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(54) **COMPRESSOR DEVICE AND METHOD FOR COMPRESSING A LIQUID VAPOUR, IN PARTICULAR STEAM**

(57) A compressor device comprises an at least substantially closed compression chamber (50) which comprises on the gas side a compression space (10) with a gas inlet (11) and a gas outlet (12) for respectively receiving a supplied gas at a first pressure and delivering it at an increased pressure. Energizable displacing means which are able and configured to alternately reduce and increase the compression space (10) are provided. The compression chamber (50) comprises an electronically switchable liquid feed (26) and an electronically switchable liquid discharge (27), each in open communication with the compression space (10). The displacing means comprise a liquid pump (30) which is connected to the liquid feed (26) on the pressure side. Control means (40) are provided, which are connected operatively to the switchable liquid feed (26), the switchable liquid discharge (27) and the liquid pump (30) to mutually adapt operation thereof in order to alternately fill the compression space (10) at least partially with a liquid and evacuate the liquid therefrom.

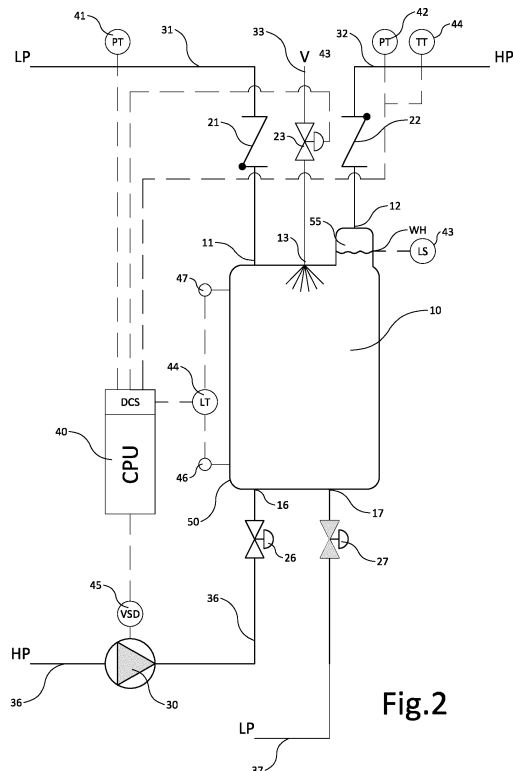


Fig.2

Description

[0001] The present invention relates to a compressor device, comprising an at least substantially closed compression chamber which comprises on the gas side a compression space with a gas inlet and a gas outlet for respectively receiving a supplied gas at a first pressure and delivering it at an increased pressure, and comprising energizable displacing means which are able and configured to alternately reduce and increase the compression space. The invention also relates to a method for compressing a liquid vapour, particularly steam, using such a compressor device.

[0002] A compressor device of the type described in the preamble is applied on large scale and in various forms for the purpose of increasing the pressure of gases. A known form is the piston compressor which draws gas in via an inlet valve during an inlet stroke by means of a reciprocally moving piston in a cylinder, and in a subsequent compression stroke compresses the gas and makes it available under increased pressure via another valve. The piston is here driven mechanically by for instance an electric motor, steam turbine or a combustion engine.

[0003] Other forms of known compressors are for instance a rotary-screw compressor and a roots blower wherein rotation of respectively two screws or lobes acting on each other reduces a mutual intermediate space, with the result that the intermediate gas is displaced and compressed. Another known compressor is a centrifugal compressor. To drive the relevant displacing members use is here also usually made of an electric motor, steam turbine or a combustion engine.

[0004] What these known forms of compressor have in common is that mechanical parts moving therein are applied as displacing means, which is unequivocally subject to wear and moreover produces sound.

[0005] The present invention has for its object, among others, to provide a compressor device which is relatively quiet and low-maintenance and which is particularly suitable for compressing a liquid vapour, such as particularly steam.

[0006] In order to achieve the stated object a compressor device of the type described in the preamble has the feature according to the invention that the compression chamber comprises an electronically switchable liquid feed and an electronically switchable liquid discharge, each in open communication with the compression space, that the displacing means comprise a liquid pump which is connected on the pressure side to the liquid feed, and that control means are provided which are connected operatively to the switchable liquid feed, the switchable liquid discharge and the liquid pump to mutually adapt operation thereof in order to alternately fill the compression space at least partially with a liquid and evacuate the liquid therefrom.

