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(54) MACHINE FOR DRYING LAUNDRY INCLUDING A HEAT PUMP UNIT AND OPERATIONAL METHOD THEREOF

(57) A machine (1) for drying laundry comprises a chamber (2) configured to accommodate textile articles (3), a drying conduit, a blower (5) configured to move a drying airflow along the drying conduit and a heat pump unit (7) configured to exchange heat with the drying conduit by means of the circulation of a working fluid subjected to phase changes. The machine (1) further comprises heating means configured to heat the drying airflow up and included in the heat pump unit (7). The heating means comprises a primary condenser (8p) and at least a secondary condenser (8s), the secondary condenser (8s) being connected in series to the primary condenser (8p). The heat pump unit (7) includes an expansion device (9p), interposed between the primary condenser (8p) and the secondary condenser (8s). The working fluid circulating in the heat pump unit (7) is cooled through the primary condenser (8p), in order to bring the working fluid to the state of a subcooled liquid. Then the pressure (p) of the working fluid is lowered through the expansion device (9p), in order to bring the working fluid the state of a mixture of vapour and liquid. Finally the working fluid is cooled through the secondary condenser (8s), in order to bring the working fluid to the state of a subcooled liquid again.

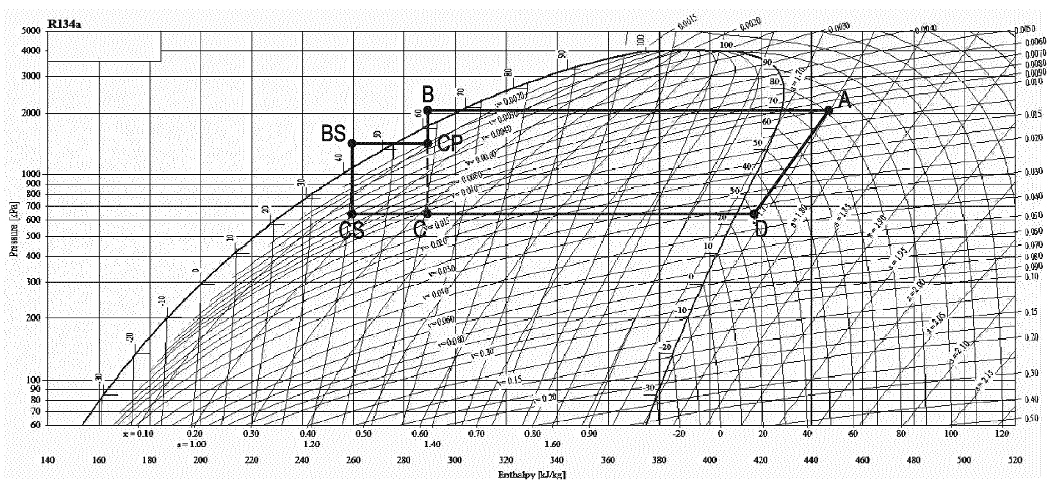

FIG.3B

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Description

[0001] The present disclosure relates to a machine for drying laundry, according to the preamble of claim 1. In particular, the machine that is the subject of the following description can be a laundry dryer or a laundry washer-dryer and includes a heat pump unit. The present disclosure moreover relates to an operational method for the heat pump unit.

[0002] Tumble dryers for clothes including a heat pump unit are spreading more and more because of the significant benefits made available by such an architecture, especially because of the high energy efficiency. In particular, the provision of a heat pump unit allows the condenser of the heat pump unit to be used for heating the laundry airflow up in the tumble dryer. Indeed the condenser may replace the electric resistance traditionally used for heating the laundry airflow up. If an electric resistance is nevertheless included in the tumble dryer, in spite of the provision of the heat pump unit, the electric resistance may be used only in the first stage of the drying process, in order to compensate the slow start of the heat pump unit and consequently to shorten the overall duration of the drying process.

[0003] In order to get further improvements in the energy efficiency of a tumble dryer for clothes having a heat pump unit, several technical solutions have been developed.

[0004] In a first known technical solution, the heat pump unit is equipped with a variable speed compressor. Such kind of compressor is instead more efficient than a fixed speed compressor. However the use of a variable speed compressor increases significantly the complexity of the control of the tumble dryer, and the production cost as well.

[0005] In a second known technical solution, the heat pump unit includes a two-stage compression circuit, that reduces the superheating of the vapour and then the energy consumptions of the heat pump unit. However the two-stage compression circuit requires a quite complex mechanics, and then has a really high production cost. Moreover the two-stage compression circuit, due to the quite complex mechanics, isn't able to guarantee the appropriate reliability throughout the whole lifetime of the tumble dryer.

[0006] A tumble dryer including a heat pump unit is disclosed in European patent EP2212463B1, revoked in opposition. The heat pump unit comprises an evaporator for cooling the tumble dryer's process airflow by evaporating a refrigerant, a condenser for heating the tumble dryer's process airflow by liquefying the refrigerant, a compressor for compressing the refrigerant upon exiting the evaporator and a throttle for decompressing the refrigerant upon exiting the condenser. European patent EP2212463B1 provides a third known technical solution intended to improve the energy efficiency of a tumble dryer having a heat pump unit. Indeed a temperature sensor, connected to the control unit of the dryer, is disposed adjacent to the condenser in order to measure a temperature of the refrigerant in the condenser. Since such temperature is an effective indication of the thermal load imposed on the heat pump unit, it allows an efficient driving of some components of the tumble dryer (for instance the blower configured to cool the heat pump unit down may be activated only when necessary, i.e. only when the temperature sensor adjacent to the condenser detects a temperature of the refrigerant higher than a predetermined threshold). However the technical solution disclosed in the European patent EP2212463B1 has the apparent drawback that the energy efficiency improvement obtained is absolutely poor taking into consideration the complexity in the control of the tumble dryer due to the use of the temperature sensor adjacent to the condenser.

[0007] In view of acknowledged prior art, a first aim of the technical solution described below is the improvement of the energy efficiency of a tumble dryer for clothes having a heat pump unit, particularly in comparison with the alternative technical solution disclosed in European patent EP2212463B1. A second aim is the reduction of the production cost of a tumble dryer for clothes having a heat pump unit, particularly in comparison with the alternative technical solutions provided with a variable speed compressor or with a two-stage compression circuit. A third aim is the increase in the reliability of a tumble dryer for clothes having a heat pump unit.

[0008] These aims and further remarkable aims are achieved by means of the present invention as defined in the following aspects.

[0009] A first aspect of the disclosure relates to a machine (1) for drying laundry, comprising:

i) a chamber (2) configured to accommodate textile articles (3);
ii) a drying conduit developing from a first end (4) to a second end (6), the first end (4) and the second end (6) being both connected to said chamber (2);
iii) a blower (5) configured to move a drying airflow along the drying conduit;
iv) a heat pump unit (7) configured to exchange heat with said drying conduit by means of the circulation of a working fluid subjected to phase changes and
v) heating means configured to heat the drying airflow up, said heating means being included in the heat pump unit (7),

characterised in that said heating means comprises a primary condenser (8p) and at least a secondary condenser (8s), said secondary condenser (8s) being connected in series to said primary condenser (8p) and in that said heat pump unit (7) includes an expansion device (9p), in particular an expansion valve, interposed between said primary condenser (8p) and said secondary condenser (8s).

[0010] A second aspect of the disclosure, depending on the first aspect of the disclosure, relates to a machine

(1), wherein said primary condenser (8p) is configured to receive said working fluid as a superheated vapour and to release said working fluid as a subcooled liquid.

[0011] A third aspect of the disclosure, depending on the second aspect of the disclosure, relates to a machine (1), wherein the expansion device (9p) interposed between said primary condenser (8p) and said secondary condenser (8s) is configured to release said working fluid as a mixture of vapour and liquid, the fraction (x) of the vapour in the mixture being lower than 0.3, preferably lower than 0.2, more preferably around 0.1.

[0012] A fourth aspect of the disclosure, depending on the third aspect of the disclosure, relates to a machine (1), wherein said secondary condenser (8s) is configured to release said working fluid as a subcooled liquid.

[0013] A fifth aspect of the disclosure, depending on the third aspect of the disclosure or on the fourth aspect of the disclosure, relates to a machine (1), wherein the expansion device (9p) interposed between said primary condenser (8p) and said secondary condenser (8s) is configured to cause a drop in the pressure (p) of said working fluid lower than 50%, preferably lower than 40%, more preferably lower than 35%.

[0014] A sixth aspect of the disclosure, depending on any aspect of the disclosure from the first aspect to the fifth aspect, relates to a machine (1), characterised in that said heating means comprises a plurality of secondary condensers (8s1-8sN), said secondary condensers (8s1-8sN) being all connected in series to said primary condenser (8p) and in that said heat pump unit (7) includes a plurality of expansion devices (9p1-9pN), in particular a plurality of expansion valves.

[0015] A seventh aspect of the disclosure, depending on the sixth aspect of the disclosure, relates to a machine (1), wherein one expansion device is positioned in said heat pump unit (7) immediately upstream to each of said secondary condensers (8s1-8sN).

[0016] An eighth aspect of the disclosure, depending on the seventh aspect of the disclosure, relates to a machine (1), wherein said secondary condensers (8s1-8sN) are configured to release said working fluid as a subcooled liquid.

[0017] A ninth aspect of the disclosure, depending on any aspect of the disclosure from the first aspect to the eighth aspect, relates to a machine (1), further comprising condensing means configured to extract moisture from the drying airflow, said condensing means being included in the heat pump unit (7) and comprising at least an evaporator (10), wherein said evaporator (10) is configured to receive said working fluid as a subcooled liquid and to release said working fluid as a superheated vapour.

[0018] A tenth aspect of the disclosure, depending on the fourth aspect of the disclosure and from the ninth aspect of the disclosure, relates to a machine (1), wherein said working fluid is a refrigerant fluid, in particular R134a, and wherein the pressure (p) of said working fluid in said primary condenser (8p) is more than twice the pressure (p) of said working fluid in said evaporator (10), preferably more than three times the pressure (p) of said working fluid in said evaporator (10), the pressure (p) of said working fluid in said primary condenser (8p) being in particular around 21 bar.

