(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 527 522 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
28.11.2012 Bulletin 2012/48

(51) Int Cl.:
D06F 58/20 *(2006.01)*

(21) Application number: **11167567.4**

(22) Date of filing: **26.05.2011**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(71) Applicant: **Electrolux Home Products Corporation N.V.**
1130 Brussel (BE)

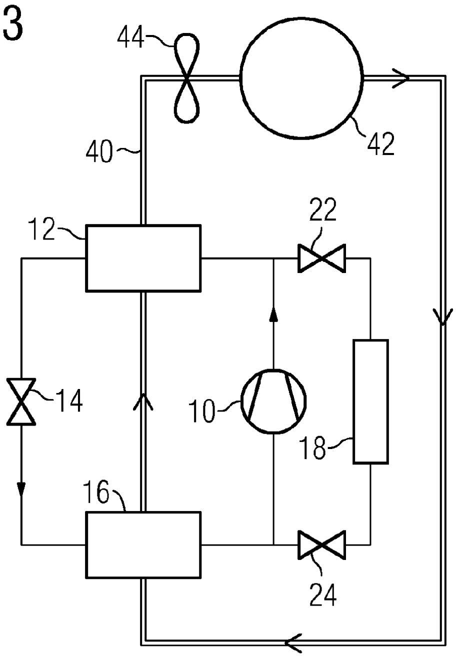
(72) Inventors:
- **Bison, Alberto**
  33080 Porcia (PN) (IT)
- **Minetto, Silvia**
  33080 Porcia (PN) (IT)
- **Cavarretta, Francesco**
  33080 Porcia (PN) (IT)
- **Mancini, Ferdinando**
  33080 Porcia (PN) (IT)
- **Passarini, Alberto**
  33080 Porcia (PN) (IT)

(74) Representative: **Nardoni, Andrea et al**
Electrolux Italia S.p.A.
Corso Lino Zanussi, 30
33080 Porcia (PN) (IT)

(54) A heat pump laundry dryer

(57) A laundry dryer with heat pump system, wherein the heat pump system comprises a closed refrigerant circuit for a refrigerant, the refrigerant circuit includes at least one compressor (10), at least one gas cooler (12), at least one expansion means (14) and at least one evaporator/gas heater (16),the refrigerant circuit is thermally coupled to a drying air circuit of the laundry dryer by the gas cooler (12) and the evaporator/gas heater (16),the gas cooler (12) is a heat exchanger and provided for heating up the drying air stream and cooling down the refrigerant, and the evaporator/gas heater (16) is a heat exchanger and provided for dehumidifying the drying air and heating up the refrigerant, the refrigerant circuit comprises a low pressure side between the outlet of the expansion means (14) and the inlet of the compressor (10), the refrigerant circuit comprises a high pressure side between the outlet of the compressor (10) and the inlet of the inlet of expansion means (14), wherein the refrigerant operates at supercritical conditions in the low pressure side of the refrigerant circuit after a transient sub-critical phase, wherein the laundry dryer comprises at least one refrigerant trap (18) fluidly connected or connectable to at least one part of the refrigerant circuit and valve means (20, 22, 24, 26) to selectively connect and/or disconnect the refrigerant trap (18) to said least one part of the refrigerant circuit

FIG 3



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Description

[0001] The present invention relates to a heat pump laundry dryer according to the preamble of claim 1. Further, the present invention relates to relates to a method for operating a heat pump laundry dryer.

[0002] In a heat pump laundry dryer, for example in a tumble dryer or in a washer-dryer machine, the heat pump technology is an efficient way to save energy during operation. The conventional heat pump system comprises a closed refrigerant circuit. The refrigerant circuit is thermally coupled with a drying air circuit for removing the moisture from the laundry contained in a drying chamber. The refrigerant in the refrigerant circuit is compressed by a compressor, condensed in a condenser, laminated in an expansion device and then vaporised in an evaporator. The condenser and the evaporator exchange heat between the refrigerant circuit and the drying air circuit. The refrigerant circuit includes a high pressure side and a low pressure side. The high pressure side extends from the outlet of the compressor via the condenser to the inlet of the expansion device. The low pressure side extends from the outlet of the expansion device via the evaporator to the inlet of the compressor.

[0003] The Applicant noted in several tests that a heat pump laundry dryer wherein the refrigerant operates at supercritical condition at least in the high pressure side of the heat pump system provides better performances in terms of heat exchanged between the drying air and the heat pump system and in terms of improved energetic efficiency. Supercritical condition in the high pressure side of the heat pump system occurs when the refrigerant operates at least at critical pressure so that the refrigerant is always in gaseous phase and no condensation takes place in the condenser which is better indicated as gas cooler.

[0004] It has been found that a heat pump laundry dryer can perform a trans-critical cycle in which the refrigerant operates at supercritical condition in the high pressure side of the heat pump system and below the critical pressure in the low pressure side of the heat pump system wherein the refrigerant, as in traditional heat pump laundry dryers, evaporates in the evaporator.

[0005] Of course, depending on the initial temperature conditions of the laundry dryer and on the initial pressure conditions of the heat pump circuit before the switching on of the compressor, it may happen that the high pressure side of the heat pump system operates below the critical pressure for a short transient state (few seconds to some minutes) after the compressor starts to operates.

[0006] Alternatively, it has been found that heat pump laundry dryer can perform a totally supercritical cycle in which the refrigerant cycle operates at supercritical condition in both the high pressure side and the low pressure side of the heat pump system and in this case no evaporation occurs at the evaporator which is better indicated as gas heater. It has to be noted that in a totally supercritical cycle, the low pressure side of the heat pump system operates below the critical pressure at the beginning of the cycle (i.e. immediately after the compressor has been switched on) for a transient trans-critical phase that precedes the totally supercritical stage, assuming that no further heating means, other than the heat pump system itself, are provided for heating the drying air and/or the refrigerant.

[0007] Carbon Dioxide (CO_2), for example, can be utilized as refrigerant to perform the trans-critical cycle and the totally supercritical cycle mentioned above in a heat pump laundry dryer, however other refrigerants can be envisaged. It has been found that the special conditions of refrigerant in trans-critical and totally supercritical cycle require a specific management of refrigerant pressure. In fact in supercritical conditions, refrigerant pressure is independent of temperature since there are no longer any refrigerant phase changes.

[0008] In case of CO_2, the refrigerant pressure at the high pressure side can range between 120 and 130 bar. The occurrence of abnormal operative conditions of the heat pump laundry dryer can increase the refrigerant pressure to undesired value. For example dust particles/manufacturing residuals can flow through the heat pump circuit and clog the expansion device or the small diameter pipes of the circuit or compressor abnormal conditions can cause the pressure to increase. It appears clear that possible overpressure conditions can damages the heat pump circuit or the laundry dryer.

[0009] Further it has been found that in case of a heat pump laundry dryer having a closed-loop drying air circuit wherein the drying air passes through the evaporator/gas heater and then through the gas cooler before re-entering the drying chamber, it is particularly expedient to provide a safety pressure management due to the peculiar interaction between the heat pump system and the closed-loop drying air circuit.

[0010] Further the applicant noted, in the test performed, that in case the heat pump system includes a variably operable expansion device for changing the expansion conditions of the refrigerant during the laundry drying cycle, the pressure of the refrigerant at supercritical condition and particularly in the high pressure side of the heat pump system tends not to remain stable when the working conditions of the expansion device change. However the fluctuations of the refrigerant pressure in the high pressure side of the heat pump system can reduce the heat exchange efficiency between the heat pump system and the drying air circuit.

[0011] The operation of the laundry dryer with the heat pump system includes two phases, namely a warm-up phase and a steady state phase. The warm-up phase is the initial phase after compressor has been switched on, wherein a certain time is needed to reach full working condition in terms of drying air temperatures. When the heat pump system starts to operate, the temperatures of the drying air is at ambient temperature. During the transitory phase, the temperatures of the drying air increases up to a desired level. During the steady state phase, the temperatures of the drying air is kept substantially constant.

[0012] While in a traditional electrically heated tumble dryer the heating power is immediately supplied to the system, in heat pump system the power must be recovered by the dehumidification of the air itself after it has passed through the clothes to be dried. At the beginning, during the warm-up phase the dehumidifying power is very low and the drying air temperature tends to increase slowly.

[0013] When the heat pump laundry dryer reaches the steady state phase, the air temperature at the outlet of the drying chamber and upstream the evaporator/gas heater is about 40-60°C, considering, for example, CO_2 as refrigerant.

[0014] In case of a heat pump laundry dryer operating a totally supercritical cycle, the pressure of the refrigerant (for example CO_2) in the high pressure side of the heat pump circuit is about 120 to 125 bar, whereas the pressure of the refrigerant (for example CO_2) in the low pressure side of the heat pump circuit is about 71 to 85 bar (CO_2 critical pressure is around 71 bar and CO_2 critical temperature is around 33°C).

[0015] It has been found that the achievement of a totally supercritical cycle requires a specific refrigerant amount management in the heat pump circuit to handle the completely different conditions occurring during the transient trans-critical phase and during the subsequent totally supercritical stage, respectively.

[0016] Particularly, it has been found that a certain amount of refrigerant is optimal either for the transient trans-critical phase or for the totally supercritical stage, but not for both conditions together. Test performed by the applicant show that during at least the beginning of the transient trans-critical phase a reduced amount of refrigerant flowing along the heat pump circuit is beneficial to prevent liquid refrigerant entering and flooding the compressor, whereas an increased amount of refrigerant flowing along the heat pump circuit is expedient to promote, or maintain, or stabilize the totally supercritical stage or to improve the efficiency of the totally supercritical stage in term of temperature available at the gas cooler for heating the drying air.

[0017] It is an object of the present invention to provide a heat pump laundry dryer, which overcomes the above problems. Further, it is an object of the present invention to provide a corresponding method for operating said heat pump laundry dryer.

[0018] The object of the present invention is achieved by the heat pump system according to claim 1.

[0019] According to the present invention there is provided a A laundry dryer with heat pump system, wherein the heat pump system comprises a closed refrigerant circuit for a refrigerant, the refrigerant circuit includes at least one compressor, at least one gas cooler, at least one expansion means and at least one evaporator/gas heater, the refrigerant circuit is thermally coupled to a drying air circuit of the laundry dryer by the gas cooler and the evaporator/gas heater, the gas cooler is a heat exchanger and provided for heating up the drying air stream and cooling down the refrigerant, and the evaporator/gas heater is a heat exchanger and provided for dehumidifying the drying air and heating up the refrigerant, the refrigerant circuit comprises a low pressure side between the outlet of the expansion means and the inlet of the compressor, the refrigerant circuit comprises a high pressure side between the outlet of the compressor and the inlet of the inlet of expansion means, wherein the refrigerant operates at supercritical conditions in the low pressure side of the refrigerant circuit after a transient sub-critical phase, wherein the laundry dryer comprises at least one refrigerant trap fluidly connected or connectable to at least one part of the refrigerant circuit and valve means to selectively connect and/or disconnect the refrigerant trap to said least one part of the refrigerant circuit.

[0020] Refrigerant trap indicates a refrigerant storage device defining a storage volume, in practise a refrigerant receiver or refrigerant vessel/tank or refrigerant charge accumulator

[0021] Preferably, the laundry dryer comprises a controller adapted to actuate the valve means so as to fluidly disconnect the refrigerant trap from the refrigerant circuit at a first operational stage of the laundry dryer, and to fluidly connect the refrigerant trap to at least one part of the refrigerant circuit at a second operational stage of the laundry dryer, wherein the second operational stage is subsequent to the first operational stage.

[0022] Preferably, at least one sensor is provided to monitor at least one physical quantity associated to the refrigerant circuit and/or to the drying air and the controller is adapted to actuate the valve means in response to the time progression of said physical quantity.

[0023] Preferably, at least one sensor is provided to monitor the temperature/pressure of the refrigerant circuit and, preferably, the at least one the physical quantity is one of the following:

the refrigerant pressure at the high pressure side of the refrigerant circuit,
the refrigerant pressure and/or temperature at the outlet of the gas cooler,
the refrigerant pressure at the low pressure side of the heat pump circuit,
the refrigerant pressure and/or temperature at the outlet of the gas heater.

[0024] Preferably, at least one sensor is provided to monitor the temperature/humidity of the drying air and, preferably, the at least one the physical quantity is the temperature of the drying air at the outlet of the drying chamber.

[0025] Preferably, the controller is adapted to actuate the valve means to fluidly disconnect the refrigerant trap from the refrigerant circuit at the first operational stage of the laundry dryer in response to the time progression of the refrigerant pressure at the high pressure side of the refrigerant circuit and/or the refrigerant pressure at the outlet of the gas cooler and/or the refrigerant temperature at the outlet of the gas cooler.

[0026] Preferably, the controller is adapted to actuate the valve means to fluidly connect the refrigerant trap to the refrigerant circuit at the second operational stage of the laundry dryer in response to the time progression of the refrigerant pressure at the low pressure side of the refrigerant circuit and/or the refrigerant pressure at the outlet of the gas heater and/or the refrigerant temperature at the outlet of the gas heater.

[0027] Preferably, the controller is adapted to actuate the valve means to fluidly disconnect the refrigerant trap from the refrigerant circuit at the first operational stage of the heat pump laundry dryer and to fluidly connect the refrigerant trap to at least a part of the refrigerant circuit at the second operational stage of the heat pump laundry dryer in response to the time progression of the temperature of the drying air at the outlet of the drying chamber.

[0028] Preferably, the first operational stage occurs before the compressor starts to operate and the second operational stage occurs while the compressor is running.

[0029] Preferably, the first operational stage occurs while the compressor is running.

[0030] Preferably, the first operational stage occurs during the transient sub-critical phase.

[0031] Preferably, the second operational stage occurs during the transient sub-critical phase.