[0007] The compressor device according to the invention is a compressor of the positive displacement type

whereby, in contrast to the known mechanical compressors where this is done with mechanical parts, the compression space is however alternately increased and reduced by repetitively letting a liquid into and out of the closed compression chamber. The inlet is here provided for by the liquid pump, which thereby supplies the energy required for the compression. Owing to this alternating evacuation and (partial) filling of the compression space, gas is drawn in and then compressed in the same order without moving mechanical parts acting on the gas for compressing for this purpose. The gas here particularly and preferably comprises the vapour phase of the liquid which is let into and discharged from the compressor space in order to alternately reduce and increase the compression space. Unless expressly stated otherwise, vapour or vapour phase will therefore in the following always be understood to mean the gaseous aggregation state of the liquid which is let into and evacuated from the compression space via respectively the liquid feed and liquid discharge.

[0008] By means of for instance switch valves in the liquid feed and liquid discharge the liquid to be pumped can be alternately supplied in the compression chamber or evacuated therefrom. The gas inlet and outlet can also be electronically controlled in similar manner, or mechanical valves or non-return valves can be applied therein.

[0009] Compressing the gas will automatically cause an increase of the temperature of the gas in the compression space. This temperature increase or even overheating as a result of the compression can be countered by application of direct water injection into compression space. A preferred embodiment of the compressor device has for this purpose the feature according to the invention that the compression chamber comprises on the gas side a liquid inlet which is connected to a liquid conduit and which debouches in the compression space. A part of the injected liquid will here evaporate in the compression space and thereby already cool the space. In order to enhance this, a further preferred embodiment of the compressor device has the feature according to the invention that the liquid inlet comprises an atomizer which debouches in the compression space.

[0010] A part of the injected liquid may also remain behind in the form of heated liquid. The energy absorbed due to heating of the remainder of the injected liquid will cause this liquid to evaporate wholly or partially when the liquid is evacuated from the compression space. The developed vapour is then compressed during a subsequent compression cycle. The same medium as pumped by the liquid pump is then preferably also used as the injected liquid.

[0011] Although the liquid can be fed and discharged alternately, a further preferred embodiment of the compressor device has the feature according to the invention that the liquid discharge is connected to an inlet of the liquid pump. The liquid thus circulates in the device so as to be reused time and again.

[0012] The temperature of the pumped liquid will like-

wise increase due to the pump energy dissipated for the compression. This dissipated energy is supplied by the liquid pump. A particular embodiment of the compressor device according to the invention has the feature here that the liquid discharge is coupled to the inlet of the liquid pump in heat-exchanging contact with a heat exchanger. In this way the dissipated pump energy can be recovered at least partially, for instance to be used elsewhere.

[0013] A full operating cycle of the compressor device comprises a suction state and a compression state. After compression, the compression space can additionally go through a state in which a free expansion or compression is provided. In order to be able to provide at least a number of these states simultaneously, a further particular preferred embodiment of the compressor device has the feature according to the invention that the compression chamber forms part of an assembly of a number of corresponding compression chambers, particularly four compression chambers or a whole multiple thereof, which are coupled to shared respective liquid conduits and respective gas conduits, that each of the compression chambers of the assembly is controlled individually by the control means, wherein the compression chambers are each operated in an individual state of a series of a corresponding number of successive cycles, wherein in each case at least one of the compression chambers will perform a compression stroke.

[0014] In a preferred embodiment use is made here of four compression chambers, wherein alternately one chamber is in the compression state and the compression spaces in the other three chambers are respectively either expanding or compressing freely or being pumped empty forcibly. Four different states, i.e.: (i) compression, (ii) free expansion, (iii) inlet pressure, and (iv) free compression, which are fulfilled successively by different compression chambers, therefore always prevail simultaneously then.

[0015] In order to allow a free expansion and/or free compression of the compression space a further particular embodiment of the compressor device has the feature according to the invention that the compression chambers are connectable in pairs on the liquid side with interposing of a switch valve which is electronically controllable by the control means. After a compression in the one chamber of the set, the intermediate switch valve can thus be opened in order to allow a free (partial) expansion which results in a free (partial) compression in the coupled compression space. This part of the energy need therefore no longer be provided by the liquid pump, this contributing to the energy efficiency of the device.

[0016] The required energy is supplied by the liquid pump. The pump capacity will therefore be adapted to a desired flow rate on the gas side and a maximum pressure ratio between the compression state and the wholly evacuated underpressure state of the compression space. In order to be able to make allowance for this sometimes varying requirement, a further preferred embodiment of the compressor device has the feature ac-

cording to the invention that the liquid pump comprises a controllable pump with a pump drive which is operatively coupled to the control means and which is able and configured to impose a variable pump capacity on the pump. The liquid pump is thus embodied with variable speed drive for the purpose of an adjustable capacity.