[0019] An eleventh aspect of the disclosure, depending on any aspect of the disclosure from the first aspect to the tenth aspect, relates to a machine (1), further comprising an electric resistance (5h) configured to heat the drying airflow up, said electric resistance (5h) being preferably positioned downstream to said heating means and upstream to said blower (5).

[0020] A twelfth aspect of the disclosure relates to an operational method for a heat pump unit (7) comprised in a machine (1) for drying laundry, wherein a working fluid subjected to phase changes is circulating in said heat pump unit (7) and wherein said heat pump unit (7) includes:

- a primary condenser (8p);
- at least a secondary condenser (8s), said secondary condenser (8s) being connected in series to said primary condenser (8p) and
- an expansion device (9p), in particular an expansion valve, interposed between said primary condenser (8p) and said secondary condenser (8s),

the operational method comprising the steps of:

A) cooling said working fluid through said primary condenser (8p), in order to bring said working fluid to the state of a subcooled liquid;
B) lowering the pressure (p) of said working fluid through said expansion device (9p), in order to bring said working fluid to the state of a mixture of vapour and liquid, the vapour being in a predetermined fraction (x) in said mixture and
C) cooling said working fluid through said secondary condenser (8s), in order to bring said working fluid to the state of a subcooled liquid again.

[0021] A thirteenth aspect of the disclosure, depending on the twelfth aspect of the disclosure, relates to an operational method for a heat pump unit, wherein said predetermined fraction (x) is lower than 0.3, preferably lower than 0.2, more preferably around 0.1.

[0022] A fourteenth aspect of the disclosure, depending on the twelfth aspect of the disclosure or on the thirteenth aspect of the disclosure, relates to an operational method for a heat pump unit, wherein the drop in the pressure (p) of said working fluid caused in step B) is lower than 50%, preferably lower than 40%, more preferable lower than 35%.

[0023] A fifteenth aspect of the disclosure, depending on any aspect of the disclosure from the twelfth aspect to the fourteenth aspect, relates to an operational method for a heat pump unit, wherein said heat pump unit (7) includes:

- a plurality of secondary condensers (8s1-8sN), said secondary condensers (8s1-8sN) being all connected in series to said primary condenser (8p) and
- a plurality of expansion devices (9p1-9pN), in particular a plurality of expansion valves, wherein one expansion device is positioned in said heat pump unit (7) immediately upstream to each of said secondary condensers (8s1-8sN),

the operational method being characterised by the further step of:

D) performing a succession of drops in the pressure (p) of said working fluid by means of said expansion devices (9p1-9pN), in order to bring said working fluid to the state of a mixture of vapour and liquid, each drop in the pressure (p) being followed by a cooling of said working fluid through said secondary condensers (8s1-8sN), in order to bring said working fluid to the state of a subcooled liquid again.

[0024] These aspects, together with further remarkable aspects that are going to be clearly detailed in the following description, are shown in the figures, wherein:

- Figure 1 represents a machine for drying laundry;
- Figure 2A represents the layout of a machine for drying laundry comprising a heat pump unit, the machine for drying laundry being according to the state of the art;
- Figure 2B represents the layout of a machine for drying laundry comprising a heat pump unit, the machine for drying laundry being according to the present disclosure;
- Figure 2C represents the layout of a machine for drying laundry comprising a heat pump unit, the machine for drying laundry being according to a first advantageous variant of the present disclosure;
- Figure 2D represents the layout of a machine for drying laundry comprising a heat pump unit, the machine for drying laundry being according to a second advantageous variant of the present disclosure;
- Figure 3A represents, by means of a pressure-enthalpy Mollier diagram, the operational method of a heat pump unit, when the machine for drying laundry comprising the heat pump unit is according to the state of the art;
- Figure 3B represents, by means of a pressure-enthalpy Mollier diagram, the operational method of a heat pump unit, when the machine for drying laundry comprising the heat pump unit is according to the present disclosure and
- Figure 3C represents, by means of a pressure-enthalpy Mollier diagram, the operational method of a heat pump unit, when the machine for drying laundry comprising the heat pump unit is according to the first advantageous variant of the present disclosure depicted in Figure 2C.

[0025] In Figure 1 a machine 1 for drying laundry is depicted. The machine 1 is able to perform at least a drying treatment on textile articles 3, this treatment being intended to reduce dramatically the moisture in the textile articles 3. The machine 1 is therefore able to treat wet clothes (e.g. clothes just washed in a laundry washing machine) and to reduce the moisture in the clothes up to a really low moisture degree (e.g. the moisture degree most appropriate for the clothes to be ironed). The machine 1 can be able to perform further treatments in addition to the drying treatment: for instance the machine 1 can be able to wash the clothes before the drying treatment. The machine 1 can be a front-loading machine (as in the example depicted in Figure 1) or a top-loading machine.

[0026] In particular, the machine 1 is a condensation-type clothes dryer, since the moisture extracted from the textile articles 3 is condensed within the machine 1, instead of being expelled to the outside. The machine 1 comprises a cabinet 70 and a chamber 2 configured to accommodate textile articles 3 housed in the cabinet 70. In order to allow the user to gain access to the chamber 2 (e.g. for loading the textile articles 3 to be dried or for unloading the textile articles 3 after a drying treatment), at least a wall of the cabinet 70 is provided with an aperture. Such aperture is kept closed during the drying treatments by means of a door 71.

[0027] In order to guarantee a homogeneous drying of the textile articles 3, the machine 1 is equipped with means for agitating the textile articles 3 inside the chamber 2. Advantageously the chamber 2 consists in a perforated drum. Movimentation means (e.g. an electric motor) are coupled to the drum: upon activating the movimentation means, the drum rotates about its own axis and consequently the textile articles are free to tumble within the drum, so avoiding entanglements that can significantly jeopardise the drying treatment effectiveness.

[0028] In order to remove the moisture from the textile articles 3, a closed-loop drying circuit is provided within the machine 1, the chamber 2 being incorporated in the drying circuit. A process drying airflow circulates in the drying circuit. The drying airflow leaves the chamber 2 dragging the moisture extracted from the textile articles 3. In the drying circuit, the humidity content of the process airflow is significantly reduced and at the end the process airflow returns to the chamber 2 capable to extract further moisture from the textile articles 3.

[0029] Figure 1 depicts schematically the closed-loop drying circuit of the machine 1. A drying conduit develops from a first end 4 to a second end 6, the first end 4 and the second end 6 of the drying conduit being both fluidically connected to the chamber 2. In order to allow the drying airflow to pass through a significant portion of the chamber 2, the first end 4 and the second end 6 are fluidically connected to different and/or quite distant regions of the chamber 2. For instance, the first end 4 is fluidically connected to a front region of the chamber 2, whilst the second end 6 is fluidically connected to a rear region of the chamber 2. In order to allow the airflow to circulate in the drying circuit, the machine 1 includes a blower 5 configured to move the drying airflow along the drying conduit. In the machine 1 depicted in Figure 1, the blower 5 is positioned immediately upstream of the second end 6 of the drying conduit. In order to prevent possible fluff dispersed in the drying airflow to damage the blower 5 and any further functional component positioned in the drying conduit, a filter 80 is advantageously positioned adjacent to the first end 4 of the drying conduit. The filter 80 is per se a known component: for instance the device disclosed in the European patent EP2458071 B1 could properly be used as filter 80 in the machine 1. This filter requires a periodic intervention for removing the fluff collected in the filter. Alternatively a self-cleaning filter may be used in the machine 1, e.g. the filter described in the International patent application WO2016/108102A1.

[0030] The drying airflow dragging the moisture withdrawn from the textile articles 3 is treated along the drying circuit. The drying airflow is at first cooled, in order to reduce the moisture content by condensation, and subsequently heated, in order to be hot and dry when released from the drying circuit. Therefore the machine 1 comprises condensing means configured to extract moisture from the drying airflow and heating means configured to heat the drying airflow up, the condensing means being disposed on the drying circuit upstream of the heating means.

[0031] The moisture extracted from the drying airflow by the condensing means in form of condensed water falls by gravity in a collecting tray 81 positioned below the condensing means. The collecting tray 81 is hydraulically connected to a container 82 typically positioned in the upper part of the machine 1. The container 82 has a capacity bigger than the capacity of the collecting tray 81 and is advantageously configured to allow its removal from the machine 1 for performing emptying operations. A condensed water container suitable for being installed in the machine 1 is disclosed in the European patent application EP2455539A2. The hydraulic connection between the collecting tray 81 and the container 82 is in particular obtained by means of a filling line 83 and by means of an overflow line 77. The filling line 83 is provided with a pump 58 capable to move the condensed water from the collecting tray 81 to the container 82. Alternatively the peristaltic device disclosed in the European patent EP1907620B1 may be used for moving condensed water along the filling line 83, such peristaltic device being coupled to the same movimentation means activating the drum.

[0032] Advantageously, the collecting tray 81 is provided with a sensor capable of detecting the level of the condensed water in the collecting tray 81 (e.g. a linear pressure sensor). When the sensor in the collecting tray 81 detects that condensed water is collecting in the collecting tray 81, the pump 58 is activated in order to move condensed water from the collecting tray 81 to the container 82. The container 82 is provided as well with a sensor capable of detecting the level of the condensed water. When the sensor in the container 82 detects that a predetermined level of condensed water has been reached, the user of the machine 1 is informed that an emptying operation of the container 82 should be executed. If such an emptying operation is not executed and the container 82 becomes full because further condensed water has come in the container 82 from the collecting tray 81, condensed water returns to the collecting tray 81 through the overflow line 77. Then the sensor in the collecting tray 81 detects that the level of the condensed water in the collecting tray 81 is increasing in the collecting tray 81 despite of the pump 58 being activated. In such a situation, the operation of the machine 1 is consequently interrupted in order to avoid any overflow of condensed water in the cabinet 70.

