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(54) **CARBON DIOXIDE COMPRESSION REFRIGERATION SYSTEM**

(57) A refrigeration system (1) comprising a primary refrigeration circuit (2) that contains carbon dioxide and is provided with a compressor device (3), a primary cooling device (4), which is designed to perform a first cooling of the carbon dioxide leaving said compressor device (3), an expansion device (5) to expand the carbon dioxide and a heat-exchanger device (6) which accumulates heat in the expanded carbon dioxide supplied by the expansion device (5), and a secondary cooling device (10) which performs a second cooling of the carbon dioxide leaving the primary cooling device (4) to cause a further drop in the temperature of the carbon dioxide from said second temperature (t_2) to a third temperature (t_3), lower than said second temperature (t_2), before the carbon dioxide is supplied to the expansion device (5).

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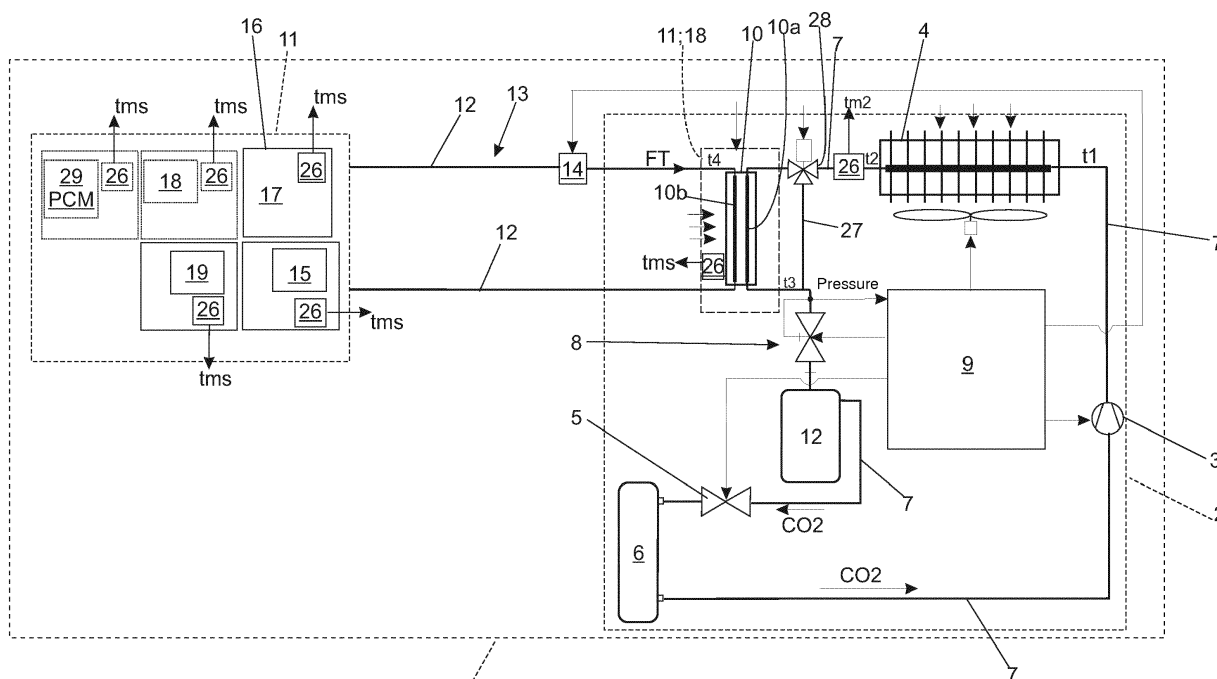


Fig. 2

Description

[0001] The present patent application concerns a carbon dioxide compression refrigeration system and related operating method.

[0002] In particular, the present invention concerns a refrigeration system designed to be used in a plant/machine for conditioning and/or temperature control and/or refrigeration, of rooms for example, to which the following discussion will explicitly refer without loss of generality.

[0003] It is known that over the years, the use in refrigeration systems of refrigerant fluids, for example, in particular, chlorofluorocarbons, hydrofluorocarbons and hydrocarbons has been progressively banned and/or abandoned due to the known environmental problems (destruction of the ozone layer, effect on global warming) and/or safety problems (risk of explosion) caused by said fluids.

[0004] For this purpose the use of a refrigerant fluid corresponding to carbon dioxide has been proposed. However, although on the one hand the use of carbon dioxide has reduced both the level of flammability of the refrigeration plant and the environmental impact, on the other its use in traditional so-called "reverse cycle" refrigeration plants presents some technical criticalities which make it substantially unsuitable for use in applications that perform conditioning/refrigeration with heat disposal by means of external air at ambient temperature.

[0005] Figure 1 shows an example of a traditional "reverse cycle" refrigeration plant, indicated by I, essentially comprising a closed refrigeration circuit II for circulation of the carbon dioxide, which is provided in turn with: a compressor III designed to compress the carbon dioxide, thus increasing the enthalpy thereof, a cooler IV designed to extract the heat from the previously compressed carbon dioxide, a first expansion valve V designed to maintain the pressure upstream, i.e. leaving the cooler IV, at a first predefined value on the basis of a control signal generated by an electronic control unit VI, a liquid receiver/separator tank VII which is at an intermediate pressure between the evaporation pressure of the carbon dioxide and the first predefined value, a second expansion valve VIII designed to cause expansion of the carbon dioxide maintaining the enthalpy constant, thus reducing the temperature and pressure thereof, and an evaporator IX designed to absorb the heat from the fluid to be cooled by means of the carbon dioxide which evaporates therein.

[0006] It is further known that the carbon dioxide is characterized by a critical temperature, i.e. a critical point temperature of approximately 31°C. This temperature is relatively low when compared with the critical temperature of the traditional refrigerant fluids and may therefore be lower than the ambient temperature.

[0007] The refrigeration system using carbon dioxide shown in Figure 1 may therefore be "transcritical" since release of the negative heat towards the outside, by the cooler IV, is performed at an ambient temperature higher than the critical temperature of the refrigerant fluid. It fol-

lows that with conditions being equal, for example the evaporation temperature, the temperature of the carbon dioxide leaving the cooler, the superheating, the overall efficiency of the compression process, the coefficient of performance of a transcritical refrigeration cycle with carbon dioxide is generally lower than a coefficient of performance of a corresponding "subcritical" cycle.

[0008] In other words, the efficiency of a reverse thermodynamic cycle using carbon dioxide is strongly influenced by the temperature thereof at the end of the cooling process, and in particular increases as the temperature decreases.

[0009] The Applicant has therefore carried out a detailed study with the objective of identifying a solution relative to a carbon dioxide compression refrigeration system which overcomes the above-mentioned drawbacks, i.e. has an efficiency greater than the carbon dioxide compression systems described above.

[0010] The object of the present invention is therefore to make available a solution which allows the above objective to be achieved.

[0011] This object is achieved by the present invention since it is relative to a carbon dioxide compression refrigeration system and to the relative operating method, devised/provided as defined in the attached claims.