[0017] The capacity can for instance be controlled on the basis of availability of the low pressure gas (residual heat in the case of steam compression) at the gas inlet. On the other hand, the capacity can for instance be controlled on the basis of the desired high pressure (high temperature heat demand in the case of vapour compression) at the gas outlet. With a view thereto, a further particular embodiment of the compressor device has the feature according to the invention that the gas inlet and the gas outlet each communicate upstream with respectively an inlet pressure sensor and an outlet pressure sensor, which pressure sensors are operatively coupled to the control means. The control means can thus adapt the rotational speed of the liquid pump to the available inlet pressure at the inlet and/or the desired outlet pressure at the outlet.

[0018] By means of level measurements or level switches it is possible to indicate when a minimum or maximum level in a compression space has been reached. For the control means, this is the signal to switch from one state to another state in the compression chamber. A particular embodiment of the compressor device has for this purpose the feature that provided in the compression chamber is a liquid level sensor which is operatively coupled to an electronic control circuit, and more particularly that the control means comprise the control circuit. The control equipment of the control means will control the switch valves for liquid to or from the compression space to open or close depending on the state intended therein.

[0019] Both the supply of liquid to the compression space and the evacuation therefrom are in particular actively imposed by the control means. For this purpose a further embodiment of the compressor device has the feature that the liquid feed and the liquid discharge comprise a switch valve which is electronically controllable by the control means. Active valves which are controlled by the control means can likewise be applied on the gas side, although an autonomous, purely mechanical drive is instead also possible. This will then automatically follow the active drive imposed on the liquid side. For this purpose a further embodiment of the compressor device has the feature according to the invention that the gas inlet and the gas outlet each comprise a non-return valve or valve with operatively opposite orientation.

[0020] The above described compressor device according to the invention is particularly suitable for compressing a liquid vapour. For this purpose the invention also relates to a method for compressing a liquid vapour, particularly steam, with the feature that the above described compressor device according to the invention is applied for this purpose, wherein a liquid vapour, partic-

ularly steam, is supplied under a first pressure at the gas inlet and a liquid vapour, particularly steam, is taken off under an increased second pressure at the gas outlet, and wherein the corresponding liquid, particularly water, is opted for the liquid feed.

[0021] For a gas cooling use is in that case preferably likewise also made of the same medium as is applied for the liquid feed and discharge. A preferred embodiment of the method according to the invention therefore has the feature that the compression chamber comprises on the gas side a liquid inlet, particularly a water inlet, which is connected to a liquid conduit, particularly a water conduit, and which debouches in the compression space, particularly via an atomizer.

[0022] The invention will be further elucidated herein-below with reference to an exemplary embodiment and an accompanying drawing. In the drawing:

- Figure 1 shows an exemplary embodiment of a compressor device according to the invention in an expansion state;
 Figure 2 shows the compressor device of figure 1 in a compression state; and
 Figure 3 shows an assembly of a number of compressor devices of figure 1 for the purpose of a fully continuous operation for steam compression.

[0023] It is otherwise noted here that the figures are purely schematic and not always drawn to (the same) scale. Some dimensions in particular may be exaggerated to greater or lesser extent for the sake of clarity. Corresponding parts are designated in the figures with the same reference numeral.

[0024] An exemplary embodiment of a compressor device according to the invention is shown schematically in figure 1. The compressor device comprises a substantially closed compression chamber 50 which provides on the gas side a compression space 10. On the gas side the compression chamber comprises a gas inlet 11 and a gas outlet 12 in the form of valves 21, 22 with opposite orientation. The inlet valve 21 lets a gas from a gas inlet 31 of relatively low pressure LP into the compression space 10 as soon as a lower pressure prevails therein, and closes in opposite direction. At a predetermined overpressure in compression space 10 the outlet valve 22 opens to a gas outlet 32 of relatively high pressure HP. In this embodiment steam is used as vapour phase of water which is applied in liquid form. This is for instance supplied at inlet 31 at a pressure LP of several tenths of a Bar and taken off at outlet 32 at an increased pressure HP in the order of 5 Bar at a temperature in the order of 150°C.

[0025] On an opposite, liquid side the compressor chamber comprises a liquid feed 16 and a liquid discharge 17 which are coupled to respective liquid conduits 36, 37. Connected between liquid conduits 36, 37 and the relevant liquid feed 16 or liquid discharge 17 is an

electronically controllable switch valve 26, 27 which is controlled by control means of a central control unit 40. Also coupled thereto is a variable frequency drive 45 of liquid pump 30 whereby a liquid can be carried to liquid feed 16 under pressure. If desired, several liquid pumps can here also be placed parallel or in series, each having a variable frequency drive, which can then each be called upon in their own optimal range of operation. Unless explicitly stated otherwise, water is in this embodiment always used as the liquid, particularly sufficiently clean process water. Water is correspondingly also applied for the gas which is let in or let out under increased pressure on the gas side, albeit in the corresponding vapour phase as steam.