[0033] Advantageously, the drying circuit is provided with at least one sensor adapted to detect the gradient of the variation of the moisture degree in the drying airflow during the operation of the machine 1. Such gradient could be indeed properly be used as the main control parameter of the drying process, because the gradient of the variation of the moisture degree in the drying airflow is directly connected to the degree of moisture in the textile articles 3. For instance, when such gradient falls below a predetermined lower threshold, the drying process is terminated with the inactivation of the condensing means and of the heating means (the activation of the blower 5 could be instead prolonged for a predetermined time interval after the detection of the lower threshold of the gradient, in order to cool the textile articles 3 down).

[0034] In order to detect the gradient of the variation of the moisture degree in the drying airflow, the technical solution described in the UK patent application GB2154721A is preferably used, wherein the gradient is measured indirectly by means of the detection of a differential temperature. For instance, the drying circuit may be equipped with a couple of temperature probes: a first temperature probe positioned upstream to the condensing means and a second temperature probe positioned downstream to the condensing means. Indeed the difference in temperatures between the first temperature probe and the second temperature probe depends on the degree of moisture in the drying airflow.

[0035] The machine 1 includes a heat pump unit 7 including a heat pump circuit configured to exchange heat with the drying circuit. In order to allow heat exchanges between the heat pump circuit and the drying circuit, a working fluid (in particular a refrigerant) circulates in the heat pump circuit. The heat pump circuit is a closed-loop circuit in which the working fluid is subjected to physical state changes. When the working fluid changes its state from liquid to vapour, heat is transferred from the airflow in the drying circuit to the working fluid in the heat pump circuit. The airflow is hence cooled and moisture can be extracted in form of condensed water. At the contrary, when the working fluid changes its state from vapour to liquid, heat is transferred from the working fluid in the heat pump circuit to the airflow in the drying circuit. The airflow is hence heated after the condensation, to be newly ready to withdraw moisture from the textile articles 3 in the chamber 2. Moreover the machine 1 advantageously includes an open-loop cooling circuit 90, apt to dissipate the heat generated by some components of the heat pump unit 7 when in operation (e.g. by the compressor). The cooling airflow is sucked from the outside by a fan 91 and is discharged to the outside after having cooled the components of the heat pump unit 7 for forced convection.

[0036] Figure 2B schematically shows the heat pump circuit included in the machine 1 according to the present disclosure and the interactions of the heat pump circuit with the drying circuit (where the heat transfers between the heat pump circuit and the drying circuit occur).

[0037] The heat pump unit 7 comprises a primary condenser 8p and a secondary condenser 8s, acting as heating means in the drying circuit. The secondary condenser 8s is connected in series to the primary condenser 8p and is in particular positioned in the heat pump circuit downstream to the primary condenser 8p. Furthermore the heat pump unit 7 includes an expansion device 9p, in particular an expansion valve, interposed between the primary condenser 8p and the secondary condenser 8s.

[0038] The heat pump unit 7 additionally comprises an evaporator 10, acting as condensing means in the drying circuit. Alternatively, the heat pump unit 7 may comprise a plurality of evaporators connected in series and/or in parallel. The evaporator 10 is connected in series to the primary condenser 8p and to the secondary condenser 8s and is in particular positioned in the heat pump circuit downstream to the secondary condenser 8s. Furthermore the heat pump unit 7 includes an expansion device 9s, in particular an expansion valve, interposed between the secondary condenser 8s and the evaporator 10.

[0039] Finally the heat pump unit 7 comprises a compressor 85, interposed between the evaporator 10 and the primary condenser 8p. The compressor 85 can be a variable speed compressor or a fixed speed compressor. The heat generated by the compressor 85 (and by possible further components of the heat pump unit 7 that tend to overheat when in operation) is dissipated by means of the cooling circuit 90.

[0040] Figure 2A representing a technical solution known in the state of the art is provided to make still clearer the contribution given by the present disclosure to the state of the art. Indeed, from a simple comparison between Figure 2B and Figure 2A, it's evident that the technical solution according to the present solution differs from the technical solution according to the state of the art because of the provision of the secondary condenser 8s and of the expansion device 9p, the secondary condenser 8s and the expansion device 9p being interposed between the primary condenser 8p and the expansion device 9s.

[0041] The expansion device 9s in the present disclosure could be undersized with respect to the state of the art, whilst the evaporator 10 in the present disclosure could be oversized with respect to the state of the art. Remaining components of the heat pump unit 7 (e.g. the compressor 85) remain substantially unchanged from the state of the art to the present disclosure.

[0042] Figure 3B is a pressure-enthalpy Mollier diagram showing the operational method of the heat pump unit 7 comprised in the machine 1 for drying laundry according to the present disclosure. As well known, Mollier diagrams provide a really effective representation of the changes to which a refrigerant fluid is subjected to when it is used as working fluid in a thermodynamic system. Three main regions could be recognised in a pressure-enthalpy Mollier diagram:

- at the center, the liquid-and-vapour mixture region;
- on the left, the subcooled liquid region, separated from the liquid-and-vapour mixture region by the saturated liquid line and
- on the right, the overheated vapour region, separated from the liquid-and-vapour mixture region by the saturated vapour line.

[0043] The shape and/or the dimension of the main regions in a pressure-enthalpy Mollier diagram depends on the refrigerant fluid. In the explicative but not limitative pressure-enthalpy Mollier represented in Figure 3C, the refrigerant named "R134a" is used as working fluid.

[0044] Several distinct lines are represented in Figure 3B:

i) isobaric lines, the pressure P being constant along each isobaric line;
ii) isoenthalpic lines, the specific enthalpy h being constant along each isoenthalpic line;
iii) isothermal lines, the temperature T being constant along each isoenthalpic line;
iv) isoentropic lines, the specific entropy s being constant along each isoentropic line;
v) isochoric lines, the specific volume v being constant along each isochoric line and
vi) isofraction lines (within the liquid-and-vapour mixture region), the fraction x of vapour in the liquid-and-vapour mixture region being constant along each isofraction line (in particular the saturated liquid line is the isofraction line with x=0, whilst the saturated vapour line is the isofraction line with x=1).

[0045] As apparent in Figure 3B, the working fluid circulating in the heat pump unit 7 depicted in Figure 2B is subjected to phase changes.

[0046] The primary condenser 8p receives the working fluid as a superheated vapour (point A). In the primary condenser 8p the working fluid is subjected to an isobaric transformation. In the example of the present disclosure shown in Figure 2B, wherein R134a is used as working fluid, the isobaric transformation in the primary condenser 8p occurs at a pressure of around 21 bar. At first, the superheated vapour is cooled up to the condensation temperature (for instance around 65° C). Then the state of the working fluid is changed progressively until the working fluid condenses entirely and becomes a saturated liquid. Lastly the working fluid continues being cooled, in order to bring the working fluid to the state of a subcooled liquid (point B).

[0047] Hence the working fluid is released from the primary condenser 8p as a subcooled liquid and enters in the expansion device 9p, in which is subjected to an isoenthalpic transformation. The pressure p of the working fluid is lowered through the expansion device 9p, in order to bring the working fluid to the state of a mixture of vapour and liquid (point CP), the vapour being in a predetermined fraction x in the mixture. Advantageously the predetermined fraction x (i.e. the fraction of vapour in the working fluid at point CP) is lower than 0.3, preferably lower than 0.2, more preferably around 0.1. Advantageously the drop in the pressure p of the working fluid caused by the isoenthalpic transformation by means of the expansion device 9p is lower than 50%, preferably lower than 40%, more preferably lower than 35%.

[0048] The working fluid is then received by the secondary condenser 8s. In the secondary condenser 8s the working fluid is subjected to a further isobaric transformation. In the example of the present disclosure shown in Figure 2B, the isobaric transformation in the secondary condenser 8s occurs at a pressure of around 15 bar. The fraction x of the vapour in the working fluid is reduced progressively in the secondary condenser 8s until the working fluid condenses entirely and becomes a saturated liquid. During the condensation of the vapour, the temperature of the working fluid stays at a constant temperature (e.g. around 50° C). Lastly the working fluid continues being cooled, in order to bring the working fluid to the state of a subcooled liquid again (point BS).

[0049] Hence the working fluid is released from the secondary condenser 8s as a subcooled liquid and enters in the expansion device 9s, in which is subjected to an isoenthalpic transformation. The pressure p of the working fluid is lowered through the expansion device 9s. By means of the expansion device 9s, the working fluid is brought to the state of a mixture of vapour and liquid at the evaporation temperature (point CS), e.g. around 25° C. The vapour is in a predetermined fraction x in the mixture when the working fluid is released from the expansion device 9s, the predetermined fraction x (i.e. the fraction of vapour in the working fluid at point CS) is preferably comprised between 0.01 and 0.25, more preferably around 0.15.

[0050] The working fluid is then received by the evaporator 10. In the evaporator 10 the working fluid is subjected to an isobaric transformation. In the example of the present disclosure shown in Figure 2B, the isobaric transformation in the secondary condenser 8s occurs at a pressure p of around 6 bar. Indeed the heat pump unit 7 is configured so that the pressure p of the working fluid in the primary condenser 8p is more than twice the pressure p of the working fluid in the evaporator 10, preferably more than three times the pressure p of the working fluid in the evaporator 10. The fraction x of the vapour in the working fluid increases progressively along the evaporator 10 until the working fluid evaporates entirely and becomes a saturated vapour. Successively the working fluid continues being heated, in order to bring the working fluid to the state of a superheated vapour (point D).

[0051] Finally the working fluid, in the state of a superheated vapour, is compressed by the compressor 85. Such a transformation is intended to increase the pressure p of the working fluid up to the pressure p (around 2000 kPa) used for the condensation of the working fluid in the primary condenser 8p.

