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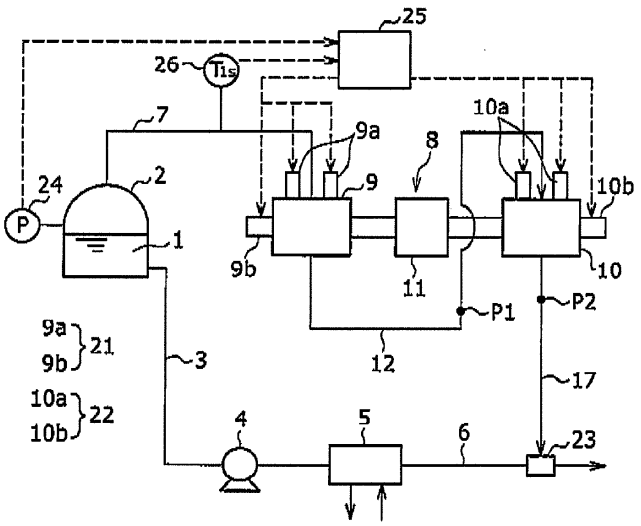
(54) Operation control method for BOG multistage displacement compressor

(57) Provided is an operation control method for a BOG multistage displacement compressor including connected multiple displacement compression units (9,10) for compressing boil off gas (BOG) generated from liquefied natural gas, including: under a predetermined state, performing operation control so that the ratio (load ratio) of a load of a low-pressure stage compression unit (9) to a load of a high-pressure stage compression unit (10) in the BOG multistage displacement compressor is larger than load ratios under states other than the predetermined state. Namely, the BOG multistage displacement compressor is configured so that suction temperature in the low-pressure stage compression unit (9) can be detected, and the predetermined state is set to a state where the detected temperature of the suction temperature is equal to or higher than a set temperature that is preset. According to such a method, even if the low-pressure stage side suction gas has a temperature higher than that in steady operation, the load (gas load) due to a differential pressure between suction gas and discharge gas on the high-pressure stage side can be prevented from exceeding an allowable gas load.

FIG. 1



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Description

BACKGROUND OF THE INVENTION

Field of the Invention:

[0001] The present invention relates to an operation control method for a BOG displacement compressor configured to compress boil off gas (hereinafter referred to as BOG) generated by natural vaporization within a tank storing liquefied natural gas (LNG) and supply the compressed gas to a plant, and more specifically, relates to an operation control method for a BOG multistage displacement compressor capable of suppressing increase in load (gas load) due to a differential pressure between suction gas and discharge gas in a high-pressure stage side compression unit in a multistage displacement compressor.

Description of the Related Art:

[0002] In an LNG station, the pressure of BOG generated by natural vaporization within an LNG storage tank is raised by a BOG compressor to a pressure of natural gas delivered to power generation plant, town gas facilities or the like, the BOG is merged with natural gas that is released from an evaporator and is main part of the merged gas, and the merged gas is delivered to each of the above facilities.

[0003] In the above-mentioned BOG compressor, since the BOG is adiabatically compressed, higher compression ratio raises the temperature of BOG. Particularly at start-up of the BOG compressor, the temperature of BOG derived from the LNG storage tank is raised close to ordinary temperature, and suction gas temperature in the BOG compressor is raised to a temperature close to the ordinary temperature (e.g., 30°C). If a state where the BOG is compressed without any treatment continues, and when the discharge pressure is 0.4 MPa, discharge gas temperature of the BOG compressor rises, for example, to about 155°C, which exceeds a compressor allowable operation temperature, e.g., 150°C, and the operation cannot be continued.

[0004] A conventional technique for solving such a problem of BOG compressors will be described with reference to Fig. 6. Fig. 6 is a view showing a configuration of LNG and BOG treatment equipment to which an operation control method according to the conventional technique is applied.

[0005] A BOG multistage compressor 38 according to the conventional technique includes a three-way valve 43, a cooler 45, temperature detectors 41, 42, and a control device 46 which governs the switching of the three-way valve 43. In the BOG multistage compressor 38, switching the three-way valve 43 can switch between an operation form (operation form 1) in which discharge gas of a low-pressure stage side compression unit 39 is cooled by the cooler 45 to reduce the temperature thereof, and then the discharge gas is supplied to a high-pressure stage side compression unit 40, and an operation form (operation form 2) in which the discharge gas of the low-pressure stage side compression unit 39 does not pass through the cooler 45 and is supplied to the high-pressure stage side compression unit 40.

[0006] In the above-mentioned operation form 1, the discharge gas temperature of the high-pressure stage side compression unit 40 can be made lower than that in the operation form 2. The operation form 1 is executed when, at the start-up of the BOG multistage compressor 38, there is fear that the suction gas temperature of the low-pressure stage side compression unit 39 is higher than that (e.g., -130°C) in steady operation (e.g., the suction gas temperature is 30°C) and the discharge gas temperature of the high-pressure stage side compression unit 40 exceeds an operation allowable temperature. In contrast, the operation form 2 is executed in the steady operation of the BOG multistage compressor 38.

[0007] The switching between both the operation forms is performed as follows. Namely, when it is detected by the temperature detector 41 that a high-pressure stage side discharge gas temperature is higher than a set temperature, the control device 46 switches the three-way valve 43 so that the operation by the operation form 2 is stopped and the operation by the operation form 1 is started. On the other hand, when a condition showing that there is no fear that the temperature of high-pressure stage side discharge gas never exceeds the operation allowable temperature is ratified, the operation by the operation form 1 is stopped, and the operation by the operation form 2 is started. According to the above-mentioned operation control method, the discharge gas temperature of the high-pressure stage side compressor 40 can be prevented from exceeding the operation allowable temperature (refer to Japanese Patent Application Laid-Open No. 2002-213366).

[0008] Namely, according to the above-mentioned conventional technique, if there is the fear that the temperature of high-pressure stage side discharge gas exceeds the operation allowable temperature, the operation (operation form 1) such that the low-pressure stage side discharge gas is cooled by the cooler 45 to reduce the temperature thereof, and supplied to the high-pressure stage side compression unit 40 is performed, and thereby the temperature of high-pressure stage side discharge gas is prevented from exceeding the operation allowable temperature.

[0009] However, according to the BOG multistage compressor 38 of the conventional technique, when the temperature

of suction gas of the low-pressure stage side compression unit 39 is higher than that in steady operation, the pressure of discharge gas of the low-pressure stage side compression unit 39 and the pressure of suction gas of the high-pressure stage side compression unit 40 become lower than the pressures of those in steady operation. Thus, the difference between the pressure of suction gas and the pressure of discharge gas (differential pressure) in the high-pressure stage side compression unit 40 is increased, resulting in an increased gas load in the high-pressure stage side compression unit 40.

[0010] The gas load means a quantity of force generated by the pressure of gas. The gas load is loaded on a casing of the compressor. If the gas load is increased in the high-pressure stage side compression unit 40, a facility that can allow for the increased gas load is needed, generally resulting in an increased size of the compressor. The conventional technique does not refer to countermeasures against such increase in gas load.

SUMMARY OF THE INVENTION

[0011] The present invention thus has an object to provide an operation control method for a BOG multistage displacement compressor that, even if the temperature of low-pressure stage side suction gas is higher than that in steady operation in the BOG multistage displacement compressor, is capable of suppressing increase in load (gas load) due to a differential pressure between suction gas and discharge gas in a high-pressure stage-side compression unit.