[0026] In the stage shown in figure 1 the compression chamber is not filled with water, or hardly so, which is indicated by the drawn low water level WL and the opened valve 27 to the outgoing liquid conduit 37. In this state the compression space fills with steam from the low pressure feed 31 and the valve 21 opened to gas inlet 11 there. Once compression space 10 has completely filled with steam, control unit 40 sends a control signal to discharge valve 27 to close it and the control unit controls feed valve 26 to open, see figure 2.

[0027] The pump 30 is also brought to the desired rotational speed by control unit 40 and variable frequency drive 45. The liquid level in compression chamber 50 is thus elevated from feed conduit 36, whereby the compression space decreases and the gas present therein is compressed. Valve 21 is now closed. In order to limit dead volume in the compression space a narrow hood 55 is provided thereon, this having a level switch 43 which generates a signal when a maximum filling level WH corresponding with a predetermined compression ratio is reached. When this level is reached, outlet valve 22 opens in order to release steam to pressure conduit 32 under the thus increased pressure. After this, the steps of figures 1 and 2 can be repeated in order to thus impart a pressure increase to the gas supplied from inlet 31 in steps and supply it under increased pressure, whereby the gas can be taken off at outlet 32.

[0028] The compressor device described here is of the positive displacement type whereby, in contrast to most mechanical compressors where this is done with mechanical parts, the necessary increase and reduction of the compression space 10 is brought about by repetitively pumping a liquid into the compression space and evacuating it therefrom. Gas is here drawn in and then compressed to an increased pressure in the same order. The gas to be compressed is supplied to compression space 10 by means of valve 21 or a switch valve. The compressed gas is also supplied under a correspondingly increased pressure via a valve 22 or switch valve to be guided to for instance a pressure vessel or supply system for consumption. The liquid to be pumped is likewise alternately supplied to or evacuated from compression space 10 with valves 26, 27.

[0029] By means of level measurements with sensors

or switches 43, 46, 47 provided for this purpose in or on compression chamber 50 it is possible to indicate when a minimum or maximum level in compression chamber 50 has been reached. These indicator signals are exchanged with control means 40 in order to switch between the different states of the compressor device. The control equipment will control the switch valves 26, 27 to open or close depending on the state to be reached. The measured values are also shared with control equipment 40 in order to have them calculate how long the feed water control valve 26 must be controlled to open so that the desired level will be reached in the compression state.

[0030] Compressing the gas will automatically cause an increase of the temperature of the gas. The temperature of the pumped liquid will likewise increase due to the pump energy dissipated by pump 30. This temperature increase (overheating) as a result of the steam compression can be countered by application of direct water injection into compression space 10. For this purpose the compressor chamber 50 comprises on the gas side an atomizer 13 which is coupled via a switch valve 23 to a feed 33 for mains water. Switch valve 23 is coupled to a controller of control unit 40 provided for this purpose.

[0031] Controller 40 comprises a temperature sensor (not shown) in compression space 10, at gas outlet 12 and/or in outlet conduit 32. The measured values are transmitted to control equipment 40 which generates a signal to control unit 40 when a threshold value is exceeded, upon which signal the control unit controls switch valve 23 to open. Liquid, cold water will hereby be fed to the atomizer and then be supplied in compression space 10 in the form of a fine mist (aerosol). Controller 40 thus controls the injection water control valve 23 indirectly until the desired value has once again been reached.

[0032] A part of the injected water will evaporate in compression space 10; a remaining part remains behind in the form of heated water. The energy absorbed for this heating and evaporation provides for a reduction of the ambient temperature in compression space 10, so that overheating therein is avoided. The heated remainder of injected water that stays behind will cause this water to evaporate wholly or partially in a subsequent low pressure state of the device, as shown in figure 1, which preferably forms part of a cycle as described below. The developed vapour is here compressed during the subsequent compression state.

[0033] Figure 3 shows an assembly of four mutually co-acting compressor spaces 51-54 which are controlled collectively by control means 40 and together perform a full cycle. Compression chambers 51-54 of the assembly are connected to a shared low pressure inlet 31 and shared high pressure outlet 32. A shared feed conduit 33 for injection water is also provided for the individual atomizers 13. For the sake of clarity the compression chambers 50 in the figure are not further provided with a hood 55 and level switch 43 as shown in figures 1 and 2, although these can also be advantageously applied here in order to limit dead volume therein to a minimum.