[0052] The pressure-enthalpy Mollier diagram in Figure 3A shows the operating method of the heat pump unit 7 comprised in the drying machine 1 depicted in Figure 2A, that represents a technical solution known in the state of the art. At the end of the condenser 8p (point B), the pressure p of the heating fluid is lowered from the condensation pressure (around 21 bar) directly to the evaporation pressure (around 6 bar) by means of the expansion device 9s (point C). The subsequent isobaric transformation in the evaporator 10 begins with a predetermined fraction x of the vapour in the working fluid, such predetermined fraction being comprised between 0.3 and 0.4.

[0053] Point C is depicted in Figure 3B as well in order to make still clearer the advantages given by the present disclosure with respect to the state of the art. The technical solution according to the present disclosure provides a higher heating power with respect to the state of the art and a higher cooling power as well. In fact, the heat pump unit 7 according to the present disclosure is able to render the condensing means of the machine 1 able to condensate more moisture in the drying conduit and simultaneously to render the heating means of the machine 1 capable to furnish more heat to the airflow in the drying conduit, without the energy consumptions of the heat pump 7 unit being increased.

[0054] The cooling power of a heat pump system depends on the difference between the specific enthalpy h of the working fluid at the end of the evaporating means and the specific enthalpy h of the working fluid at the beginning of the evaporating means.

[0055] According to the state of the art, the cooling power of the heat pump 7 is represented by the difference between the specific enthalpy hD of the working fluid at the end of the evaporator 10 (around 415 kJ/kg in the example shown in Figure 3A) and the specific enthalpy hC of the working fluid at the beginning of the evaporator 10 (around 290 kJ/kg in the example shown in Figure 3A).

[0056] According to the present disclosure, the cooling power of the heat pump 7 is represented by the difference between the specific enthalpy hD of the working fluid at the end of the evaporator 10 (around 415 kJ/kg in the example shown in Figure 3B) and the specific enthalpy hCS of the working fluid at the beginning of the evaporator 10 (around 260 kJ/kg in the example shown in Figure 3B). Therefore the heat pump unit 7 according to the present disclosure is capable to provide an additional cooling power if compared with the heat pump unit 7 according to the state of the art, due to the higher specific enthalpy h increase in the evaporator 10.

[0057] The heating power of a heat pump system depends on the difference between the specific enthalpy h of the working fluid at the beginning of the condensation means and the specific enthalpy h of the working fluid at the end of the condensation means.

[0058] According to the state of the art, the heating power of the heat pump 7 is represented by the difference between the specific enthalpy hA of the working fluid at the beginning of the condenser 8p (around 450 kJ/kg in the example shown in Figure 3A) and the specific enthalpy hB of the working fluid at the end of the condenser 8p (around 290 kJ/kg in the example shown in Figure 3A).

[0059] According to the present disclosure, the heating power of the heat pump 7 is represented by the difference between the specific enthalpy hA of the working fluid at the beginning of the primary condenser 8p (around 450 kJ/kg in the example shown in Figure 3B) and the specific enthalpy hBS of the working fluid at the end of the secondary condenser 8s (around 260 kJ/kg in the example shown in Figure 3B). Therefore the heat pump unit 7 according to the present disclosure is capable to provide an additional heating power if compared with the heat pump unit 7 according to the state of the art, due to the additional specific enthalpy h increase in the secondary condenser 8s.

[0060] The energy consumption of a heat pump system depends on the mechanical power required by the working fluid to be compressed. Such a mechanical power depends on the difference between the specific enthalpy h of the working fluid at the end of the compression means and the specific enthalpy h of the working fluid at the beginning of the condensation means.

[0061] The mechanical power required by the working fluid to be compressed in the heat pump unit 7 according to the present disclosure is equal to the mechanical power required by the working fluid to be compressed in the heat pump unit 7 according to the state of the art. Indeed, in both cases the mechanical power required by the heat pump 7 is represented by the difference between the specific enthalpy hA of the working fluid at the end of the compressor 85 (around 450 kJ/kg in the examples shown in Figure 3A and in Figure 3B) and the specific enthalpy hD of the working fluid at the beginning of the compressor 85 (around 415 kJ/kg in the example shown in Figure 3A and in Figure 3B).

[0062] In view of the foregoing, the Coefficient Of Performance (COP) of the heat pump unit 7 according to the present disclosure is higher than the Coefficient Of Performance (COP) of the heat pump unit 7 according to the state of the art.

[0063] Figure 2C schematically shows the heat pump circuit included in the machine 1 according to a first advantageous variant of the present disclosure.

[0064] In the first advantageous variant of the present disclosure, the heat pump unit 7 comprises a primary condenser 8p and a plurality of secondary condensers 8s1-8sN (in the exemplary embodiment of Figure 2C the number of secondary condensers 8s1-8sN is equal to three). The secondary condensers 8s1-8sN are all connected in series to the primary condenser 8p and are in particular positioned in the heat pump circuit downstream to the primary condenser 8p.

[0065] In the first advantageous variant of the present disclosure, the heat pump unit 7 comprises a plurality of expansion devices 9p1-9pN, in particular a plurality of expansion valves. The number of the expansion devices 9p1-9pN is equal to the number of the secondary condensers 8s1-8sN. Each expansion device is positioned in the heat pump unit 7 immediately upstream to the respective secondary condenser.

[0066] In the first advantageous variant of the present disclosure, the heat pump unit 7 additionally comprises an evaporator 10, acting as condensing means in the drying circuit. Alternatively, the heat pump unit 7 may comprise a plurality of evaporators connected in series and/or in parallel. The evaporator 10 is connected in series to the primary condenser 8p and to the secondary condensers 8s1-8sN and is in particular positioned in the heat pump circuit downstream to the secondary condensers 8s1-8sN.

[0067] Furthermore, in the first advantageous variant of the present disclosure, the heat pump unit 7 includes an expansion device 9s, in particular an expansion valve, interposed between the last of the secondary condensers 8sN and the evaporator 10.

[0068] Finally, in the first advantageous variant of the present disclosure, the heat pump unit 7 comprises a compressor 85, interposed between the evaporator 10 and the primary condenser 8p. The heat generated by the compressor 85 (and by possible further components of the heat pump unit 7 that tend to overheat when in operation) is dissipated by means of the cooling circuit 90.

[0069] Figure 3C is a pressure-enthalpy Mollier diagram showing the operational method of the heat pump unit 7 comprised in the machine 1 for drying laundry according to the first advantageous variant of the present disclosure. The explicative but not limitative representation of Figure 3C is the pressure-enthalpy Mollier diagram wherein the working fluid is the refrigerant named "R134a".

[0070] As apparent in Figure 3C, the working fluid circulating in the heat pump unit 7 depicted in Figure 2C is subjected to phase changes.

[0071] The primary condenser 8p receives the working fluid as a superheated vapour (point A). In the primary condenser 8p the working fluid is subjected to an isobaric transformation. In the example of the first advantageous variant of the present disclosure shown in Figure 2C, wherein R134a is used as working fluid, the isobaric transformation in the primary condenser 8p occurs at a pressure of around 21 bar. At first, the superheated vapour is cooled up to the condensation temperature (for instance around 65° C). Then the state of the working fluid is changed progressively until the working fluid condenses entirely and becomes a saturated liquid. Lastly the working fluid continues being cooled, in order to bring the working fluid to the state of a subcooled liquid (point B).

[0072] Hence the working fluid, after having been released from the primary condenser 8p, is subjected to a succession of an isoenthalpic transformation in an expansion device followed by an isobaric transformation in a secondary condenser. Each expansion device is configured to reduce the pressure p of the working fluid, the reduction in the pressure p being sufficient to bring the working fluid to the state of a mixture of vapour and liquid (points CP1-CPN). The secondary condenser positioned downstream to each expansion device is configured to reduce progressively the temperature T of the working fluid, the reduction in the temperature T being sufficient to condense the working fluid entirely and to continue cooling the working fluid, so that the working fluid is released as a subcooled liquid from each secondary condenser (points BS1-BSN).

[0073] Therefore in the operational method of the heat pump unit 7 according to the first advantageous variant of the present disclosure, a succession of drops in the pressure p of the working fluid by means of the expansion devices 9p1-9pN is executed, in order to bring the working fluid the state of a mixture of vapour and liquid, each drop in the pressure p being followed by a cooling of the working fluid through the secondary condensers 8s1-8sN, in order to bring the working fluid the state of a subcooled liquid again.

[0074] By means of the expansion device 9s, the working fluid is then brought to the state of a mixture of vapour and liquid at the evaporation temperature (point CS), e.g. around 25° C. The vapour is in a predetermined fraction x in the mixture when the working fluid is released from the expansion device 9s, the predetermined fraction x (i.e. the fraction of vapour in the working fluid at point CS) is preferably comprised between 0.01 and 0.15, more preferably around 0.05.

[0075] The working fluid is then received by the evaporator 10. In the evaporator 10 the working fluid is subjected to an isobaric transformation. In the example of the first advantageous variant of the present disclosure shown in Figure 2C, the isobaric transformation in the secondary condenser 8s occurs at a pressure p of around 6 bar. Indeed the heat pump unit 7 is configured so that the pressure p of the working fluid in the primary condenser 8p is more than twice the pressure p of the working fluid in the evaporator 10, preferably more than three times the pressure p of the working fluid in the evaporator 10. The fraction x of the vapour in the working fluid increases progressively along the evaporator 10 until the working fluid evaporates entirely and becomes a saturated vapour. Successively the working fluid continues being heated, in order to bring the working fluid to the state of a superheated vapour (point D).

[0076] Finally the working fluid, in the state of a superheated vapour, is compressed by the compressor 85. Such a transformation is intended to increase the pressure p of the working fluid up to the pressure p (around 2000 kPa) used for the condensation of the working fluid in the primary condenser 8p.

[0077] The technical solution according to the first advantageous embodiment of the present disclosure provides a higher heating power with respect to the state of the art and a higher cooling power as well. The heating power and the cooling power provided by the heat pump unit 7 shown in Figure 2C are even higher than the heating power and the cooling power provided by the heat pump unit 7 shown in Figure 2B, without the energy consumptions of the heat pump 7 unit being increased.

