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(54) **REFRIGERATION APPARATUS AND USE THEREOF**

(57) A refrigeration apparatus, comprising a main refrigerant circuit (1), including a compressor (2), a condenser (4), an expansion valve (6), and a refrigerant passage (61) extending within an evaporator (8), the apparatus comprising a coolant passage (71) extending within the evaporator (8). The refrigeration apparatus further comprises a lubrication branch (20), connected to a supply part (4, 16) of the main circuit (1) to derive a lubrication refrigerant flow (91) for lubrication of said compressor (2). The refrigeration apparatus further comprises a subcooling branch (40), comprising: a subcooling inlet (41), connected to the coolant passage (71), so as to derive a subcooling coolant flow (92) from the main coolant flow (93), and a subcooling outlet (42), connected to the coolant passage (71), for reintroducing the subcooling coolant flow (92) into the main coolant flow (93); and a subcooling heat exchanger (31), being configured for enabling an exchange of heat between the subcooling coolant flow (92) circulating through the subcooling branch (40) and the lubrication refrigerant flow (91) circulating through the lubrication branch (20), so that the lubrication refrigerant flow (91) may be cooled by the subcooling coolant flow (92) within the subcooling heat exchanger (31).

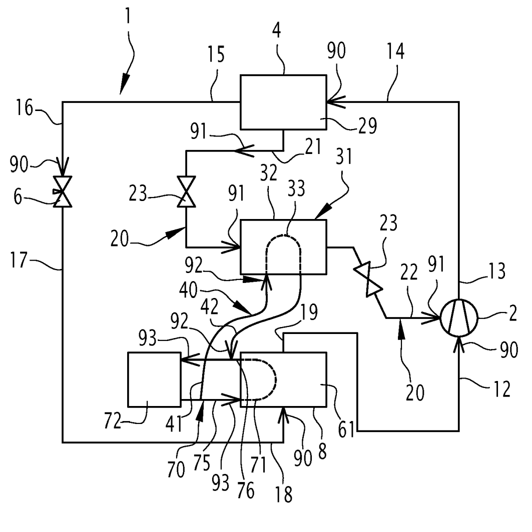

FIG.1

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Description

[0001] The present invention concerns a refrigeration apparatus, a refrigeration system comprising such a refrigeration apparatus and the use of said refrigeration apparatus and said refrigeration system.

[0002] The invention relates to the domain of machines that implement a thermodynamic cycle to a refrigerant, for producing a refrigeration effect.

[0003] A refrigerating apparatus is known from EP 1 400 765 A2, comprising a refrigerant passage including a screw compressor, a condenser, an expansion valve and an evaporator. This known apparatus comprises a bypass flow passage, branching at a part of said refrigerant passage, between the condenser and the expansion valve, routing the refrigerant through throttle means, and communicating with a rotor cavity of the screw compressor. The refrigerant contains a quantity of lubricant, so that lubrication of the rotor cavity is achieved by the same fluid that is also used as the refrigerant in the passage, and in the absence of oil.

[0004] For successfully lubricating the rotor cavity, one must ensure that a significant part of the refrigerant reaching the rotor cavity is in a liquid state. This is usually the case when the refrigerating apparatus is operating at high load, corresponding in particular to a high flow of refrigerant. When the refrigerating apparatus is operating at full load, the refrigerant emitted by the condenser is generally entirely in a liquid state, or in a diphasic state with little proportion of the refrigerant in gaseous state.

[0005] However, if the need for refrigeration is lower, the apparatus may be operating at low load, including in particular a smaller flow of refrigerant. During low load operation of the apparatus, it may happen that the refrigerant circulating through the bypass flow passage is not entirely in liquid state and contains a non-negligible proportion of refrigerant in gaseous state, or even a high proportion of refrigerant in gaseous state. Since refrigerant in a gaseous state is not able to sufficiently lubricate the compressor, there is a risk of damaging or destroying the compressor due to a lack of lubrication during low load operation of the apparatus.

[0006] An aim of the invention is to propose a refrigeration apparatus where satisfactory lubrication of the compressor by means of the refrigerant is obtained even during low load operation of the refrigeration apparatus.

[0007] An object of the invention is to provide a refrigeration apparatus, comprising a main refrigerant circuit, including:

- a compressor, including a compressor inlet and a compressor outlet,
- a condenser, including a condenser inlet, connected to the compressor outlet, and a condenser outlet,
- an expansion valve, including a valve inlet, connected to the condenser outlet and a valve outlet, and
- a refrigerant passage, extending at least partially within an evaporator of the refrigeration apparatus, the refrigerant passage including a refrigerant passage inlet, connected to the valve outlet, and a refrigerant passage outlet, connected to the compressor inlet, the refrigeration apparatus also including a coolant passage extending at least partially within the evaporator and including a coolant passage inlet and a coolant passage outlet,

[0008] According to the invention the main refrigerant circuit is configured for a loop circulation of a main refrigerant flow of a refrigerant, successively through the compressor, the condenser, the expansion valve, and the refrigerant passage,

[0009] According to the invention the evaporator is configured for enabling an exchange of heat between the main refrigerant flow circulating through the refrigerant passage and a main coolant flow of a coolant circulating through the coolant passage,

[0010] According to the invention the refrigeration apparatus further comprises a lubrication branch, comprising:

- a lubrication inlet, connected to a supply part of the main circuit, the supply part consisting in the condenser, the valve inlet, and any part of the main circuit between the condenser outlet and the valve inlet, the lubrication inlet being configured to derive a lubrication refrigerant flow from the main refrigerant flow circulating through the supply part; and
- a lubrication outlet, connected to the compressor so as to feed the compressor with the lubrication refrigerant flow, for lubrication of said compressor with the refrigerant of the lubrication refrigerant flow,

[0011] According to the invention, the refrigeration apparatus further comprises:

- a subcooling branch, comprising:
  - oa subcooling inlet, connected to the coolant passage, so as to derive a subcooling coolant flow from the main coolant flow, and
  - oa subcooling outlet, connected to the coolant passage, for reintroducing the subcooling coolant flow into the main coolant flow; and
- a subcooling heat exchanger, being configured for enabling an exchange of heat between the subcooling coolant flow circulating through the subcooling branch and the lubrication refrigerant flow circulating through the lubrication branch, so that the lubrication refrigerant flow may be cooled by the subcooling coolant flow within the subcooling heat exchanger.