[0012] In order to attain the above-mentioned object, the operation control method for a BOG multistage displacement compressor according to the present invention adopts the following means. Namely, an operation control method for a BOG multistage displacement compressor including connected multiple stages of displacement compression units for compressing BOG generated from liquefied natural gas, includes: under a predetermined state, performing operation control so that the ratio (load ratio) of a load of a low-pressure stage compression unit to a load of a high-pressure stage compression unit in the BOG multistage displacement compressor is larger than load ratios under states other than the predetermined state. The "load" in the present application is a nominal value of the ratio of "gas treatment quantity attained by a capacity adjusting device" to "gas treatment quantity when the capacity adjusting device is not operated" (the "gas treatment quantity when the capacity adjusting device is not operated" corresponds to a treatment quantity with 100% load).

[0013] According to such an operation control method, the operation control method for a BOG multistage displacement compressor including connected multiple stages of displacement compression units for compressing BOG generated from liquefied natural gas, includes: under a predetermined state, performing operation control so that the ratio (load ratio) of a load of a low-pressure stage compression unit to a load of a high-pressure stage compression unit in the BOG multistage displacement compressor is larger than load ratios under states other than the predetermined state. Since the operation is performed with a large load ratio R means that a compression ratio of the low-pressure stage compression unit is increased and a compression ratio of the high-pressure stage compression unit is decreased. Accordingly, the gas load on the high-pressure stage side is also reduced. Consequently, even if the temperature of low-pressure stage side suction gas is higher than that in steady operation, the load (gas load) due to the differential pressure between suction gas and discharge gas in the high-pressure stage compression unit can be suppressed from increasing, and the gas load on the high-pressure stage side can be prevented from exceeding an allowable gas load.

[0014] In the above-mentioned operation control method for a BOG multistage displacement compressor of the present invention, the BOG multistage displacement compressor may be configured so that suction temperature in the low-pressure stage compression unit can be detected, and the predetermined state may be set to a state where the detected temperature of the suction temperature is equal to or higher than a set temperature that is preset.

[0015] According to such an operation control method, since the BOG multistage displacement compressor is configured so that suction temperature in the low-pressure stage compression unit can be detected, and the predetermined state is set to a state where the detected temperature of the suction temperature is equal to or higher than a set temperature that is preset, the increase in load (gas load) due to the differential pressure between suction gas and discharge gas in the high-pressure stage compression unit can be suppressed even if the temperature of low-pressure stage side suction gas is higher than that in steady operation, and the gas load on the high-pressure stage side can be prevented from exceeding the allowable gas load, as described above.

[0016] In the above-mentioned operation control method for a BOG multistage displacement compressor of the present invention, the BOG multistage displacement compressor may be configured so that a differential pressure between suction pressure and discharge pressure of the high-pressure stage compression unit can be detected, and the predetermined state may be a state since it is determined that the differential pressure is equal to or more than a first set differential pressure that is preset, until it is determined that the differential pressure reaches a second set differential pressure that is preset and smaller than the first set differential pressure.

[0017] According to such an operation control method, since the BOG multistage displacement compressor is configured so that a differential pressure between suction pressure and discharge pressure of the high-pressure stage compression unit can be detected, and the predetermined state is a state since it is determined that the differential

pressure is equal to or more than a first set differential pressures that is preset, until it is determined that the differential pressure reaches a second set differential pressure that is preset and smaller than the first set differential pressure, the increase in load (gas load) due to the differential pressure between suction gas and discharge gas in the high-pressure stage compression unit can be suppressed similarly to the above even if the temperature of low-pressure stage side suction gas is higher than that in steady operation, and the gas load on the high-pressure stage side can be prevented from exceeding the allowable gas load.

[0018] Since the operation form is decided based on the differential pressure on the high-pressure stage side directly involved in the gas load on the high-pressure stage side, the increase in load (gas load) due to the differential pressure between suction gas and discharge gas in the high-pressure stage compression unit can be surely suppressed even if the pressure of discharge gas on the high-pressure stage side is fluctuated due to fluctuation in gas demand quantity at a supply destination or the like, and the gas load can be prevented from exceeding the allowable gas load.

[0019] In the above-mentioned operation control method for a BOG multistage displacement compressor of the present invention, when the operation control is performed so that the load ratio under the predetermined state is larger than load ratios under states other than the predetermined state, discharge gas of the low pressure compression unit may pass through a cooler, and be supplied to the high-pressure stage compression unit.

[0020] According to such an operation control method, since, when performing the operation control so that the load ratio under the predetermined state is larger than load ratios under states other than the predetermined state, discharge gas of the low pressure compression unit passes through a cooler, and is supplied to the high-pressure stage compression unit, the increase in load (gas load) due to the differential pressure between suction gas and discharge gas in the high-pressure stage compression unit can be suppressed similarly to the above, even if the temperature of low-pressure stage-side suction gas is higher than that in steady operation, and the gas load on the high-pressure stage side from is prevented from exceeding the allowable gas load. In addition, the temperature rise of discharge gas on the low-pressure stage side can be also suppressed and the temperature of discharge gas on the high-pressure stage side is prevented from exceeding an allowable upper limit temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021]

Fig. 1 is a systematic diagram of LNG and BOG treatment equipment to which an operation control method for a BOG multistage displacement compressor according to Embodiment 1 of the present invention is applied;
Fig. 2 is a view for illustrating temporal change in BOG temperature just after start-up in the operation control method for a BOG multistage displacement compressor according to Embodiment 1 of the present invention;
Fig. 3 is a systematic diagram of LNG and BOG treatment equipment to which an operation control method for a BOG multistage displacement compressor according to Embodiment 2 of the present invention is applied;
Fig. 4 is a systematic diagram of LNG and BOG treatment equipment to which an operation control method for a BOG multistage displacement compressor according to Embodiment 3 of the present invention is applied;
Fig. 5 is a systematic diagram of LNG and BOG treatment equipment to which an operation control method for a BOG multistage displacement compressor according to Embodiment 4 of the present invention is applied; and
Fig. 6 is a view for illustrating a configuration of LNG and BOG treatment equipment to which an operation control method according to a related art is applied.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] In order to explain an operation control method for a BOG multistage displacement compressor according to Embodiment 1 of the present invention, a case in which a reciprocating compressor is applied to the BOG multistage displacement compressor will be given as an example with reference to Figs. 1 and 2. Fig. 1 is a systematic diagram of LNG and BOG treatment equipment to which the operation control method for a BOG multistage displacement compressor according to Embodiment 1 of the present invention is applied, and Fig. 2 is a view for illustrating temporal change in BOG temperature just after start-up in the operation control method for a BOG multistage displacement compressor according to Embodiment 1 of the present invention.

[0023] The BOG multistage displacement compressor according to Embodiment 1 of the present invention is a BOG multistage compressor 8 for compressing BOG generated by natural vaporization within an LNG storage tank 2 storing liquefied natural gas (LNG) 1 and supplying the compressed BOG to a plant not shown, which is composed of a reciprocating compressor including a low-pressure stage compression unit 9 and a high-pressure stage compression unit 10. The low-pressure stage compression unit 9 is configured so as to be capacity-adjustable by a low-pressure stage capacity adjusting device 21 including a suction valve unloader 9a and a head end unloader 9b, and the high-pressure stage compression unit 10 is configured so as to be capacity-adjustable by a high-pressure stage capacity adjusting

device 22 including a suction valve unloader 10a and a head end unloader 10b.