[0078] According to the first variant of the present disclosure, the cooling power of the heat pump 7 is represented by the difference between the specific enthalpy hD of the working fluid at the end of the evaporator 10 (around 415 kJ/kg in the example shown in Figure 3C) and the specific enthalpy hCS of the working fluid at the beginning of the evaporator 10 (around 230 kJ/kg in the example shown in Figure 3C). Therefore the heat pump unit 7 according to the first advantageous variant of the present disclosure is capable to provide an additional cooling power if compared with the heat pump unit 7 according to the state of the art, due to the higher specific enthalpy h increase in the evaporator 10.

[0079] According to the first variant of the present disclosure, the heating power of the heat pump 7 is represented by the difference between the specific enthalpy hA of the working fluid at the beginning of the primary condenser 8p (around 450 kJ/kg in the example shown in Figure 3C) and the specific enthalpy hBSN of the working fluid at the end of the last secondary condenser 8sN (around 230 kJ/kg in the example shown in Figure 3C). Therefore the heat pump unit 7 according to the present disclosure is capable to provide an additional heating power if compared with the heat pump unit 7 according to the state of the art, due to the additional specific enthalpy h increases in the secondary condensers 8s1-8sN.

[0080] The mechanical power required by the working fluid to be compressed in the heat pump unit 7 according to the first advantageous variant of the present disclosure is equal to the mechanical power required by the working fluid to be compressed in the heat pump unit 7 according to the state of the art. Indeed, in the first advantageous variant of the present disclosure too, the mechanical power required by the heat pump 7 is represented by the difference between the specific enthalpy hA of the working fluid at the end of the compressor 85 (around 450 kJ/kg in the example shown in Figure 3C) and the specific enthalpy hD of the working fluid at the beginning of the compressor 85 (around 415 kJ/kg in the example shown in Figure 3C).

[0081] In view of the foregoing, the Coefficient Of Performance (COP) of the heat pump unit 7 according to the first advantageous variant of the present disclosure is higher than the Coefficient Of Performance (COP) of the heat pump unit 7 according to the state of the art.

[0082] Figure 2D schematically shows the machine 1 according to a second advantageous variant of the present disclosure. The machine 1 in Figure 2D differs from the machine 1 in Figure 2B in that the machine 1 according to the second advantageous embodiment of the present disclosure further comprises an electric resistance 5h configured to heat the drying airflow up.

[0083] During the first stage of the drying process, the heating means included in the heat pump unit 7 (i.e. the primary condenser 8p and the secondary condenser 8s) are less effective because they require a few minutes to reach the operating conditions at regime. The provision of the electric resistance 5h in the drying airflow makes the machine 1 a hybrid machine, wherein the electric resistance 5h can be conveniently activated during the first stage of the drying process, in order to shorten the duration of the entire drying process. Indeed the electric resistance 5h reaches very quickly its operating conditions at regime. Advantageously, the electric resistance 5h is positioned in the drying circuit downstream to the heating means included in the heat pump unit 7 and upstream to the blower 5. Alternatively, the electric resistance 5h is positioned in the drying circuit downstream to the blower 5. Just for the sake of example, the electric resistance disclosed in European patent EP1538255B1 could be properly used in the second advantageous variant of the present disclosure depicted in Figure 2D.

[0084] The heat pump unit shown in Figure 2D includes only one secondary condenser (i.e. the secondary condenser 8s). However it's possible to combine the provision of the electric resistance 5h in the drying circuit with the provision of a plurality of secondary condensers 8s1-8sN in the heat pump unit 7.

[0085] It's absolutely apparent from the description above, that significant advantages are achieved by means of the present disclosure. Especially, the machine 1 according to the present disclosure has a high energy efficiency and allows the drying process of the textile articles 3 to be significantly shortened. Indeed the machine 1 distinguishes from the tumble dryer described in European patent EP2212463B1 (and from any other tumble dryer comprising a heat pump unit known in the state of the art) because of its greater energy efficiency and because of its greater time efficiency.

Claims

1. Machine (1) for drying laundry, comprising:

i) a chamber (2) configured to accommodate textile articles (3);
ii) a drying conduit developing from a first end (4) to a second end (6), the first end (4) and the second end (6) being both connected to said chamber (2);
iii) a blower (5) configured to move a drying airflow along the drying conduit;
iv) a heat pump unit (7) configured to exchange heat with said drying conduit by means of the circulation of a working fluid subjected to phase changes and
v) heating means configured to heat the drying airflow up, said heating means being included in the heat pump unit (7),

characterised in that said heating means comprises a primary condenser (8p) and at least a secondary condenser (8s), said secondary condenser (8s) being connected in series to said primary condenser (8p) and **in that** said heat pump unit (7) includes an expansion device (9p), in particular an expansion valve, interposed between said primary condenser (8p) and said secondary condenser (8s).

2. Machine (1) according to claim 1, wherein said primary condenser (8p) is configured to receive said working fluid as a superheated vapour and to release said working fluid as a subcooled liquid.

3. Machine (1) according to claim 2, wherein the expansion device (9p) interposed between said primary condenser (8p) and said secondary condenser (8s) is configured to release said working fluid as a mixture of vapour and liquid, the fraction (x) of the vapour in the mixture being lower than 0.3, preferably lower than 0.2, more preferably around 0.1.

4. Machine (1) according to claim 3, wherein said secondary condenser (8s) is configured to release said working fluid as a subcooled liquid.

5. Machine (1) according to claim 3 or 4, wherein the expansion device (9p) interposed between said primary condenser (8p) and said secondary condenser (8s) is configured to cause a drop in the pressure (p) of said working fluid lower than 50%, preferably lower than 40%, more preferably lower than 35%.

6. Machine (1) according to any of the previous claims, **characterised in that** said heating means comprises a plurality of secondary condensers (8s1-8sN), said secondary condensers (8s1-8sN) being all connected in series to said primary condenser (8p) and

in that said heat pump unit (7) includes a plurality of expansion devices (9p1-9pN), in particular a plurality of expansion valves.

7. Machine (1) according to claim 6, wherein one expansion device is positioned in said heat pump unit (7) immediately upstream to each of said secondary condensers (8s1-8sN).

8. Machine (1) according to claim 7, wherein said secondary condensers (8s1-8sN) are configured to release said working fluid as a subcooled liquid.

9. Machine (1) according to any of the previous claims, further comprising condensing means configured to extract moisture from the drying airflow, said condensing means being included in the heat pump unit (7) and comprising at least an evaporator (10), wherein said evaporator (10) is configured to receive said working fluid as a subcooled liquid and to release said working fluid as a superheated vapour.

10. Machine (1) according to claims 4 and 9, wherein said working fluid is a refrigerant fluid, in particular R134a, and wherein the pressure (p) of said working fluid in said primary condenser (8p) is more than twice the pressure (p) of said working fluid in said evaporator (10), preferably more than three times the pressure (p) of said working fluid in said evaporator (10), the pressure (p) of said working fluid in said primary condenser (8p) being in particular around 21 bar.

11. Machine (1) according to any of the previous claims, further comprising an electric resistance (5h) configured to heat the drying airflow up, said electric resistance (5h) being preferably positioned downstream to said heating means and upstream to said blower (5).

12. Operational method for a heat pump unit (7) comprised in a machine (1) for drying laundry, wherein a working fluid subjected to phase changes is circulating in said heat pump unit (7) and wherein said heat pump unit (7) includes:

- a primary condenser (8p);
- at least a secondary condenser (8s), said secondary condenser (8s) being connected in series to said primary condenser (8p) and
- an expansion device (9p), in particular an expansion valve, interposed between said primary condenser (8p) and said secondary condenser (8s),

the operational method comprising the steps of:

A) cooling said working fluid through said primary condenser (8p), in order to bring said working fluid to the state of a subcooled liquid;
B) lowering the pressure (p) of said working fluid through said expansion device (9p), in order to bring said working fluid to the state of a mixture of vapour and liquid, the vapour being in a predetermined fraction (x) in said mixture and
C) cooling said working fluid through said secondary condenser (8s), in order to bring said working fluid to the state of a subcooled liquid again.

13. Operational method according to claim 12, wherein said predetermined fraction (x) is lower than 0.3, preferably lower than 0.2, more preferably around 0.1.

14. Operational method according to claim 12 or 13, wherein the drop in the pressure (p) of said working fluid caused in step B) is lower than 50%, preferably lower than 40%, more preferable lower than 35%.

15. Operational method according to any of the claims 12 to 14, wherein said heat pump unit (7) includes:

- a plurality of secondary condensers (8s1-8sN), said secondary condensers (8s1-8sN) being all connected in series to said primary condenser (8p) and
- a plurality of expansion devices (9p1-9pN), in particular a plurality of expansion valves, wherein one expansion device is positioned in said heat pump unit (7) immediately upstream to each of said secondary condensers (8s1-8sN),

the operational method being **characterised by** the further step of:

D) performing a succession of drops in the pressure (p) of said working fluid by means of said expansion devices (9p1-9pN), in order to bring said working fluid to the state of a mixture of vapour and liquid, each drop in the pressure (p) being followed by a cooling of said working fluid through said secondary condensers (8s1-8sN), in order to bring said working fluid to the state of a subcooled liquid again.