[0012] Thanks to the invention, the lubrication refrigerant flow, used for lubricating the compressor, is cooled by the subcooling coolant flow through the subcooling heat exchanger, prior to introduction of the lubrication refrigerant flow into the compressor. Thus, the subcooling heat exchanger ensures that the lubrication refrigerant flow is in liquid form or ensures at least that the lubrication refrigerant flow contains enough refrigerant in liquid form for achieving sufficient lubrication of the compressor. The subcooling coolant flow is derived from the main coolant flow at a stage where the coolant is at the lowest temperature, namely at the evaporator or close to the evaporator. Thus, the subcooling coolant flow is at a lower temperature than the lubrication refrigerant flow.

[0013] Further advantageous features of the invention are defined below:

- The subcooling inlet is connected to a coolant passage inlet of the coolant passage, so as to derive the subcooling coolant flow from the main coolant flow circulating through the coolant passage inlet, and the subcooling outlet is connected to a coolant passage outlet of the coolant passage, for reintroducing the subcooling coolant flow into the main coolant flow circulating through the coolant passage outlet.
- The refrigerant passage comprises an evaporator tank of the evaporator, the evaporator tank being connected to the refrigerant passage inlet, for admitting the main refrigerant flow into the evaporator tank, and to the refrigerant passage outlet, for discharging the main refrigerant flow from the evaporator tank ; and the coolant passage comprises at least one heat exchange duct of the evaporator, the heat exchange duct extending within the evaporator tank so as to be surrounded by the main refrigerant flow received within the evaporator tank, the heat exchange duct being connected to the coolant passage inlet, for admitting the main coolant flow into the heat exchange duct, and to the coolant passage outlet, for discharging of the main coolant flow from the heat exchange duct.
- The subcooling heat exchanger is positioned outside of the evaporator.
- The subcooling heat exchanger comprises: a heat exchange tank, belonging to the lubrication branch and being configured so that the lubrication refrigerant flow circulates through the heat exchange tank; and a heat exchange passage, belonging to the subcooling branch, being positioned within the heat exchange tank and being configured so that the subcooling coolant flow circulates through the heat exchange passage.
- The lubrication branch comprises: an inlet duct, connecting the lubrication inlet to the heat exchange tank, for circulation of the lubrication refrigerant flow from the lubrication inlet to the heat exchange tank, and comprising an open inlet end positioned within the heat exchange tank for admission of the lubrication refrigerant flow into the heat exchange tank; and an outlet duct, connecting the heat exchange tank to the lubrication outlet, for circulation of the lubrication refrigerant flow from the heat exchange tank to the lubrication outlet, and comprising an open outlet end positioned within the heat exchange tank, at a lower height than the open inlet end.
- The heat exchange tank is positioned at a higher height than the lubrication outlet, so that the compressor is fed with the lubrication refrigerant flow by gravity.
- The heat exchange tank comprises at least one liquid level sensor, detecting the presence of liquid refrigerant at a respective height within the heat exchange tank.
- The heat exchange passage is a coil duct.
- For being connected to the supply part, the lubrication inlet is connected to a bottom part of the condenser.
- The compressor is a positive displacement-type compressor.
- The compressor is a screw compressor comprising two meshing screw rotors and bearings, the screw-rotors being supported by the bearings, and the lubrication outlet is connected to the compressor so as to feed the bearings and the screw rotors with the lubrication refrigerant flow, for lubrication of said bearings and screw rotors.

[0014] The invention also concerns a refrigeration system, comprising a refrigeration apparatus as defined above, and comprising a main coolant circuit, including the coolant passage and at least one client device to be cooled by the main coolant flow, the main coolant circuit being configured for loop circulation of the main coolant flow through the main coolant circuit, successively through the coolant passage and said at least one client device, the coolant of the main coolant flow preferably comprising water.

[0015] The invention also concerns a use of the refrigeration apparatus as defined above, or of the refrigeration system as defined above, the use including:

- closed loop circulation of the main refrigerant flow successively through the compressor inlet, the compressor, the compressor outlet, the condenser inlet, the condenser, the condenser outlet, the valve inlet, the expansion valve, the valve outlet, the refrigerant passage inlet, the refrigerant passage, and the refrigerant passage outlet;
- derivation of the lubrication refrigerant flow from the main refrigerant flow circulating through the supply part, by the lubrication inlet,
- circulation of the lubrication refrigerant flow through the lubrication branch, successively through the lubrication inlet, the subcooling heat exchanger and the lubrication outlet,
- derivation of the subcooling coolant flow from the main coolant flow circulating through the coolant passage, by the subcooling inlet,
- circulation of the subcooling coolant flow through the

subcooling branch, successively through the subcooling inlet, the subcooling heat exchanger and the subcooling outlet,

- exchange of heat between the subcooling coolant flow and the lubrication refrigerant flow in the subcooling heat exchanger, so that the lubrication refrigerant flow is cooled by the subcooling coolant flow,
- feeding of the compressor, by the lubrication outlet, with the lubrication refrigerant flow that was cooled by the subcooling coolant flow in the subcooling heat exchanger, for lubrication of the compressor, and
- reintroduction, by the subcooling outlet, of the subcooling coolant flow that has cooled the lubrication refrigerant flow in the subcooling heat exchanger, into the main coolant flow circulating through the coolant passage.

[0016] Exemplary embodiments according to the invention and including further advantageous features of the invention are explained below, referring to the attached drawings, wherein:

- figure 1 is a synoptic drawing showing an embodiment of a refrigeration system, including a refrigeration apparatus according to the invention;
- figure 2 is a synoptic drawing showing only a part of the refrigeration apparatus of figure 1.

[0017] Figure 1 shows a refrigeration system, including a refrigeration apparatus. The refrigeration apparatus comprises a main refrigerant circuit 1 forming a closed loop for looped circulation of a main refrigerant flow 90 of refrigerant therein. During the circulation of the main refrigerant flow 90 of refrigerant through the main refrigerant circuit 1, the refrigerant endures a thermodynamic cycle imparted by the components of the main refrigerant circuit 1.

[0018] The refrigerant of the refrigeration apparatus is a fluid material chosen to ensure both functions of refrigerant and lubricant. Preferably, the refrigerant used in the apparatus is a hydrofluoroolefin (HFO), for example R 1234ze (1,3,3,3-tetrafluoroprop-1-ene).

[0019] In addition to the refrigeration apparatus, the refrigeration system comprises a main coolant circuit 70, also designated as "coolant network", forming a closed loop for looped circulation of a main coolant flow 93 therein. The main coolant circuit 70 is connected to the refrigeration apparatus. In the embodiment of figures 1 and 2, the main coolant circuit 70 comprises one client device 72 and forms a single loop. The client device 72 is a device which the refrigeration apparatus aims to cool, by retrieving heat from the coolant of the circuit 70 as explained below. For example, the client device is a fan coil unit for air conditioning of a building, or is an air handling unit. The circuit 70 may comprise one or more circulators, not shown in the figures, for circulating the coolant through the circuit 70.