[0012] The present invention will now be described with reference to the attached drawings, which illustrate a non-limiting embodiment example thereof, in which:

- Figure 1 shows a circuit diagram of a refrigeration plant produced according to the known art;
- Figure 2 shows a circuit diagram of a refrigeration plant produced according to the teachings of the present invention;
- Figure 3 shows a circuit diagram of a refrigeration plant produced according to a first variation of the present invention;
- Figure 4 shows a circuit diagram of a refrigeration plant produced according to a second variation of the present invention;
- Figure 5 shows a circuit diagram of a refrigeration plant produced according to a third variation of the present invention;
- Figure 6 shows a circuit diagram of the refrigeration plant shown in Figure 2 according to an embodiment variation.

[0013] The present invention will now be described in detail with reference to the attached Figures to enable a person skilled in the art to produce it and use it. Various modifications to the embodiments described will be immediately evident to persons skilled in the art and the generic principles described can be applied to other embodiments and applications without departing from the protective scope of the present invention, as defined in the attached claims. Therefore, the present invention should not be considered limited to the embodiments described and illustrated, but must be given the widest pro-

protective scope in accordance with the principles and characteristics described and claimed here.

[0014] With reference to Figure 2, the number 1 indicates overall a refrigeration system, which is designed to be used in a plant/machine to perform conditioning and/or temperature control and/or refrigeration of a heat-carrying fluid. The heat-carrying fluid can correspond preferably to air, for example, the air of an indoor environment, or water, for example, the water circulating in a plant or a machine.

[0015] The refrigeration system 1 comprises a closed cycle refrigeration circuit 2 which is adapted, in use, to be crossed by a refrigeration fluid corresponding to carbon dioxide CO₂.

[0016] The refrigeration circuit 2 comprises: a compressor device 3, a primary cooler device 4, an expansion device 5, and a heat exchanger device 6, which are connected to one another in sequence, one after the other, by means of a series of relative connection ducts 7.

[0017] In the example illustrated, the heat exchanger device 6 can be arranged in an environment to be cooled or be associated with a hydraulic plant and preferably comprises an evaporator or any similar exchange apparatus, which is designed to accumulate/absorb the heat from the heat-carrying fluid present in the environment or circulating in the hydraulic plant, by means of the previously cooled carbon dioxide in the gaseous state and supplies the carbon dioxide downstream, i.e. at the input to the compressor device 3.

[0018] The compressor device 3 is designed to compress the carbon dioxide received from the heat exchanger device 6 and supplies it at high pressure to the primary cooling device 4 which provides, in turn, for cooling of the carbon dioxide at high pressure and discharging of the heat absorbed into the external environment. According to an embodiment example, the primary cooler device 4 can be associated with or correspond to an air cooling system or similar systems, and therefore be provided with appropriate cooling fans operated in a known manner by electric devices (electric motors). In use, the primary cooler device 4 receives the incoming carbon dioxide at a first temperature t_1 and supplies it outgoing at a second temperature t_2 lower than the first temperature t_1 ($t_2 < t_1$). The second temperature t_2 can be approximately equal to the ambient temperature $t_0 + \Delta t_0$ where Δt_0 is a temperature interval depending substantially on the efficiency of the exchange process with the external air.

[0019] As regards the expansion device 5, it is arranged along the refrigeration circuit 2 downstream of the primary cooler device 4 and upstream of the heat exchanger device 6 and can comprise for example an expansion valve or any similar device designed to cause controlled expansion and/or evaporation of the carbon dioxide maintaining the enthalpy constant, thus reducing temperature and pressure.

[0020] According to a possible embodiment example shown in Figure 2, the refrigeration circuit 2 can further comprise preferably, but not necessarily, a flow rate reg-

ulator device 8, for example an expansion valve which is designed to control/maintain the pressure of the carbon dioxide upstream, i.e. leaving the primary cooler device 4, at a first value predefined on the basis of a control signal generated by an electronic control unit 9.

[0021] According to a possible embodiment example shown in Figure 2, the refrigeration circuit 2 can further comprise, preferably but not necessarily, a liquid receiver/separator tank 12 which is arranged downstream of the flow rate regulator device 8 and is structured so as to contain a given quantity of fluid and separates the carbon dioxide in the gaseous state from the carbon dioxide in the liquid state to supply the latter to the expansion device 5.

[0022] According to a preferred embodiment shown in Figure 2, the refrigeration circuit 2 further appropriately comprises at least one secondary cooling device 10, which is arranged along the refrigeration circuit 2 downstream of the primary cooling device 4 and upstream of the expansion device 5, and is structured to perform a second cooling of the carbon dioxide to supply it outgoing at a third temperature t_3 lower than the second cooling temperature t_2 ($t_3 < t_2$).

[0023] The Applicant has found that by further reducing the temperature t of the carbon dioxide supplied leaving the primary cooling device 4, by means of the secondary cooling device 10, a considerable increase in efficiency of the refrigeration system 1 is obtained.

[0024] According to a preferred embodiment shown in Figure 2, the secondary cooling device 10 can be appropriately associated with an external auxiliary heat source 11, which is designed to supply the secondary cooling device 10 with a heat-carrying fluid FT having the fourth temperature t_4 to transfer the heat from the carbon dioxide to the heat-carrying fluid FT so as to cause a drop in the temperature of the carbon dioxide at the third temperature t_3 .

[0025] According to a preferred embodiment example shown in Figure 2, the secondary cooling device 10 can comprise preferably an internal duct 10a through which the carbon dioxide circulates and preferably, but not necessarily, an internal duct 10b, which can be connected to the external auxiliary heat source 11 through ducts 12 to receive from the same the heat-carrying fluid FT at the fourth temperature t_4 preferably lower than the third temperature t_3 ($t_4 + \Delta t_4 = t_3$). Preferably, the ducts 12, the external auxiliary heat source 11, and the internal duct 10b define an auxiliary cooling circuit 13 designed to extract heat from the carbon dioxide which flows through the duct 10a.

[0026] According to a preferred embodiment example shown in Figure 2, the external heat source 11 can be appropriately a natural thermal energy reservoir (infinite reservoir) i.e. present in nature. According to a possible embodiment, the natural thermal energy reservoir 11 can be a natural water reservoir 15.

[0027] The natural water reservoir 15 can advantageously correspond, by choice, to: a water well, a water

basin, a lake, a torrent, a river, the sea, groundwater, or any other similar natural reservoir in which the water has the fourth temperature t_4 . In this case, the auxiliary circuit 13 can expediently comprise at least one electric pump 14, which can be arranged along a duct 12 of the auxiliary circuit 13 hydraulically connecting the natural reservoir 15 to the duct 10b, and is designed to supply, under the control of the electronic control unit 9, the water (or a heat-carrying fluid FT associated with the water) at the fourth temperature t_4 to the secondary exchanger device 10. The Applicant has found that this solution is extremely simple and inexpensive to produce since it requires, in order to be implemented, only the use of an electric pump and a series of ducts and the secondary exchanger.

[0028] It is understood that according to the present invention, the external heat source 11 is not limited to the natural water reservoir 15 described above, but alternatively, or additionally, can comprise a ground 16. Figure 6 schematically shows this embodiment, in which the ground 16 can be associated with the secondary cooling device 10 via a geothermal system 17. The geothermal system 17 can comprise, for example, one or more geothermal probes 17a (only one of which is illustrated) connected to the duct 10b via the ducts 12 to supply to the same a heat-carrying fluid FT at the fourth temperature t_4 by means, preferably but not necessarily, of the pump 14.

