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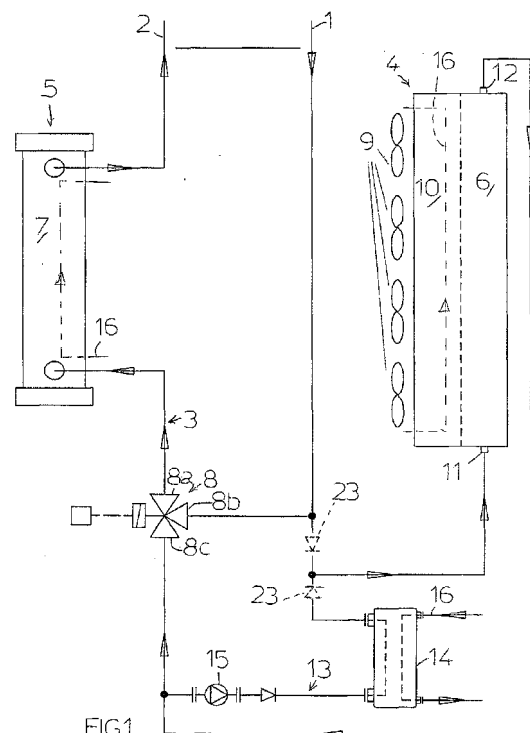
BA ME(30) Priority: **13.06.2011 IT MI20111061**(71) Applicant: **Climaveneta S.p.A.****31100 Treviso (IT)**

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(57) A system for the refrigeration of a liquid suitable for circulating between at least one inlet (1) and at least one outlet (2) of a primary liquid cooling circuit (3), comprises at least a first air-cooled refrigeration unit (4) having at least a first air-cooled cooling coil (6) inserted on the primary liquid cooling circuit (3), at least a second refrigeration unit (5) with a cooling cycle having at least one evaporator (7) inserted on the primary liquid cooling circuit (3) in cascade with the first air-cooled cooling coil (6), means for shutting off the first air-cooled cooling coil (6) from the primary liquid cooling circuit (3), forced air ventilation means suitable for acting on at least the first air-cooled cooling coil (6) and on at least a second air-cooled cooling coil (10) provided for at least one condenser of the second refrigeration unit (5) for condensing the refrigerant fluid operating in the cooling cycle, there being further provided a secondary liquid circuit (13) on which at least the first air-cooled cooling coil (6) and at least one secondary exchanger (14) for subcooling the refrigerant fluid leaving the second air-cooled cooling coil are inserted.



Description

[0001] The present invention relates to a system for the refrigeration of a liquid and a method for controlling the system.

[0002] The present invention relates in particular to what is commonly known as a free-cooling system, which generally has a first air-cooled refrigeration unit having a first air-cooled cooling coil inserted on the liquid cooling circuit, a second refrigeration unit with a cooling cycle having an evaporator inserted on the liquid cooling circuit in cascade with the first air-cooled cooling coil, a three-way valve for shutting off the first air-cooled cooling coil from the liquid cooling circuit, and fans designed to act simultaneously on the first air-cooled cooling coil and on a second air-cooled cooling coil placed side by side with the first cooling coil and provided for a condenser of the second cooling unit for the condensation of the refrigerant fluid operating in the cooling cycle.

[0003] When the outdoor air temperature is lower than the temperature of the liquid to be chilled, the free-cooling system enables autonomous cooling of the liquid to be favoured thanks to a direct exchange of heat with the air.

[0004] The liquid to be chilled generally consists of water or a solution of water and glycol even if the same concepts can be extended to any liquid whatsoever. Three different operating modes can be distinguished according to the temperature of the outdoor air compared to the temperature to which it is desired to cool the liquid and the cooling load to be handled.

[0005] Let us indicate the "set point" temperature we want to cool the liquid to as $T_{\text{set-point}}$, the air temperature as T_{air} , the temperature of the liquid on the outlet side of the first cooling coil as T_{outfc} and the temperature of the liquid on the outlet side of the evaporator as T_{outevap} .

[0006] In the free-cooling operating mode, $T_{\text{air}} < T_{\text{outfc}} = T_{\text{outevap}} = T_{\text{set-point}}$.

[0007] When the air temperature is lower than the temperature we want to cool the liquid to ($T_{\text{set-point}}$), the three-way valve diverts the flow of the liquid to be cooled toward the first cooling coil so that it is cooled by a direct exchange of heat with the outdoor air. If the air temperature is sufficiently low to cool the liquid to its set point temperature the compressor of the cooling cycle will not start up and the system will work substantially as a dry cooler, using the fans only.