[0024] On the other hand, an LNG extraction line 3 is connected to the LNG storage tank 2 of liquefied natural gas (LNG) 1, an LNG pump 4 and an evaporator 5 for vaporizing LNG with seawater or the like are connected to the line 3, and a gas transfer line 6 for the vaporized gas is connected to, for example, a gas turbine of a power generation plant not shown. A BOG delivery line 7 is connected to a top portion of the LNG storage tank 2, and the BOG multistage compressor 8 is connected to the BOG delivery line 7.

[0025] The BOG multistage compressor 8 is configured to simultaneously drive the low-pressure stage compression unit 9 and the high-pressure stage compression unit 10 by one drive motor 11. The BOG delivery line 7 is connected to the suction side of the low-pressure stage compression unit 9, and the discharge side of the low-pressure stage compression unit 9 is connected to the suction side of the high-pressure stage compression unit 10 by an intermediate line 12. A discharge line 17 on the discharge side of the high-pressure stage compression unit 10 of the BOG multistage compressor 8 is connected to the gas transfer line 6 through a junction portion 23.

[0026] The LNG storage tank 2 includes a pressure detector 24 for detecting gas pressure of BOG in the tank 2, and a detection value thereof is input to a controller 25. The controller 25 performs operation control so as to start and operate the BOG multistage compressor 8 when the gas pressure of BOG in the tank 2 detected by the pressure detector 24 exceeds a set pressure, and to stop the compressor 8 when the gas pressure of BOG in the tank 2 is reduced to a predetermined value.

[0027] Next, the operation control method according to Embodiment 1 of then present invention to be executed in this equipment is described with reference to Fig. 2. In Fig. 2, a temperature curve A indicates the temperature of suction gas on the low-pressure stage side, a pressure curve B indicates the pressure of discharge gas on the high-pressure stage side at a position P2 on the discharge line 17 of Fig. 1, a pressure curve C indicates the pressure of discharge gas on the low-pressure stage side (the pressure of suction gas on the high-pressure stage side) at a position P1 on the intermediate line 12 of Fig. 1, and a gas load curve D indicates the gas load (compression load) on the high-pressure stage side.

<Operation Control Method (1)>

[0028] When the BOG multistage compressor 8 is started, the temperature of suction gas of the low-pressure stage compression unit 9 (the temperature of BOG derived from the LNG storage tank 2) maintains substantially the same level as that at start-up for an extremely short time and gradually drops, as shown by the temperature curve A of Fig. 2.

[0029] When the load ratio (or the ratio of the load of the low-pressure stage compression unit to the load of the high-pressure stage compression unit) is equal to that in steady operation, the pressure of suction gas on the high-pressure stage side starts from the level obtained at start-up, and reaches a level of P_11 which is lower than a pressure P_13 of suction gas in steady operation within an extremely short time (time sl), as shown by a dashed-dotted line in the pressure curve C of Fig. 2. Thereafter, the pressure of suction gas on the high-pressure stage side gradually increases according to the change of the pressure curve C, and stabilizes at the pressure P_13.

[0030] On the other hand, the pressure of discharge gas on the high-pressure stage side starts from the level obtained at start-up, reaches a pressure P_hl, which is obtained in steady operation, in an extremely short time (time sl), and gets into a stabilized state, as shown by the pressure curve B of Fig. 2. Accordingly, the gas load on the high-pressure stage side with the same load ratio as in steady operation starts from zero, exceeds an allowable gas load GL_h on the high-pressure stage side in an extremely short time, and reaches a high level of GL_4, as shown by a dashed-dotted line in the gas load curve D of Fig. 2. Thereafter, it gradually decreases and stabilizes near a gas load Gel_2.

[0031] In the operation control method according to Embodiment 1 of the present invention, when the BOG multistage compressor 8 is started, the controller 25 performs operation control on the low-pressure stage capacity adjusting device 21 and the high-pressure stage capacity adjusting device 22 during the time from the start-up to time s2 described below so that the load ratio R is larger than that in steady operation. For example, the control is performed so that the low-pressure stage side load is 100% and the high-pressure stage side load is 75%.

[0032] By such an operation control method, the pressure of discharge gas on the low-pressure stage side (the pressure of suction gas on the high-pressure stage side) rises and reaches a pressure P_14 at time s2 as shown by a solid line of the pressure curve C in Fig. 2. On the other hand, the pressure of discharge gas on the high-pressure stage side starts from the level obtained at start-up, reaches the pressure P_h1, which is obtained in steady operation, and, after an extremely short time (time s1), gets into a stabilized state, similarly to the case in which the load ratio is the same as in steady operation. The gas load increases during the time from the start-up to time s1 and reaches a GL_3 at the time s1 as shown by a solid line of the pressure curve D of Fig. 2. Note that this GL_3 is suppressed to a level lower than the allowable gas load GL_h. After the time s1, the gas load decreases and reaches GL_1 at time s2.

[0033] The controller 25 compares a temperature of low-pressure stage-side suction gas detected by the temperature detector 26 with a set temperature T1 (e.g., -45°C) that is preset. As a result of the comparison, when the detected temperature of low-pressure stage-side suction gas reaches the set temperature T1 (or when the detected temperature

of low-pressure stage-side suction gas becomes lower than the set temperature T1) that is, at the time s2 in Fig. 2, the controller 25 controls the operation of the low-pressure stage capacity adjusting device 21 and the high-pressuro stage capacity adjusting device 22, so that the load ratio R is equal to that in steady operation. For example, the control is performed so that the low-pressure stage-side load is 100%, and the high-pressure stage-side load is 100%.

[0034] Due to above, after the time s2, the pressure of discharge gas on the lower pressure stage side (the pressure of suction gas on the high-pressure stage side) temporally decreases. To the contrary, the gas load on discharge stage side accordingly increases. The pressure of discharge gas on the low-pressure stage side (the pressure of suction gas on the high-pressure stage side) decreases to the P_12 until time s3, and starts to increase again. Accordingly, the gas load on the discharge stage side increases until the time s3 and then starts to decrease. Thereafter (after the time s3), the pressure of low-pressure stage-side discharge gas (the pressure of high-pressure stage-side suction gas) further gradually increases and gets into a stabilized state at the pressure P_13, and the gas load on the discharge stage side gradually decreases and gets into a stabilized state at the gas load GL_2.

[0035] According to the operation control method for a BOG multistage displacement compressor of Embodiment 1 of the present invention, the increase in load (gas load) due to the differential pressure between suction gas and discharge gas in the high-pressure stage compression unit can be suppressed to prevent the gas load from exceeding the allowable gas load GL_h.