[0029] The Applicant has found that this solution is extremely advantageous as it could expediently use/exploit geothermal systems already present/installed in a domestic system.

[0030] In particular, according to the embodiment shown in Figure 6, the refrigeration system 1 can further comprise a dry cooler 35 consisting, for example, of a water battery provided with cooling fans. The dry cooler 35 is designed to be selectively connected to the probe 17 in such a way that the heat source 16, i.e. the ground, can be thermally regenerated. The Applicant has found that regeneration of the ground is particularly expedient to avoid a reduction in efficiency of the system 1 caused by the thermal drift of the ground.

[0031] Therefore, in order to always ensure maximum efficiency of the system 1 and simultaneously re-balance the original temperature of the ground, the system 1 temporarily connects the dry cooler 15 to the probe/s 17 preferably according to the temperature of the ground and/or the temperature of the heat-carrying fluid FT and at the same time excludes the geothermal probe 17a from the thermal exchange with the secondary exchanger 10. According to the example shown in Figure 6, the system 1 can be provided with at least one three-way valve 42 or any similar apparatus, which is arranged along a relative duct 12 and is configured to connect, by command, the probe 17 to the second cooling device 10 or alternatively to the dry cooler 15.

[0032] The external heat source 11 could further comprise, alternatively or additionally to the solutions described above, an adiabatic cooling device 18. According

to this embodiment, the adiabatic cooling device 18 can preferably integrate/comprise the secondary cooling device 10. For example, the adiabatic cooling device 18 can comprise a box-type metal frame provided with through slits (not illustrated), an evaporator device (not illustrated) defined by a wet pack/evaporator arranged inside the frame, and fan devices (not illustrated) which are coupled to the frame in the area of through openings obtained on the frame and are designed to circulate air inside the frame, thus passing through the wet pack/evaporator. Inside the frame the secondary cooling device 10 can also be arranged/integrated. In use, the flow of air generated by the fans passes through the wet pack/evaporator. The air extracted releases heat to the water of the pack which, by evaporating, causes saturation of the air, lowering the temperature thereof to the fourth temperature t_4 .

[0033] Due to the action of the fans and the wet pack/evaporator, the flow of air at the fourth temperature t_4 is then pushed towards the secondary cooling device 10 and in particular towards its duct 10a thus determining additional cooling of the carbon dioxide circulating in the duct 10a which therefore drops to the third temperature t_3 .

[0034] It is understood that the adiabatic cooling device 18 is not limited to the solution described above but could comprise any similar adiabatic air cooling equipment. For example it is possible to use a cooling device which, instead of being provided with the wet pack/evaporator, is provided with nozzles (not illustrated) designed to generate water, preferably nebulized. In use, the nebulized water generated by the nozzles is crossed by the air extracted by the fans and causes therein a lowering of the temperature to the fourth temperature t_4 . The air cooled to the fourth temperature t_4 is then pushed/blown towards the secondary cooling device 10 thus striking the duct 10a and therefore determining the second cooling of the carbon dioxide circulating in the duct 10a.

[0035] According to a different embodiment shown in Figure 2 (by a broken line), the adiabatic cooling device 18, instead of performing direct cooling of the carbon dioxide by means of the air previously cooled (according to the procedure described above), carries out indirect cooling of the carbon dioxide by means of the heat-carrying fluid circulating through the auxiliary cooling circuit 13. In this case, the adiabatic cooling device 18 can be associated with the auxiliary cooling circuit 13 so as to perform "air" adiabatic cooling of the heat-carrying fluid FT, for example the water, and cause release of the heat from the carbon dioxide to the heat-carrying fluid FT inside the secondary cooling device 10.

[0036] According to a different embodiment, the external heat source 11 could further comprise, alternatively or in addition to the solutions described above, at least one evaporation tower 19 or cooling tower with forced circulation and/or induced flow (not illustrated). The evaporation tower is known and will not be further described, or only to specify that it can have nozzles at the top de-

signed to emit jets of water inside the tower, and is provided, at its base, with a container or well which is designed to collect the water emitted by the nozzles. In use, the water emitted by the nozzles is cooled by the air which rises due to the chimney effect or owing to the presence of fans. The cooled water therefore precipitates towards the base of the tower inside the container.

[0037] According to the present invention the secondary cooling device 10 can be associated with the cooled water container in the tower. For this purpose, for example, the duct 10a could be arranged inside the container so as to be immersed and therefore in contact with the cooled water.

[0038] According to a further embodiment, the external auxiliary heat source 11 could comprise a tank 29 of heat-carrying fluid FT, which is hydraulically connected to the secondary cooling device 10 to circulate in the same the heat-carrying fluid FT, and contains phase change materials (PCM) which, in use, are designed to cool the heat-carrying fluid FT.

[0039] PCMs are materials used for storing thermal energy in the form of latent heat. Release and absorption of the energy occurs during the phase change, when the latent solidification and liquefaction heat is exploited around a constant temperature characteristic of each material. In this specific case, the PCM passes from the solid state to the liquid state receiving the heat coming from the CO₂ cycle.

[0040] The tank 29 can be structured so that the heat exchange between the phase change materials and the heat-carrying fluid FT inside it occurs via a direct or indirect contact. For example, the tank 29 can be structured so that the phase change materials remain in use partially or completely immersed in the heat-carrying fluid FT. According to a different embodiment example, the tank 29 could comprise an internal hydraulic duct (for example one or more probes or coil section/s or similar) arranged in thermal contact (coupled) with the phase change materials. Alternatively the duct can contain the refrigerant itself and therefore constitute the exchanger 10.

[0041] It should be noted that phase change materials are designed to release or absorb energy in the form of latent heat, during the phase change from liquid to solid and vice versa. The amount of heat exchanged during the phase change is much greater than the sensible amount exchanged, and this makes these materials conveniently suitable for storing thermal energy. The phase change materials can be enclosed in containers positioned inside the tank 29. The phase change material containers can be arranged in the tank 29 so as to be in direct contact with the heat-carrying fluid (immersed in the fluid) or in indirect contact (the fluid flows inside a coil). The cooled heat-carrying fluid then in turn cools the carbon dioxide circulating through the secondary cooling device 10.

[0042] Therefore in use, when the temperature of the heat-carrying fluid FT/refrigerant exceeds a predefined temperature threshold, transition of the phase change

materials occurs, from the solid state to the liquid state and, during the transition, the materials absorb heat from the heat-carrying fluid FT and appropriately cool it.

[0043] The Applicant has found it expedient to use phase change materials since they are characterized by a constant temperature useful for cooling the CO₂ to the target temperature.

[0044] According to a different embodiment shown in Figure 3, the secondary cooling device 10 can be associated with and/or contain an auxiliary cooling device 20 of an external auxiliary refrigeration plant 21.