[0034] In each stage of a full operating cycle of the assembly of figure 3 a compression chamber 51 is in each case in a suction state, as described in figure 1, and another compression chamber 52 in a compression state, as shown in figure 2. In addition, in each stage of the assembly one of the compression chambers can expand freely 54 and another compression chamber can compress freely 53 following compression. For this purpose adjacent compression chambers 53, 54 are coupled in pairs by means of a controllable intermediate valve 25 which is controlled by control means 40.

[0035] Of the four vessels 51-54, one compression chamber is thus in each case alternately in the compression state while another compression chamber suctions. In the shown stage of the assembly of figure 3 four different states thus prevail simultaneously, divided over the compression chambers 51-54, i.e.: (i) compression (52), (ii) free expansion (54), (iii) inlet pressure (51), and (iv) free compression (53). The required energy will be supplied by a shared liquid pump 30. The capacity, i.e. the rotational speed, thereof will be determined on the basis of the desired flow rate and the desired compression ratio between state (i) and (iii).

[0036] By means of level measurements with sensors or switches 43, 46, 47 provided for this purpose in or on compression chamber 51-54 it is possible to indicate when a minimum or maximum level in a compression chamber 51-54 has been reached. These indicator signals are exchanged with control means 40 in order to switch between different states of the compression chambers 51-54 in each stage per cycle. The control equipment will control the switch valves 26, 27 to open or close depending on the state. The level of all compression chambers 51-54 will be measured. The measured values are transmitted to control equipment 40. The control equipment calculates the average value of all compression chambers 51-54 and controls the relevant feed water control valve 26 so that the desired value will be reached.

[0037] The capacity can be controlled on the basis of availability of the low pressure gas, particularly residual heat in the case of steam compression. On the other hand, the capacity can be controlled on the basis of high pressure high temperature heat demand. For this purpose an inlet pressure sensor 41, and outlet pressure sensor 42 and an outlet temperature sensor 44 are respectively coupled to the control means 40 in order to monitor respectively the low inlet pressure and high outlet pressure. The compression liquid pump 30 is embodied with variable speed drive 45 in order to be able to accommodate a changed demand. Control means 40 can thereby control the rotational speed of liquid pump 30 so that the desired value is reached.

[0038] Compression chambers 51-54 of the assembly of figure 3 are coupled to a shared feed conduit 36 and discharge conduit 37. Pump 30 is received therebetween. Any residual heat can be recovered by means of a heat exchanger 50 provided for this purpose between

feed conduit 36 and discharge conduit 37.

[0039] Although the invention has been further elucidated above with reference to only a single exemplary embodiment, it will be apparent that the invention is by no means limited thereto. On the contrary, many variations and embodiments are still possible within the scope of the invention for a person with ordinary skill in the art.

Claims

1. Compressor device, comprising an at least substantially closed compression chamber which comprises on the gas side a compression space with a gas inlet and a gas outlet for respectively receiving a supplied gas at a first pressure and delivering it at an increased pressure, and comprising energizable displacing means which are able and configured to alternately reduce and increase the compression space, **characterized in that** the compression chamber comprises an electronically switchable liquid feed and an electronically switchable liquid discharge, each in open communication with the compression space, that the displacing means comprise a liquid pump which is connected on the pressure side to the liquid feed, and that control means are provided which are connected operatively to the switchable liquid feed, the switchable liquid discharge and the liquid pump to mutually adapt operation thereof in order to alternately fill the compression space at least partially with a liquid and evacuate the liquid therefrom.
2. Compressor device according to claim 1, **characterized in that** the compression chamber comprises on the gas side a liquid inlet which is connected to a liquid conduit and which debouches in the compression space.
3. Compressor device according to claim 2, **characterized in that** the liquid inlet comprises an atomizer which debouches in the compression space.
4. Compressor device according to one or more of the preceding claims, **characterized in that** the liquid discharge is connected to an inlet of the liquid pump.
5. Compressor device according to claim 4, **characterized in that** the liquid discharge is coupled to the inlet of the liquid pump in heat-exchanging contact with a heat exchanger.
6. Compressor device according to one or more of the preceding claims, **characterized in that** the compression chamber forms part of an assembly of a number of corresponding compression chambers, particularly four compression chambers which are coupled to shared respective liquid conduits and re-

spective gas conduits, that each of the compression chambers of the assembly is controlled individually by the control means, wherein the compression chambers are each operated in an individual state of a series of a corresponding number of successive cycles, wherein in each case at least one of the compression chambers will perform a compression stroke.