<Example>

[0036] Example of the operation control method for a BOG multistage displacement compressor according to Embodiment 1 of the present invention is then described with reference to Fig. 1. In the steady operation of the multistage displacement compressor, both the primary side compression unit 9 and the secondary side compression unit 10 are operated with 100% load (Comparative Example-1 of Table 1). According to the BOG multistage displacement compressor of Embodiment 1 of the present invention, when it is under the predetermined state, for example, at the start-up, the primary side compression unit 9 and the secondary compression unit 10 are operated with 100% load and with 75% load, respectively, by the capacity adjusting devices 21 (the suction valve unloader 9a, the head end unloader 9b, etc.) and 22 (the suction valve unloader 10a, the head end unloader 10b, etc.) of the primary side compression unit 9 and the secondary compression unit 10. Namely, the load ratio in start-up is larger than the load ratio in steady operation (refer to Example of Table 1).

[0037] In Table 1, start-up operation states of the BOG multistage displacement compressor according to a related art. are also given for showing the effects of the present invention. One operation state is an operation form (Comparative Example-2 of Table 1) in which both the primary side compression unit 9 and the secondary side compression unit 10 are operated with 100% load. The other operation state is an operation form (Comparative Example-3) in which both the primary side compression unit 9 and the secondary side compression unit 10 are operated with 75% load. In both Comparative Example-2 and Comparative Example-3, the load ratio is equal to the load ratio in steady operation.

[Table 1]

	Operating Condition	Load Ratio	Operation Form	
			Primary Side Compression Unit	Secondary Side Compression Unit
Comparative Example-1	Steady operation		100%-Load operation	100%-Load operation
Comparative Example-2	At start-up	Same as in steady operation	100%-Load operation	100%-Load operation
Comparative Example-3	At start-up	Same as in steady operation	75%-Load operation	75%-Load operation
Example	At start-up	Larger than in steady operation	100%-Load operation	75%-Load operation

[0038] Table 2 shows suction/discharge gas pressures of the primary side compression unit 9 and the secondary side compression unit 10, and compression loads and tension loads of the primary side compression unit 9 and the secondary side compression unit 10, in each operation form of Table 1. As shown in Comparative Example-1 of Table 2, in the steady operation state of the BOG multistage displacement compressor, the compression load on the secondary side is about 8,990 kgf. However, in the start-up operation state of the BOG multistage displacement compressor according

to a related art, the compression load on the secondary side reaches a level exceeding the allowable gas load of 9,000 kgf, concretely, 9,040 kgf in Comparative Example-2 and 9,020 kgf in Comparative Example-3, as shown in Comparative Examples-2 and 3 of Table 2.

[0039] On the other hand, in the start-up operation state of the BOG multistage displacement compressor according to Embodiment 1 of the present invention, the compression load on the secondary side is suppressed to a level not exceeding 9,000 kgf of the allowable gas load, concretely, to 8,400 kgf, as shown in Example of Table 2. This effect of Example is obtained by setting the load ratio in the start-up operation larger than that in the steady operation.

[Table 2]

	Pressure [bar/t]				Gas Load [kgf] (Allowable gas load is 9,000 kgf in both stages)							
	Primary Suction	Primary Discharge	Secondary Suction	Secondary Discharge	Primary Compression Load	Property (Primary Compression Load)	Primary Tension Load	Property (Primary Tension Load)	Secondary Compression Load	Property (Secondary Compression Load)	Secondary Tension Load	Property (Secondary Tension Load)
Comparative Example-1	1.1	3.2	3.0	9.0	5850	OK	5780	OK	8990	OK	8660	OK
Comparative Example-2	1.1	3.1	3.0	9.0	5760	OK	5680	OK	9040	NG	8710	OK
Comparative Example-3	1.1	3.1	3.0	9.0	5790	OK	5720	OK	9020	NG	8690	OK
Example	1.1	3.6	3.4	9.0	7830	OK	6920	OK	8400	OK	8080	OK

[0040] Next, in order to explain an operation control method for a BOG multistage displacement compressor according to Embodiment 2 of the present invention, a case in which a screw compressor is applied to the BOG multistage compressor is given as an example with reference to Fig. 3. Fig. 3 is a systematic diagram of LNG and BOG treatment equipment to which the operation control method for a BOG multistage displacement compressor of Embodiment 2 of the present invention is applied.

[0041] Embodiment 2 of the present invention has the same structure as the above-mentioned Embodiment 1 except that the type of the BOG multistage displacement compressor and the structures of the low-pressure stage capacity adjusting device and the high-pressure stage capacity adjusting device are differed from those in Embodiment 1. Therefore, about the differences from the above-mentioned Embodiment 1 are described below while assigning the same

reference numbers to the same ones as Embodiment 1.

[0042] Namely, according to the operation control method for a BOG multistage displacement compressor of Embodiment 1, in the BOG multistage compressor 8 composed of a reciprocating compressor, the capacity of the low-pressure stage compression unit 9 is adjusted by the low-pressure stage capacity adjusting device 21 including the suction valve unloader 9a and the head end unloader 9b, and the capacity of the high-pressure stage compression unit 10 is adjusted by the high pressure capacity adjusting device 22 including the suction valve unloader 10a and the head end unloader 10b.

[0043] In contrast, according to the operation control method for a BOG multistage displacement compressor of Embodiment 2 shown in Fig. 3, in a BOG multistage compressor 18 composed of a screw compressor, the capacity of a low-pressure stage compression unit 19 is adjusted by a low-pressure stage capacity adjusting device including a slide valve 19a and the capacity of a high-pressure stage compression unit 20 is adjusted by a high-pressure stage capacity adjusting device including a slide valve 20a.

[0044] By the operation control method for a BOG multistage displacement compressor according to Embodiment 2 of the present invention, also, the increase in load (gas load) due to the differential pressure between suction gas and discharge gas in the high-pressure stage compression unit 20 can be suppressed similarly to the above-mentioned Embodiment 1, and the gas load can be prevented from exceeding the allowable gas load GL_h.

[0045] In order to explain an operation control method for a BOG multistage displacement compressor according to Embodiment 3 of the present invention, a case in which a reciprocating compressor is applied to the BOG multistage compressor will be given as an example with reference to Fig .4. Fig. 4 is a systematic diagram of LNG and BOG treatment equipment to which an operation control method for a BOG multistage displacement compressor according to Embodiment 3 of the present invention is applied.

[0046] Embodiment 3 of the present invention is in common with the above-mentioned Embodiment 1 in many structural paints. Therefore, in Fig. 4, the same reference numbers are assigned to the same ones as in Embodiment 1 (Fig. 1) to omit the description thereof. A difference of Embodiment 3 of the present invention from Embodiment 1 is that the former includes a differential pressure gauge 27 so that a differential pressure ΔP between the pressure of discharge gas on the low-pressure stage side located at a position P1 on the intermediate line 12 (the pressure of high-pressure stage-side suction gas) and the pressure of discharge gas on the high-pressure stage side located at a position P2 on the discharge line 17 can be detected, while the latter includes the temperature detector 26 provided in the BOG delivery line 7 so that the temperature of suction gas on the low-pressure stage side can be detected. The difference is mainly described below.

[0047] Namely, according to the operation control method of the BOG multistage displacement compressor 8 of Embodiment 1, the temperature of low-pressure stage-side suction gas is detected by the temperature detector 26 interposed in the BOG delivery line 7, and the operation control is performed by the operation control method (1). In contrast, according to the operation control method of the BOG multistage displacement compressor 8 of Embodiment 3 shown in Fig. 4, the differential pressure ΔP between the pressure of low-pressure stage side discharge gas (the pressure of high-pressure stage-side suction gas) and the pressure of high-pressure stage side discharge gas is detected by the differential pressure gauge 27, and the operation control is performed by an operation control method (2) which will be described below.