[0045] In the example shown in Figure 3, the external auxiliary refrigeration plant 21 can perform a reverse thermal cycle, for example corresponding to a heat pump for heating utilities, and comprise, in addition to the auxiliary cooler device 20 containing for example the duct 10b, an auxiliary compressor device 22, an auxiliary heat exchanger device 23, and an auxiliary expansion device 24 connected in sequence to one another by means of ducts 25 through which a refrigerant fluid circulates. The performance of a reverse thermal cycle by the external auxiliary refrigeration plant 21 is known and substantially equivalent to the cycle implemented by the refrigeration plant shown in Figure 1 and consequently will not be further described, or only to specify that the auxiliary heat exchanger device 23 can be air or water operated and, in use, is crossed by the heat-carrying fluid FT having the fourth temperature t₄. Furthermore the auxiliary heat exchanger device 23 can be coupled to the secondary cooling device 10 so that the heat of the carbon dioxide circulating in the duct 10a is released to the heat-carrying fluid FT circulating in the auxiliary heat exchanger device 20.

[0046] With reference to Figures 2 and 3, the refrigeration system 1 can be provided with an electronic temperature detection system, which is designed to supply the electronic control unit 9 with electrical signals indicative of the temperature t₄ of the heat-carrying fluid FT supplied by the external heat source 11, the temperature of the heat-transfer fluid FT supplied by the adiabatic cooling device 18, and the temperature t₂ of the carbon dioxide supplied at the outlet of the main cooling device 4.

[0047] For this purpose, the electronic temperature detection system could comprise temperature sensors 26 which can be arranged: at the outlet of the main cooling device 4 to supply a signal tm₂ indicative of the temperature t₂ of the carbon dioxide supplied at the outlet of the main cooling device 4; at the natural water reservoir 15 (if used in this embodiment) to supply a signal tms indicative of the temperature of the heat-carrying fluid FT corresponding to or associated with the water; at the geothermal system 16 (if used in this embodiment) to supply a signal tms indicative of the temperature of the heat-carrying fluid FT cooled by the ground; at the adiabatic cooling device (if used in this embodiment) to supply a signal tms indicative of the temperature of the air or of the cooling water; at the evaporation tower 19 to supply a signal tms indicative of the temperature of the heat-

carrying fluid FT associated with the water cooled in the tower; at the tank 29 provided with the phase change materials (if used in this embodiment) to supply a signal tms indicative of the temperature of the heat-carrying fluid FT.

[0048] The refrigeration system 1 according to the embodiments shown in Figures 2 and 3 can be provided preferably with a by-pass duct 27 which connects the outlet of the primary cooling device 4 to the outlet of the secondary cooling device 10, and valve means 28, for example an electrically operated three-way valve, designed to connect, on the basis of a control signal, the outlet of the primary cooling device 4 to the inlet of the secondary cooling device 10 or, alternatively, to the inlet of the flow rate regulator device 8 thus by-passing the secondary cooling device 10.

[0049] According to a possible embodiment the electronic control unit 9 can be configured so as to determine the temperature t2 downstream of the main cooling device 4 on the basis of the temperature measured tm2 supplied by the measurement sensors 26, determine the temperature t4 on the basis of the temperature measured tms, compare the temperature t2 with a target temperature tob, compare the temperature t2 with the temperature t4, and control the valve means 28 on the basis of the outcome of said comparisons.

[0050] Preferably, the electronic control unit 9 controls the valve means 28 so as to establish communication with the outlet of the primary cooling device 4 at the inlet of the secondary cooling device 10 thus providing the second cooling of the carbon dioxide when a first and a second condition occur/are met, in which the first condition is met/occurs when the temperature t2 is greater than the target temperature ($t2 > tob$) while the second condition is met/occurs when the temperature t2 is greater than the temperature t4.

[0051] Alternatively, when the first and/or the second condition are not met, the electronic control unit 9 controls the valve means 28 so as to establish communication with the outlet of the primary cooling device 4 at the outlet of the secondary cooling device 10 thus excluding the latter from the refrigeration circuit 2.

[0052] The operation of the refrigeration system 1 according to the various embodiments described above can be easily deduced from the above and consequently will not be further described. The use of a secondary cooling device downstream of the primary cooling device traditionally present in reverse cycle refrigeration plants allows the temperature of the carbon dioxide to be further lowered before supplying it at the inlet to the expansion valve and to the heat exchanger device, thus conveniently increasing the plant efficiency.

[0053] Lastly, it is clear that modifications and variations can be made to the refrigeration system and operating method described and illustrated above without departing from the scope of the present invention defined by the attached claims.

[0054] The embodiment illustrated in Figure 4 is rela-

tive to an embodiment variation of the present invention and corresponds to a refrigeration system 30, which is similar to the refrigeration system 1, the component parts of which will be indicated, where possible, by the same reference numbers as those indicating corresponding parts of the refrigeration system 1. The refrigeration system 30 differs from the refrigeration system 1 due to the fact that it comprises a plurality of external heat sources 11, which contain respective heat-carrying fluids FTi and are connected to the secondary cooling device 10 by means of a hydraulic circuit 31 which is structured to selectively establish communication between the external heat sources 11 and the secondary cooling device 10, thus selectively supplying to the latter the heat-carrying fluid FTi of the external heat source 11 selected.

[0055] According to a possible embodiment example shown in Figure 4, the hydraulic circuit 31 can comprise a series of electrically operated on-off valves 32, expediently arranged along relative ducts 12 which connect the external heat sources 11 to the secondary cooling device 10, while the measurement sensors 26 supply to the electronic control unit 9 an electric signal indicative of the temperature tmsi (i, between 1 and n, is the number of sources) associated with the fourth temperature t4 of the relative heat-carrying fluid FTi. The electronic control unit 9 can be configured so as to receive the temperatures tmsi, compare the temperatures tmsi with each other, determine the external heat source 11 with lower temperature tmsi on the basis of the comparison, and operate the valves 32 when the first and second condition occur, so as to associate with the secondary cooling device 10 the external heat source 11 determined, i.e. having lower temperature tmsi and therefore exclude the remaining external heat sources 11.

[0056] According to a possible embodiment, the electronic control unit 9 can monitor continuously or at predefined intervals the temperatures tmsi of the external heat sources 11 and operate the valves 32 to switch/deviate the connection of the secondary cooling device 10 from a current external heat source 11 to another external heat source 11 having a temperature t4 lower than the temperature t4 of the remaining external heat sources 11 and in particular the one supplying the secondary cooling device 10.

[0057] Due to this plant, thermal exchange between the carbon dioxide and the most appropriate external heat source 11, i.e. the one with temperature lower than the others, is always ensured.

[0058] In use the electronic control unit 9 operates the valves 32 to connect to the secondary cooling device 10 the most appropriate external heat source 11, i.e. the one having a temperature t4 lower than the other sources 11, and if the first and second condition are met, it operates the valve 28 to perform the second cooling of the carbon dioxide to supply it at the outlet at the third temperature t3.

[0059] The embodiment illustrated in Figure 5 concerns an embodiment variation relative to a refrigeration system 40, which is similar to the refrigeration systems

1 and 30, and the component parts of which will be indicated, where possible, by the same reference numbers as those that indicate corresponding parts of the refrigeration systems 1 and 30. The refrigeration system 40 differs from the refrigeration systems 1 and 30 due to the fact that it comprises a plurality of secondary cooling devices 10 each of which is associated with a respective external heat source 11, a plurality of by-pass ducts 27 each of which is associated with a corresponding secondary cooling device 10, and a plurality of valve means 28, for example three-way valves, each of which is arranged along a section of duct 7 connected to the inlet of each secondary cooling device 10 and is designed to connect by command the section of duct 7 to the inlet of the secondary cooling device 10 or, alternatively, to the inlet of the by-pass duct 27 thus excluding the secondary cooling device 10 from the passage of the carbon dioxide, then supplying the latter directly downstream of the secondary cooling device 10.