[0020] In an alternative embodiment, the main coolant circuit 70 may comprise several client devices 72 to be fed with coolant of the circuit 70. In this case, the main coolant circuit 70 may form a loop with derivate branches for feeding the several client devices 72.

[0021] Preferably, the coolant of the circuit 70 comprises water, or is constituted by water. In the refrigeration system, the coolant is preferably always in liquid form, at a temperature comprised for example between 7-12 °C.

[0022] The main refrigerant circuit 1 comprises a compressor 2, a condenser 4, an expansion valve 6 and a refrigerant passage 61. The refrigeration apparatus comprises an evaporator 8, through which the refrigerant passage 61 extends at least partially. The refrigerant passage 61 may belong to the evaporator 8 and may be entirely comprised within the evaporator 8. The compressor 2 comprises a compressor inlet 12 and a compressor outlet 13. The condenser 4 includes a condenser inlet 14, connected to the compressor outlet 13, and a condenser outlet 15. The expansion valve 6 includes a valve inlet 16, connected to the condenser outlet 15 and a valve outlet 17. The passage 61 includes a refrigerant inlet 18, connected to the valve outlet 17, and a refrigerant outlet 19, connected to the compressor inlet 12. The inlet 18 is designated as "refrigerant passage inlet". The refrigerant of the flow 90 preferably enters the evaporator 8 by means of the inlet 18. The outlet 19 is designated as "refrigerant passage outlet". The refrigerant of the flow 90 preferably exits the evaporator 8 by means of the outlet 19.

[0023] For obtaining the thermodynamic cycle of the refrigerant, the flow 90 of the aforementioned refrigerant is circulated through the main circuit 1 in a closed loop, successively through the compressor 2, outlet 13, inlet 14, condenser 14, outlet 15, inlet 16, expansion valve 6, outlet 17, inlet 18, refrigerant passage 61, i.e. through the evaporator 8, then outlet 19, inlet 12, and through the compressor 2 again, and so on. For this purpose, the refrigerant is compressed by compressor 2. In the figures, the direction of the flow 90 is illustrated by arrows.

[0024] Preferably, the circulation of the flow 90 of refrigerant through the main circuit 1 is only imparted by the work of the compressor 2. However, if necessary, additional compressor or pumps may be implemented. More generally, depending on the application, the main circuit 1 may comprise additional components than the compressor 2, condenser 4, expansion valve 6 and passage 61, for example, an additional expansion valve, or an additional branch for deriving a portion of the flow 90 from a part of the main refrigerant circuit to another part of the main refrigerant circuit, or an additional heat exchanger, that may have an economizer function.

[0025] Preferably, in a steady-state, during a high load operation of the refrigerating apparatus:

- in the compressor 2, the refrigerant is in a gaseous state, and is compressed from a low pressure to a

high pressure, which raises the temperature of the refrigerant from a low temperature to a high temperature;
- in the outlet 13 and in the inlet 14, the refrigerant is in a gaseous state, or essentially gaseous state, is at the high temperature and the high pressure;
- in the condenser 4, the refrigerant is in a diphasic state, including gaseous and liquid refrigerant, and is condensed to a liquid state by the condenser 4;
- in the outlet 15 and in the inlet 16, the refrigerant is in a liquid state, or essentially liquid state, is at the high pressure, and may be at the high temperature or at a temperature between the high temperature and the low temperature;
- in the expansion valve 6, the refrigerant is brought to the low pressure, which lowers the temperature of the refrigerant to the low temperature while evaporating the refrigerant to the diphasic state;
- in the outlet 17 and in the inlet 18, the refrigerant is in a diphasic-state, where a major part is liquid and a smaller part is gaseous, and the refrigerant is at the low temperature and the low pressure;
- in the passage 61, through the evaporator 8, the refrigerant is in a diphasic state, including gaseous and liquid refrigerant, and is evaporated to a gaseous state by the evaporator 8;
- in the outlet 19 and in the inlet 12, the refrigerant is in a gaseous state, or essentially gaseous state, at the low pressure and at a low temperature, or at a temperature between the low and the high temperature.

[0026] For example, the low temperature is approximately between 5-10°C, the high temperature is approximately between 35-40°C, the low pressure is approximately between 3-4 bar, and the high pressure is approximately between 6-10 bar.

[0027] Considering the above, the main circuit 1 comprises a high-pressure part, consisting in the compressor outlet 13, the condenser 4 and the valve inlet 16, and a low pressure part, consisting in the valve outlet 17, the passage 61 and the compressor inlet 12.

[0028] The main circuit 1 comprises a so-called "supply part", which covers only a portion of the high pressure part, where the refrigerant is mostly in liquid state and high pressure, the supply part preferably consisting in the condenser 4, the valve inlet 16, and any part of the main circuit 1 between the condenser outlet 15 and the valve inlet 16, i.e. downstream from the outlet 15 and upstream from the inlet 16. The supply part advantageously constitutes a part of the circuit 1 where the refrigerant of the flow 90 is in the most appropriate state to be used as lubricant.

[0029] Preferably, the compressor 2 is a positive displacement-type compressor, also called volumetric compressor, such as piston compressor, scroll compressor, roots compressor or screw compressor. More preferably, the compressor 2 is a screw compressor, comprising two parallel meshing screw rotors, for imparting compression to the refrigerant. The screw rotors are supported in rotation relative to a frame of the compressor 2 by at least four bearings of the compressor 2, each of the screw rotors being individually supported by two of the four bearings. The compressor 2 is equipped with a motor, driving one of the screw rotors in rotation, the second screw rotor being also driven in rotation by meshing with the first screw rotor.

[0030] The compressor 2 is configured to be lubricated by the refrigerant, and not by a separate lubricant. Thus, the compressor 2 may be qualified as an "oil-free compressor". Preferably, the entire refrigeration apparatus is oil-free.

[0031] Preferably, the condenser 4 comprises or constitutes a heat exchanger, able to exchange heat between the refrigerant of the main circuit 1 and water, or ambient air, or any other suitable medium able to absorb heat from the main flow 90 of refrigerant circulating through the condenser 4.

[0032] For the refrigeration apparatus to ensure cooling of the coolant of the circuit 70, the circuit 70 comprises a coolant passage 71, extending at least partially through the evaporator 8. Thus, the circuit 70 is thermally linked to the refrigeration apparatus at the evaporator 8 of the refrigeration apparatus. The coolant passage 71 may belong to the evaporator 8 and may be entirely comprised within the evaporator 8.