<Operation Control Method (2)>

[0048] According to this operation control method (2), when the BOG multistage compressor 8 is started, the controller 25 compares the differential pressure ΔP detected by the differential pressure gauge 27 with a firs set differential pressure $\Delta P1$ that is preset within the controller 25. When the differential pressure ΔP detected by the differential pressure gauge 27 is larger than the first set differential pressure $\Delta P1$, the controller 25 controls the operation of the low-pressure stage capacity adjusting device 21 and the high-pressure stage capacity adjusting device 22 so that the load ratio R is larger than that in steady operation.

[0049] For example, the control is performed so that the low-pressure stage-side load is 100% and the high-pressure stage-side load is 75%. Accordingly, the gas load on the high-pressure stage side is suppressed to a level lower than the allowable gas load GL_h.

[0050] The controller 25 further compares the differential pressure ΔP detected by the differential pressure gauge 27 with a second set differential pressure $\Delta P2$. As a result of the comparison, when the differential pressure ΔP detected by the differential pressure gauge 27 is smaller than the second differential pressure $\Delta P2$, the controller 25 controls the operation of the low-pressure stage capacity adjusting device 21 and the high-pressure stage capacity adjusting device 22 so that the load ratio R is equal to that in steady operation. For example, the low-pressure stage-side load is set to 100%, and the high-pressure stage-side load is set to100%. The second set differential pressure $\Delta P2$ is preset to a value smaller than the first set differential pressure $\Delta P1$.

[0051] In this way, according to the operation control method for a BOG multistage displacement compressor of Embodiment 3 of the present invention, the operation form is decided based on the differential pressure ΔP on the high-

pressure stage side that is directly related to the gas load on the high-pressure stage side. Thus, even if the pressure of discharge gas on the high-pressure stage side is fluctuated due to fluctuation of the quantity of gas demanded by supply destination or the like, the increase in load (gas load) due to the differential pressure between suction gas and discharge gas in the high-pressure stage compression unit 10 can be surely suppressed and the gas load can be prevented from exceeding the allowable gas load GL_h.

[0052] Next, in order to explain an operation control method for a BOG multistage displacement compressor according to Embodiment 4 of the present invention, a case in which a reciprocating compressor is applied to the BOG multistage compressor is given as an example with reference to Fig. 5. Fig. 5 is a systematic diagram of LNG and BOG treatment equipment to which the operation control method for a BOG multistage displacement compressor of Embodiment 4 of the present invention is applied.

[0053] Embodiment 4 of the present invention is in common with the above-mentioned Embodiment 1 in many structural points. Therefore, in Fig. 5, the same reference numbers are assigned to the same members as in Embodiment 1 (Fig. 1) to omit the description thereof. Differences between Embodiment 4 of the present invention and Embodiment 1 are mainly described below.

[0054] In the BOG multistage displacement compressor according to Embodiment 4 of the present invention, a three-way valve 13 is connected to the middle of the intermediate line 12. The three-way valve 13 includes, at its outlet side, a selector port 13a connected to the intermediate line 12, and a selector port 13b connected to a bypass line 14. A cooler 15 is connected to the bypass line 14, and its downstream side is connected to the intermediate line 12. The cooler 15 includes a cooling pipe 16 through which cooling water such as seawater is passed. The selector ports 13a, 13b of the three-way valve 13 are switched by a control valve 28, and the control valve 28 is controlled by the controller 25 for the opening/closing.

<Operation Control Method (3)>

[0055] In this operation control method (3), when the BOG multistage compressor 8 is started, the controller 25 compares a temperature of low-pressure stage-side suction gas detected by the temperature detector 26 with a set temperature T1 (e.g., -45°C) that is preset. As a result of the comparison, when the temperature is higher than the set temperature T1, the controller 25 controls the control valve 28 for the opening/closing so that an outlet port of the three-way valve 13 is switched to the selector port 13b. Simultaneously, the controller 25 controls the operation of the low-pressure stage capacity adjusting device 21 and the high-pressure stage capacity adjusting device 22 so that the load ratio R is larger than that in steady operation. For example, the control is performed so that the low-pressure stage side load is 100%, and the high-pressure stage side load is 75%.

[0056] BOG from the BOG delivery line 7 is compressed by the low-pressure stage compression unit 9, branched from the intermediate line 12 at the selector port 13b of the three-way valve 13, introduced into the bypass line 14, and cooled by the cooler 15. The BOG is then merged into the intermediate line 12 to enter the high-pressure stage compression unit 10, compressed therein, passes the discharge line 17 and the junction portion 23, and then is supplied together with natural gas in the gas transfer line 6 to the plant.

[0057] Thereafter, when the temperature of discharge gas from the low-pressure stage compression unit 9 drops to the set temperature T1 or lower, the controller 25 controls the control valve 28 for the opening/closing so that the outlet port of the three-way valve 13 is switched to the selector port 13a, and thereby the discharge gas from the low-pressure stage compression unit 9 is directly supplied from the intermediate line 12 to the high-pressure stage compression unit 10. Simultaneously, the controller 25 controls the operation of the low-pressure stage capacity adjusting device 21 and the high-pressure stage capacity adjusting device 22 so that the load ratio R is equal to that in steady operation. For example, the operation is performed so that the low-pressure stage-side load is 100%, and the high-pressure stage-side load is 100%.

[0058] Also according to the operation control method for a BOG multistage displacement compressor of Embodiment 4 of the present invention, the increase in load (gas load) due to the differential pressure between suction gas and discharge gas in the high-pressure stage compression unit 10 can be suppressed to prevent the gas load from exceeding the allowable gas load GL_h. When the operation of the low-pressure stage capacity adjusting device 21 and the high-pressure stage capacity adjusting device 22 is controlled so that the load ratio R is larger than that in steady operation, the gas load on the low-pressure stage side is increased in stead of reduction of the gas load on the high-pressure stage side, and the temperature of discharge gas on the low-pressure stage side rises.

[0059] However, since the operation of the low-pressure stage capacity adjusting device 21 and the high-pressure stage capacity adjusting device 22 is controlled so that the load ratio R is larger than that in steady operation, and since the other operation is simultaneously controlled so that the BOG compressed by the low-pressure stage compression unit 9 passes the bypass line 14, is cooled by the cooler 15, and then merges into the intermediate line 12 to enter the high-pressure stage compression unit 10, the temperature of discharge gas on the low-pressure stage side is suppressed from rising. Therefore, the temperature of discharge gas on the high-pressure stage side never exceeds an allowable

upper limit temperature.

<Example>

[0060] Example of the operation control method for a BOG multistage displacement compressor according to Embodiment 4 of the present invention is described with reference to Fig. 5. In the steady operation of the multistage displacement compressor, both the primary side compression unit 9 and the secondary side compression unit 10 are operated with 100% load (Comparative Example-4 of Table 3). According to the BOG multistage displacement compressor of Embodiment 4 of the present invention, under the predetermined state, for example at the start-up, the primary side compression unit 9 and the secondary side compression unit 10 are operated respectively with 100% load and with 75% load by the capacity adjusting devices 21 (the suction valve unloader 9a, the head end unloader 9b, etc.) and 22 (the suction valve unloader 10a, the head end unloader 10b, etc.) of the primary side compression unit 9 and the secondary side compression unit 10. Namely, the load ratio in start-up is larger than the load ratio in steady operation (refer to Example of Table 3).