[0032] Preferably, the second operational stage occurs at supercritical conditions.

[0033] Preferably, at the second operational stage of the heat pump laundry dryer, the refrigerant trap is connected to at least a portion of the low pressure side of the refrigerant circuit.

[0034] Preferably, the control unit is adapted to actuate the valve means so as to fluidly connect the refrigerant trap to the at least one part of the refrigerant circuit at a time interval which precedes the first operational stage of the heat pump laundry dryer so that a certain amount of refrigerant can enter into the refrigerant trap.

[0035] Preferably, the time interval in which the refrigerant trap is fluidly connected to at least one part of the refrigerant circuit can occur before the compressor starts to operate or while the compressor is running.

[0036] Preferably, the valve means comprise an on/off valve connecting the refrigerant trap to a part of the refrigerant circuit, and the controller closes the on/off valve at a first operational stage of the laundry dryer, and opens the on/off valve at a second operational stage of the laundry dryer, wherein the second operational stage is subsequent to the first operational stage.

[0037] Preferably, said part of the refrigerant circuit is located upstream of or downstream of the gas cooler.

[0038] Preferably, the valve means comprise a first on/off valve connecting the refrigerant trap to a first part of the refrigerant circuit and a second on/off valve connecting the refrigerant trap to a second part of the refrigerant circuit and wherein the controller closes the first on/off valve at a first operational stage of the laundry dryer, and opens the second on/off valve at a second operational stage of the laundry dryer, wherein the second operational stage is subsequent to the first operational stage. Preferably, the first part of the refrigerant circuit is the outlet of the gas cooler and the second part of the refrigerant circuit is outlet of the gas heater.

[0039] Preferably, the first part of the refrigerant circuit is the outlet of the gas cooler and the second part of the refrigerant circuit is inlet of the gas cooler.

[0040] Preferably, the first part of the refrigerant circuit is the inlet of the gas heater and the second part of the refrigerant circuit is outlet of the gas heater.

[0041] Preferably, the first part of the refrigerant circuit is the outlet of the gas cooler and the second part of the refrigerant circuit is inlet of the gas heater.

[0042] Preferably, the first part of the refrigerant circuit is the inlet of the gas cooler and the second part of the refrigerant circuit is outlet of the gas heater.

[0043] Preferably, a throttling device is arranged between the second on/off valve and the second part of the refrigerant circuit.

[0044] Preferably, the refrigerant circuit comprises an internal heat exchanger for transferring heat from the high pressure side to the low pressure side of the refrigerant circuit, the internal heat exchanger comprises a high pressure portion interconnected between the outlet of the condenser and the inlet of the expansion means and a low pressure portion interconnected between the outlet of the gas heater and the inlet of the compressor.

[0045] Preferably, the first part of the refrigerant circuit is located upstream or downstream of the high pressure portion of the internal heat exchanger, and wherein the second part of the refrigerant circuit is located upstream or downstream of the low pressure portion of the internal heat exchanger.

[0046] Preferably, the refrigerant of the heat pump system is carbon dioxide

[0047] The novel and inventive features believed to be the characteristic of the present invention are set forth in the appended claims.

[0048] The invention will be described in further detail with reference to the drawings, in which

FIG 1 illustrates a schematic diagram of a refrigerant circuit with a refrigerant trap for a heat pump system according to a first embodiment of the present invention,

FIG 2 illustrates a schematic diagram of the pressure of a refrigerant as a function of the time during the operation of the heat pump system according to the embodiments of the present invention,

FIG 3 illustrates a schematic diagram of the refrigerant circuit with the refrigerant trap for the heat pump system according to a second embodiment of the present invention,

FIG 4 illustrates a schematic diagram of the refrigerant circuit with the refrigerant trap for the heat pump system according to a third embodiment of the present invention,

FIG 5 illustrates a schematic diagram of a refrigerant circuit with the refrigerant trap for the heat pump system according to a fourth embodiment of the present invention,

FIG 6 illustrates a schematic diagram of the refrigerant circuit with the refrigerant trap for the heat pump system according to a fifth embodiment of the present invention,

FIG 7 illustrates a schematic diagram of the refrigerant circuit with the refrigerant trap for the heat pump system according to a sixth embodiment of the present invention,

FIG 8 illustrates a schematic diagram of the refrigerant circuit with the refrigerant trap for the heat pump system according to a seventh embodiment of the present invention,

FIG 9 illustrates a schematic diagram of the refrigerant circuit with the refrigerant trap for the heat pump system according to an eighth embodiment of the present invention,

FIG 10 illustrates a schematic diagram of the refrigerant circuit with the refrigerant trap for the heat pump system according to a ninth embodiment of the present invention,

FIG 11 illustrates a schematic diagram of the refrigerant circuit with the refrigerant trap for the heat pump system according to a tenth embodiment of the present invention,

FIG 12 illustrates a schematic diagram of the refrigerant circuit with the refrigerant trap for the heat pump system according to an eleventh embodiment of the present invention,

FIG 13 illustrates a schematic diagram of the refrigerant circuit with the refrigerant trap for the heat pump system according to a twelfth embodiment of the present invention,

FIG 14 illustrates a schematic diagram of the refrigerant circuit with the refrigerant trap for the heat pump system according to a thirteenth embodiment of the present invention, and

FIG 15 illustrates a schematic diagram of the refrigerant circuit with the refrigerant trap for the heat pump system according to a fourteenth embodiment of the present invention.

[0049] For making the description of the present invention clearer, Carbon Dioxide (CO_2) has been considered as reference refrigerant and accordingly the data mentioned for explanatory purpose in the following description reflect such choice. However, the skilled person can easily appreciate that the present invention is not limited to Carbon Dioxide refrigerant but on the contrary the invention can be applied to any arbitrary substance with similar physical and chemical properties as carbon dioxide and in general to any refrigerants adapted to operate in supercritical conditions at least at the high pressure side of the heat pump circuit.

[0050] FIG 1 illustrates a schematic diagram of a heat pump laundry dryer according to a first embodiment of the present invention wherein the refrigerant operates at supercritical conditions at least in the high pressure side of the heap pump circuit and a refrigerant trap is fluidly connected and/or connectable to at least one part of the heat pump circuit.

[0051] The heat pump laundry dryer laundry comprises a refrigerant circuit including a compressor 10, a gas cooler 12, expansion means 14, an evaporator/gas heater 16, a refrigerant trap 18 and an on/off valve 20. The refrigerant circuit forms a closed loop. The heat pump laundry dryer laundry further comprises a drying air circuit 40 for circulating drying air inside a drying chamber 42 in which the laundry to be dried is arranged. The drying chamber can be formed, preferably, as a rotatable drum and a fan/blower 44 is provided for causing the drying air to circulate along the drying air circuit 40.

The refrigerant circuit is thermally coupled with the drying air circuit 40 by the gas cooler 12 and the evaporator/gas heater 16. The gas cooler 12 and the evaporator/gas heater 16 are heat exchangers. Further, the gas cooler 12 transfers heat from the refrigerant to the drying air so that the refrigerant cools down and the drying air is heated up before entering the drying chamber, and the evaporator/gas heater 16 transfers heat from the drying air to the refrigerant so that the drying air is cooled and dehumidified and the refrigerant evaporates or heats up.

[0052] It is to be noted that in case of a trans-critical cycle, the refrigerant evaporates in the evaporator 16; in case of a totally-supercritical cycle there is no refrigerant evaporation and the heat exchanger that transfers heat from the drying air to the refrigerant is indicated as gas heater 16.

[0053] Preferably, the drying air circuit 40 forms a loop wherein the drying air exits the drying chamber 42, flows over the evaporator/has heater 16, flows over the gas cooler 12 and the re-enter the drying chamber 40 as depicted in figure 1. Preferably, the drying air circuit 40 forms a closed-loop drying circuit.

[0054] The compressor 10, the gas cooler 12, the expansion means 14 and the evaporator/gas heater 16 are connected as a closed loop. The outlet of the compressor 10 is connected to the inlet of the gas cooler 12. The outlet of the gas cooler 12 is connected to the inlet of the expansion means 14. The outlet of the expansion means 14 is connected to the inlet of the evaporator/gas heater 16. The outlet of the evaporator/gas heater 16 is connected to the inlet of the compressor 10 again.

[0055] A refrigerant flows in the refrigerant circuit counter clockwise in FIG 1. The refrigerant is compressed by the compressor 10, cooled down in the gas cooler 12, then laminated in the expansion means 14 and vaporised or simply heated up in the evaporator/gas heater 16.

[0056] The refrigerant circuit comprises a high pressure side and a low pressure side. The high pressure side extends from the outlet of the compressor 10 via the gas cooler 12 to the inlet of the expansion device 14. The low pressure side extends from the outlet of the expansion device 14 via the evaporator/gas heater 16 to the inlet of the compressor 10.

[0057] Between the outlet of the compressor 10 and the inlet of the gas cooler 12 the refrigerant circuit is connected via an on/off valve 20 to the refrigerant trap 18. Thus, the refrigerant trap 18 is connected to the high pressure side of the refrigerant circuit via the on/off valve 20. Preferably, the on/off valve 20 is an electrically controlled valve.

[0058] Before the heat pump system starts to operate, the temperatures of the refrigerant and of the components of the refrigerant circuit are usually the same of the ambient air. The pressure of the refrigerant is the same within the whole refrigerant circuit. The value of the pressure depends on the amount of the refrigerant and on the temperature of the ambient. For example, the pressure may be about 45 to 65 bar, in case of CO_2 as refrigerant. When the heat pump system starts and the compressor 10 is switched on, then the pressure at the inlet of the compressor 10 immediately decreases and, at the same time, the pressure at the outlet of the compressor 10 increases. Then the pressure levels at the high pressure side as well as at the low pressure side increase during the operation of the heat pump system. This behaviour is typical for all such heat pump systems and is shown in FIG 2. In FIG 2 the pressure p_h in the high pressure side and the pressure p_1 in the low pressure side are shown as a function of the time t.

[0059] If the on/off valve 20 is open before the compressor 10 starts to operate, the pressure in the refrigerant trap 18 is the same as in the rest of the refrigerant circuit. The on/off valve 20 is closed just before the compressor 10 is started in order to keep the pressure level in the refrigerant trap 18 equal to the initial value.

[0060] If the pressure level in the high pressure side of the refrigerant circuit becomes higher than a predetermined maximum safety limit during the operation, then the safety on/off valve 20 is opened. In particular, between the compressor 10 and the gas cooler 12 the pressure has its maximum value. The maximum limit should be about 135 bar for safety reasons. In this way, a part of the refrigerant moves from the refrigerant circuit to the refrigerant trap 18 in order to reduce the pressure to a safe level. The on/off valve 20 is kept open until the pressure of the refrigerant circuit decreases to acceptable values.

[0061] When said part of the refrigerant moves into the refrigerant trap 18, then the pressure in the refrigerant trap 18 increases. The refrigerant trap 18 has a suitable volume, so that it can receive a certain amount of the refrigerant keeping the pressure level in the refrigerant circuit lower than the safety limit.

[0062] There is a pressure gradient between the high pressure side of the refrigerant circuit and the refrigerant trap 18 in order to allow the refrigerant moving from the refrigerant circuit into the refrigerant trap 18. The refrigerant moves from the refrigerant circuit into the refrigerant trap 18 only if the pressure in the refrigerant trap 18 is lower than the pressure in the high pressure side of the refrigerant circuit.

[0063] When the operation has been finished and the compressor 10 is switched off, then the on/off valve 20 is opened, so that the pressure levels become the same in the refrigerant circuit as well as in the refrigerant trap 18. Since the compressor 10 does not work, no pressure gradient occurs. The refrigerant circuit releases heat to the environment, thereby cooling down to the ambient temperature level. The pressure level in the refrigerant circuit decreases also. The on/off valve 20 remains open, until the compressor 10 switches on as above-mentioned.

[0064] In this way, a dangerous increase of the pressure in the refrigerant circuit is prevented without leakages of refrigerant out of the heat pump system. A continuous maintenance of the heat pump system is not required if overpressure occurs.

[0065] Further, the heat pump system includes a control unit for operating the on/off valve 20. Said control unit may be dedicated to the on/off valve 20 or be a part of a control unit of the laundry dryer. The control unit operates the on/off valve 20 in response to temperature and/or pressure values detected by sensors at the high pressure side of the refrigerant circuit. In particular, said sensors are arranged between the outlet of the compressor 10 and the inlet of the gas cooler 12. Additionally or alternatively, said sensors may be arranged at the low pressure side of the refrigerant circuit, in particularly between the outlet of the evaporator/gas heater 16 and the inlet of the compressor 10. Further, the sensors may be arranged at the refrigerant trap 18.

[0066] For safety reasons, a pressure relief valve may be provided at the refrigerant trap 18 for discharging the refrigerant in the case of overpressure.

[0067] FIG 3 illustrates a schematic diagram of a heat pump laundry dryer according to a second embodiment of the present invention. The drying air circuit 40 has the same structure as the drying air circuit of the first embodiment.

[0068] The refrigerant circuit of the second embodiment has the same structure as the refrigerant circuit of the first embodiment in FIG 1. Instead of the on/off valve 20, the refrigerant circuit of the second embodiment comprises a first on/off valve 22 and a second on/off valve 24. The first on/off valve 22 and the second on/off valve 24 may be electrically driven valves.

[0069] The first on/off valve 22 connects the outlet of the compressor 10 and the inlet of the gas cooler 12 to the refrigerant trap 18. In a similar way, the second on/off valve 24 connects the outlet of the evaporator/gas heater 16 and the inlet of the compressor 10 to the refrigerant trap 18. Preferably, the first on/off valve 22 is arranged close to the outlet of the compressor 10, and the second on/off valve 24 is arranged close to the inlet of the compressor 10, respectively. When the first on/off valve 22 is opened, then the refrigerant trap 18 is connected to the high pressure side of the refrigerant circuit. When the second on/off valve 24 is opened, then the refrigerant trap 18 is connected to the low pressure side of the refrigerant circuit.