[0033] The coolant passage 71 comprises a coolant inlet 75 and a coolant outlet 76. The inlet 75 is designated as "coolant passage inlet". The coolant of the flow 93 preferably enters the evaporator 8 through the inlet 75. The outlet 76 is designated as "coolant passage outlet". The coolant of the flow 93 preferably exits the evaporator 8 by means of the outlet 76. The devices 72 are fed with the flow 93 of coolant emitted at the outlet 76, and the flow 93 of coolant that has passed through the devices 72 is admitted at the inlet 75.

[0034] Preferably, at the inlet 75, the temperature of flow 93 is at the highest, while at the outlet 76, the temperature of the flow 93 is at the lowest, since the coolant was cooled in the evaporator 8. For example, the temperature of the coolant is at approximately 12°C at the inlet 75 and at approximately 7°C at the outlet 76.

[0035] The evaporator 8 comprises or constitutes a heat exchanger, configured for enabling heat exchange between the flow 90 of refrigerant circulating though the passage 61 and the flow 93 of coolant circulating through the passage 71. In the evaporator 8, the refrigerant of the flow 90 cools the coolant of the flow 93 by exchange of heat with the flow 93 within the evaporator 8. Flows 90 and 93 are not brought into contact or mixed together. Instead, the flows 90 and 93 are circulated close to each other with separation by a thin heat-conductive wall of the evaporator 8, provided along passages 61 and 71, promoting heat exchange between the flows 90 and 93. Thus, within the evaporator 8, the flow 90 retrieves heat from the flow 93 for cooling of said flow 93. Thus, the flow

90 is heated by the flow 93 within the evaporator 8.

[0036] The refrigeration apparatus comprises a lubrication refrigerant branch 20 distinct from the main refrigerant circuit 1 and from the main coolant circuit 70, and connected to the main refrigerant circuit 1. The lubrication branch 20 is a passage for a flow 91 of refrigerant originating from the main refrigerant flow 90 of the main circuit 1. The flow 91 is designated as "lubrication refrigerant flow". The lubrication flow 91 is a flow of refrigerant, formed by a portion of the main flow 90.

[0037] The branch 20 comprises an inlet 21, designated as "lubrication inlet" and an outlet 22, designated as "lubrication outlet". The inlet 21 is connected to the main refrigerant circuit 1 at a bottom part 29 of the condenser 4, which belongs to the supply part of the main circuit 1. Alternatively, the inlet 21 could be connected for example between the condenser 4 and the expansion valve 6, preferably at the condenser outlet 15. Alternatively, for connection of the inlet 21, any portion of the supply part of the main circuit 1 may be chosen, since, in the supply part of the main circuit 1, at least a part of the refrigerant is in liquid phase.

[0038] Preferably, the inlet 21 derives the refrigerant flow 91 from the main refrigerant flow 90 that has already circulated through the condenser inlet 14, that has already exchanged heat with the water, ambient air or similar medium through the condenser 4, and that has not yet circulated through the condenser outlet 15. More preferably, the inlet 21 derives the flow 91 at the bottom part 29 of the condenser 4 where liquid-state refrigerant from the flow 90 is received by gravity.

[0039] In a preferred alternative, the inlet 21 derives the flow 91 from the main flow 90 that circulates through the condenser outlet 15, where there is a good chance that most or all of the refrigerant of the flow 90 is in liquid form.

[0040] The flow 91 is introduced into the branch 20 by the inlet 21. The outlet 22 is connected to the compressor 2, for feeding the compressor with the lubrication refrigerant flow 91, for lubrication of said compressor 2 by means of the flow 91. The outlet 22 is connected at inlets of the compressor 2 that differ from the inlet 12, for feeding mechanical parts of the compressor 2 that require lubrication. Preferably, the outlet 22 is connected to inlets of the compressor 2 that feed the bearings and/or the compression cavities formed by the screw rotors, so that they are lubricated by the liquid refrigerant of the flow 91 fed by the branch 20.

[0041] Optionally, the branch 20 comprises one or more valves 23, such as solenoid valves and/or throttle valves, for adjusting the flow rate of the flow 91 admitted within the branch 20 and introduced into the compressor 2.

[0042] As explained above, during high load operation of the apparatus, the flow 91 of refrigerant derived at the inlet 21 is usually liquid. However, at a lower load of the apparatus, the refrigerant of the flow 91 may be diphasic at the inlet 21. For ensuring that, when reaching the compressor 2, the refrigerant of the flow 91 is in liquid form, or is in diphasic form with sufficient proportion of liquid refrigerant, the refrigerant apparatus comprises a subcooling heat exchanger 31 and a subcooling coolant branch 40 for cooling the refrigerant of the flow 91.

[0043] The subcooling coolant branch 40 is distinct from the main refrigerant circuit 1, from the main coolant circuit 70 and from the branch 20. The subcooling coolant branch 40 is connected to the main coolant circuit 70. The branch 40 is a passage for a flow 92 of coolant, originating from the main coolant flow 93 of the main coolant circuit 70. The flow 92 is designated as "subcooling coolant flow". The subcooling coolant flow 92 is a flow of coolant, formed by a portion of the main coolant flow 93.

[0044] The subcooling coolant branch 40 comprises an inlet 41, designated as "subcooling inlet", and an outlet 42, designated as "subcooling outlet".

[0045] The inlet 41 is connected to the coolant passage 71 of the main coolant circuit 70, preferably at an exterior part of the evaporator 8 or within the evaporator 8. Preferably, the inlet 41 derives the flow 92 from the flow 93 of coolant which has not yet exchanged heat with the flow 90 of refrigerant within the evaporator 8 but which has already cooled all the client devices 72 of the circuit 70. The flow 92 is introduced into the branch 40 by the inlet 41. Preferably, the inlet 41 is connected to the inlet 75 at an exterior location of the evaporator 8.

[0046] The outlet 42 is connected to the coolant passage 71 of the main coolant circuit 70, preferably at an exterior part of the evaporator 8 or within the evaporator 8. Preferably, the outlet 42 reintroduces the derived coolant flow 92 into the coolant flow 93 the main coolant circuit 70, after said coolant flow 93 has exchanged heat with the refrigerant flow 90 in the evaporator 8 and before the coolant flow 93 has cooled any client device 72 from the circuit 70. Preferably, the outlet 42 is connected to the outlet 76 at an exterior location of the evaporator 8.

[0047] More generally, it is preferred that the outlet 42 is connected to the circuit 70 downstream relative to the inlet 41. In this case, since the main coolant flow 93 is circulated through the circuit 70, for example by means of a non-shown circulator, connecting the inlet 41 upstream relative to the outlet 42 enables that the subcooling coolant flow 92 is also circulated, without further circulator, since the upstream pressure is higher than the downstream pressure in the passage 71 of the main coolant circuit 70.