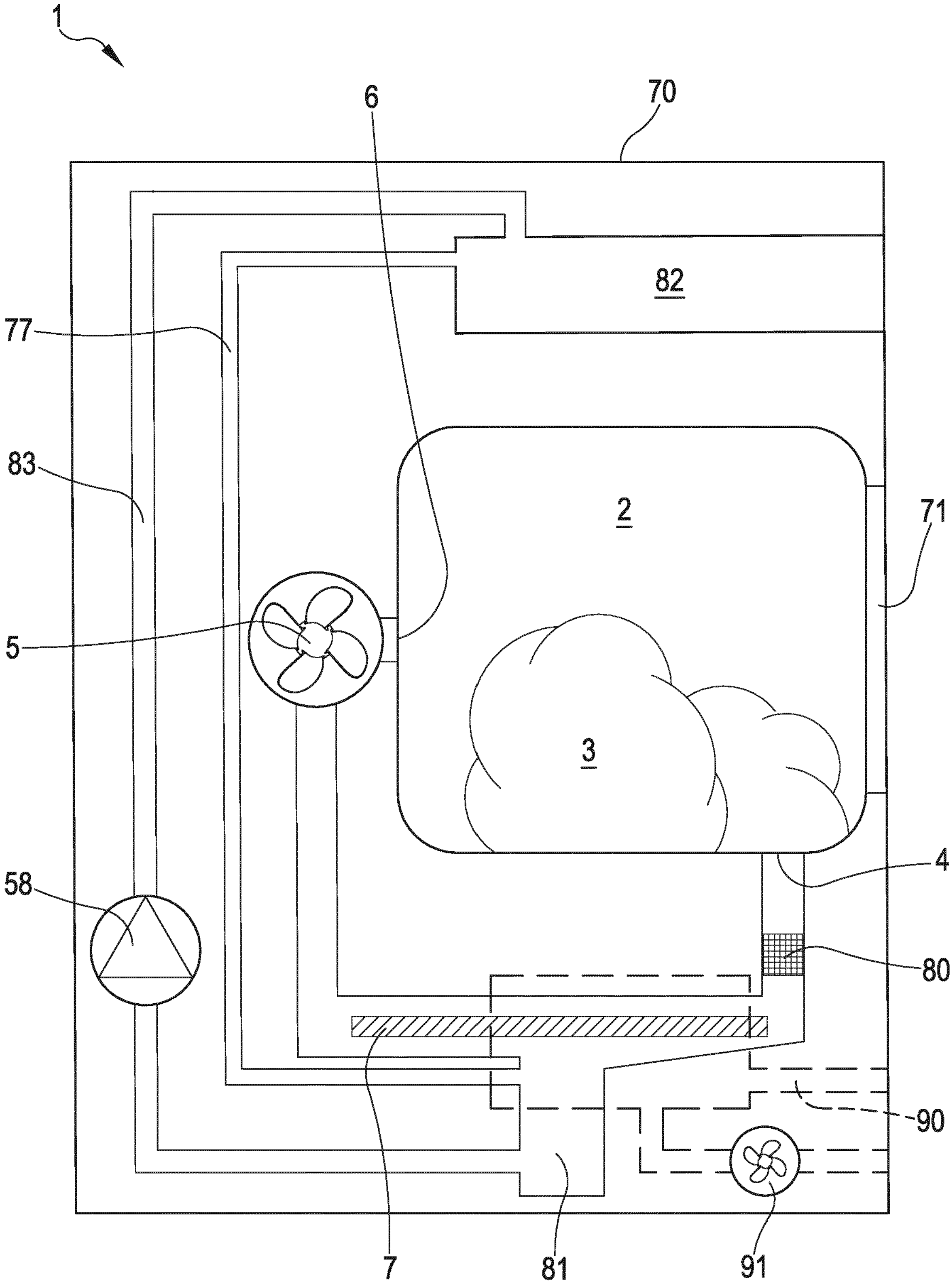


FIG.1

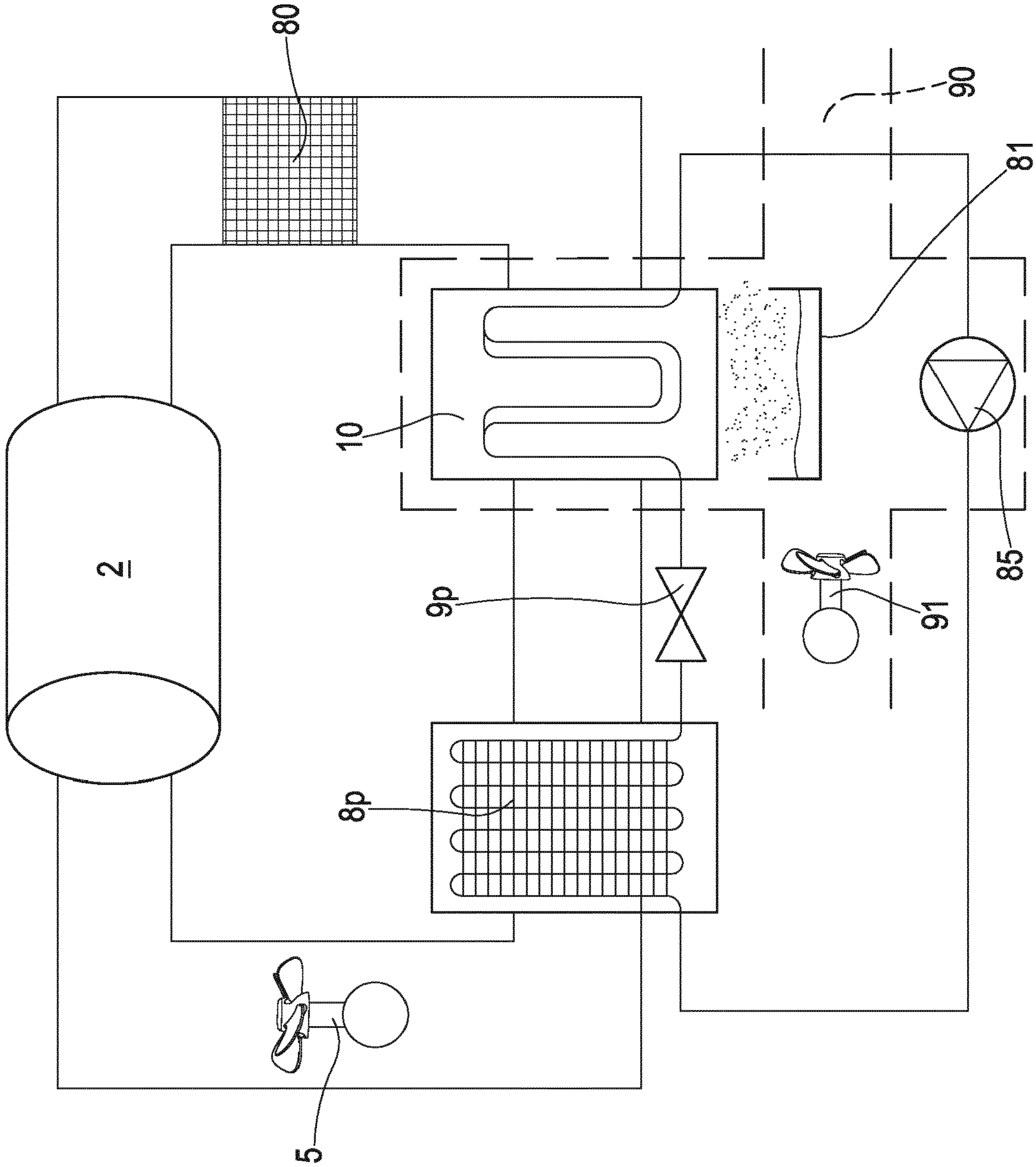