[0061] In Table 3, start-up operation states of the BOG multistage displacement compressor according to a related art are given for showing the effects of the present invention. One operation state is an operation form (Comparative Example-5 of Table 3) where both the primary side compression unit 9 and the secondary side compression unit 10 are operated with 100% load. The other is an operation form (Comparative Example-6 of Table 3) where both the primary side compression unit 9 and the secondary side compression unit 10 are operated with 75% load. In both Comparative Example-5 and Comparative Example-6, the load ratio is equal to the load ratio in steady operation.

[Table 3]

	Operating Condition	Load Ratio	Operation Form		Use/Nonuse of Cooler
			Primary Side Compression Unit	Secondary Side Compression Unit	
Comparative Example-4	Steady operation		100%-Load operation	100%-Load operation	Unused
Comparative Example-5	At start-up	Same as in steady operation	100%-Load operation	100%-Load operation	Used
Comparative Example-6	At start-up	Same as in steady operation	75%-Load operation	75%-Load operation	Used
Example	At start-up	Larger than in steady operation	100%-Load operation	75%-Load operation	Used

[0062] Table 4 shows suction/discharge gas pressures of the primary side compression unit 9 and the secondary side

compression unit 10 in each operation form of Table 1, and compression loads and tension loads of the primary side compression unit 9 and the secondary side compression unit 10. As shown in Comparative Example-4 of Table 3, when the BOG multistage displacement compressor is in the steady operation state, the compression load on the secondary side is about 8,490 kfg. However, when the load ratio in start-up is set to the same value as the load ratio in steady operation, the compression load on the secondary side reaches 9,230 kgf (1.09 times that in Comparative Example 4) and 8,970 kgf (1.06 times that in Comparative Example-4) as shown in Comparative Examples-5, 6 in Table 4.

[0063] On the other hand, in the start-up operation state of the BOG multistage displacement compressor according to Embodiment 4 of the present invention, as shown in Example of Table 4, the compression load on the secondary side is suppressed to 8,540 kgf (1.01 times that in Comparative Example-4). In Example, the effect is obtained by setting the load ratio to a value larger than that in steady operation and performing the operation control so that the BOG compressed by the low-pressure stage compression unit 9 passes the bypass line 14, is cooled by the cooler 15, and then merges into the intermediate line 12 to enter the high-pressure stage compression unit 10.

[Table 4]

	Pressure [barA]				Gas Load [kgf] (Values in parenthesis are ratios to Comparative Example 4)			
	Primary Suction	Primary Discharge	Secondary Suction	Secondary Discharge	Primary Compression Load	Primary Tension Load	Secondary Compression Load	Secondary Tension Load
Comparative Example-4	1.1	3.5	3.4	9.0	8160	8190	9490	8150
Comparative Example-5	1.1	3.0	2.9	9.0	6380 (0.78)	6300 (0.78)	9230 (1.09)	8910 (1.09)
Comparative Example-6	1.1	3.2	3.1	9.0	7010 (0.86)	6940 (0.86)	8970 (1.06)	8640 (1.06)
Example	1.1	3.5	3.4	9.0	8030 (0.98)	7950 (0.98)	8540 (1.01)	8260 (1.01)

[0064] As described so far, according to the operation control method for a BOG multistage displacement compressor of the present invention, under a predetermined state, operation control is performed so that the ratio (road ratio) of the load R of the low-pressure stage compression unit to the load of the high-pressure stage compression unit in the BOG multistage displacement compressor is larger than those under states other than the predetermined state. The operation performed with a large load ratio R means that compression ratio of the low-pressure stage compression unit is increased, and compression ratio of the high-pressure stage compression unit is decreased. Accordingly, the gas load on the high-pressure stage side is reduced. Thus, even if the low-pressure stage-side suction gas has a temperature higher than that in steady operation, the gas load on the high-pressure stage side can be prevented from exceeding an allowable gas load.

[0065] In the above-mentioned embodiments, the operation control method for a BOG multistage displacement compressor according to the present invention has been described while taking a reciprocating compressor and a screw compressor as examples, and the capacity adjusting device is explained while taking a suction valve unloader, a head end unloader and a slide valve as examples. However, the present invention is never limited to them, but the operation control method for a BOG multistage displacement compressor according to the present invention can be applied to various types of displacement compressors and BOG displacement compressors including capacity adjusting devices of various configurations.

[0066] Provided is an operation control method for a BOG multistage displacement compressor including connected multiple displacement compression units for compressing boil off gas (BOG) generated from liquefied natural gas, including: under a predetermined state, performing operation control so that the ratio (load ratio) of a load of a low-pressure stage compression unit to a load of a high-pressure stage compression unit in the BOG multistage displacement compressor is larger than load ratios under states other than the predetermined state. Namely, the BOG multistage displacement compressor is configured so that suction temperature in the low-pressure stage compression unit can be detected, and the predetermined state is set to a state where the detected temperature of the suction temperature is equal to or higher than a set temperature that is preset. According to such a method, even if the low-pressure stage side suction gas has a temperature higher than that in steady operation, the load (gas load) due to a differential pressure between suction gas and discharge gas on the high-pressure stage side can be prevented from exceeding an allowable gas load.

Claims

1. An operation control method for a BOG multistage displacement compressor including connected multiple stages of displacement compression units for compressing BOG generated from liquefied natural gas, comprising:

   under a predetermined state, performing operation control so that the ratio (load ratio) of a load of a low-pressure stage compression unit to a load of a high-pressure stage compression unit in the BOG multistage displacement compressor is larger than load ratios under states other than the predetermined state.

2. The operation control method for a BOG multistage displacement compressor according to claim 1, wherein the BOG multistage displacement compressor is configured so that suction temperature in the low-pressure stage compression unit can be detected, and the predetermined state is set to a state where the detected temperature of the suction temperature is equal to or higher than a set temperature that is preset.

3. The operation control method for a BOG multistage displacement compressor according to claim 1, wherein
   the BOG multistage displacement compressor is configured so that a differential pressure between suction pressure and discharge pressure of the high-pressure stage compression unit can be detected, and
   the predetermined state is a state since it is determined that the differential pressure is equal to or more than a first set differential pressure that is preset, until it is determined that the differential pressure reaches a second set differential pressure that is preset and smaller than the first set differential pressure.

4. The operation control method of a BOG multistage displacement compressor according to claim 1, wherein when the operation control is performed so that the load ratio under the predetermined state is larger than load ratios under states other than the predetermined state, discharge gas of the low pressure compression unit passes through a cooler, and is supplied to the high-pressure stage compression unit.

