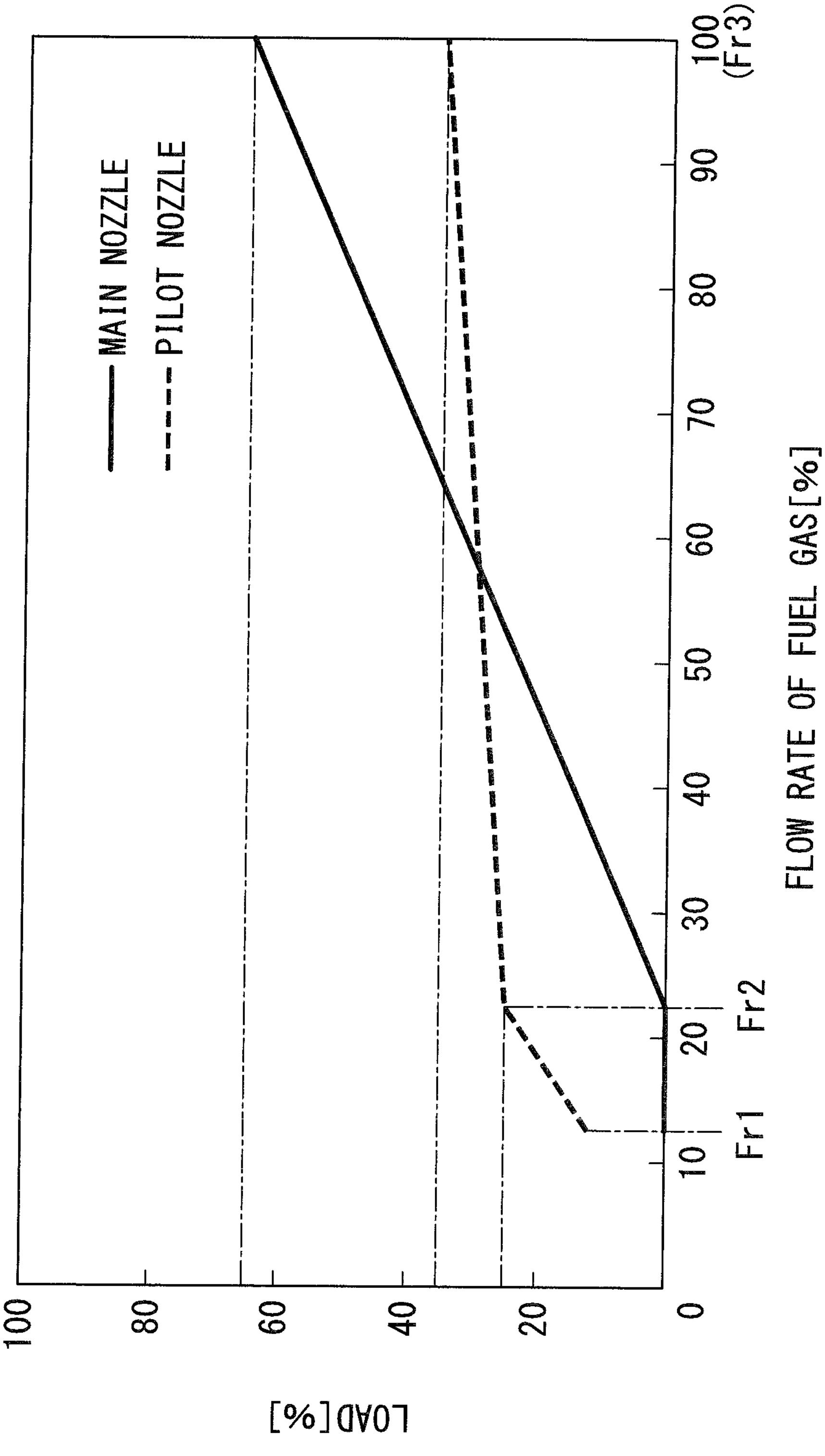
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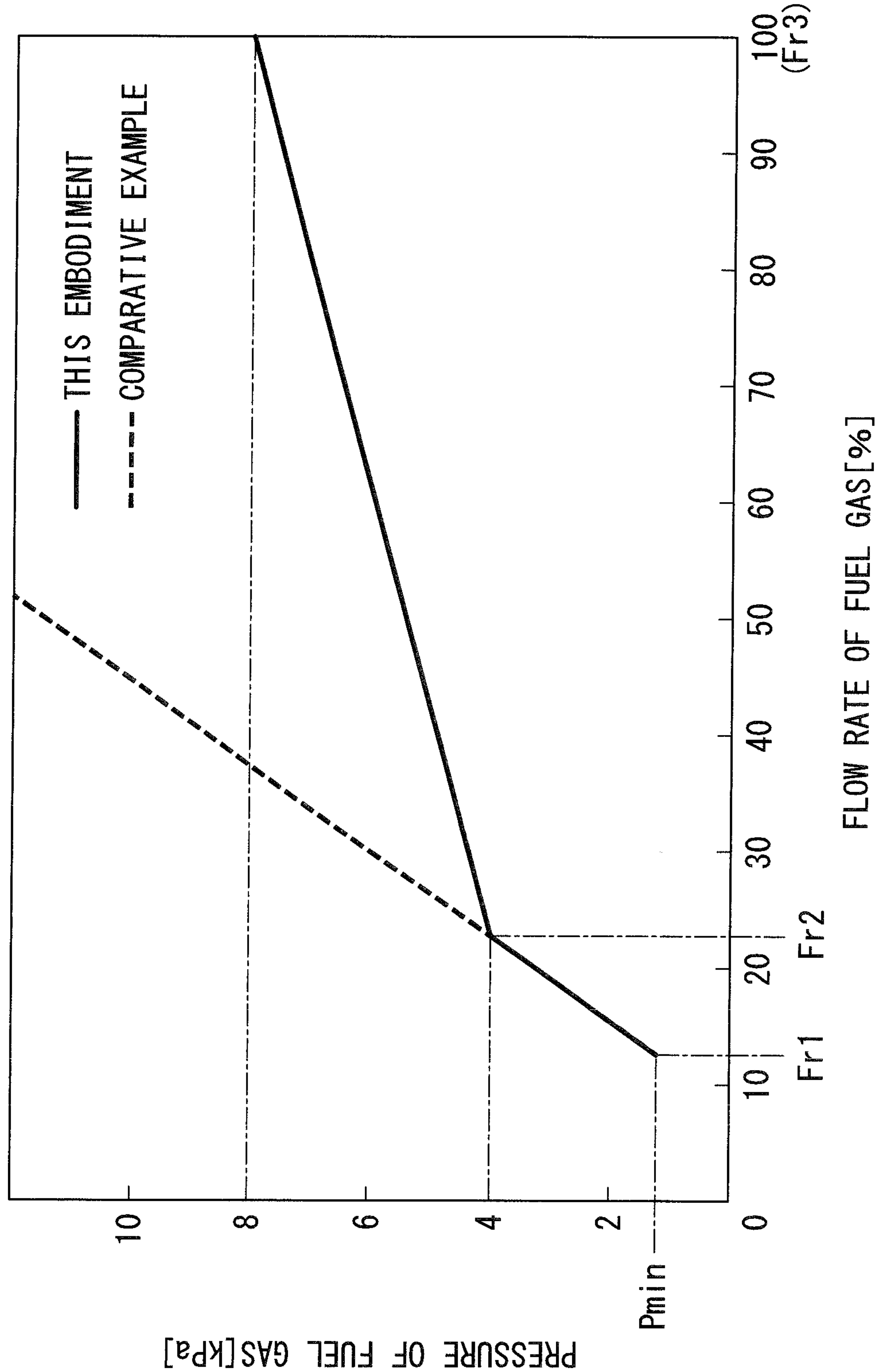
FIG. 5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6
8
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40
50
60
70
80
90
100
(Fr3)
Fr1
Fr2