[0070] Before the heat pump system starts to operate, the temperatures of the refrigerant and of the components of the refrigerant circuit are the same of the ambient air. The pressure level of the refrigerant is the same within the whole refrigerant circuit. The value of the pressure depends on the amount of refrigerant in the circuit and on the temperature of the ambient. The pressure may be about 45 bar to 65 bar, in case of CO_2 as refrigerant. When the heat pump system starts to operate and the compressor 10 is switched on, then the pressure at the inlet of the compressor 10 immediately decreases and, at the same time, the pressure at the outlet of the compressor 10 increases. Then the pressure levels at the high pressure side and at the low pressure side of the refrigerant circuit increase during the operation. This behaviour is shown in FIG 2.

[0071] When the heat pump system is not working and the on/off valves 22 and 24 are open, then the pressure levels of the refrigerant in the refrigerant circuit and in the refrigerant trap 18 are the same. The pressure depends on the ambient temperature and on the amount of refrigerant.

[0072] Just before the compressor 10 starts to operate, only the first on/off valve 22 is closed while the second on/off valve 24 is kept open. In this way, the pressure in the refrigerant trap 18 decreases as the pressure level in the low pressure side of the refrigerant circuit, while the pressure level in the high pressure side of the refrigerant circuit increases as previously described. After some minutes of compressor working, the second on/off valve 24 is closed and the internal pressure in the tank is kept at a very low pressure level, i.e. lower than the initial pressure value.

[0073] During the operation the pressure levels in the high pressure side as well as in the low pressure side of the refrigerant circuit increase, while the pressure in the refrigerant trap 18 remains constant and at a low pressure level.

[0074] If the pressure level in the high pressure side becomes higher than a predetermined value during the operation, then the first on/off valve 22 is opened. The predetermined value may be slightly lower than the maximum safety value, which is about 135 bar. In this way, a part of the refrigerant moves from the refrigerant circuit to the refrigerant trap 18 reducing the pressure level in the high pressure side of the refrigerant circuit. The first on/off valve 22 is kept open until the high pressure level decreases to an acceptable value. When said part of the refrigerant has been moved into the refrigerant trap 18, then the pressure inside the refrigerant trap 18 increases. The volume of the refrigerant trap 18 is adapted for receiving an amount of the refrigerant keeping the internal pressure lower than said predetermined value.

[0075] Further, since the initial pressure level in the refrigerant trap 18 is relative low, the refrigerant trap 18 can receive a relative big amount of refrigerant. Thus, the refrigerant trap 18 can be relatively small.

[0076] A pressure gradient occurs between the high pressure side of the refrigerant circuit and the refrigerant trap 18 in order to allow the refrigerant moving from the heat pump circuit to the refrigerant trap 18, if this is necessary. The refrigerant moves from the refrigerant circuit to the refrigerant trap 18 only, if the pressure level in the refrigerant trap 18 is lower than the pressure level in the high pressure side of the refrigerant circuit.

[0077] In a similar way, a pressure gradient occurs between the refrigerant trap 18 and the low pressure side of the refrigerant circuit in order to convey the refrigerant back to the refrigerant circuit.

[0078] When the operation has been finished and the compressor is switched off, then the second on/off valve 24 is open, so that the pressure levels are immediately the same in the refrigerant circuit and in the refrigerant trap 18. Since the compressor 10 does not work, no pressure gradient occurs. The refrigerant circuit releases heat to the environment, the refrigerant cools down to the ambient temperature level, and the pressure also decreases. At the beginning of the following operation, the second on/off valve 24 is still open. When the compressor 10 starts working, the refrigerant in the refrigerant trap 18 is sucked by the compressor 10 and moved from the refrigerant trap 18 to the refrigerant circuit.

[0079] In this way, dangerous increases of the pressure are prevented without leakages of refrigerant out of the heat pump system. The continuous intervention of maintenance is not required if overpressure occurs.

[0080] In a modification of the second embodiment, the first on/off valve 22 may be a passive mechanical valve set to be opened, if the pressure exceeds a predetermined pressure level.

[0081] A control unit, which may be dedicated to the on/off valves 22 and 24 or a part of the controller of the heat pump laundry dryer, is adapted to operate the on/off valves 22 and 24 in response to temperature and/or pressure values detected by sensors provided at the high pressure side of the refrigerant circuit, in particular between the outlet of the compressor 10 and the inlet of the gas cooler 12, and/or provided at the low pressure side of the refrigerant circuit, in particular between the outlet of the evaporator/gas heater 16 and the inlet of the compressor 10 and, and/or provided at the refrigerant trap 18.

[0082] For safety reasons a pressure relief device, e.g. a valve, may be provided at the refrigerant trap 18 for discharging the refrigerant in the case of overpressure.

[0083] FIG 4 illustrates a schematic diagram of the heat pump laundry dryer according to a third embodiment of the present invention. In figure 4 the drying air circuit has been omitted, but it is clear that what disclosed in connection with the first and second embodiment is applicable to the present embodiment.

[0084] The refrigerant circuit of the third embodiment is adapted to control the supercritical pressure of the refrigerant at the high pressure side or low pressure side of the heat pump circuit in response to the actuation of variable expansion means of heat pump circuit. In particular the third embodiment is adapted to maintain the supercritical pressure at favourable conditions by smoothing the supercritical pressure variations that occurs when the variable expansion means of heat pump circuit are operated. The third embodiment is adapted to maintain constant the high or low pressure level depending on the fact that the variable expansion means acts respectively to control the low or the high pressure level.

[0085] The third embodiment is applicable to both trans-critical and totally-supercritical cycle.

[0086] The refrigerant circuit of the third embodiment has substantially the same structure as the refrigerant circuit of the second embodiment shown in FIG 3. However, the first on/off valve 22 connects the outlet of the gas cooler 12 and the inlet of the expansion means 14 to the refrigerant trap 18. The on/off valves 22 and 24 are electronic valves. The refrigerant trap 18 is connected to the high pressure side of the refrigerant circuit, i.e. between the gas cooler 12 and the expansion means 14, when the first on/off valve 22 is open. The refrigerant trap 18 is connected to the low pressure side, in particular close to the compressor suction, when the second on/off valve 24 is open.

[0087] Before the heat pump system starts working, the temperatures of the refrigerant and of all components are the same as of ambient air. The pressure of the refrigerant is the same in the whole circuit and the pressure level depends on the amount of refrigerant in the circuit and on the temperature of the ambient air. The pressure may be about 45 bar to 65 bar.

[0088] When the heat pump system starts and the compressor 10 is switched on, then the pressure at the suction of the compressor 10 immediately becomes lower and, at the same time, the pressure at the discharge of the compressor 10 becomes higher than the initial value. Afterwards the high and low pressure level increases during the operation as shown in FIG 2.

[0089] When the heat pump system is not working and the both on/off valves 22 and 24 are open, then the pressure levels of the refrigerant in the heat pump circuit and in the refrigerant trap 18 are the same.

[0090] Before the compressor 10 starts to operate, the second on/off valve 24 is closed while the first on/off valve 22 is kept open. In this way, the pressure level in the refrigerant trap 18 increases like the pressure level in the high pressure side of the refrigerant circuit, while the pressure level in the low pressure side of the refrigerant circuit increases as previously described.

[0091] During the operation the pressure levels in the low pressure side, in the high pressure side and in the refrigerant trap 18, which is at the same level of the high pressure side, increase. After a certain time of working of the compressor 10, the first on/off valve 22 is closed and the internal pressure in the refrigerant trap 18 is kept to an intermediate value, which may be for example 90 bar to 100 bar, while the pressure level in the low pressure side is lower than 85 bar.

[0092] The embodiment mentioned above can be particularly useful, when the refrigerant circuit includes variable expansion means 14. The heat pump system can be provided of variable expansion means 14 in order to adjust the pressure level in the low pressure side according to the variable thermodynamic conditions during the operation.

[0093] The pressure level in the low pressure side must be kept high in order to obtain a high refrigerant density at the suction of the compressor 10 and then a high refrigerant flow rate and cooling capacity. However, an excessive pressure level in the low pressure side may correspond to a too high refrigerant temperature at the evaporator/gas heater 16 with consequently penalizations of the power of the heat pump system. Thus, according to the current thermodynamic conditions during the operation, the expansion means 14 increase or decrease the pressure level in the low pressure side.

[0094] However, the expansion means 14 changes the pressure drops given to the refrigerant in such a way that both

pressure levels in the low pressure side and in the high pressure side change at the same time. If the pressure level in the low pressure side has to be decreased, then the expansion means 14 acts increasing the pressure drops, i.e. the opening degree of the valve of the expansion means 14 is reduced. The pressure level in the low pressure side is decreased, but the pressure levels in high pressure side increase.
On the contrary, if the pressure level in the low pressure side has to be increased, then the expansion means 14 acts decreasing the pressure drops, i.e. the opening degree of the valve of the expansion means 14 is increased. The pressure level in the low pressure side is increased, but the pressure level in the high pressure side decreases.

[0095] The pressure level in the high pressure side should be kept about 120 bar to 125 bar during the operation, so that the temperature of the refrigerant enables the drying air in the drying circuit to be heated up to a desired level. Higher values of the pressure can be dangerous for safety reasons as discloses in the first and second embodiments.

[0096] Conversely, in case the pressure level in the high pressure side is not sufficiently high, e.g. lower than 120 bar to 125 bar, the drying air could not be heated enough. The refrigerant trap 18 and the on/off valves 22 and 24 allow the expansion means 14 adjusting the pressure level in the low pressure side without changing the pressure level in the high pressure side.

[0097] In order to balance the increasing of the pressure level in the high pressure side in response to the actuation of variable expansion means 14 to decrease the pressure level in the low pressure side, the opening of the first on/off valve 22 enables a part of the refrigerant to move to the refrigerant trap 18, wherein the pressure level in the high pressure side is kept at a desired value.
In this case the second on/off valve 24 is closed. In this way the pressure level in the high pressure side of the refrigerant circuit remains substantially similar to the pressure level before the actuation of the variable expansion means

[0098] In order to balance the decreasing the pressure level in the high pressure side in response to the actuation of the variable expansion means 14 to increase the pressure level in the low pressure side, the opening of the second on/off valve 24 enables a part of the refrigerant to move from the refrigerant trap 18 to the refrigerant circuit, and also in this case the pressure level in the high pressure side is kept at the desired value. In this case the first on/off valve 22 is closed.
The opening of the on/off valve 24 enables the overall amount of the refrigerant flowing along the heat pump circuit to increase and as a consequence the pressure at the compressor outlet (i.e. high pressure side) tends to increase accordingly.

[0099] In this way the pressure level in the high pressure side of the refrigerant circuit remains substantially similar to the pressure level before the actuation of the variable expansion means

[0100] The refrigerant trap 18 allows to decrease or to increase the pressure level in the high pressure side, thereby counter-balancing the variations of the pressure level in the high pressure side due to the working conditions of the heat pump system, which change during the operation. Further variations can be actively introduced, if the heat pump system includes means to adjust the refrigerant flow rate as the controllable valve mentioned above or a variable speed compressor.

[0101] The pressure level in the high pressure side can be controlled by following the same control unit described above even if a variable speed compressor or other active means are provided to change the thermodynamic parameter of the heat pump system.

[0102] The variable expansion means 14 can also adjust the pressure level in the high pressure side according to the variable thermodynamic conditions during the operation.

[0103] The expansion means 14 changes the pressure drops given to the refrigerant in such a way that both pressure levels in the low pressure side and in the high pressure side change at the same time. If the pressure level in the high pressure side has to be increased, then the expansion means 14 acts increasing the pressure drops, i.e. the opening degree of the valve of the expansion means 14 is reduced. The pressure level in the high pressure side is increased, but the pressure levels in low pressure side decreases.
On the contrary, if the pressure level in the high pressure side has to be decreased, then the expansion means 14 acts decreasing the pressure drops, i.e. the opening degree of the valve of the expansion means 14 is increased. The pressure level in the high pressure side is decreased, but the pressure level in the low pressure side increases.

[0104] The pressure level in the low pressure side must be kept high in order to obtain a high refrigerant density at the suction of the compressor 10 and then a high refrigerant flow rate and cooling capacity. However, an excessive pressure level in the low pressure side may correspond to a too high refrigerant temperature at the evaporator/gas heater 16 with consequently penalizations of the power of the heat pump system. Thus, according to the current thermodynamic conditions during the operation, the expansion means 14 increase or decrease the pressure level in the low pressure side.

[0105] The pressure level in the high pressure side should be kept about 120 bar to 125 bar during the operation, so that the temperature of the refrigerant allows the drying air in the drying circuit being heated up to a desired level. Higher values of the pressure can be dangerous for safety reasons as discloses in the first and second embodiments.

[0106] Conversely, in case the pressure level in the high pressure side is not sufficiently high, e.g. lower than 120 bar to 125 bar, the drying air could not be heated enough. The refrigerant trap 18 and the on/off valves 22 and 24 allow the expansion means 14 adjusting the pressure level in the low pressure side without changing the pressure level in the high pressure side.

[0107] In order to balance the increasing of the pressure level in the low pressure side in response to the actuation of variable expansion means 14 to decrease the pressure level in the high pressure side, the opening of the first on/off valve 22 enables a part of the refrigerant to move to the refrigerant trap 18, wherein the pressure level in the high pressure side is kept at a desired value.