7. Compressor device according to claim 6, **characterized in that** the compression chambers are connectable in pairs on the liquid side with interposing of a switch valve which is electronically controllable by the control means.
8. Compressor device according to one or more of the preceding claims, **characterized in that** the liquid pump comprises a controllable pump with a pump drive which is operatively coupled to the control means and which is able and configured to impose a variable pump capacity on the pump.
9. Compressor device according to one or more of the preceding claims, **characterized in that** the gas inlet and the gas outlet each communicate upstream with respectively an inlet pressure sensor and an outlet pressure sensor, which pressure sensors are operatively coupled to the control means.
10. Compressor device according to one or more of the preceding claims, **characterized in that** provided in the compression chamber is a liquid level sensor which is operatively coupled to an electronic control circuit.
11. Compressor device according to claim 10, **characterized in that** the control means comprise the control circuit.
12. Compressor device according to one or more of the preceding claims, **characterized in that** the liquid feed and the liquid discharge comprise a switch valve which is electronically controllable by the control means.
13. Compressor device according to one or more of the preceding claims, **characterized in that** the gas inlet and the gas outlet each comprise a non-return valve or valve with operatively opposite orientation.
14. Method for compressing a liquid vapour, particularly steam, with the feature that a compressor device according to one or more of the preceding claims is applied for this purpose, wherein the liquid vapour, particularly steam, is supplied under a first pressure at the gas inlet and is taken off under an increased second pressure at the gas outlet, and wherein the corresponding liquid, particularly water, is opted for

the liquid feed.

- 15.** Method according to claim 14, **characterized in that** the compression chamber comprises on the gas side a liquid inlet, particularly a water inlet, which is connected to a liquid conduit, particularly a water conduit, and which debouches in the compression space, particularly via an atomizer.

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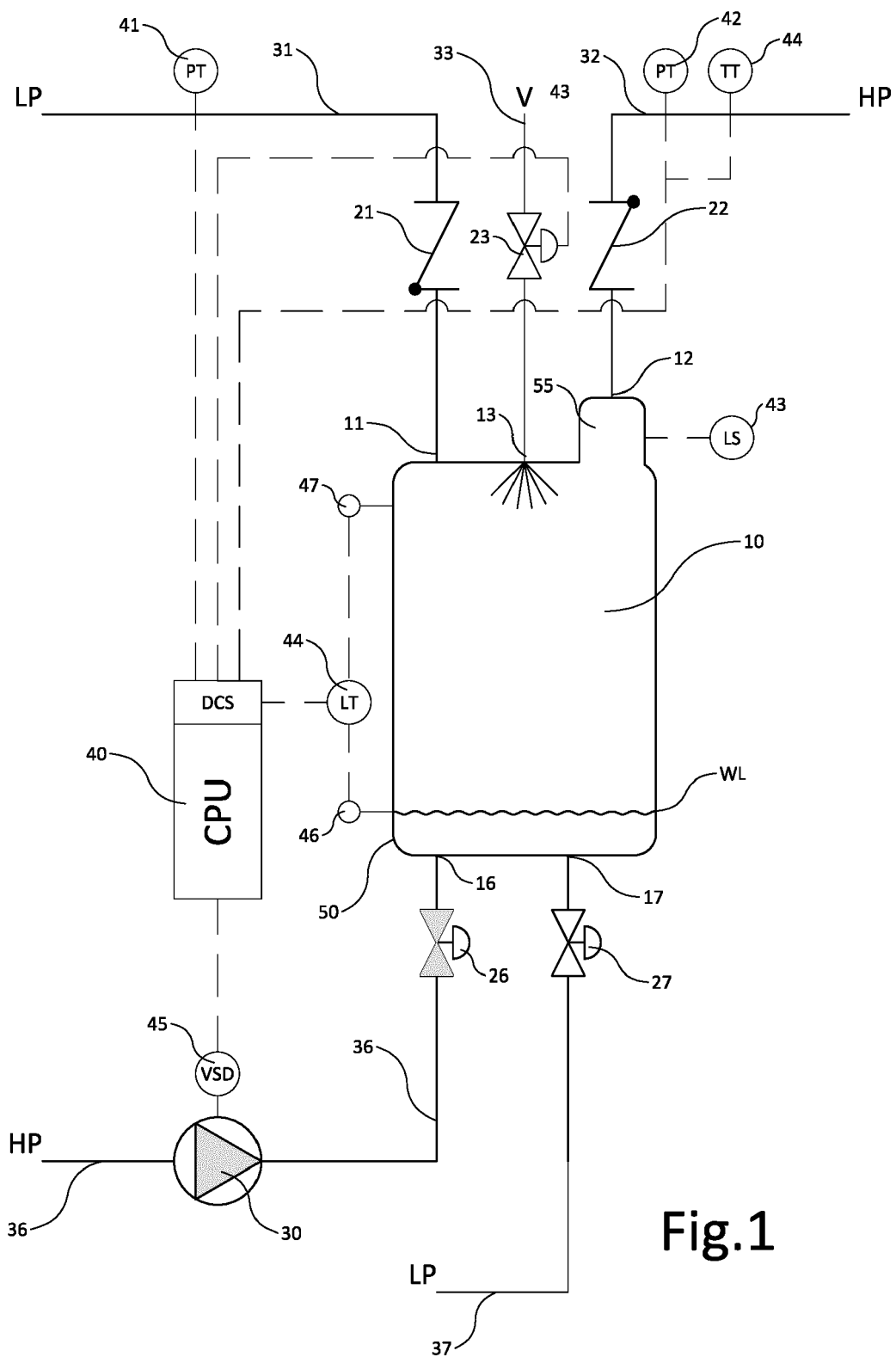