[0060] According to this embodiment, the electronic control unit 9 can be configured so as to receive the temperatures t_{msi} , compare the temperatures t_{msi} with one another, determine the external heat source 11 which has the lowest temperature t_{msi} on the basis of the comparison, and operate the valve means 28 when the first and second condition are met, so as to operate the secondary cooling device 10 associated with the external heat source 11 determined, i.e. presenting the lowest temperature t_{msi} thus excluding the remaining secondary cooling devices 10 from the refrigeration circuit 2.

[0061] It should be pointed out, however, that according to one possible embodiment, the electronic control unit 9 can control the valve means 28 so that the secondary cooling devices 10 are individually and alternatively connected/included in the refrigeration circuit 2, one after the other on the basis of the temperatures t_{mi} measured. For example, the secondary cooling devices 10 can be selectively connected to the refrigeration circuit 2 according to a decreasing sequential order of temperatures measured t_i . In this way, the carbon dioxide is cooled when it sequentially passes through the secondary cooling devices 10 by means of heat-carrying fluids F_{ti} which have progressively decreasing temperatures measured t_{msi} .

[0062] It is understood that the refrigeration system 1 can be structured so that the arrangement of the secondary cooling devices 10 along the section 7 which connects the outlet of the main cooling device 4 to the inlet of the flow rate regulating device 8 is such as to ensure that the carbon dioxide sequentially passes through the secondary cooling devices 10 according to an order of decreasing temperatures t_4 . For example, according to the embodiment shown in Figure 5, the three secondary cooling devices 10 are arranged along the section 7 so that the carbon dioxide leaving the main cooling device 4 passes in sequence through the first secondary cooling device 10 having the temperature $t_4' < t_3$, the second secondary cooling device 10 having the temperature $t_4'' < t_4'$ and

the third secondary cooling device 10 having the temperature $t_4''' < t_4''$.

[0063] It should be noted that the secondary cooling devices 10 can therefore be conveniently exploited individually, allowing exchange with one single external heat source 11, or in series according to the relative temperatures.

[0064] This embodiment conveniently increases the efficiency of the refrigeration system 1 since it allows the carbon dioxide to undergo a series of heat exchanges, in which each heat exchange is performed on the basis of a temperature difference between the carbon dioxide and the heat-carrying fluid supplied by the relative external heat source 11 which, thanks to the multiple exchange, is considerably reduced.

Claims

1. A refrigeration system (1)(30)(40) comprising a primary refrigeration circuit (2) that contains carbon dioxide and is provided with:

- a compressor device (3) to compress the carbon dioxide,
- a primary cooling device (4), which is designed to perform a first cooling of the carbon dioxide leaving said compressor device (3) so as to extract the heat from the carbon dioxide to cause a drop in the temperature of the carbon dioxide from a first temperature (t_1) to a second temperature (t_2),
- expansion means (5) designed to expand the carbon dioxide supplied by the primary cooling device (4), and
- a heat-exchanger device (6) designed to accumulate heat in the expanded carbon dioxide supplied by the expansion means (5) and then supply the carbon dioxide to said compressor device (3);

said system (1) being **characterized in that** it comprises at least one secondary cooling device (10), which is located downstream of said primary cooling device (4) and upstream of said expansion means (5), and is designed to perform a second cooling of the carbon dioxide leaving said primary cooling device (4) to cause a further drop in the temperature of the carbon dioxide from said second temperature (t_2) to a third temperature (t_3), lower than said second temperature (t_2), before the carbon dioxide is supplied to said expansion means (5).

2. A refrigeration system according to claim 1, wherein said secondary cooling device (10) is thermally/hydraulically associated with at least one external auxiliary heat source (11) designed to supply the secondary cooling device (10) with a heat-carrying fluid

(FT) having a fourth temperature (t4), lower than the third temperature (t3), so as to transfer heat from the carbon dioxide to the heat-carrying fluid (FT) and so cause a drop in the temperature of the carbon dioxide to said third temperature (t3).

3. A refrigeration system according to claim 1 or 2, wherein said external auxiliary heat source (11) comprises at least one natural water reservoir (15) containing a heat-carrying fluid (FT) corresponding to, or thermally associated with, water.
4. A refrigeration system according to claim 2, wherein said external auxiliary heat source (11) comprises a ground (16) and a geothermal cooling system (17), which is associated with the ground (16), for cooling the heat-carrying fluid (FT).
5. A refrigeration system according to claim 2, wherein said external auxiliary heat source (11) comprises at least one air-water adiabatic cooling device (18) designed to cool the heat-carrying fluid (FT).
6. A refrigeration system according to claim 2, wherein said external auxiliary heat source (11) comprises cooling means comprising phase change materials (PCM).
7. A refrigeration system according to claim 1, wherein said secondary cooling device (10) is thermally/hydraulically associated with an external auxiliary refrigeration system (21) provided with a compressor device (22) to compress said heat-carrying fluid (FT), a cooling device (23) that is designed to perform cooling of the heat-carrying fluid (FT) leaving said compressor device (22) so as to extract heat therefrom, expansion means (24) designed to expand the heat-carrying fluid (FT) supplied by the cooling device (23), and a heat-exchanger device (20) that is associated with said secondary cooling device (10) and is designed to extract heat from the carbon dioxide circulating in said secondary cooling device (10) so as to reduce its temperature to said third temperature (t3).
8. A refrigeration system according to claim 2, wherein said secondary cooling device (10) is thermally/hydraulically associable with a plurality of external auxiliary heat sources (11); said system comprising valve means (28) controllable to selectively connect said secondary cooling device (10) to a single external auxiliary heat source (11) belonging to said plurality of external auxiliary heat sources (11).
9. A refrigeration system according to claim 2, comprising a plurality of secondary cooling devices (10) connected in series, one after the other, and thermally/hydraulically associated with a plurality of respec-

tive external auxiliary heat sources (11); said system comprising valve means (28) that can be controlled to perform the second cooling of the carbon dioxide by means of one or more secondary cooling devices (10).

10. A refrigeration system according to claim 8 or 9, comprising electronic control means (9) configured so as to determine, via temperature sensor means (26), the temperature (tmsi) of said heat-carrying fluid (FT) supplied by the external auxiliary heat sources (11), and compare said temperatures (tmsi) with each other to determine the external auxiliary heat source (11) having the lower temperature.
11. A refrigeration system according to claim 8 and 10, wherein said electronic control means (9) are configured so as to control said valve means (28) to connect, each time, said secondary cooling device (10) to the determined external auxiliary heat source (11) associated with the lower temperature.
12. A refrigeration system according to claim 9 and 10, wherein said electronic control means (9) are configured so as to control said valve means (28) to selectively connect a secondary cooling device (10) having said lower temperature (tmsi) to said refrigeration circuit (2).
13. A refrigeration system according to claim 9 and 10, wherein said electronic control means (9) are configured so as to control said valve means (28) to connect a series of secondary cooling devices (10) to said refrigeration circuit (2) in order to cause the carbon dioxide to pass through said secondary cooling devices (10) following an order of decreasing temperatures of the respective heat-carrying fluids (FT).
14. A method of operating a refrigeration system (1) that comprises a primary refrigeration circuit (2) which contains carbon dioxide and is provided with:
 - a compressor device (3) to compress the carbon dioxide,
 - a primary cooling device (4), which is designed to perform a first cooling of the carbon dioxide leaving said compressor device (3) so as to extract the heat from the carbon dioxide to cause a drop in the temperature of the carbon dioxide from a first temperature (t1) to a second temperature (t2),
 - expansion means (5) designed to expand the carbon dioxide supplied by the primary cooling device (4), and
 - a heat-exchanger device (6) designed to accumulate heat in the expanded carbon dioxide supplied by the expansion means (5) and then supply the carbon dioxide to said compressor

device (3);

said method being **characterized by** performing a second cooling of the carbon dioxide by means of a secondary cooling device (10), which is located downstream of said primary cooling device (4) and upstream of said expansion means (5), to cause a further drop in the temperature of the carbon dioxide from said second temperature (t2) to a third temperature (t3), lower than said second temperature (t2), before it is supplied to said expansion means (5).