In this case the second on/off valve 24 is closed. In this way the pressure level in the low pressure side of the refrigerant circuit remains substantially similar to the pressure level before the actuation of the variable expansion means

[0108] In order to balance the decreasing of the pressure level in the low pressure side in response to the actuation of the variable expansion means 14 to increase the pressure level in the high pressure side, the opening of the second on/off valve 24 enables a part of the refrigerant to move from the refrigerant trap 18 to the refrigerant circuit, wherein also in this case the pressure level in the low pressure side is kept at the desired value. In this case the first on/off valve 22 is closed.

The opening of the on/off valve 22 enables part of the refrigerant to move from the trap to the circuit.

[0109] In this way the pressure level in the low pressure side of the refrigerant circuit remains substantially similar to the pressure level before the actuation of the variable expansion means.

[0110] The refrigerant trap 18 is designed that its internal pressure is kept between the desired high pressure level and the maximum low pressure level allowed to the system. In this way the pressure gradient between the high pressure side of the refrigerant circuit and the refrigerant trap 18 and the pressure gradient between the refrigerant trap 18 and the low pressure side of the refrigerant circuit are guaranteed. The refrigerant moves from the higher pressure side to the lower pressure side.

[0111] When a part of the refrigerant moves into the refrigerant trap 18, then the pressure in the refrigerant trap 18 increases, and when the part of the refrigerant moves from the refrigerant trap 18, then the pressure decreases.

[0112] A control unit, which may be dedicated or be a part of the controller of the heat pump laundry dryer, is adapted to operate the on/off valves 22 and 24 in response to temperature and/or pressure values detected by sensors provided at the high pressure side of the refrigerant circuit, in particular between the outlet of the compressor 10 and the inlet of the gas cooler 12, and/or provided at the low pressure side of the refrigerant circuit, in particular between the inlet of the compressor 10 and the evaporator/gas heater 16, and/or provided at the refrigerant trap 18. Preferably the refrigerant trap 18 is provided with a thermal insulation to avoid thermal losses, in fact if the temperature of the refrigerant trap 18 and the refrigerant as well decreases also the pressure of the refrigerant inside the refrigerant trap 18 decreases. As a consequence the pressure gradient needed to move the refrigerant from the refrigerant circuit to the refrigerant trap 18 and vice-versa could vary during the operation of the heat pump system.

[0113] FIG 5 illustrates a schematic diagram of a heat pump laundry dryer according to a fourth embodiment of the present invention. In figure 5 the drying air circuit has been omitted, but it is clear that what disclosed in connection with the first and second embodiment is applicable to the present embodiment.

[0114] The structure of the refrigerant circuit of the fourth embodiment is identical with the structure of the second embodiment in FIG 3. The on/off valves 22 and 24 are electronic valves.

[0115] The refrigerant circuit of the fourth embodiment is adapted to control the supercritical pressure of the refrigerant at the high pressure side of the heat pump circuit in response to the actuation of variable expansion means of heat pump circuit. In particular the fourth embodiment is adapted to maintain the supercritical pressure at favourable conditions by smoothing the supercritical pressure variations that occurs when the variable expansion means and/or variable speed compressor of heat pump circuit are operated. The fourth embodiment is applicable to both trans-critical and totally-supercritical cycle.

[0116] The control of the on/off valves 22 and 24 is performed in the same way and with the same purpose as described in connection with the third embodiment of figure 4 and in particular so as to decrease or to increase the supercritical pressure level in the high pressure side, thereby counter-balancing the variations of the supercritical pressure level in the high pressure side due to the changing working conditions of the heat pump system.

[0117] The difference of the fourth embodiment with respect to the third embodiment consists in that the fourth embodiment provides that a part of compressed refrigerant at compressor outlet flows into the refrigerant trap 18 (once the on/off valve 22 is open) without passing through the gas cooler 12 so that a part of the refrigerant compressing work is wasted, whereas in the third embodiment of figure 4 the compressed gas pass through the gas cooler 12 first and then a part of it flows into the refrigerant trap 18 (once the on/off valve 22 is open).

[0118] Further, in the fourth embodiment of figure 4, the first on/off valve 22 is arranged at the high pressure side of the heat pump circuit and particularly between the outlet of compressor 10 and inlet of gas cooler 12 the outlet of the compressor 10, where the pressure is at the highest level. Therefore, the first on/off valve 22 can be used as a safety pressure relief in order to avoid overpressure. The approach is the same as the one described in connection with the second embodiment of figure 3.

[0119] In fact, if the supercritical pressure level in the high pressure side exceeds a safety limit, then the first on/off

valve 22 is opened and a part of the refrigerant is discharged into the refrigerant trap 18. In this way, dangerous pressure increases are avoided without leakages of refrigerant out of the heat pump system.
For safety reasons a further pressure relief device, e.g. a valve, can be provided at the refrigerant trap 18 for discharging the refrigerant in case of overpressure.

[0120] FIG 6 illustrates a schematic diagram of a heat pump laundry dryer according to a fifth embodiment of the present invention. Also in this case the drying air circuit has been omitted, but it is clear that what disclosed in connection with the first and second embodiment is applicable to the present embodiment.
The fifth embodiment is applicable to both trans-critical a totally-supercritical cycle.

[0121] The refrigerant circuit of the fifth embodiment includes additionally a third on/off valve 26.

[0122] The first on/off valve 22 connects the outlet of the gas cooler 12 and the inlet of the expansion means 14 to the refrigerant trap 18. The second on/off valve 24 connects the outlet of the evaporator/gas cooler 16 and the inlet of the compressor 10 to the refrigerant trap 18. The third on/off valve 26 connects the outlet of the compressor 10 and the inlet of the gas cooler 12 to the refrigerant trap 18.

[0123] The way of working of the first on/off valve 22 and the second on/off valve 24 is the same as in the third embodiment of FIG 4 in order to maintain the supercritical pressure level at favourable conditions by smoothing the supercritical pressure variations that occurs when the variable expansion means and/or the variable speed compressor of heat pump circuit are operated.
An additional pipe connects the high pressure side of the refrigerant circuit, upstream of the gas cooler 12 to the refrigerant trap 18, via the third on/off valve 26 as in the fourth embodiment. The third on/off valve 26 is arranged close to the discharge of the compressor 10. The third on/off valve 26 acts as safety means.

[0124] If the high pressure becomes higher than a predetermined value, e.g. about 130 to 135 bar, the third on/off valve 26 is opened, and a part of the refrigerant moves into the refrigerant trap 18.

[0125] The on/off valves 22, 24 and 26 are electrically driven valves. The third on/off valve 26 also may be a passive mechanical valve set to be opened when the pressure exceeds a predetermined set-point.

[0126] The fifth embodiment obtains the benefits of the third and second embodiments. For safety reasons a pressure relief device, e.g. a valve, may be provided at the refrigerant trap 18 for discharging refrigerant in case of overpressure.

[0127] FIG 7-15 refers to embodiments of a heat pump laundry dryer wherein the refrigerant operates at supercritical conditions both in the high pressure side and low pressure side of the heat pump circuit and a refrigerant trap is fluidly connected and/or connectable to at least one part of the heat pump circuit in order to manage the amount of refrigerant during the transient trans-critical phase and during the totally supercritical stage.

[0128] The heat pump laundry dryer laundry comprises a refrigerant circuit including a compressor 10, a gas cooler 12, expansion means 14, a gas heater 16, a refrigerant trap 18 and valve means 22, 24, 26 fluidly connecting or disconnecting the refrigerant trap 18 to the refrigerant circuit. The gas cooler 12 and the gas heater 16 are heat exchangers. Particularly, the gas cooler 12, transfers heat from the refrigerant (which cools down) to the drying air, whereas the gas heater 16 transfers heat from the drying air to the refrigerant (which heats up).
The heat pump laundry dryer laundry further comprises a drying air circuit (omitted in FIG 7-15) for circulating drying air inside a drying chamber in which the laundry to be dried is arranged. The drying chamber can be formed, preferably, as a rotatable drum and a fan/blower is provided for driving the drying air along the drying air circuit. The refrigerant circuit is thermally coupled with the drying air circuit by the gas cooler 12 and the gas cooler 16. The gas cooler 12 heats up the drying air in the drying air circuit, and the gas cooler 16 cools and dehumidifies the drying air in the drying air circuit.

[0129] Preferably, the drying air circuit forms a loop wherein the drying air exits the drying chamber, flows over the gas heater 16, flows over the gas cooler 12 and the re-enter the drying chamber. Preferably, the drying air circuit forms a closed-loop drying circuit.

[0130] The applicant has realized that due to the different working conditions that the heat pump laundry dryer passes through during the laundry drying cycle, it is expedient that a first amount of refrigerant flows along the refrigerant circuit at a first operational stage of heat pump laundry dryer and a second amount of refrigerant greater that the first amount flows along the heat pump circuit at a second operational stage of heat pump laundry dryer subsequent to the first operation stage.

[0131] In practise, if the refrigerant amount is optimised for the transient trans-critical phase so as to prevent any liquid refrigerant from entering the inlet of the compressor, the heat pump circuit does not contain enough refrigerant amount to rapidly promote a totally-supercritical stage or to maintain the totally-supercritical stage or to stabilize the totally-supercritical stage or to improve the totally-supercritical stage in terms of efficiency.
On the contrary, if the refrigerant amount is optimised for rapidly promoting the totally-supercritical stage or maintaining the totally-supercritical stage or stabilizing the totally-supercritical stage or improving the totally-supercritical stage in terms of efficiency, the heat pump circuit contains an excess amount of refrigerant that causes the compressor flooding at the beginning of the cycle.

[0132] Therefore a certain amount of refrigerant should be available at the second operational stage of the heat pump laundry dryer so as to make the refrigerant amount adapted to effectively promote and/or support the totally-supercritical stage.

[0133] The present invention provides for

- fluidly disconnecting the refrigerant trap from the refrigerant circuit at first operational stage of the heat pump laundry dryer so as to retain a certain amount of refrigerant inside the refrigerant trap and for
- fluidly connecting at least one part of the heat pump circuit to the refrigerant trap at a second operational stage of the heat pump laundry dryer subsequent (following) to the first operational stage so as to make said certain amount available to the heat pump circuit.

[0134] The present invention provides for retaining (retain storing or entrapping or capturing) a certain amount of refrigerant in the refrigerant trap from the refrigerant circuit at a first operational stage of the heat pump laundry dryer and releasing it from the refrigerant trap to the heat pump circuit afterwards at a second operational stage of the heat pump laundry dryer.

[0135] First operational stage indicates at least a working phase of the laundry dryer wherein the compressor is operating or wherein the compressor is not working (the electric motor of the compressor is de-energized).

In practise first operational stage can occur before the compressor starts to operate or after the compressor is switched on (i.e. while the compressor is working).

[0136] Preferably, the present invention provides for fluidly connecting at least one part of the refrigerant circuit to the refrigerant trap at a time interval which precedes the first operational stage of the heat pump laundry dryer so that a certain amount of refrigerant can enter into the refrigerant trap.

[0137] The time interval in which the at least one part of the heat pump circuit is fluidly connected to the refrigerant trap can occur before the compressor starts to operate or after the compressor has been switched on (i.e. while the compressor is working/running).

[0138] In a preferred embodiment of the present invention the first operational stage occurs before the compressor starts to operate and the second operational stage occurs while the compressor is running.

[0139] In a further preferred embodiment of the present invention first operational stage occurs while the compressor is working.

[0140] In a even further preferred embodiments of the present invention, the time interval in which the at least one part of the heat pump circuit is fluidly connected to the refrigerant trap and which precedes the first operational stage of the heat pump laundry dryer occur while the compressor is working.

[0141] In general, first operational stage and second operational stage of the heat pump laundry dryer represent operating phases of the laundry dryer wherein the refrigerant amount for providing optimum conditions of the heat pump system are different.

[0142] The first operational stage of the heat pump laundry dryer can occur during warm-up phase of the heat pump laundry dryer wherein the temperatures of the drying air increases up to a predetermined level.

The second operational stage of the heat pump laundry dryer, which follows the first operational stage, can occur during warm-up phase of the heat pump laundry dryer wherein the temperatures of the drying air increases up to a predetermined level, or during steady state phase of the heat pump laundry dryer wherein the temperature of the drying air are kept substantially close to said predetermined level or during the transition between the warm-up phase and the steady state phase.

[0143] A certain amount of refrigerant is stored in a volume (i.e. refrigerant trap) connecting one, two or more parts of the refrigerant circuit, which are characterised by different thermodynamic status of the refrigerant, specifically different density and/or different pressure. Preferably, the storage volume connects high density refrigerant regions from which a certain amount of refrigerant is retained to low density refrigerant regions where the certain amount of refrigerant is released, thereby making it available for the thermodynamic cycle of the refrigerant.

The storage volume can be selectively connected to different parts of the refrigerant circuit via suitable valve means.

[0144] Further, at the second operational stage of the heat pump laundry dryer the storage volume can be connected to different portions of the refrigerant circuit so that the refrigerant can be released to different sections of the refrigerant circuit wherein the refrigerant has different thermodynamic conditions.

[0145] As an alternative, the refrigerant trap can be fluidly connected to the same portion of the refrigerant circuit but at different moments, at the second operational stage and, preferably, at a third operational stage of the heat pump laundry which follows the second one, wherein the refrigerant has different characteristic particularly in terms of density and/or pressure.

[0146] Preferably, at the second operational stage of the heat pump laundry dryer, the refrigerant trap is connected to at least a portion of the low pressure side of the refrigerant circuit.

[0147] The heat pump laundry dryer comprises valve means, preferably one or more valves, for connecting the refrigerant trap to at least one part of the refrigerant circuit.

The heat pump laundry dryer comprises a control unit adapted to actuate the valve means so as to fluidly disconnect the refrigerant trap from the refrigerant circuit at a first operational stage of the heat pump laundry dryer, and to fluidly connect the refrigerant trap to at least one part of the refrigerant circuit at a second operational stage of the heat pump laundry dryer, wherein the second operational stage is subsequent to the first operational stage.