[0048] Alternatively, the inlet 41 may be connected at the outlet 76 and the outlet 42 may be connected at the inlet 75. However, in this case, a circulator or any other circulation means may be implemented for imparting a circulation of the flow 92 through the branch 40.

[0049] In any case, it is preferred that the outlet 42 is connected at a part of passage 71 different from the part of the passage 71 where the inlet 41 is connected.

[0050] The subcooling heat exchanger 31 is configured for enabling or promoting an exchange of heat between the flows 91 and 92, so that the refrigerant of the flow 91 is sub-cooled by exchange of heat with the coolant of the flow 92, within the subcooling heat exchanger 31. The flows 91 and 92 are not brought into contact or mixed together. Instead, the flows 91 and 92 are circulated close to each other with separation by a thin heat-conductive wall of the heat exchanger 31, promoting heat exchange between the flows 91 and 92. Thus, within the exchanger 31, the flow 91 is cooled by the flow 92, and the flow 92 is heated by the flow 91.

[0051] Since the refrigerant of the lubrication flow 91 is cooled in the heat exchanger 31, the apparatus ensures that the refrigerant of the lubrication flow 91 is in liquid-state, or has a high proportion of liquid refrigerant, when entering the compressor 2 at the outlet 22. Even when the apparatus operates at low load, i.e. low flow rate of the main refrigerant flow 90, appropriate lubrication of the compressor 2 is ensured.

[0052] The branch 40 may be provided with a suitable valve, such as a throttle valve or solenoid valve, not shown in the figures, for adjusting or disabling the circulation of the flow 92 depending on the current load of the refrigeration apparatus. For example, the circulation of the flow 92 may be interrupted or reduced when the apparatus operates at high load for improving thermal efficiency of the refrigeration apparatus. For example, the circulation of the flow 92 may be enabled or increased when the apparatus operates a low load for improving lubrication of the compressor 2.

[0053] As shown in figures 1 and 2, the subcooling heat exchanger 31 is positioned outside of the evaporator 8, preferably outside of the main refrigerant circuit 1 and preferably outside of the main coolant circuit 70. Thus, implementing the heat exchanger 31 in an existing refrigeration system is made easier, since the refrigeration system, including the evaporator 8, does not need to be modified significantly, but only requires appropriate connections with the heat exchanger 31.

[0054] As shown in figure 2, the subcooling heat exchanger 31 preferably comprises a heat exchange tank 32 and a heat exchange passage 33.

[0055] In the example of figure 2, the tank 32 advantageously belongs to the branch 20, whereas the heat exchange passage 33 advantageously belongs to the branch 40. In other non-shown embodiments, this may be the opposite. More generally, one branch of the refrigeration apparatus, chosen among the lubrication refrigerant branch and the subcooling coolant branch, comprises the tank 32, while the other branch comprises the heat exchange passage 33.

[0056] In the case illustrated in figure 2, a quantity of refrigerant for lubrication from the flow 91 is received by the tank 32, allowing easy measuring of the proportion of liquid refrigerant received in the tank 32. The liquid refrigerant of the flow 91 received in the tank 32 may constitute a supply of liquid refrigerant that may be used at specific operation stages where little liquid refrigerant is available, for example during starting of the refrigeration apparatus.

[0057] The flow 91 circulates through the tank 32, when circulating in the branch 20 from the inlet 21 to the outlet 22. For this purpose, the branch 20 preferably comprises an inlet duct 24, connecting the lubrication inlet 21 to the heat exchange tank 32, for circulation of the lubrication flow 91 from the lubrication inlet 21 to the heat exchange tank 32. The duct 24 crosses through a bottom wall of the tank 32 and comprises an open inlet end 25, positioned within the heat exchange tank 32, for admission of the lubrication flow 91 into the heat exchange tank 32 at the vicinity of a top wall of the tank 32. The branch 20 also preferably comprises an outlet duct 26, connecting the heat exchange tank 32 to the lubrication outlet 22, for circulation of the lubrication flow 91 from the heat exchange tank 32 to the lubrication outlet 22. The duct 26 crosses through the bottom wall of the tank 32 and comprises an open outlet end 27, positioned within the heat exchange tank 32 at the vicinity of the bottom wall of the tank 32, or at the bottom wall of the tank 32. Thus, the outlet end 27 is at a lower height than the inlet end 25.

[0058] During operation, the refrigerant of the flow 91 temporarily rests in the tank 32 where heat is exchanged with the coolant flow 92 received in the passage 33. In the tank 32, the refrigerant of the flow 91 is either fully liquid, in particular during high load operation of the apparatus, or diphasic, in particular during low load operation of the apparatus. When diphasic, the liquid refrigerant sits at the bottom of the tank 32 while the gaseous refrigerant is located at the top. Thus, since the inlet end 25 is located above the outlet end 27, agitation of the refrigerant of the tank 32 is reduced, avoiding reintroduction of gaseous refrigerant into the liquid refrigerant of the tank 32 if the admitted refrigerant is partially gaseous. In addition, with the outlet end 27 being located at the vicinity of the bottom wall of the tank, the risk of admitting gas bubbles into the outlet end 27 is reduced, even if a level 94 of liquid refrigerant in the tank 32 is low.

[0059] Preferably, the heat exchange tank 32 comprises two liquid level sensors 35 and 36, each configured for detecting the presence of liquid refrigerant within the heat exchange tank 32, at a respective height. The sensor 35 is configured to detect the presence of liquid refrigerant in the tank at the same height than, or slightly above, the outlet end 27. Thus, the sensor 35 may be used for detecting when the amount of available liquid refrigerant in the tank 32 is too low for correct lubrication of the compressor 2 in steady-state of the refrigerating apparatus, for example during low load operation of the refrigerating apparatus. The sensor 36 is configured to detect the presence of liquid refrigerant in the tank 32 at a higher height than the sensor 35, between the height of the end 25 and the height of the end 27. The sensor 36 may be used for detecting when the amount of available liquid refrigerant in the tank 32 is above or below an acceptable level for starting the refrigerating apparatus, which may require that a high amount of liquid refrigerant is available in the tank 32 for lubrication of the compressor 2. In the case illustrated in figure 2, the level 94 of liquid refrigerant received within the tank 32 is at a height comprised between sensors 35 and 36, so that only sensor 35 detects the presence of liquid refrigerant.

[0060] If one of the sensors 35 and/or 36 detect that liquid refrigerant is not available at their respective height, operating of the compressor 2 may be interrupted to avoid the risk of damage to the compressor 2.