Fig.1

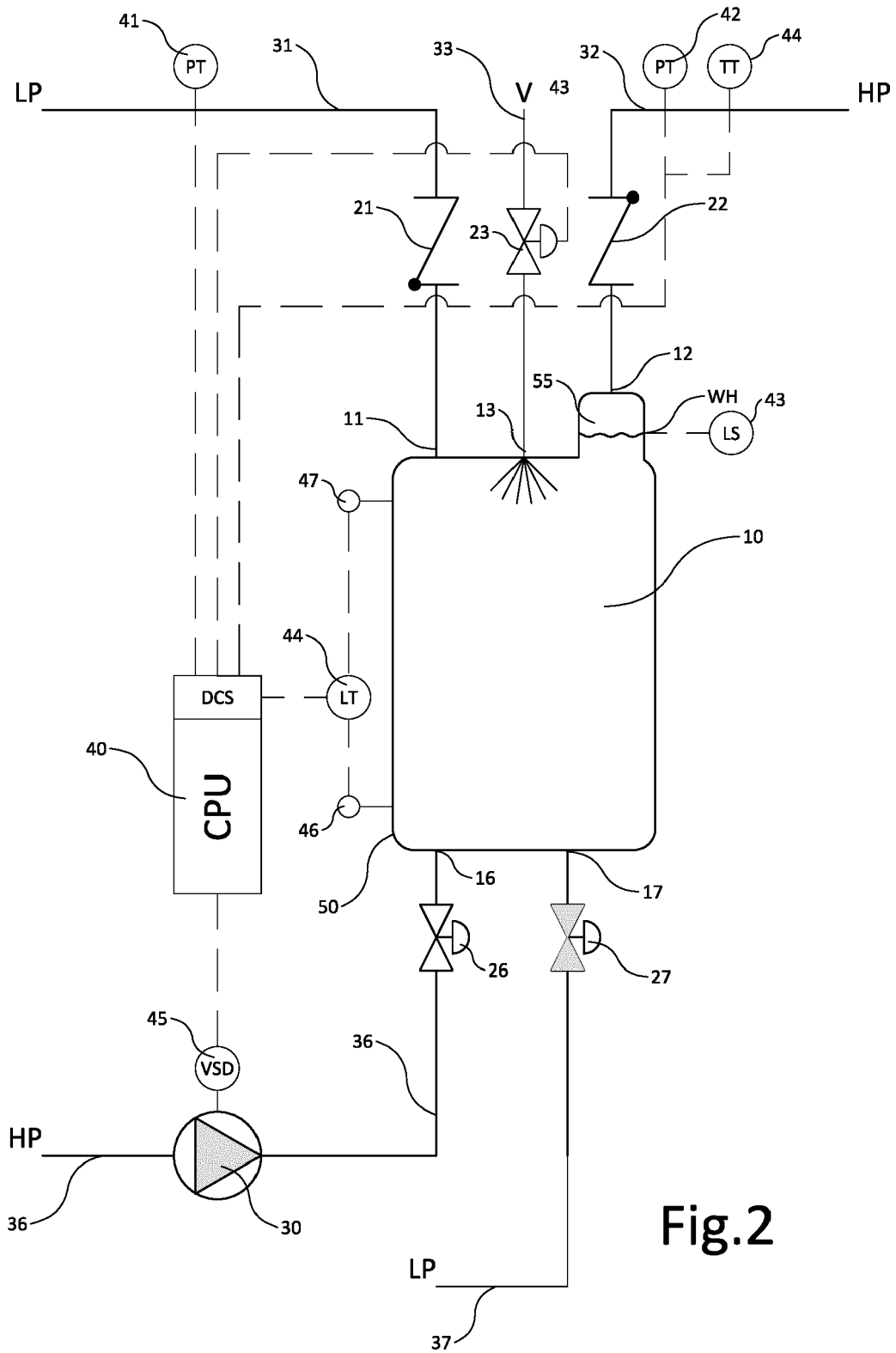


Fig.2

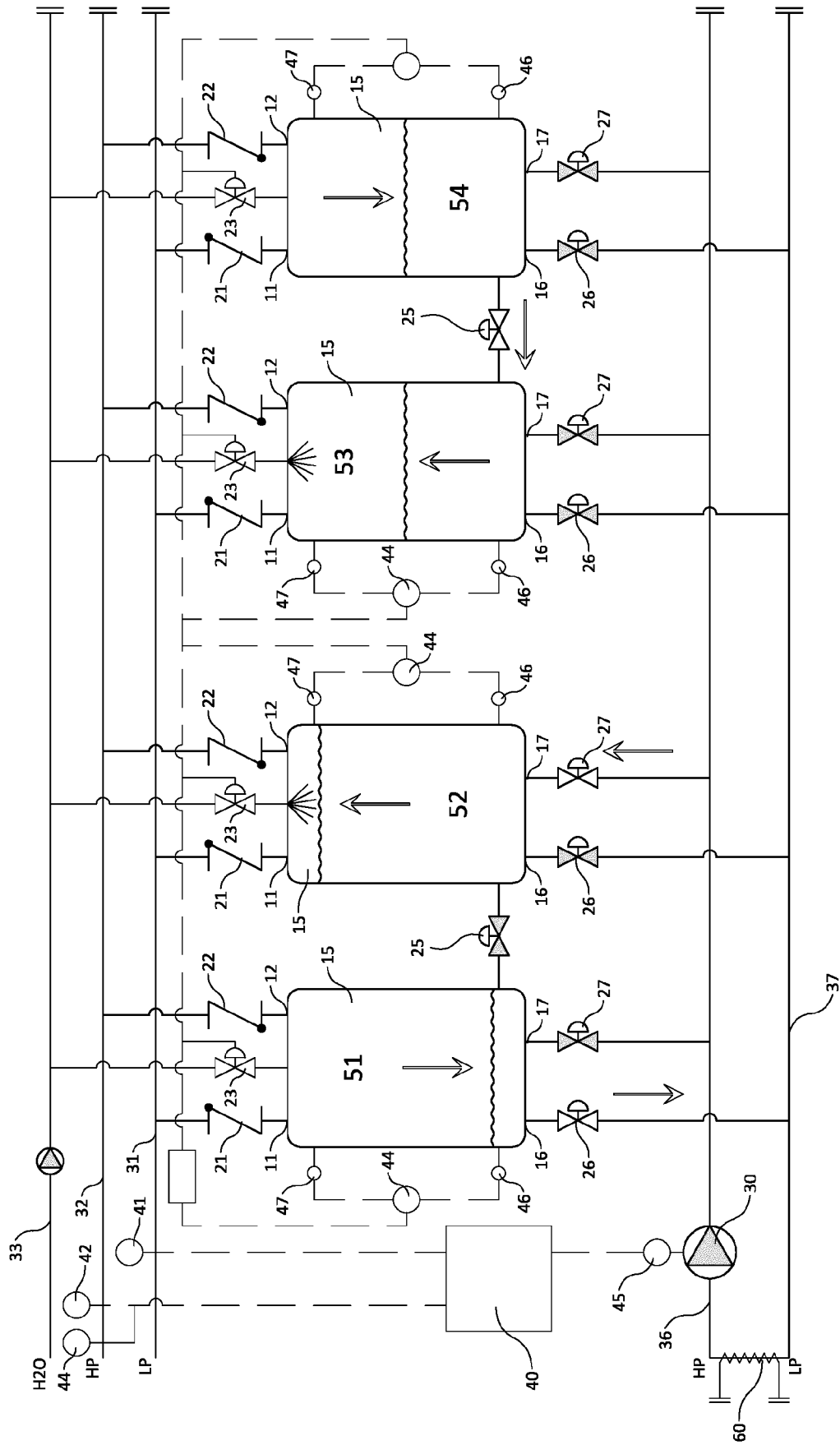


Fig.3



EUROPEAN SEARCH REPORT

Application Number

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	----- -/--		
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 20 September 2023	Examiner Lange, Christian
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			



EUROPEAN SEARCH REPORT

Application Number

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X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			
T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EPO FORM 1503 03.82 (P04C01)

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