[0148] Further, the control unit adapted to actuate the valve means so as to fluidly connect the refrigerant trap to the at least one part of the refrigerant circuit at a time interval which precedes the first operational stage of the heat pump laundry dryer so that a certain amount of refrigerant can enter into the refrigerant trap.

[0149] Preferably, once the drying cycle is concluded, the control unit operates the valve means so as to fluidly connects the refrigerant trap to at least a part of the refrigerant circuit and the valve means remain open till when in the subsequent drying cycle the control unit operates the valve meant so as to disconnect the refrigerant trap from the refrigerant circuit at the first operational stage of the heat pump laundry dryer.

[0150] The heat pump laundry dryer comprises sensors to monitor at least one physical quantity associated to the heat pump circuit and/or to the drying air and the control unit is adapted to actuate the valve means in response to the time progression of said physical quantity.

[0151] Preferably heat pump laundry dryer comprises at least one sensor to monitor the temperature/pressure of the heat pump circuit and, preferably, the at least one the physical quantity is the refrigerant pressure at the high pressure side of the heat pump circuit and/or the refrigerant pressure at the outlet of the gas cooler and/or the refrigerant temperature at the outlet of the gas cooler and/or the refrigerant pressure at the low pressure side of the heat pump circuit and/or the refrigerant pressure at the outlet of the gas heater and/or the refrigerant temperature at the outlet of the gas heater.

[0152] Preferably heat pump laundry dryer comprises at least one sensor to monitor the temperature/humidity of the drying air and, preferably, the at least one the physical quantity being the temperature of the drying air at the outlet of the drying chamber.

[0153] Preferably, the control unit actuates the valve means to fluidly disconnect the refrigerant trap from the refrigerant circuit at the first operational stage of the heat pump laundry dryer in response to the time progression of the refrigerant pressure at the high pressure side of the heat pump circuit and/or the refrigerant pressure at the outlet of the gas cooler and/or the refrigerant temperature at the outlet of the gas cooler.

[0154] Preferably, the control unit actuates the valve means to fluidly disconnect the refrigerant trap from the refrigerant circuit at the first operational stage of the heat pump laundry dryer and to fluidly connect the refrigerant trap to at least one part of the refrigerant circuit at the second operational stage of the heat pump laundry dryer in response to the time progression of the refrigerant pressure at the low pressure side of the heat pump circuit and/or the refrigerant pressure at the outlet of the gas heater and/or the refrigerant temperature at the outlet of the gas heater.

[0155] Preferably, the control unit actuates the valve means to fluidly connect the refrigerant trap to the at least one part of the refrigerant circuit at the first and at the second operational stage of the heat pump laundry dryer in response to the time progression of the temperature of the drying air at the outlet of the drying chamber.

[0156] FIG 7 illustrates a schematic diagram of a heat pump laundry dryer according to a sixth embodiment of the present invention. The refrigerant circuit of the second embodiment comprises a first on/off valve 22 and a second on/off valve 24. The first on/off valve 22 and the second on/off valve 24 may be electrically driven valves.

[0157] The first on/off valve 22 connects the outlet of the gas cooler 12 and the inlet of the expansion means 14 to the refrigerant trap 18. In a similar way, the second on/off valve 24 connects the outlet of the gas heater 16 and the inlet of the compressor 10 to the refrigerant trap 18.

[0158] When the first on/off valve 22 is opened, then the refrigerant trap 18 is connected to the high pressure side of the refrigerant circuit. When the second on/off valve 24 is opened, then the refrigerant trap 18 is connected to the low pressure side of the refrigerant circuit.

[0159] The control unit opens the first on/off valve 22 at a first operational stage of the heat pump laundry dryer so that a certain amount of refrigerant flown into the refrigerant trap 18. The first on/off valve 22 is then closed by the control unit so that a part of the refrigerant is retained in the refrigerant trap 18.
The control unit opens the second on/off valve 24 at a second operational stage of the heat pump laundry dryer so that the refrigerant contained in the refrigerant trap 18 is again available to the refrigerant circuit.

[0160] Preferably, a throttling device 28 is interconnected between the second on/off valve 24 on the one hand, the inlet of the compressor 10 and the outlet of the gas heater 16 on the other hand. The throttling device 28 is provided to smooth the transfer of the refrigerant from the refrigerant trap 18 to the refrigerant circuit to avoid a sudden introduction of the refrigerant into the refrigerant circuit.

[0161] FIG 8 illustrates a schematic diagram of a heat pump laundry dryer according to a seventh embodiment of the present invention. In the seventh embodiment the series of the first on/off valve 22, the refrigerant trap 18 and the second on/off valve 24 is connected parallel to the gas cooler 12.
Preferably, a throttling device 28 can be interconnected between the second on/off valve 24 on the one hand, the outlet of the compressor 10 and the inlet of the gas heater 16 on the other hand.
The control of the first on/off valve 22 and second on/off valve 24 is the same as the one described with reference to the sixth embodiment.

[0162] FIG 9 illustrates a schematic diagram of a heat pump laundry dryer according to an eighth embodiment of the present invention. In the eighth embodiment the series of the first on/off valve 22, the refrigerant trap 18 and the second on/off valve 24 is connected parallel to the gas heater 16.

[0163] Preferably, a throttling device 28 can be interconnected between the second on/off valve 24 on the one hand, the inlet of the compressor 10 and the outlet of the gas heater 16 on the other hand for smoothing the transfer of the refrigerant from the refrigerant trap 18 to the refrigerant circuit to avoid a sudden introduction of the refrigerant into the refrigerant circuit.

[0164] The control of first on/off valve 22 and the second on/off valve 24 is the same as the one described with reference to the sixth embodiment.

[0165] FIG 10 illustrates a schematic diagram of the heat pump laundry dryer according to a ninth embodiment of the present invention. In the ninth embodiment the series of the first on/off valve 22, the refrigerant trap 18 and the second on/off valve 24 is connected parallel to the expansion means 14.

[0166] Preferably, a throttling device 28 can be interconnected between the second on/off valve 24 on the one hand, the outlet of the expansion means 14 and the inlet of the gas heater 16 on the other hand for smoothing the transfer of the refrigerant from the refrigerant trap 18 to the refrigerant circuit to avoid a sudden introduction of the refrigerant into the refrigerant circuit.

[0167] The control of first on/off valve 22 and the second on/off valve 24 is the same as the one described with reference to the sixth embodiment.

[0168] FIG 11 illustrates a schematic diagram of the heat pump laundry dryer according to a tenth embodiment of the present invention. In the tenth embodiment the series of the first on/off valve 22, the refrigerant trap 18 and the second on/off valve 24 is connected parallel to the compressor 10.

[0169] Preferably, a throttling device 28 can be interconnected between the second on/off valve 24 on the one hand, the inlet of the compressor 10 and the outlet of the gas heater 16 on the other hand for smoothing the transfer of the refrigerant from the refrigerant trap 18 to the refrigerant circuit to avoid a sudden introduction of the refrigerant into the refrigerant circuit.

[0170] The control of first on/off valve 22 and the second on/off valve 24 is the same as the one described with reference to the sixth embodiment.

[0171] The table below contains numerical values of the temperature, the pressure and the density of the refrigerant inside the refrigerant trap 18, for the embodiments illustrated in FIG 7 to FIG 11, wherein at a time interval before the first operational stage of the heat pump laundry dryer the first on/off valve 22 is open and the second on/off valve 24 is closed, considering that the refrigerant within the refrigerant trap 18 is in equilibrium with the refrigerant at the connection section between the refrigerant circuit and the refrigerant trap 18 and the refrigerant trap has a volume of 1 m^3.

embodiment:	FIG 7	FIG 8	FIG 9	FIG 10	FIG 11
on/off valve 22:	open	open	open	open	open
on/off valve 24:	closed	closed	closed	closed	closed
temperature (°C):	20	20	5	20	45
pressure (bar):	75	75	40	75	75
density (kg/m^3):	819	819	505	819	209

[0172] Then, at the first operational stage, the refrigerant trap 18 is fluidly disconnected from the refrigerant circuit and a certain amount of refrigerant is retained inside the refrigerant trap 18 till the second operational stage.

[0173] The next table contains the numerical values of temperature, pressure and density of the refrigerant within the refrigerant circuit when the refrigerant trap 18 is fluidly disconnected from the refrigerant circuit, and considering the refrigerant temperature, pressure and density at the connection section between the refrigerant circuit and the refrigerant trap 18. In particular, as regards the embodiments illustrated in FIG 7 to FIG 11, the first on/off valve 22 is closed and the second on/off valve 24 is closed, so that the connection section between the refrigerant circuit and the refrigerant trap 18 is substantially close to the second on/off valve 24.

embodiment:	FIG 7	FIG 8	FIG 9	FIG 10	FIG 11
on/off valve 22:	closed	closed	closed	closed	closed
on/off valve 24:	closed	closed	closed	closed	closed
temperature (°C):	40	90	40	18	30

(continued)

embodiment:	FIG 7	FIG 8	FIG 9	FIG 10	FIG 11
pressure (bar):	55	60	55	55	55
density (kg/m^3):	130	105	130	181	145

[0174] The next table contains the numerical values of the density net result for the embodiments illustrated in FIG 7 to FIG 11, once the second valve on/off valve 24 is open and the refrigerant within the refrigerant trap 18 is in equilibrium with the refrigerant at the connection section between the refrigerant circuit and the refrigerant trap 18.

embodiment:	FIG 7	FIG 8	FIG 9	FIG 10	FIG 11
density net result (kg/m^3):	689	714	375	637	64

[0175] As it is evident, after the opening of the second on/off valve 24, the high density refrigerant inside the trap 18 is made available to the refrigerant circuit, thereby increasing the density of the whole refrigerant flowing along the refrigerant circuit. Therefore the refrigerant trap 18 provides an extra amount of refrigerant to promote and/or support the totally-supercritical cycle during the changing working conditions of the heat pump laundry dryer.

[0176] Comparing the tables above, the greater the difference between the densities is, the smaller is the dimension of the refrigerant trap 18.

[0177] It is to be noted that in the above examples and tables, the second operational stage occurs during the transient trans-critical phase and the extra amount of refrigerant is made available to the low pressure side.

[0178] However, in alternative or in addition, the second operational stage can occur during the totally supercritical stage and the extra amount of refrigerant is made available to the low pressure side and/or to the high pressure side of the refrigerant circuit.

[0179] FIG 12 illustrates a schematic diagram of a heat pump laundry refrigerant according to an eleventh embodiment of the present invention. In the eleventh embodiment the series of the first on/off valve 22, the refrigerant trap 18 and the second on/off valve 24 is connected parallel to the series of the expansion means 14 and the gas heater 16.

[0180] The eleventh embodiment of the present invention includes an internal heat exchanger 30. The internal heat exchanger 30 comprises a high pressure portion 32 and a low pressure portion 34. The high pressure portion 32 of the internal heat exchanger 30 is interconnected between the outlet of the gas cooler 12 and the inlet of the expansion means 14. The low pressure portion 34 of the internal heat exchanger 30 is interconnected between the outlet of the evaporator 16 and the inlet of the compressor 10.

[0181] The eleventh embodiment presents several possible benefits. The presence of the internal heat exchanger 30 allows a better management of the refrigerant superheating during the transient trans-critical phase and it leads to an increasing of the cooling effect when the refrigerant is released from the refrigerant trap 18.

[0182] In figure 12 the refrigerant trap 18 is connected downstream of the high pressure portion 32 internal heat exchanger 30 and upstream of low pressure portion 34 of the high pressure portion 32. Alternatively, the refrigerant trap 18 might be connected also upstream of or downstream of the internal heat exchanger 30 both on the high pressure side and low pressure side.

[0183] Downstream of the high pressure portion 32 of the internal heat exchanger 30 the density of the refrigerant is higher due to the cooling effect of said internal heat exchanger 30.

[0184] In another embodiment, preferably, the refrigerant trap 18 can be connected downstream of the high pressure portion 32 of the internal heat exchanger 30, as in FIG 12, and downstream of the low pressure portion 34 of the internal heat exchanger 30, i.e. between the outlet of the low pressure portion 34 and the inlet of the compressor 10.

[0185] In order to avoid possible refrigerant liquid droplets formation (during the transitory trans-critical conditions), the embodiment of FIG 12 is advantageous, since the high pressure portion 32 of the internal heat exchanger 30 vaporizes and superheats the refrigerant flowing through the low pressure portion 32 of the internal heat exchanger 30 before the latter enters the compressor 10.

[0186] Preferably, a throttling device 28 can provided downstream of the second on/off valve 24 for smoothing the transfer of the refrigerant from the refrigerant trap 18 to the refrigerant circuit.

[0187] The control of first on/off valve 22 and the second on/off valve 24 is the same as the one described with reference to the sixth embodiment.

[0188] Different arrangements of the refrigerant trap 18 and the valve means might be conceived, mainly if the refrigerant is to be released at different conditions. For example, in two different moments of the cycle according to FIG 13 or in different moments and different places according to FIG 14.

[0189] FIG 13 illustrates a schematic diagram of a heat pump laundry dryer according to a twelfth embodiment of the present invention. In the twelfth embodiment a series is interconnected between the outlet of the gas cooler 12 and the inlet of the compressor. Said series includes the first on/off valve 22, the second on/off valve 24, a third on/off valve 26, the refrigerant trap 18 and a further refrigerant trap 38.

[0190] The first on/off valve 22, the refrigerant trap 18 and the second on/off valve 24 are connected in series. The further refrigerant trap 38 and the third on/off valve 26 are also connected in series. The further refrigerant trap 38 and the third on/off valve 26 are parallel to the refrigerant trap 18 and the second on/off valve 24.