[0061] In a non-shown embodiment, the tank 32 comprises a number of liquid level sensors different than two, each detecting the presence of liquid refrigerant in the tank 32 at a respective height.

[0062] The heat exchange passage 33 is positioned within the heat exchange tank 32, so as to be surrounded by the refrigerant of the flow 91. The passage 33 is configured so that the coolant flow 92 circulating through the branch 40 circulates through the passage 33, when circulating from the inlet 41 to the outlet 42. Preferably, as shown in figure 2, the passage 33 is a coil duct, promoting heat exchange. The coil duct is preferably made of a material with high heat conductivity such as copper or the like. The coil duct has the advantage that it does not induce too much pressure drop for the flow 92 flowing through. However, instead of a coil duct, any other suitable shape may be implemented for the passage 33, promoting heat exchange without inducing too much pressure drop of the flow 92 and too much agitation for the flow 91 sitting in the tank 32.

[0063] The heat exchange passage 33 comprises a coolant inlet 43, connected to the subcooling inlet 41 by an inlet duct of the branch 40. The heat exchange passage 33 comprises a coolant outlet 44, connected to the subcooling outlet 42 by an outlet duct of the branch 40. The inlet 43 and the outlet 44 are preferably positioned at a peripheral wall of the heat exchange tank 32. The peripheral wall is preferably vertical, and connects the top wall to the bottom wall of the tank 32.

[0064] For better thermal efficiency, the inlet 43 is preferably at a different height, such as a lower height, than the outlet 44, as shown in figure 2. The coil duct of the passage 33, connecting the inlet 43 to the outlet 44, is preferably vertical overall. As shown in figure 2, the inlet 43 is preferably connected to the tank 31 at the bottom of the tank 31, or at least at the vicinity of the outlet 27, so that the flow 92 entering the heat exchange passage 33 is close to the outlet 27. In this case, as shown in figure 2, the heat exchanger 32 is preferably a counterflow heat exchanger.

[0065] Preferably, the heat exchange tank 32, and in particular the open outlet end 27, is positioned at a higher height than the compressor 2, so that the compressor is fed with the lubrication refrigerant flow 91 under the effect of gravity. Thus, the need for a circulator for circulating the flow 91 is reduced.

[0066] Preferably, as depicted in figure 2, the evaporator 8 is a flooded heat exchanger, such as a flooded tube heat exchanger. In this case, the refrigerant passage 61 comprises a tank, designated as "evaporator tank", receiving the refrigerant from the flow 90 of the main refrigerant circuit 1. Preferably, the tank 61 is of generally cylindrical shape, as this is the case in figure 2. The inlet 18 is preferably connected at the bottom of the tank 61 for admission of the flow 90 into the tank 61 by the bottom thereof. The outlet 19 is preferably connected at the top of the tank 61 for discharging of the flow 90 into the tank 61 by the top thereof. In operation of the refrigeration apparatus, the refrigerant of the flow 90 received within the tank 61 is advantageously in diphasic form, so that the liquid part of the received refrigerant sits at the bottom of the tank 61, whereas the gaseous part of the received refrigerant evaporates towards the top of the tank 61, when receiving heat from the coolant flow 93 circulating through the coolant passage 71.

[0067] Preferably, the coolant passage 71 comprises a heat exchange duct, as depicted in figure 2, crossing through the evaporator tank 61 so as to be surrounded by the refrigerant received in the tank 61. The coolant flow 93 flows through the heat exchange duct 71 so that heat is exchanged between said coolant flow 93 and the refrigerant flow 90 received within the tank 61. For this purpose, one end of the exchange duct 71 is connected to the inlet 75 whereas the other end of the exchange duct 71 is connected to the outlet 76.

[0068] The heat exchange duct 71 is preferably made of a heat conductive material, such as copper or the like, so as to promote exchange of heat between the flows 90 and 93.

[0069] The heat exchange duct 71 may be in the form of a coil duct.

[0070] Alternatively, the coolant passage 71 may comprise several heat exchange ducts, each connected to the inlet 75 and 76, each crossing through the tank 61 so as to be surrounded with the refrigerant of the main circuit 1 received within the tank 61, and each circulated by a portion of the flow 93.

[0071] The valves 23, when both closed, may also be used for temporarily storing refrigerant within the branch 20, in particular within the tank 32 of the heat exchanger 31, especially for periods of time when the refrigeration apparatus is stopped, allowing that liquid-state refrigerant is available in the tank 31 before re-starting. For this purpose, one valve 23 is positioned upstream from the tank 32 and the other valve 23 is positioned downstream of from tank 32.

[0072] Alternatively, at least one of the subcooling inlet and the subcooling outlet is positioned within the evaporator tank 61, preferably the subcooling inlet. Thus, the subcooling coolant flow 92 is derived from the part of the coolant passage 71 extending within the evaporator tank 61, namely the heat exchange duct. Thus, the derived subcooling coolant flow 92 is at a lower temperature, which may be useful at starting of the refrigeration apparatus.

[0073] Alternatively, two subcooling inlets may be provided for deriving the flow 92, one connected to the inlet 75 and the other connected to the heat exchange duct 71. The branch 40 may be provided with appropriate valves for selecting by means of which of the subcooling inlets the flow 92 is derived, depending on the operation stage of the refrigeration apparatus.

[0074] Alternatively, where the evaporator is a flooded heat exchanger, the refrigerant passage of the evaporator constitutes the heat exchange duct whereas the coolant passage of the evaporator constitutes the evaporator tank. Each feature disclosed for an embodiment disclosed above may be implemented in any other embodiment disclosed above, as long as technically feasible.

Claims

1. A refrigeration apparatus, comprising a main refrigerant circuit (1), including:

    - a compressor (2), including a compressor inlet (12) and a compressor outlet (13),
    - a condenser (4), including a condenser inlet (14), connected to the compressor outlet (13), and a condenser outlet (15),
    - an expansion valve (6), including a valve inlet (16), connected to the condenser outlet (15) and a valve outlet (17), and
    - a refrigerant passage (61), extending at least partially within an evaporator (8) of the refrigeration apparatus, the refrigerant passage (61) including a refrigerant passage inlet (18), connected to the valve outlet (17), and a refrigerant passage outlet (19), connected to the compressor inlet (12), the refrigeration apparatus also including a coolant passage (71) extending at least partially within the evaporator (8) and including a coolant passage inlet (75) and a coolant passage outlet (76),

    wherein the main refrigerant circuit (1) is configured for a loop circulation of a main refrigerant flow (90) of a refrigerant, successively through the compressor (2), the condenser (4), the expansion valve (6), and the refrigerant passage (61),
    wherein the evaporator (8) is configured for enabling an exchange of heat between the main refrigerant flow (90) circulating through the refrigerant passage (61) and a main coolant flow (93) of a coolant circulating through the coolant passage (71),
    wherein the refrigeration apparatus further comprises a lubrication branch (20), comprising:

    - a lubrication inlet (21), connected to a supply part (4, 16) of the main circuit (1), the supply part (4, 16) consisting in the condenser (4), the valve inlet (16), and any part of the main circuit (1) between the condenser outlet (15) and the valve inlet (16), the lubrication inlet (21) being configured to derive a lubrication refrigerant flow (91) from the main refrigerant flow (90) circulating through the supply part (4, 16); and
    - a lubrication outlet (22), connected to the compressor (2) so as to feed the compressor (2) with the lubrication refrigerant flow (91), for lubrication of said compressor (2) with the refrigerant of the lubrication refrigerant flow (91), **characterized in that** the refrigeration apparatus further comprises:
    - a subcooling branch (40), comprising:

        ◦ a subcooling inlet (41), connected to the coolant passage (71), so as to derive a subcooling coolant flow (92) from the main coolant flow (93), and
        ◦ a subcooling outlet (42), connected to the coolant passage (71), for reintroducing the subcooling coolant flow (92) into the main coolant flow (93); and

    - a subcooling heat exchanger (31), being configured for enabling an exchange of heat between the subcooling coolant flow (92) circulating through the subcooling branch (40) and the lubrication refrigerant flow (91) circulating through the lubrication branch (20), so that the lubrication refrigerant flow (91) may be cooled by the subcooling coolant flow (92) within the subcooling heat exchanger (31).

2. The refrigeration apparatus according to claim 1, wherein:

    - the subcooling inlet (41) is connected to a coolant passage inlet (75) of the coolant passage (71), so as to derive the subcooling coolant flow (92) from the main coolant flow (93) circulating through the coolant passage inlet (75), and
    - the subcooling outlet (42) is connected to a coolant passage outlet (76) of the coolant passage (71), for reintroducing the subcooling coolant flow (92) into the main coolant flow (93) circulating through the coolant passage outlet (76).

3. The refrigeration apparatus according to any one of the preceding claims, wherein:

    - the refrigerant passage (61) comprises an evaporator tank of the evaporator (8), the evaporator tank being connected to the refrigerant passage inlet (18), for admitting the main refrigerant flow (90) into the evaporator tank, and to the refrigerant passage outlet (19), for discharging the main refrigerant flow (90) from the evaporator tank ; and
    - the coolant passage (71) comprises at least one heat exchange duct of the evaporator (8), the heat exchange duct extending within the evaporator tank so as to be surrounded by the

main refrigerant flow received within the evaporator tank, the heat exchange duct being connected to the coolant passage inlet (75), for admitting the main coolant flow (93) into the heat exchange duct, and to the coolant passage outlet (76), for discharging of the main coolant flow (93) from the heat exchange duct.

4. The refrigeration apparatus according to any one of the preceding claims, wherein the subcooling heat exchanger (31) is positioned outside of the evaporator (8).

5. The refrigeration apparatus according to any one of the preceding claims, wherein the subcooling heat exchanger (31) comprises:

- a heat exchange tank (32), belonging to the lubrication branch (20) and being configured so that the lubrication refrigerant flow (91) circulates through the heat exchange tank (32), and
- a heat exchange passage (33), belonging to the subcooling branch (40), being positioned within the heat exchange tank (32) and being configured so that the subcooling coolant flow (92) circulates through the heat exchange passage (33).

6. The refrigeration apparatus according to claim 5, wherein the lubrication branch (20) comprises:

- an inlet duct (24), connecting the lubrication inlet (21) to the heat exchange tank (32), for circulation of the lubrication refrigerant flow (91) from the lubrication inlet (21) to the heat exchange tank (32), and comprising an open inlet end (25) positioned within the heat exchange tank (32) for admission of the lubrication refrigerant flow (91) into the heat exchange tank (32); and
- an outlet duct (26), connecting the heat exchange tank (32) to the lubrication outlet (22), for circulation of the lubrication refrigerant flow (91) from the heat exchange tank (32) to the lubrication outlet (22), and comprising an open outlet end (27) positioned within the heat exchange tank (32), at a lower height than the open inlet end (25).

7. The refrigeration apparatus according to any one of claims 5 or 6, wherein the heat exchange tank (32) is positioned at a higher height than the lubrication outlet (22), so that the compressor (2) is fed with the lubrication refrigerant flow (91) by gravity.

8. The refrigeration apparatus according to any one of claims 5 to 7, wherein the heat exchange tank (32) comprises at least one liquid level sensor (35, 36), detecting the presence of liquid refrigerant at a respective height within the heat exchange tank (32).

9. The refrigeration apparatus according to any one of claims 5 to 8, wherein the heat exchange passage (33) is a coil duct.

10. The refrigeration apparatus according to any one of the preceding claims, wherein, for being connected to the supply part (4, 16), the lubrication inlet (21) is connected to a bottom part (29) of the condenser (4).

11. The refrigeration apparatus according to any one of the preceding claims, wherein the compressor (2) is a positive displacement-type compressor.

12. The refrigeration apparatus according to any one of the preceding claims, wherein:

- the compressor (2) is a screw compressor comprising two meshing screw rotors and bearings, the screw-rotors being supported by the bearings, and
- the lubrication outlet (22) is connected to the compressor (2) so as to feed the bearings and the screw rotors with the lubrication refrigerant flow (91), for lubrication of said bearings and screw rotors.

13. A refrigeration system, comprising a refrigeration apparatus according to any one of the preceding claims, and comprising a main coolant circuit (70), including the coolant passage (71) and at least one client device (72) to be cooled by the main coolant flow (93), the main coolant circuit (70) being configured for loop circulation of the main coolant flow (93) through the main coolant circuit (70), successively through the coolant passage (71) and said at least one client device (72), the coolant of the main coolant flow (93) preferably comprising water.