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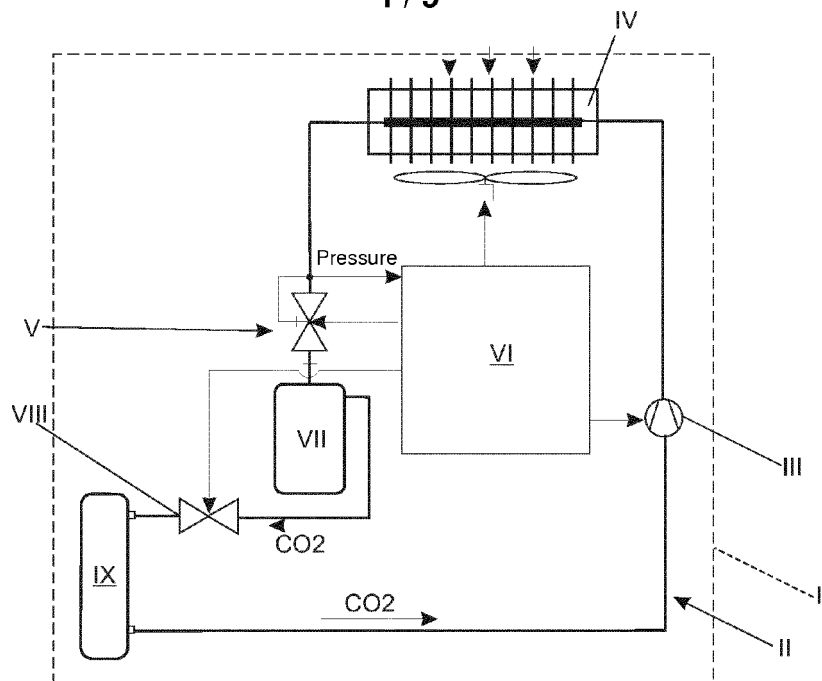