FIG. 1

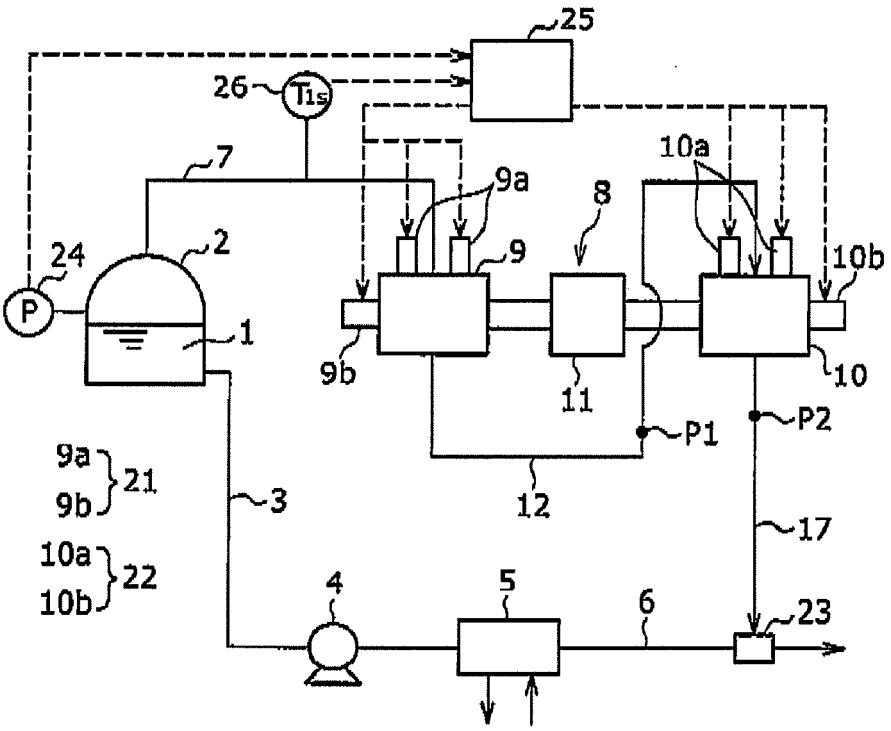
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FIG. 2

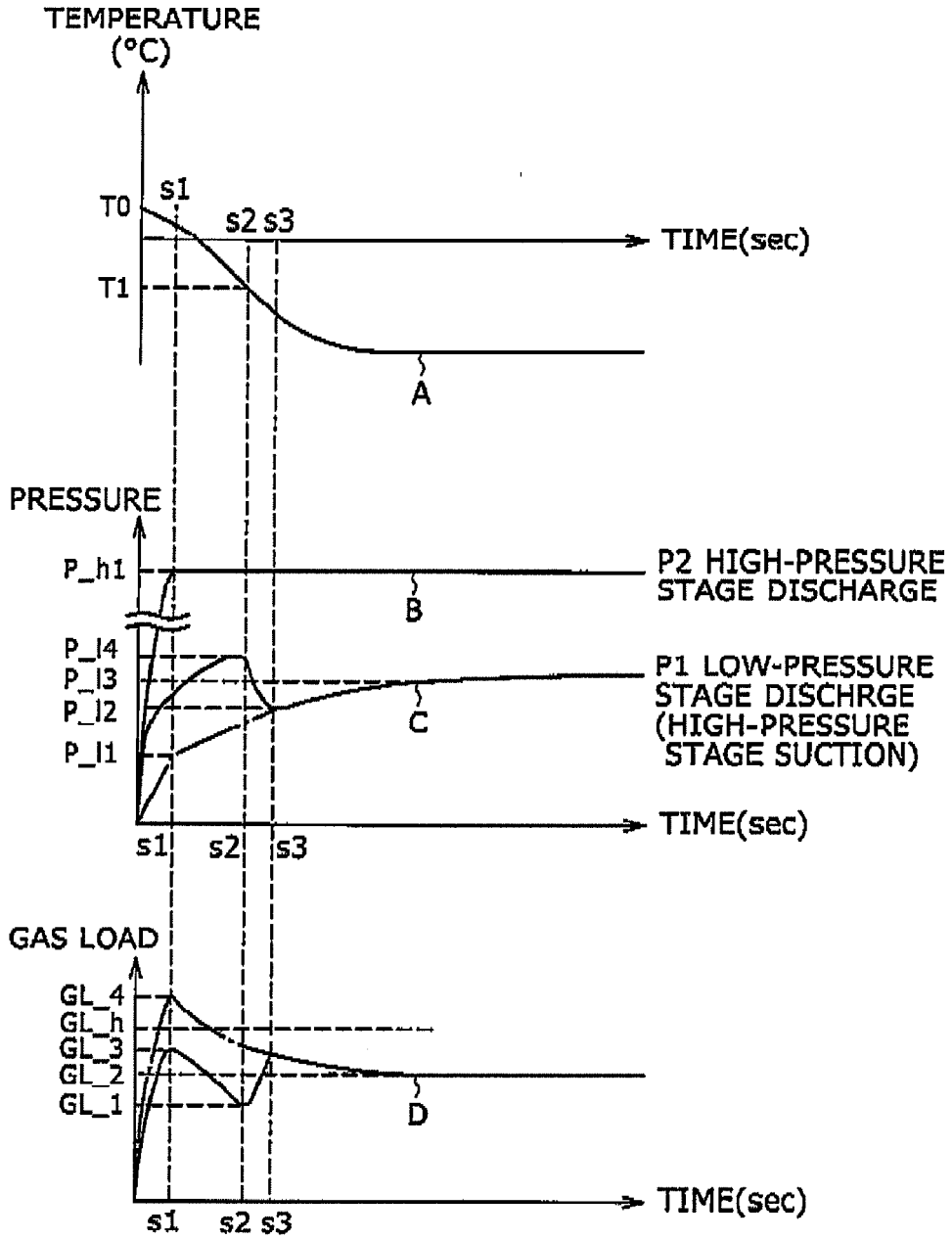
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FIG. 3

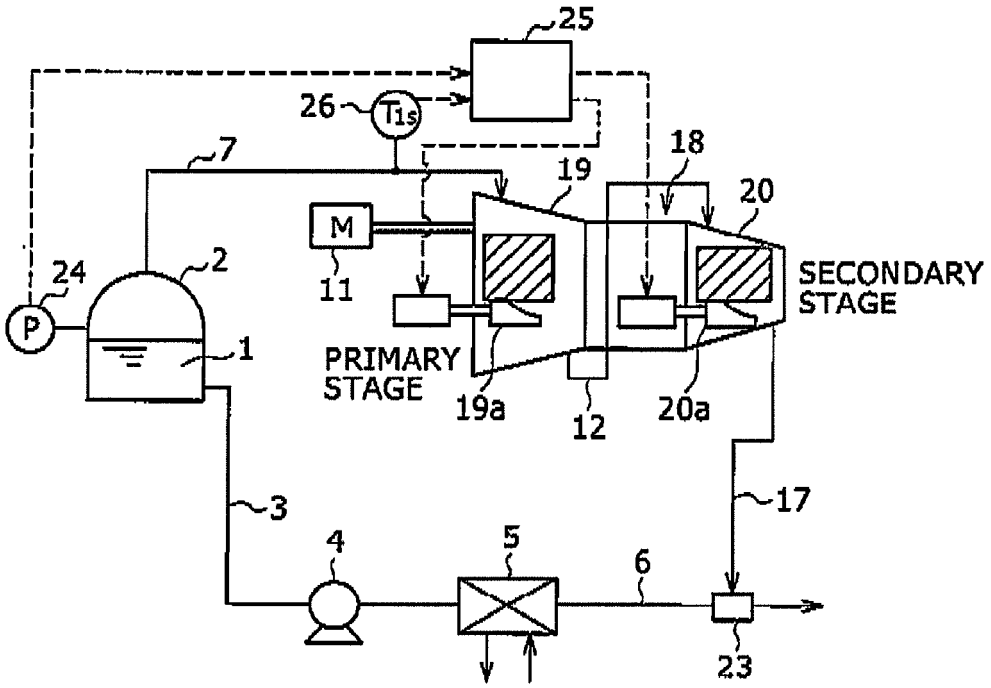
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FIG. 4