[0191] Preferably, a throttling device 28 can be arranged downstream the second on/off valve 24 and/or the third on/off valve 26 for smoothing the transfer of the refrigerant from the refrigerant trap 18 to the refrigerant.

[0192] The control of the first on/off valve 22 and the second on/off valve 24 is the same as the one described with reference to the sixth embodiment. But in the specific case the first on/off valve 22 fluidly connects also the further refrigerant trap 38 to the refrigerant circuit, so that a certain amount of refrigerant is retained in the refrigerant trap 18 and in the further refrigerant trap 38. The refrigerant contained in the refrigerant trap 18 and in the further refrigerant trap 38 can be made available to the refrigerant circuit in different moments, for example at a second operational stage of the heat pump laundry dryer via the second on/off valve 24 and at a third operational stage of the heat pump laundry dryer via the third on/off valve 26, wherein the third operational stage id subsequent to the second operational stage.

[0193] FIG 14 illustrates a schematic diagram of a heat pump laundry refrigerant according to a thirteenth embodiment of the present invention. In the thirteenth embodiment a further series is interconnected between the outlet of the gas cooler 12 and the inlet of the compressor. Said further series includes the first on/off valve 22, the refrigerant trap 18 and the third on/off valve 26. The second on/off valve 24 is interconnected between the refrigerant trap 18 and the outlet of the compressor 10.

[0194] In this way, it is possible to make the refrigerant contained in the trap 18 available to the refrigerant circuit in different sections of the refrigerant circuit via the opening of the on/off valve 24 and 26

[0195] The next table contains the numerical values of the temperature, the pressure and the density of the refrigerant for the embodiment illustrated in FIG 14.

embodiment:	FIG 14	FIG 14	FIG 14
on/off valve 22:	open	closed	closed
on/off valve 24:	closed	closed	closed
on/off valve 26:	closed	closed	closed
temperature (°C):	20	90	70
pressure (bar):	75	60	45
density (kg/m^3):	819	105	82

[0196] Wherein the 819 kg/m^3 value refers to the density of the refrigerant at a time interval before the first operational stage of the heat pump laundry dryer with the on/off valve 22 open and considering the refrigerant within the refrigerant trap 18 in equilibrium with the refrigerant at the connection section between the refrigerant circuit and the refrigerant trap 18, the refrigerant trap having a volume of 1 m^3. The 105 kg/m^3 value refers to the density of the refrigerant at the refrigerant circuit section, which is close (in proximity) to the second on/off valve 24 when the refrigerant trap 18 is fluidly disconnected from the refrigerant circuit and the 82 kg/m^3 value refers to the density of the refrigerant at the refrigerant circuit section, which is close (in proximity) to the third on/off valve 26 when the refrigerant trap 18 is fluidly disconnected from the refrigerant circuit.

[0197] The density net result for the embodiment illustrated in FIG 14 is 714 kg/m^3 when the second on/off valve 24 is open. Hence an extra refrigerant amount is available to the refrigerant circuit when at the second operational stage of the heat pump laundry dryer the second on/off valve 24 is open, and considering that the refrigerant within the refrigerant trap 18 is in equilibrium with the refrigerant at the connection section between the refrigerant circuit and the refrigerant trap 18.

[0198] The density net result for the embodiment illustrated in FIG 14 is 737 kg/m^3 when the third on/off valve 26 is open. Hence an extra refrigerant amount is available when at the second operational stage of the heat pump laundry dryer the third on/off valve 26 is open, and considering that the refrigerant within the refrigerant trap 18 is in equilibrium with the refrigerant at the connection section between the refrigerant circuit and the refrigerant trap 18.

[0199] As it is evident, after the opening of the second on/off valve 24 or the third on/off valve 26, the high density refrigerant inside the trap 18 is made available to the refrigerant circuit, thereby increasing the density of the whole refrigerant flowing along the refrigerant circuit. The refrigerant trap 18 provides an excess of refrigerant amount to promote and /or support the totally-supercritical cycle during the changing working conditions of the heat pump laundry dryer.

[0200] A throttling device 28 can be provided downstream of the second on/off valve 24 and/or the third on/off valve 26 for smoothing the transfer of the refrigerant from the refrigerant trap 18 to the refrigerant circuit.

[0201] FIG 15 illustrates a schematic diagram of a heat pump laundry dryer according to a fourteenth embodiment of the present invention. In the fourteenth embodiment the refrigerant trap 18 is connected via the on/off valve 24 to the outlet of the gas cooler 12.

[0202] The control unit opens the on/off valve 24 before the first operational stage of the heat pump laundry dryer, it closes the on/off valve 24 at the first operational stage so as to retain a certain amount of refrigerant inside the refrigerant trap 18 and then the control unit opens the on/off valve 24 at a second operational stage of the heat pump laundry dryer, thereby making the refrigerant available again to the refrigerant circuit.

[0203] The table below illustrates the possible constellations.

embodiment:	FIG 15
on/off valve 24:	open
temperature (°C):	20
pressure (bar):	75
density (kg/m^3):	819
on/off valve 24:	closed
on/off valve 24:	open
temperature (°C):	30
pressure (bar):	100
density (kg/m^3):	771

[0204] Wherein the 819 kg/m^3 value refers to the density of the refrigerant at a time interval before the first operational stage of the heat pump laundry dryer with the on/off valve 22 open and considering the refrigerant within the refrigerant trap 18 in equilibrium with the refrigerant at the connection section between the refrigerant circuit and the refrigerant trap 18, the refrigerant trap having a volume of 1 m^3 and wherein the 771 kg/m^3 value refers to the density of the refrigerant at the refrigerant circuit section close (in proximity) to the second on/off valve 24 when the refrigerant trap 18 is fluidly disconnected from the refrigerant circuit.

[0205] The density net result for the embodiment illustrated in FIG 15 is 47 kg/m^3 when the on/off valve 24 is opened. Hence an extra refrigerant amount is available when at a second operational stage of the heat pump laundry dryer, the on/off valve 24 is opened, and considering that the refrigerant within the refrigerant trap 18 is in equilibrium with the refrigerant at the connection section between the refrigerant circuit and the refrigerant trap 18.

[0206] As it is evident, after the opening of the on/off valve 24, the high density refrigerant inside the trap 18 is made available to the refrigerant circuit, thereby increasing the density of the whole refrigerant flowing along the refrigerant circuit. The refrigerant trap 18 provides an excess of refrigerant amount to promote and/or support the totally-supercritical cycle during the changing working conditions of the heat pump laundry dryer.

[0207] In an alternative embodiment, the refrigerant trap 18 is connected via the on/off valve 24 to the inlet of the gas cooler 12.

[0208] In order to avoid possible heat losses from the refrigerant in the refrigerant trap 18, the latter ca be thermally insulated.

[0209] The release of the refrigerant from the refrigerant trap 18 and its accumulation in the refrigerant trap 18 should be managed by opening and closing the on/off valves 22, 24 and 26 at the inlet and at the outlet of the refrigerant trap 18. The control logic of the on/off valves 22, 24 and 26 considers switching criteria based on different parameters, such as refrigerant temperature and/or pressure of the refrigerant circuit upstream and/or downstream of the accumulation volume. There are temperature and/or pressure sensors provided at the key points of the refrigerant circuit. The accumulation and releasing management bases on the cycle time as well, by opening and closing the on/off valves 22, 24 and 26 at fixed temporal references.

[0210] If the refrigerant trap 18 is connected to pipes of the refrigerant circuit working at different pressure levels, the throttling device 28, e.g. a capillary tube, may be used to release the refrigerant smoothly. In FIG 7, 10, 11, 12, 12 and 14 the throttling device 28 might be included or not.

[0211] In order to obtain an appropriate amount of refrigerant in the refrigerant circuit and the proper superheating at the inlet of the compressor 10, during the transient trans-critical phase, the on/off valves 22, 24 and 26, which are in a certain sense also expansion means, may be opened and closed or according to a pulsing width modulation criteria, so that an intensive decreasing of the refrigerant pressure is avoided and the formation of refrigerant droplets is prevented.

[0212] The proper location of the refrigerant trap 18 can provide further advantages. For example, in the case of FIG 7, if the refrigerant trap 18 is located in a the drying airflow downstream the drying chamber and preferably downstream of the evaporator/gas heater 16, when the on/off valve 22 is open during the trapping phase, then the temperature of the refrigerant may be significantly lower than temperature at the gas cooler 12. This thus results in a higher density.

[0213] In practise during the movement of the refrigerant from the refrigerant circuit to the refrigerant trap 18, the drying air leaving the drying chamber or after passing through the evaporator/gas heater 16 can cool the refrigerant, since the temperature of the drying air is lower than the temperature of the refrigerant. Once the refrigerant is stored in the refrigerant trap 18, (when all the on/off valves 22, 24 and/or 26 are closed), then an additional cooling does not lead to higher density since the volume of the refrigerant trap 18 is fixed.

[0214] However, as long as the temperature of the refrigerant inside the refrigerant trap 18 is higher than the drying air, the refrigerant trap 18 can preheat the drying air before the latter enters the gas cooler 12.

[0215] Further, reflector/baffle/valve means may be provided to bypass the refrigerant trap 18, when the temperature of the drying air is higher than the temperature of the refrigerant inside the refrigerant trap 18.

[0216] Although illustrative embodiments of the present invention have been described herein with reference to the accompanying drawings, it is to be understood that the present invention is not limited to that precise embodiments, and that various other changes and modifications may be affected therein by one skilled in the art without departing from the scope or spirit of the invention. All such changes and modifications are intended to be included within the scope of the invention as defined by the appended claims.

List of reference numerals

[0217]

10	compressor
12	condenser
14	expansion means
16	evaporator
18	refrigerant trap
20	on/off valve
22	first on/off valve
24	second on/off valve
26	third on/off valve
28	throttling device
30	internal heat exchanger
32	high pressure portion
34	low pressure portion
38	further refrigerant trap
p	pressure
p_h	pressure in the high pressure side

p_l pressure in the low pressure side

t time

Claims

1. A laundry dryer with heat pump system, wherein:

- the heat pump system comprises a closed refrigerant circuit for a refrigerant,
- the refrigerant circuit includes at least one compressor (10), at least one gas cooler (12), at least one expansion means (14) and at least one evaporator/gas heater (16),
- the refrigerant circuit is thermally coupled to a drying air circuit of the laundry dryer by the gas cooler (12) and the evaporator/gas heater (16),
- the gas cooler (12) is a heat exchanger and provided for heating up the drying air stream and cooling down the refrigerant, and
- the evaporator/gas heater (16) is a heat exchanger and provided for dehumidifying the drying air and heating up the refrigerant,
- the refrigerant circuit comprises a low pressure side between the outlet of the expansion means (14) and the inlet of the compressor (10),
- the refrigerant circuit comprises a high pressure side between the outlet of the compressor (10) and the inlet of the inlet of expansion means (14),
- wherein the refrigerant operates at supercritical conditions in the low pressure side of the refrigerant circuit after a transient sub-critical phase

characterized in, that
the laundry dryer comprises at least one refrigerant trap (18) fluidly connected or connectable to at least one part of the refrigerant circuit and valve means (20, 22, 24, 26) to selectively connect and/or disconnect the refrigerant trap (18) to said least one part of the refrigerant circuit

2. The laundry dryer according to claim 1, wherein the laundry dryer comprises a controller adapted to actuate the valve means (20, 22, 24, 26) so as to fluidly disconnect the refrigerant trap (18) from the refrigerant circuit at a first operational stage of the laundry dryer, and to fluidly connect the refrigerant trap (18) to at least one part of the refrigerant circuit at a second operational stage of the laundry dryer, wherein the second operational stage is subsequent to the first operational stage.

3. The laundry dryer according to claim 2, wherein at least one sensor is provided to monitor at least one physical quantity associated to the refrigerant circuit and/or to the drying air and the controller is adapted to actuate the valve means (22, 24, 26) in response to the time progression of said physical quantity.

4. The laundry dryer according to claim 3, wherein at least one sensor is provided to monitor the temperature/pressure of the refrigerant circuit and, preferably, the at least one the physical quantity is one of the following:

- the refrigerant pressure at the high pressure side of the refrigerant circuit,
- the refrigerant pressure and/or temperature at the outlet of the gas cooler,
- the refrigerant pressure at the low pressure side of the heat pump circuit,
- the refrigerant pressure and/or temperature at the outlet of the gas heater.

5. The laundry dryer according to claim 3, wherein at least one sensor is provided to monitor the temperature/humidity of the drying air and, preferably, the at least one the physical quantity is the temperature of the drying air at the outlet of the drying chamber.

6. The laundry dryer according to claim 2, wherein the controller is adapted to actuate the valve means (22, 24, 26) to fluidly disconnect the refrigerant trap (18) from the refrigerant circuit at the first operational stage of the laundry dryer in response to the time progression of the refrigerant pressure at the high pressure side of the refrigerant circuit and/or the refrigerant pressure at the outlet of the gas cooler (12) and/or the refrigerant temperature at the outlet of the gas cooler (12).

7. The laundry dryer according to claim 2, wherein the controller is adapted to actuate the valve means (22, 24, 26) to fluidly connect the refrigerant trap (18) to the refrigerant circuit at the second operational stage of the laundry dryer in response to the time progression of the refrigerant pressure at the low pressure side of the refrigerant circuit and/or the refrigerant pressure at the outlet of the gas heater (16) and/or the refrigerant temperature at the outlet of the gas heater (16).

8. The laundry dryer according to claim 2, wherein the controller is adapted to actuate the valve means (22, 24, 26) to fluidly disconnect the refrigerant trap (18) from the refrigerant circuit at the first operational stage of the heat pump laundry dryer and to fluidly connect the refrigerant trap (18) to at least a part of the refrigerant circuit at the second operational stage of the heat pump laundry dryer in response to the time progression of the temperature of the drying air at the outlet of the drying chamber.