14. A use of the refrigeration apparatus according to any one of claims 1 to 12, or of the refrigeration system according to claim 13, the use including:

- closed loop circulation of the main refrigerant flow (90) successively through the compressor inlet (12), the compressor (2), the compressor outlet (13), the condenser inlet (14), the condenser (4), the condenser outlet (15), the valve inlet (16), the expansion valve (6), the valve outlet (17), the refrigerant passage inlet (18), the refrigerant passage (61), and the refrigerant passage outlet (19);
- derivation of the lubrication refrigerant flow (91) from the main refrigerant flow (90) circulating through the supply part (4, 16), by the lubrication inlet (21),

- circulation of the lubrication refrigerant flow (91) through the lubrication branch (20), successively through the lubrication inlet (21), the subcooling heat exchanger (31) and the lubrication outlet (22),
- derivation of the subcooling coolant flow (92) from the main coolant flow (93) circulating through the coolant passage (71), by the subcooling inlet (41),
- circulation of the subcooling coolant flow (92) through the subcooling branch (40), successively through the subcooling inlet (41), the subcooling heat exchanger (31) and the subcooling outlet (42),
- exchange of heat between the subcooling coolant flow (92) and the lubrication refrigerant flow (91) in the subcooling heat exchanger (31), so that the lubrication refrigerant flow (91) is cooled by the subcooling coolant flow (92),
- feeding of the compressor (2), by the lubrication outlet (22), with the lubrication refrigerant flow (91) that was cooled by the subcooling coolant flow (92) in the subcooling heat exchanger (31), for lubrication of the compressor (2), and
- reintroduction, by the subcooling outlet (42), of the subcooling coolant flow (92) that has cooled the lubrication refrigerant flow (91) in the subcooling heat exchanger (31), into the main coolant flow (93) circulating through the coolant passage (71).

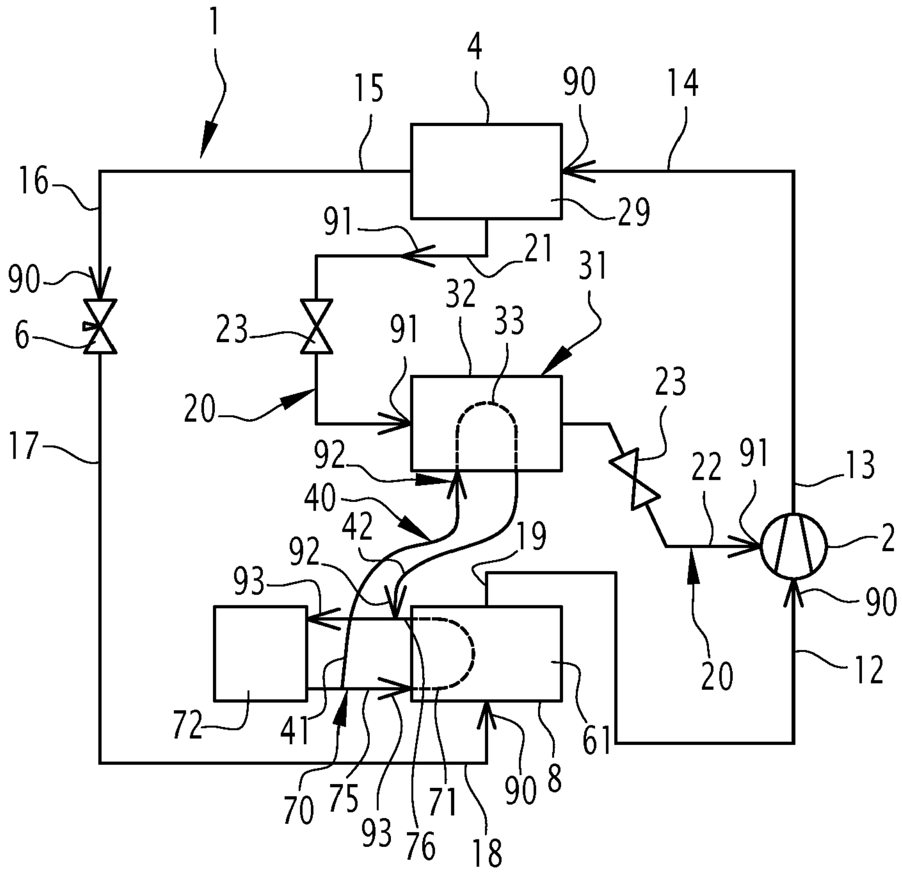
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FIG.1

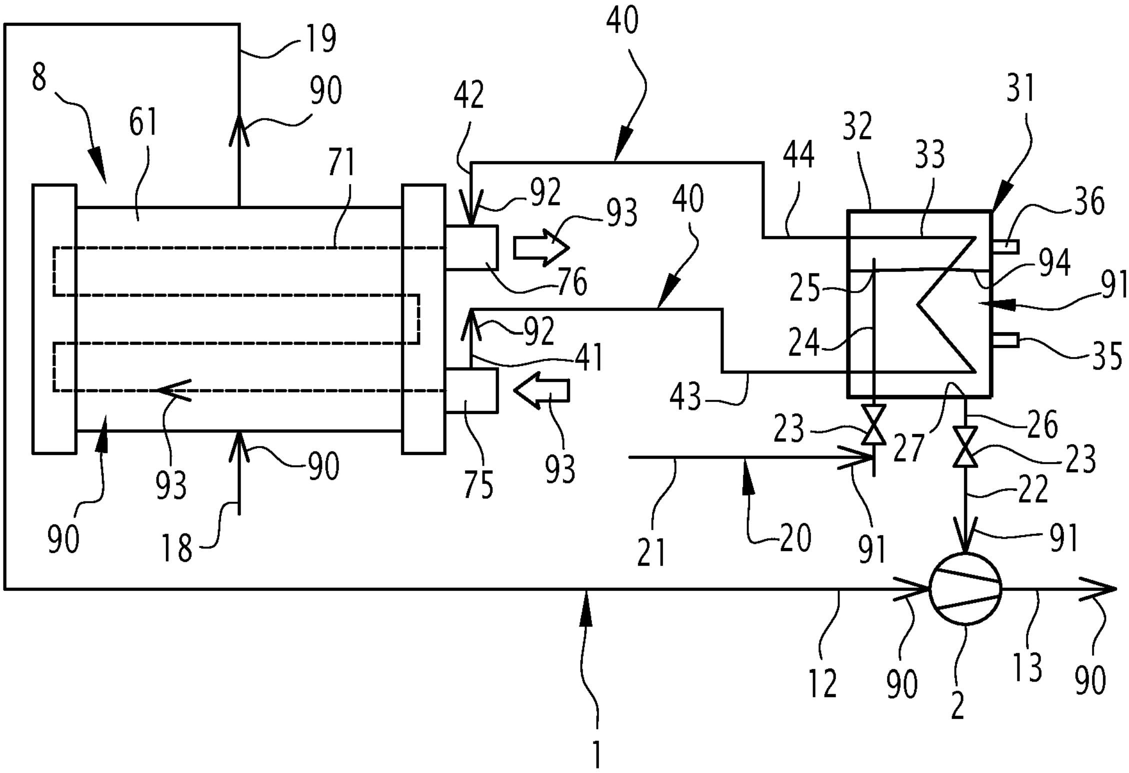
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FIG.2

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EUROPEAN SEARCH REPORT

Application Number
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