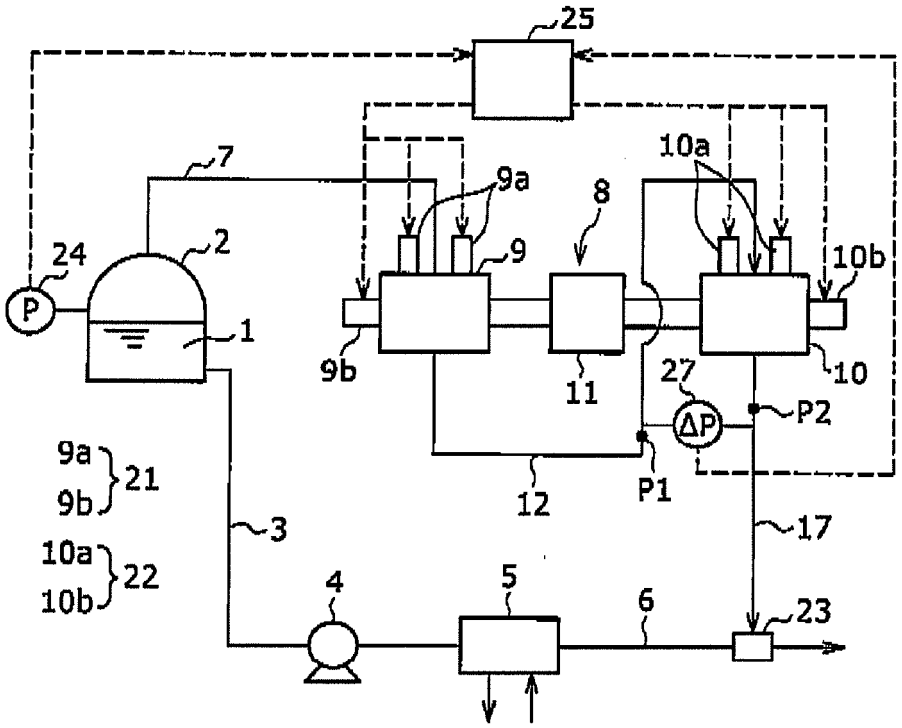
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FIG. 5

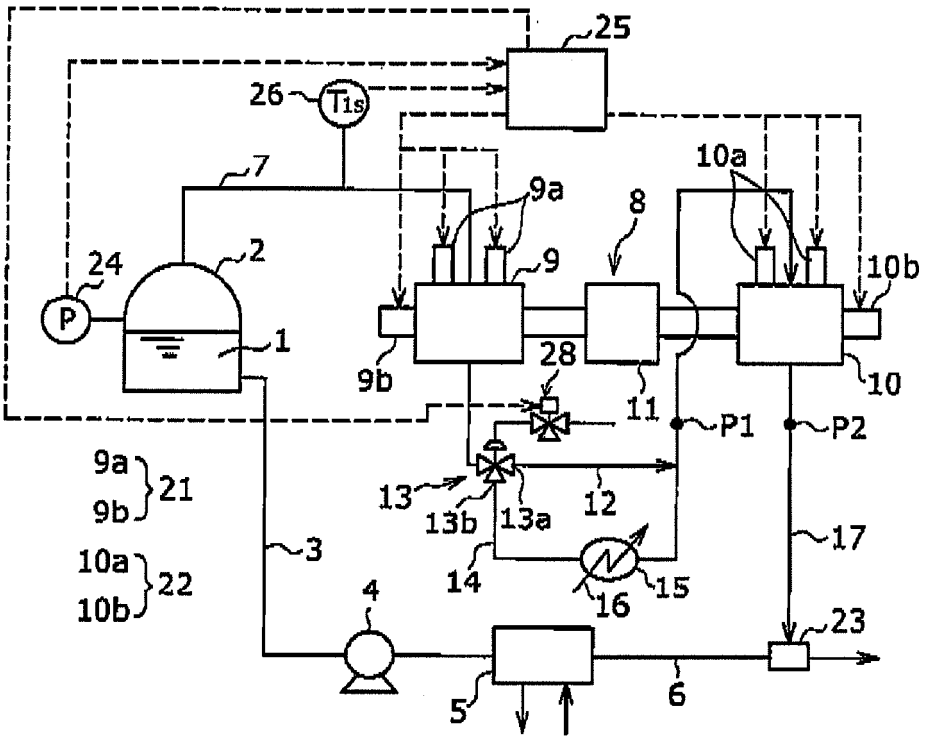
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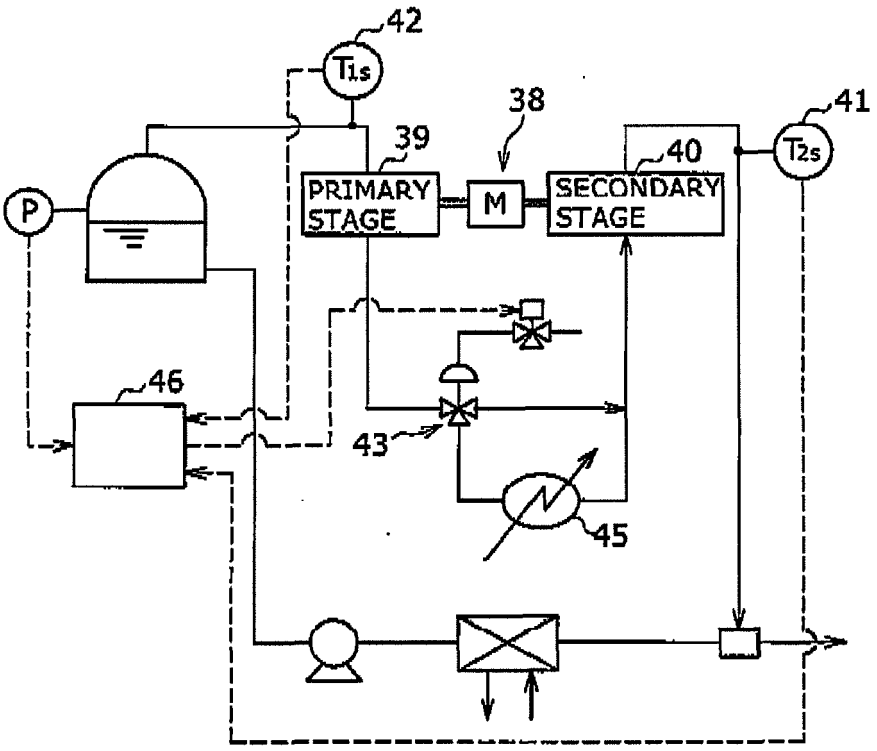
FIG. 6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