9. The laundry dryer according to claim 2, wherein the first operational stage occurs before the compressor (10) starts to operate and the second operational stage occurs while the compressor is running.

10. The laundry dryer according to claim 2, wherein the first operational stage occurs while the compressor is running.

11. The laundry dryer according to claim 10, wherein the first operational stage occurs during the transient sub-critical phase.

12. The laundry dryer according to any one of the preceding claims 9-11, wherein the second operational stage occurs during the transient sub-critical phase.

13. The laundry dryer according to any one of the preceding claims 9-11, wherein the second operational stage occurs at supercritical conditions.

14. The laundry dryer according to any one of the preceding claims 2 to 13, wherein at the second operational stage of the heat pump laundry dryer, the refrigerant trap is connected to at least a portion of the low pressure side of the refrigerant circuit.

15. The laundry dryer according to any one of the preceding claims 2 to 14, wherein the control unit is adapted to actuate the valve means (22, 24, 26) so as to fluidly connect the refrigerant trap (18) to the at least one part of the refrigerant circuit at a time interval which precedes the first operational stage of the heat pump laundry dryer so that a certain amount of refrigerant can enter into the refrigerant trap.

16. The laundry dryer according to any one of the preceding claims 2 to 15, wherein the valve means (22, 24, 26) comprise an on/off valve (24) connecting the refrigerant trap (18) to a part of the refrigerant circuit, and the controller closes the on/off valve (24) at a first operational stage of the laundry dryer, and opens the on/off valve (24) at a second operational stage of the laundry dryer, wherein the second operational stage is subsequent to the first operational stage.

17. The laundry dryer according to any one of the preceding claims 2 to 16, wherein said part of the refrigerant circuit is located upstream of or downstream of the gas cooler (12).

18. The laundry dryer according to any one of the preceding claims 2 to 17, wherein the valve means (20, 22, 24, 26) comprise a first on/off valve (22) connecting the refrigerant trap (18) to a first part of the refrigerant circuit and a second on/off valve (24) connecting the refrigerant trap (18) to a second part of the refrigerant circuit and wherein the controller closes the first on/off valve (22) at a first operational stage of the laundry dryer, and opens the second on/off valve (24) at a second operational stage of the laundry dryer, wherein the second operational stage is subsequent to the first operational stage.

19. The laundry dryer according to claim 18, wherein the first part of the refrigerant circuit is the outlet of the gas cooler (12) and the second part of the refrigerant circuit is outlet of the gas heater (12).

20. The laundry dryer according to any one of the preceding claims, wherein the first part of the refrigerant circuit is the outlet of the gas cooler (12) and the second part of the refrigerant circuit is inlet of the gas cooler (16).

21. The laundry dryer according to any one of the preceding claims , wherein the first part of the refrigerant circuit is the inlet of the gas heater (16) and the second part of the refrigerant circuit is outlet of the gas heater (16).

22. The laundry dryer according to any one of the preceding claims, wherein the first part of the refrigerant circuit is the outlet of the gas cooler (12) and the second part of the refrigerant circuit is inlet of the gas heater (16).

23. The laundry dryer according to any one of the preceding claims, wherein the first part of the refrigerant circuit is the inlet of the gas cooler (12) and the second part of the refrigerant circuit is outlet of the gas heater (16).

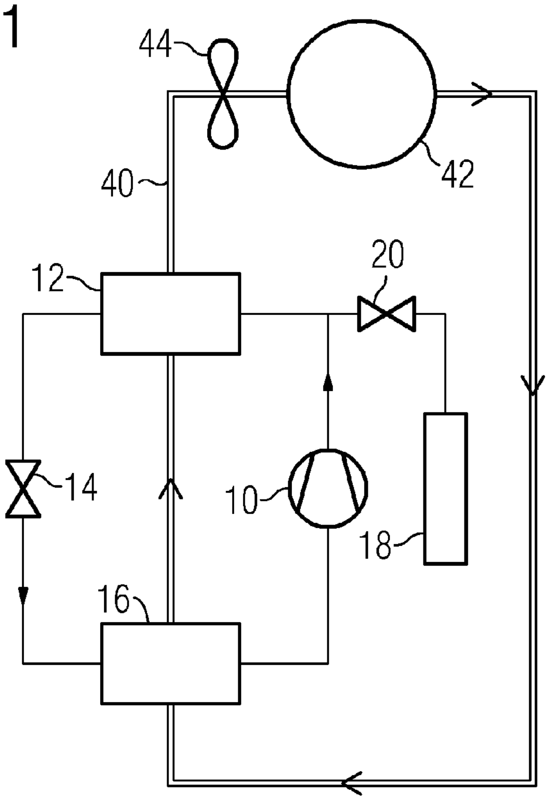
24. The laundry dryer according to any one of the preceding claims 16 to 23, wherein a throttling device (28) is arranged between the second on/off valve (24) and the second part of the refrigerant circuit.

25. The laundry dryer according to any one of the preceding claims 2 to 24, wherein the refrigerant circuit comprises an internal heat exchanger (30) for transferring heat from the high pressure side to the low pressure side of the refrigerant circuit, the internal heat exchanger (30) comprises a high pressure portion (32) interconnected between the outlet of the condenser (12) and the inlet of the expansion means (14) and a low pressure portion (34) interconnected between the outlet of the gas heater (16) and the inlet of the compressor (10).

26. The laundry dryer according to any one of the preceding claims 25, wherein the first part of the refrigerant circuit is located upstream or downstream of the high pressure portion (32) of the internal heat exchanger (30), and wherein the second part of the refrigerant circuit is located upstream or downstream of the low pressure portion (34) of the internal heat exchanger (30).

27. The laundry dryer according to any one of the preceding claims, wherein the refrigerant of the heat pump system is carbon dioxide

FIG 1


44
42
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12
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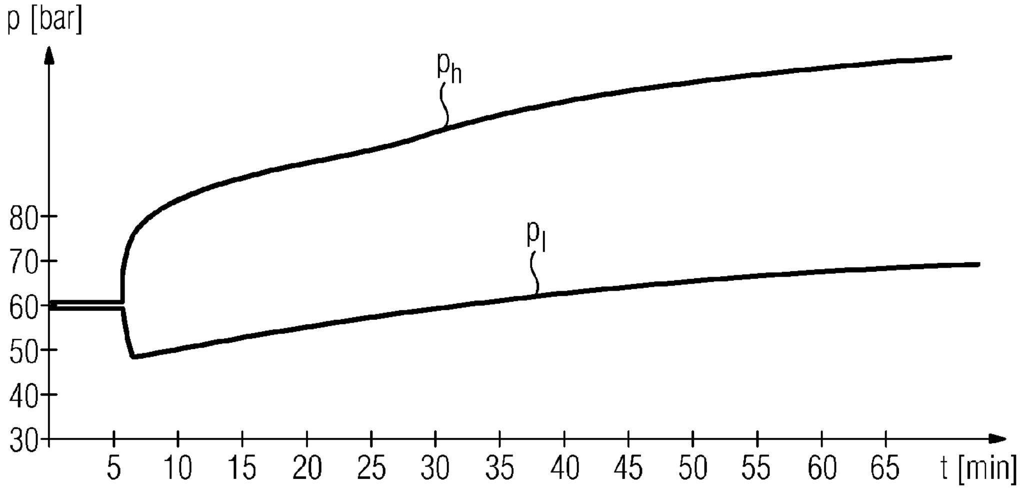
10
18
16

FIG 2


p [bar]
p_h
p_l
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65
t [min]