FIG.2A

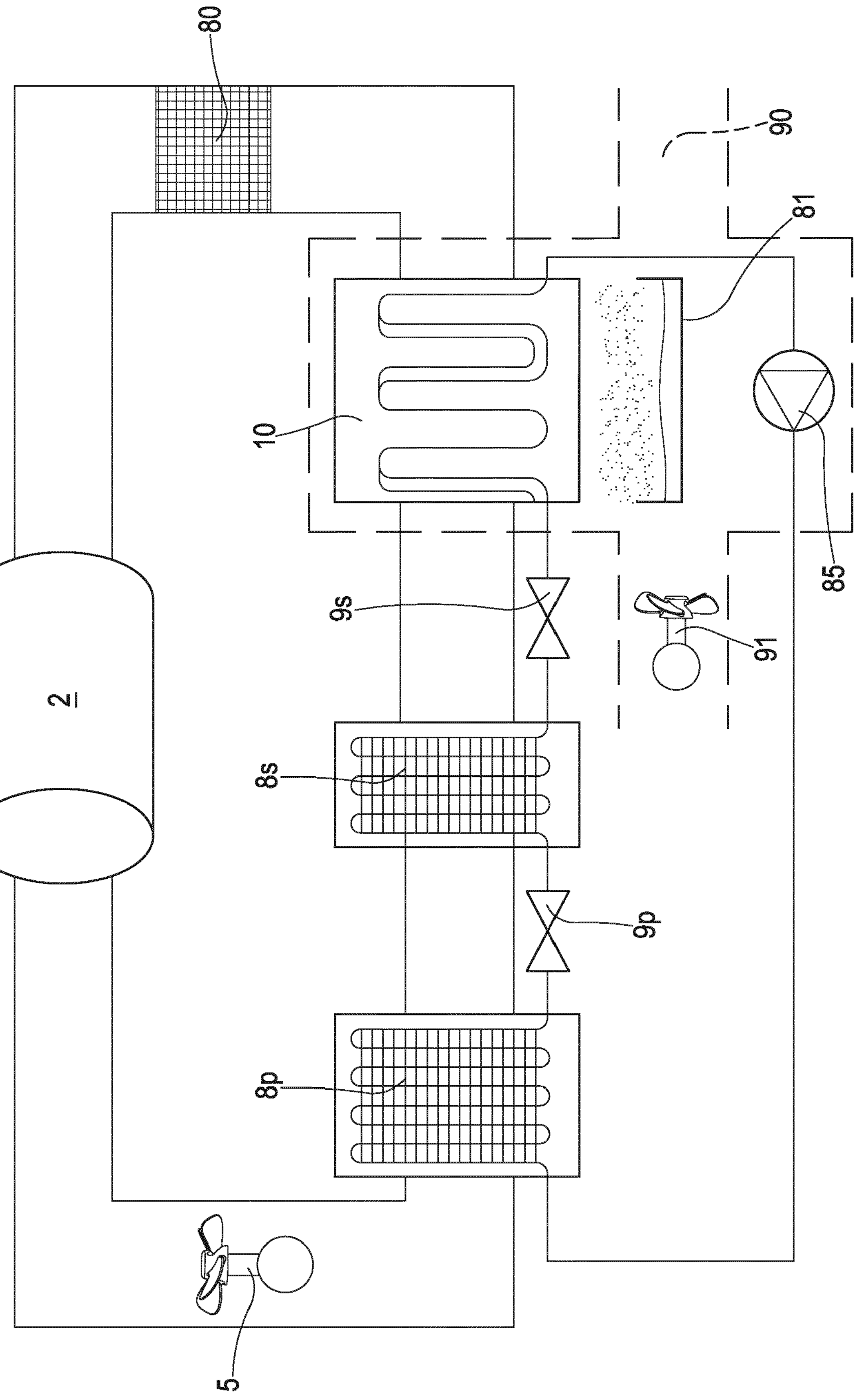
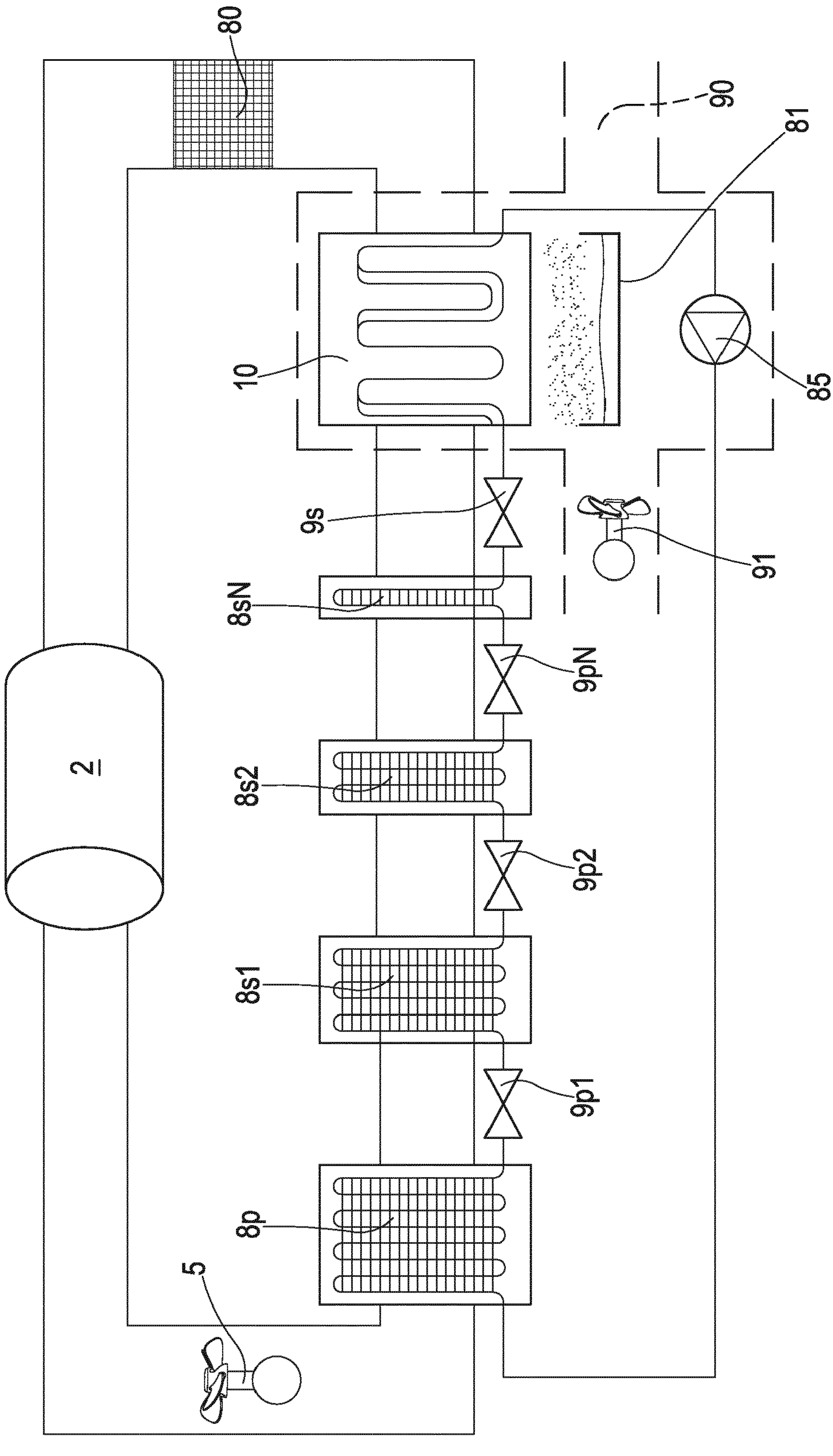