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2017/003831

A. CLASSIFICATION OF SUBJECT MATTER

F23N1/00(2006.01)i, *B63H21/38*(2006.01)i, *F01K15/04*(2006.01)i, *F23K5/00*(2006.01)i, *B63H21/08*(2006.01)n

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F23N1/00, B63H21/08, B63H21/38, F01K15/04, F23K5/00

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2017
Kokai Jitsuyo Shinan Koho	1971-2017	Toroku Jitsuyo Shinan Koho	1994-2017

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2008-281271 A (Rinnai Corp.), 20 November 2008 (20.11.2008), entire text; all drawings (Family: none)	1-5
A	JP 2009-2529 A (Rinnai Corp.), 08 January 2009 (08.01.2009), entire text; all drawings (Family: none)	1-5
A	JP 62-39330 B2 (Matsushita Electric Industrial Co., Ltd.), 22 August 1987 (22.08.1987), entire text; all drawings (Family: none)	1-5

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

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 March 2017 (23.03.17)	04 April 2017 (04.04.17)

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3,Kasumigaseki,Chiyoda-ku, Tokyo 100-8915,Japan	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2017/003831

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 58-53245 B2 (Yamatake-Honeywell Co., Ltd.), 28 November 1983 (28.11.1983), entire text; all drawings & WO 1982/001576 A1 & EP 65011 A1 & AU 7801581 A & DK 282382 A	1-5
A	JP 41-8729 B1 (Kawasaki Heavy Industries, Ltd.), 09 May 1966 (09.05.1966), entire text; all drawings (Family: none)	1-5
A	US 2010/0058770 A1 (SIEMENS CORP.), 11 March 2010 (11.03.2010), entire text; all drawings & WO 2010/027383 A1 & EP 2334987 A1 & CN 102144131 A	1-5

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2014118047 A **[0004]**