FIG 3

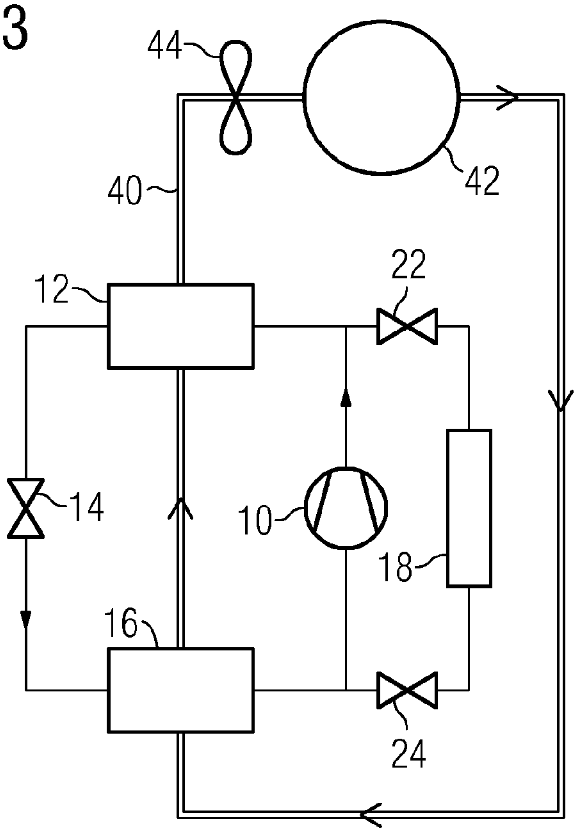


FIG 4

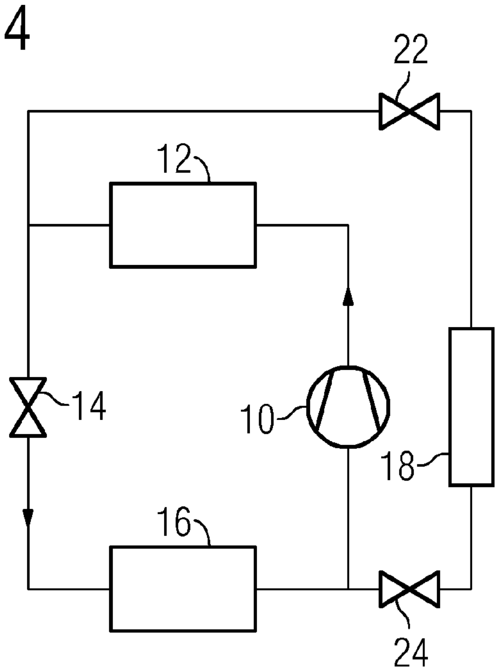


FIG 5

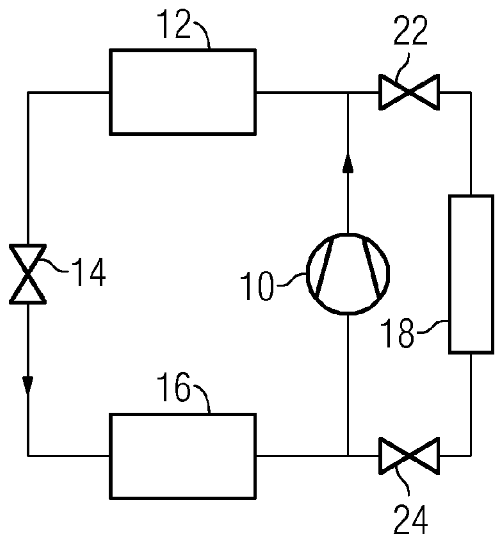


FIG 6

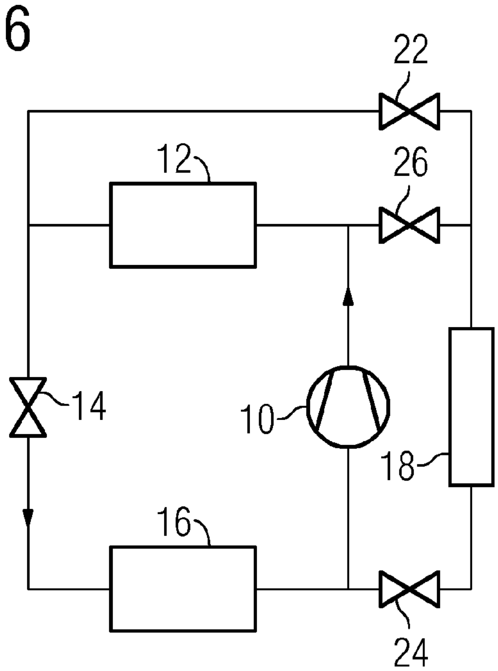


FIG 7

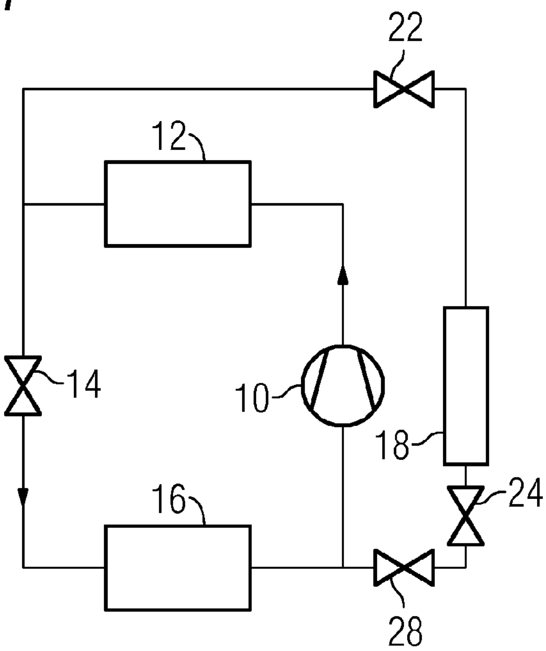


FIG 8

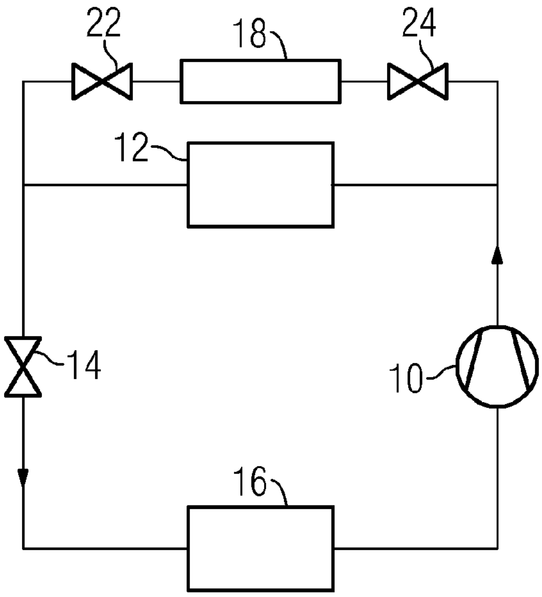


FIG 9

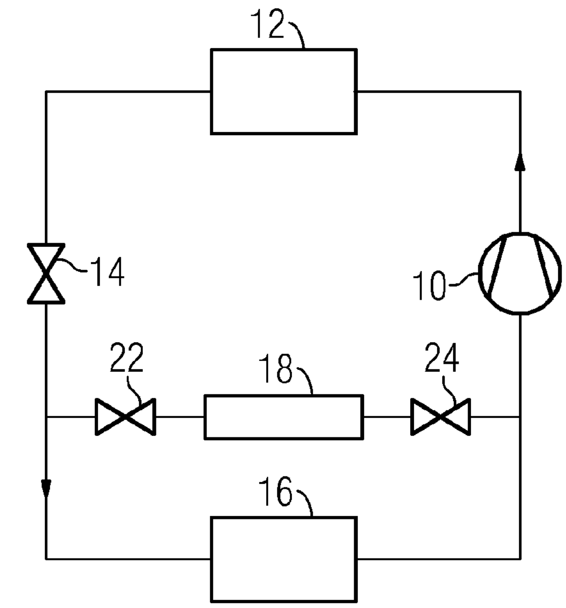


FIG 10

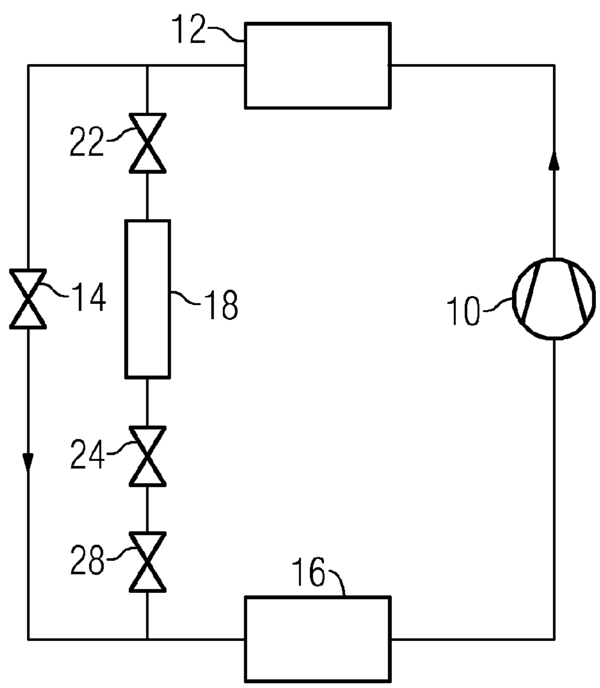


FIG 11

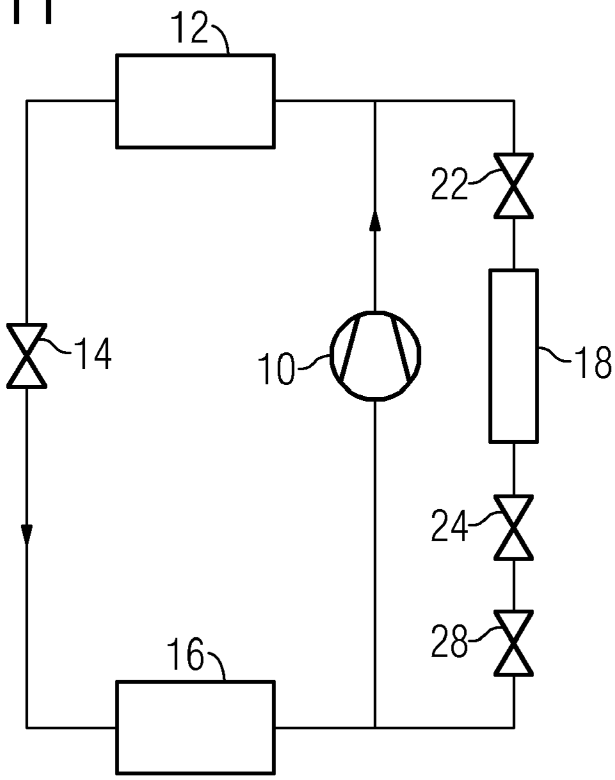


FIG 12

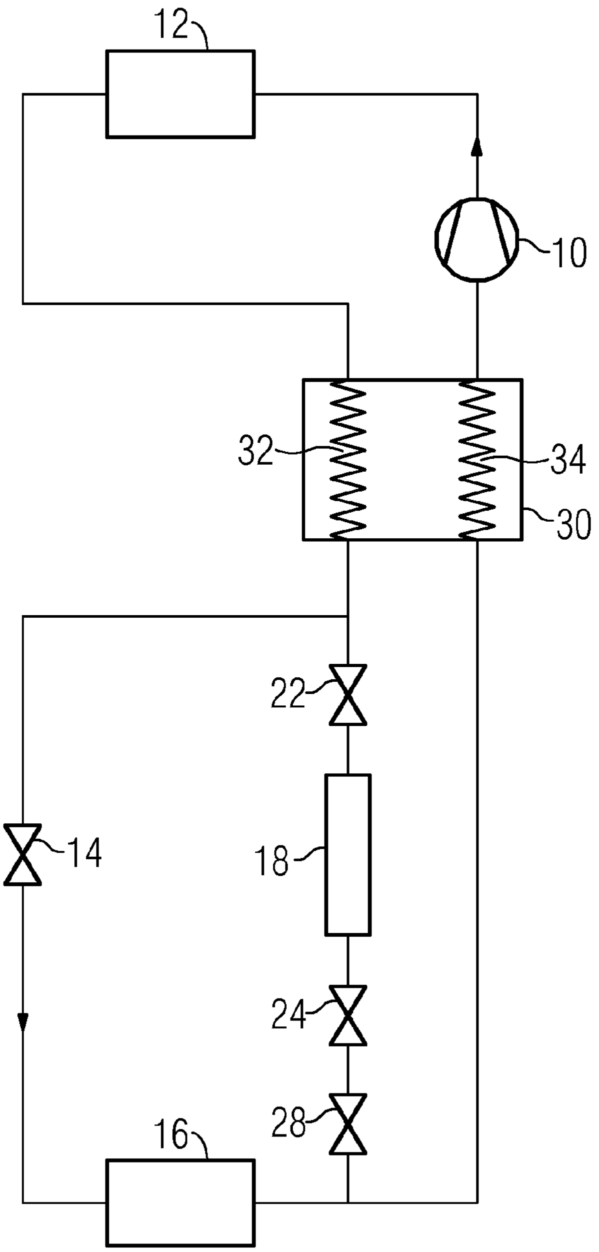


FIG 13

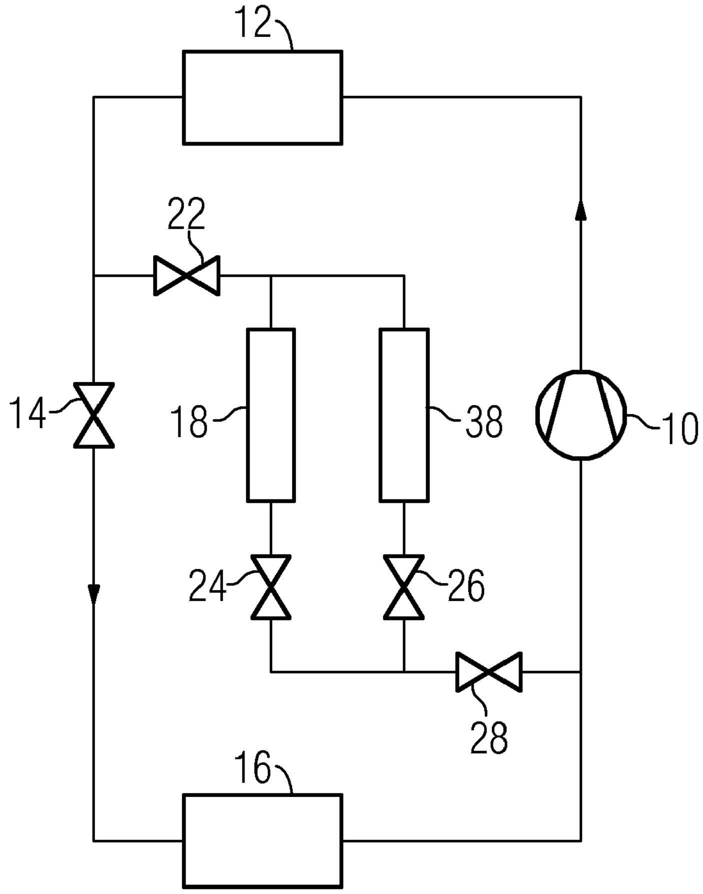


FIG 14

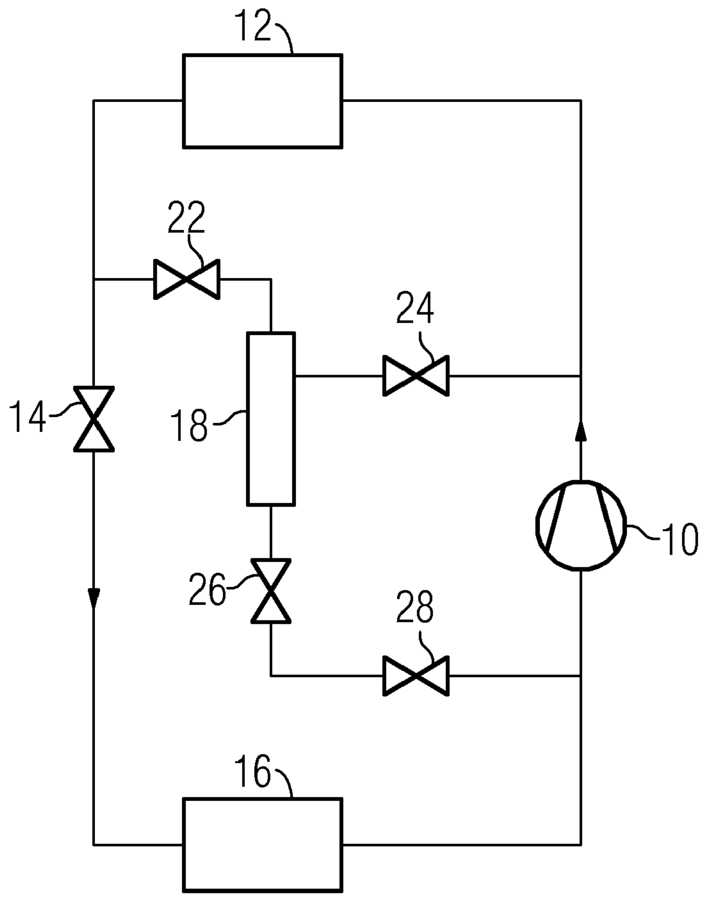
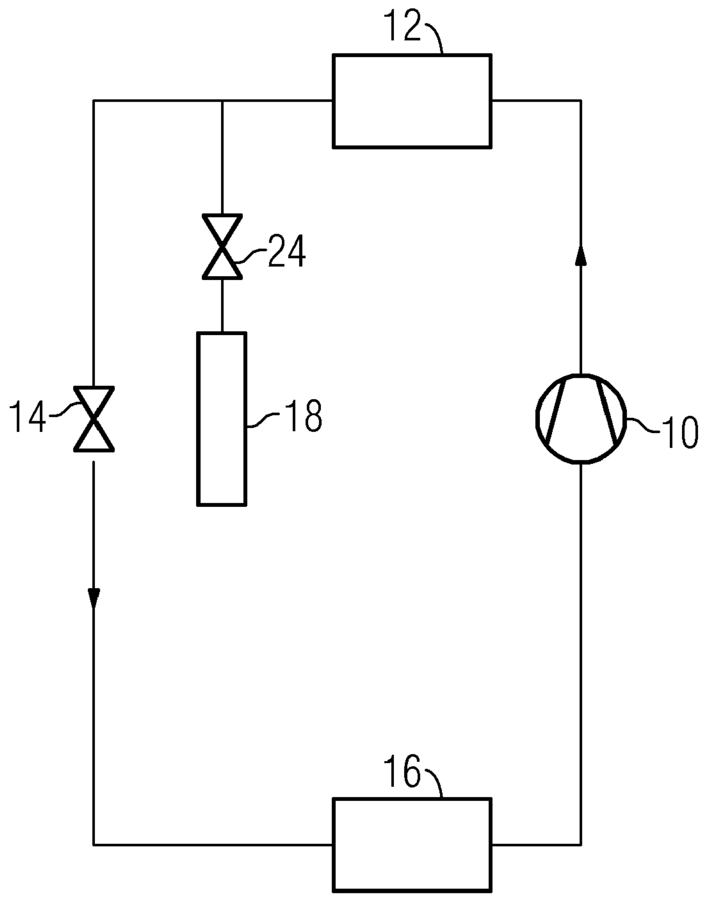


FIG 15



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EUROPEAN SEARCH REPORT

Application Number
EP 11 16 7567

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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D06F

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	27 October 2011	Hannam, Martin

CATEGORY OF CITED DOCUMENTS

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