FIG.2B

FIG.2C



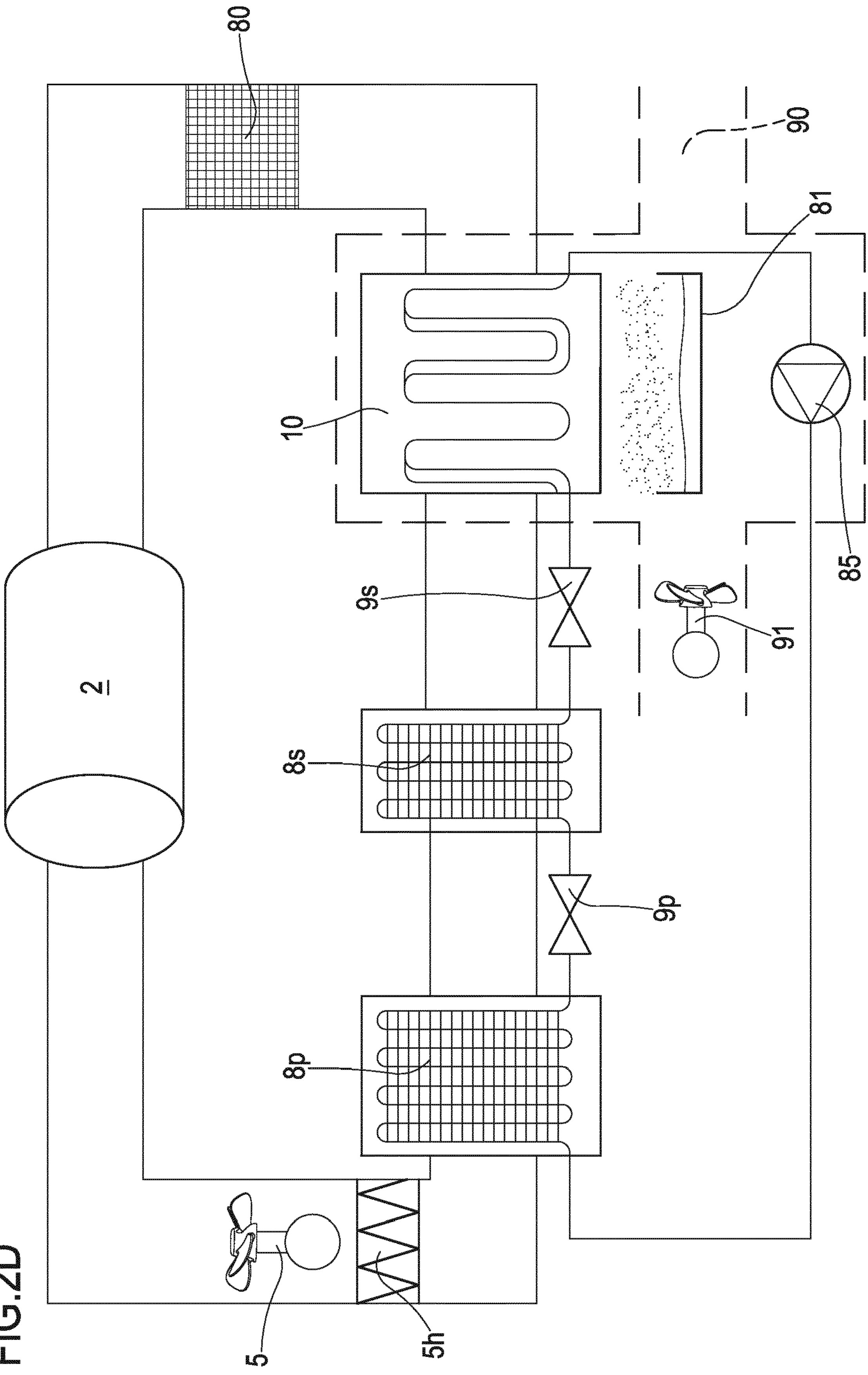


FIG.2D

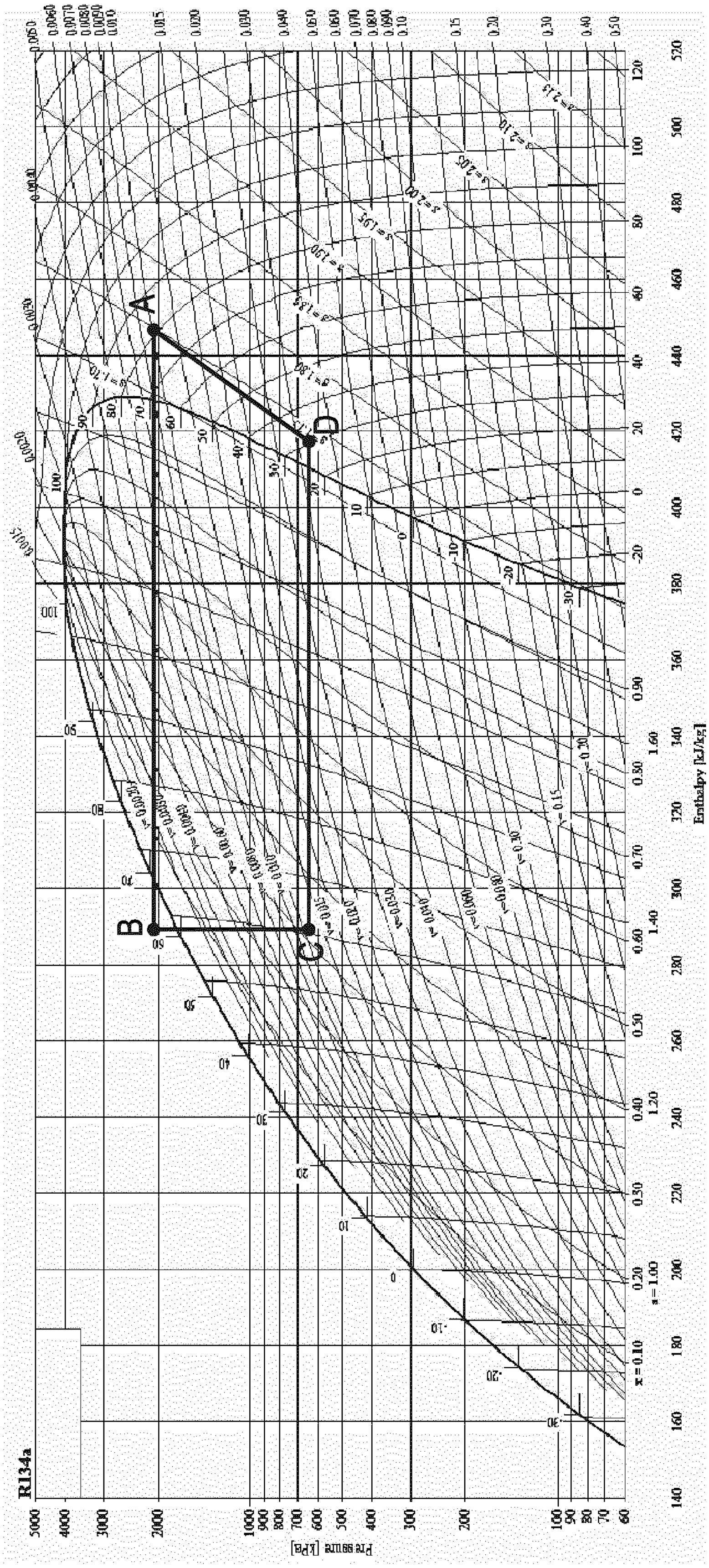


FIG.3A

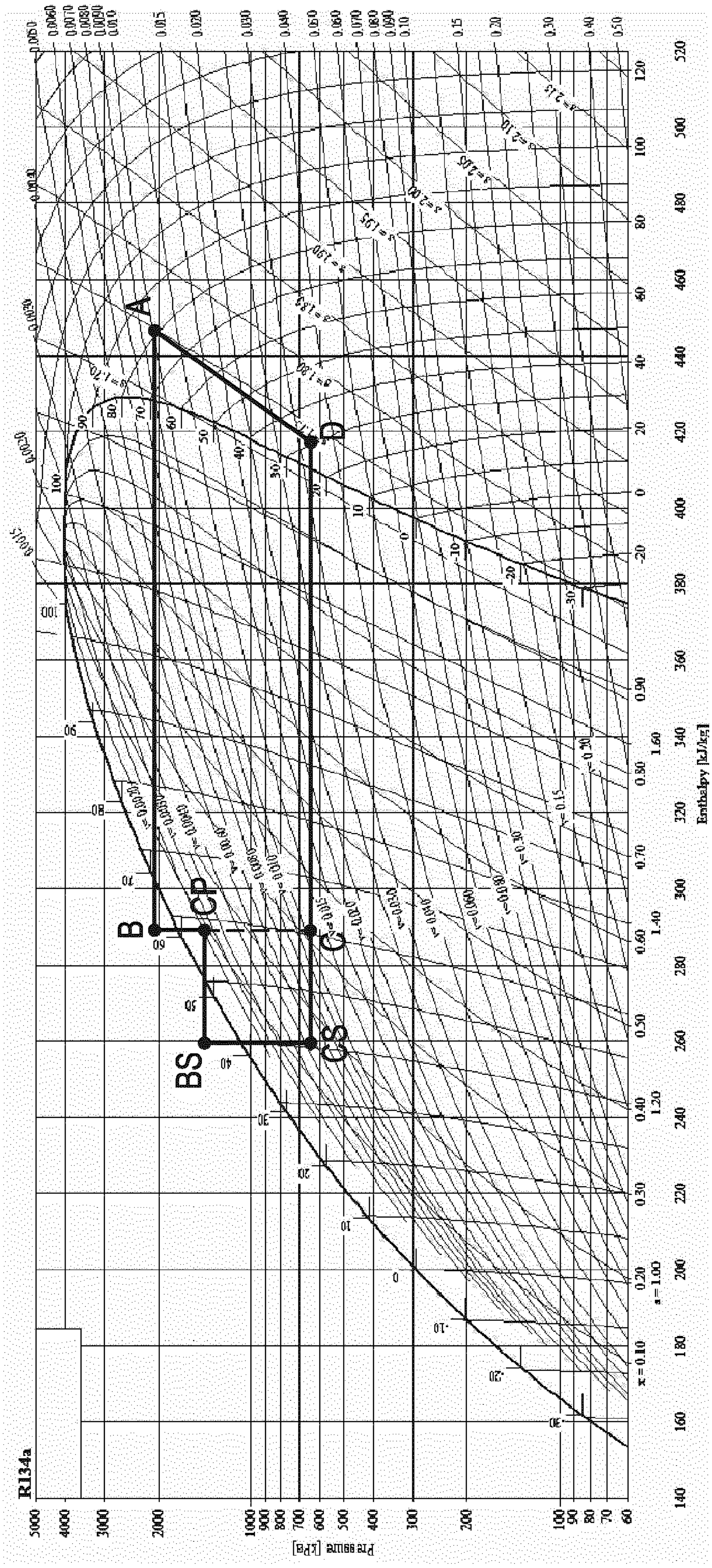


FIG.3B

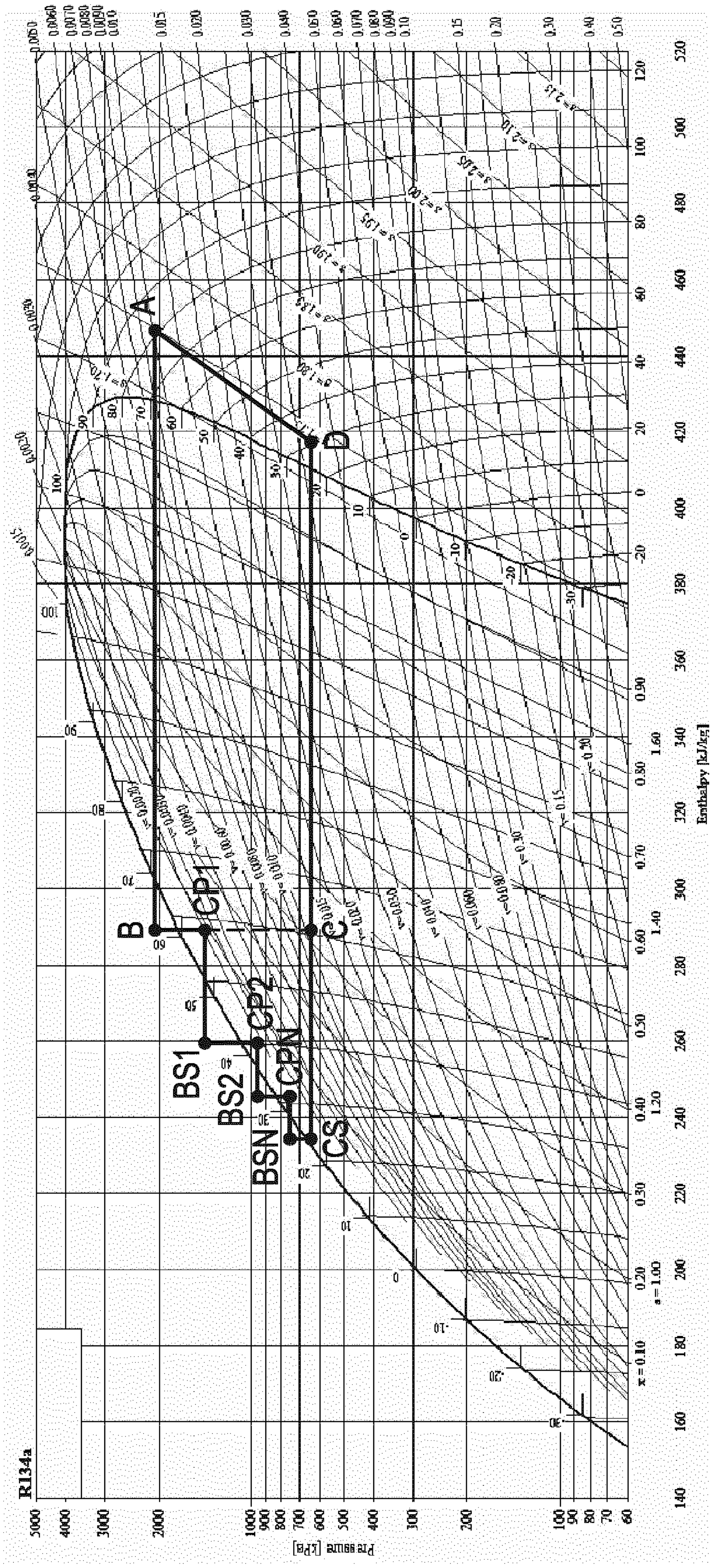

R134a
A
B
C
D
CP1
CP2
CPN
BS1
BS2
BSN
CS
Enthalpy [kJ/kg]
Pressure [kPa]

FIG.3C

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EUROPEAN SEARCH REPORT

Application Number
EP 17 15 2942

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
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