Fig. 1

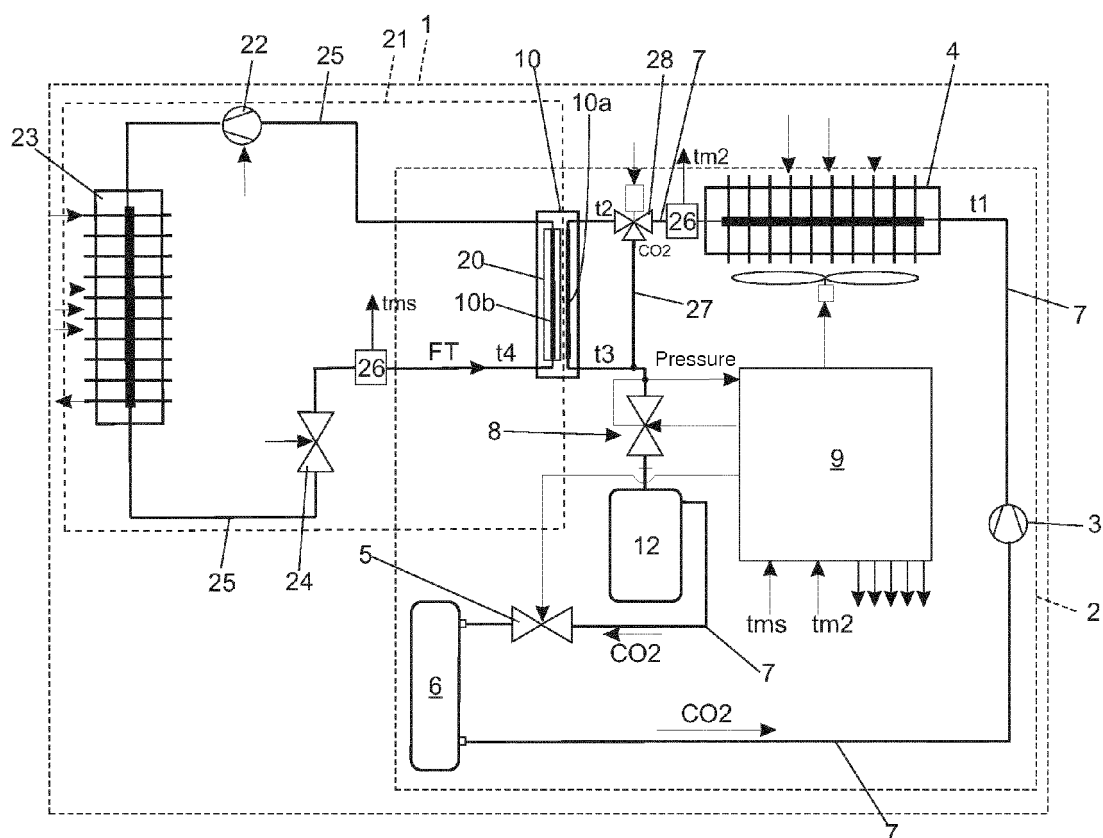


Fig. 3

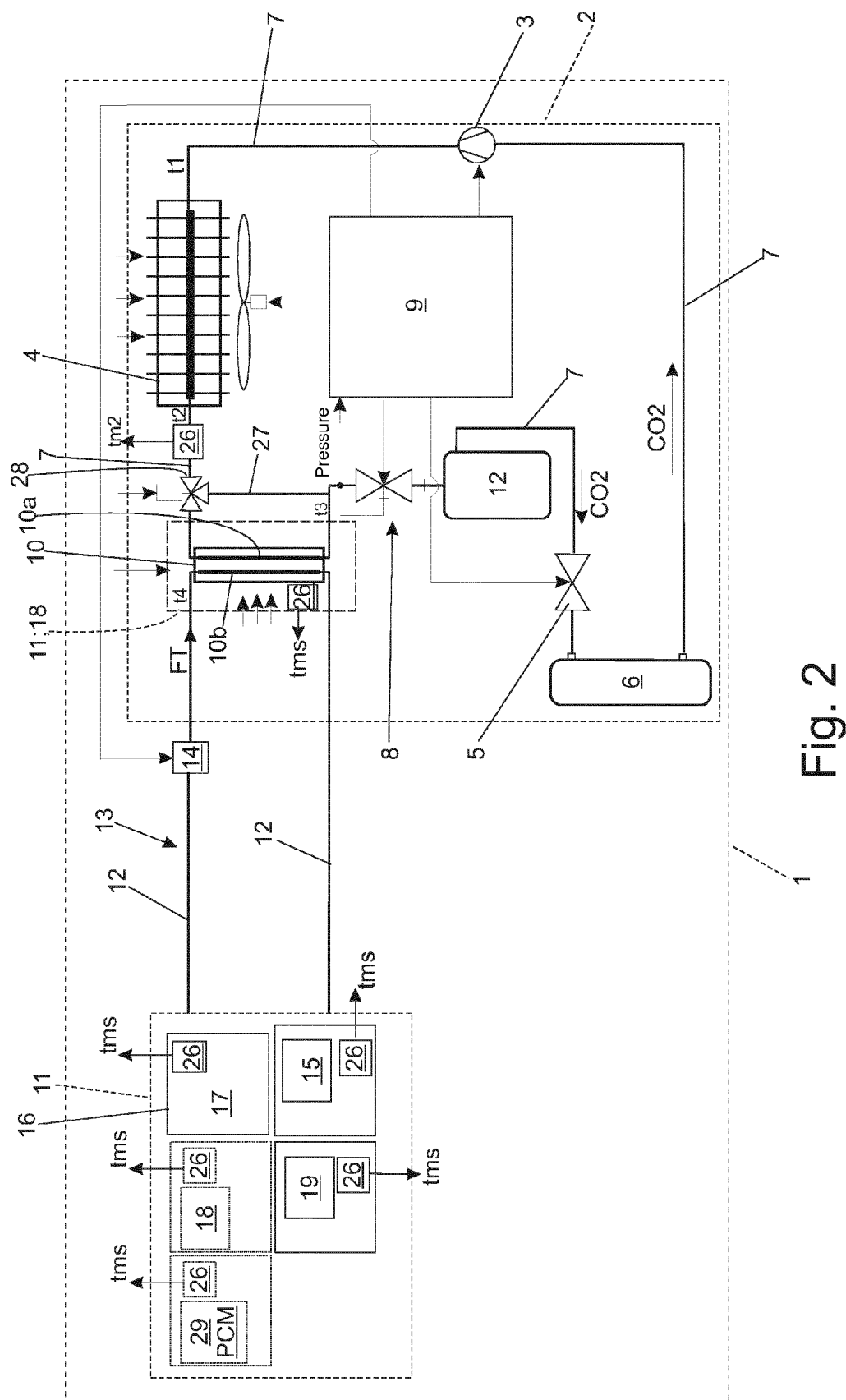


Fig. 2

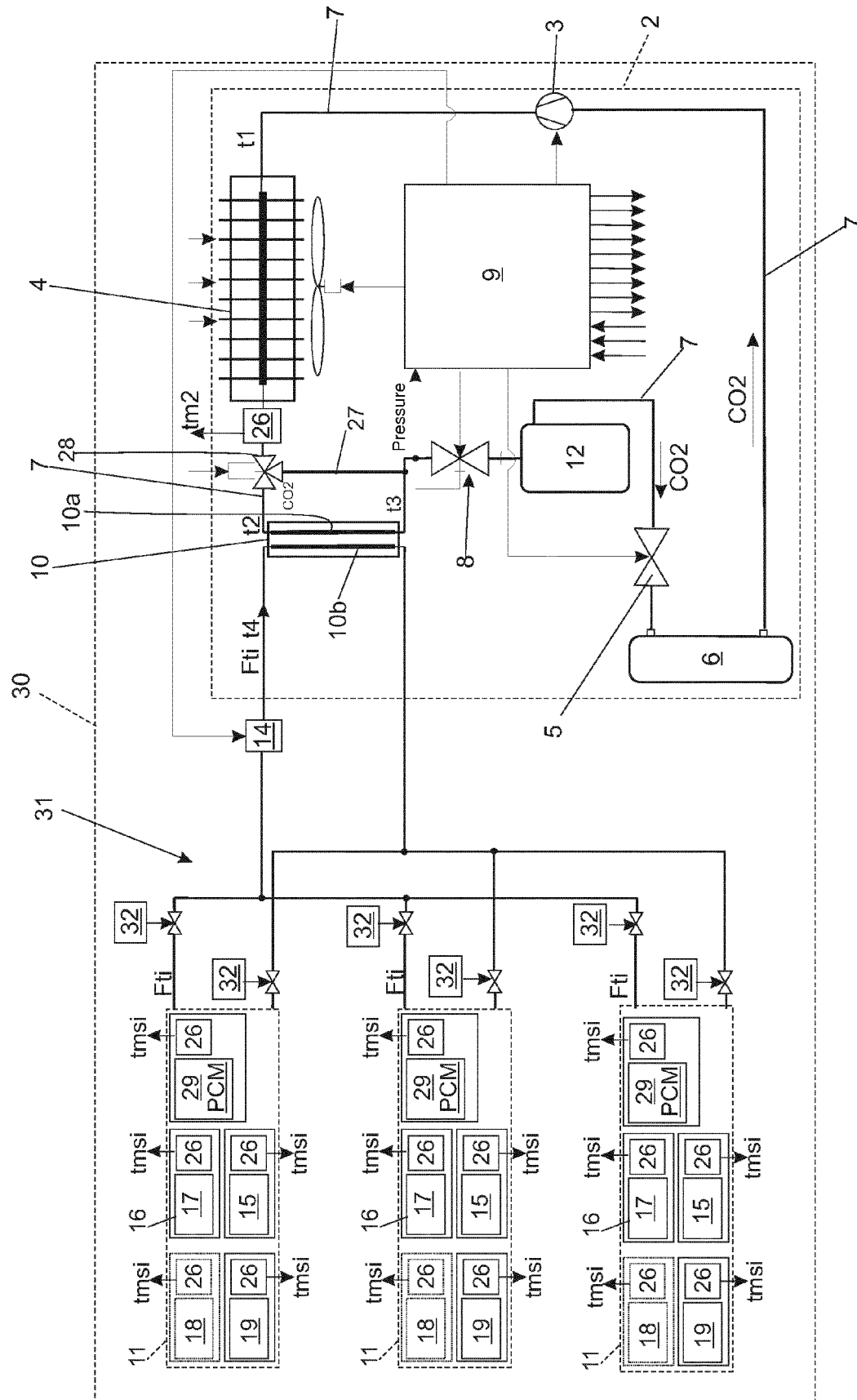


Fig. 4

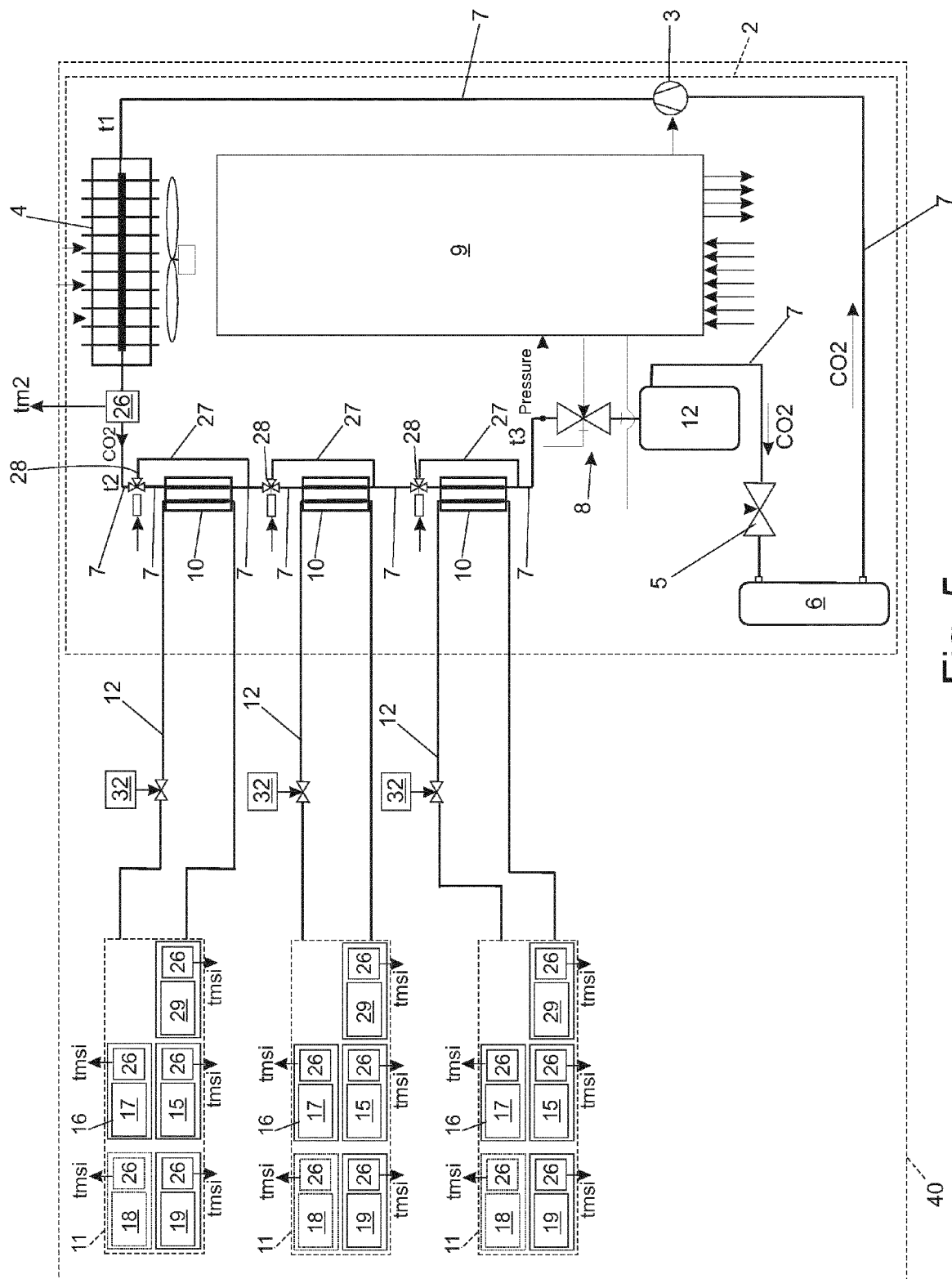


Fig. 5

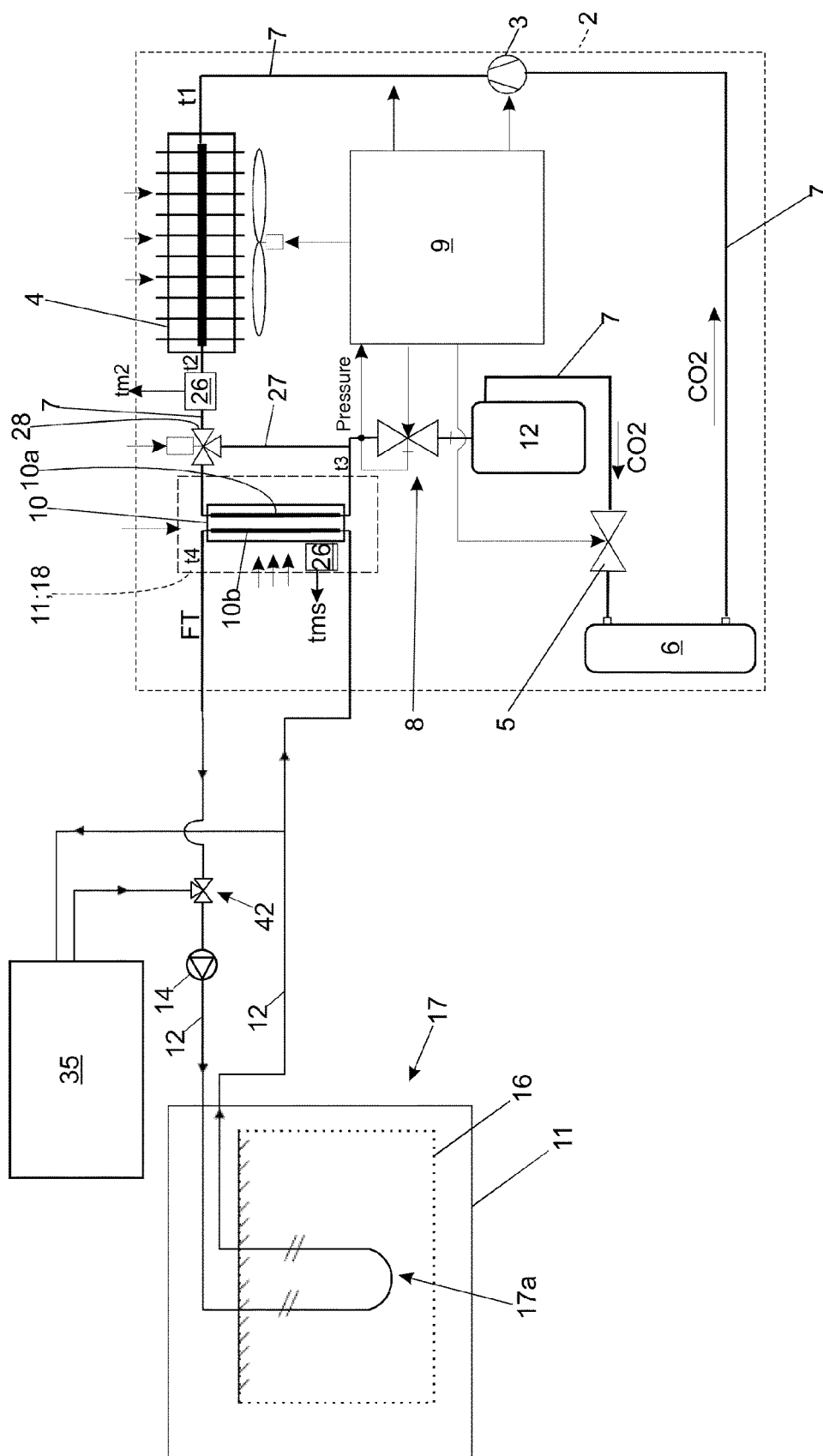


Fig. 6



EUROPEAN SEARCH REPORT

Application Number
EP 16 17 7348

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			TECHNICAL FIELDS SEARCHED (IPC)
			F25B
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 23 September 2016	Examiner Amous, Moez
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82