[0008] In the mixed operating mode, the air temperature is lower than the temperature of the liquid to be cooled but $T_{\text{outfc}} > T_{\text{set-point}} = T_{\text{outevap}}$. When the air temperature is lower than the temperature of the liquid to be chilled but the temperature of the liquid leaving the first cooling coil has not yet reached the set-point temperature, the liquid is further cooled in the evaporator thanks to the cooling circuit of the second refrigeration unit.

[0009] The efficiency of this constructive solution in this operating mode is tied to the fact that it exploits the air flow delivered by the fans to achieve a dual effect: to cool

the liquid in the first cooling coil and cause the refrigerant fluid to condense in the second cooling coil.

[0010] In the chiller operating mode the air temperature is higher than the temperature of the liquid to be chilled.

[0011] When the outdoor air temperature is higher than the temperature of the liquid to be chilled it is not possible to work in the free-cooling mode: the three-way valve is diverted toward the evaporator and the system works by cooling the liquid thanks solely to the cooling circuit of the second refrigeration unit. Compared to a simple chiller of equal size, a free-cooling system displays a much higher efficiency in the free-cooling and mixed operating modes, whereas it has limits in the chiller operating mode.

[0012] The main defect of a traditional free-cooling system is tied to the fact that, when it works in the chiller operating mode because the outdoor air temperature is higher than the temperature of the liquid to be chilled, the first cooling coil, despite being inactive, increases the pressure drops on the air side, thus reducing the useful flow that runs into the second cooling coil.

[0013] In other words, the first cooling coil placed side by side with the second cooling coil causes an increase in the condensation temperature to the detriment of the efficiency of the second refrigeration unit, the maximum cooling capacity that can be provided and the operating limits of the system in terms of maximum air temperature.

[0014] The presence of the first cooling coil limits the maximum number of rows that can be dedicated to the second cooling coil, both because of reasons tied to physical bulk and to avoid excessively increasing the pressure drops on the air side, which would lead the fans to work in a non-efficient point of their characteristic curve.

[0015] Compared to a chiller of equal size, a traditional free-cooling system thus has a lower cooling yield and efficiency.

[0016] Alternatively, it is possible to increase the rotation speed of the fans to offset the higher pressure drops of the first cooling coil and dissipate a higher condensation capacity; however, this causes an increase in the noisiness and electrical input of the fans.

[0017] The technical task the present invention has set itself is therefore to realize a refrigeration system of the free-cooling type, which allows the aforementioned technical drawbacks of the prior art to be eliminated.

[0018] Within the scope of this technical task, one object of the invention is to realize a refrigeration system of the free-cooling type, which has an improved efficiency and cooling yield when it works in the chiller mode.

[0019] The technical task, as well as these and other objects according to the present invention are achieved by realizing a system for the refrigeration of a liquid suitable for circulating between at least one inlet and at least one outlet of a primary liquid cooling circuit, comprising at least a first air-cooled refrigeration unit having at least a first air-cooled cooling coil inserted on the primary liquid cooling circuit, at least a second refrigeration unit with a cooling cycle having a refrigerant fluid circuit with at least one evaporator inserted on the primary liquid cooling cir-

cuit in cascade with the first air-cooled cooling coil, and means for shutting off the first air-cooled cooling coil from the primary liquid cooling circuit inserted on the primary circuit, **characterized in that** it comprises forced air ventilation means suitable for acting on at least the first air-cooled cooling coil and on at least a second air-cooled cooling coil provided for at least a condenser of the second cooling unit for the condensation of the refrigerant fluid operating in the cooling cycle, in that said first and second air-cooled cooling coils are side by side and share said forced ventilation means, and in that it includes a secondary liquid circuit on which at least the first air-cooled cooling coil and at least one secondary exchanger for subcooling the refrigerant fluid leaving the second air-cooled cooling coil are inserted.

[0020] The present invention also discloses a method for controlling said system, **characterized in that** the first cooling coil, when it is shut off from the primary circuit, is included into a secondary liquid circuit on which there is also included at least one secondary exchanger for subcooling the refrigerant fluid leaving the second air-cooled cooling coil, and the circulation of liquid in the secondary circuit is activated.

[0021] Preferably, in said secondary exchanger said liquid and said refrigerant fluid circulate in countercurrent.

[0022] In the secondary circuit a lower liquid flow rate is established than in the primary circuit.

[0023] Preferably, the number of feed manifolds of the first cooling coil is decreased when it is included into the secondary circuit, in such a way as to increase the number of passages of liquid through the first cooling coil.

[0024] The system exploits the presence of the first cooling coil when the surrounding conditions preclude working in the free-cooling or mixed mode, including it in the secondary circuit which enables the refrigerant fluid leaving the second cooling coil to be subcooled.

[0025] When the system works in the chiller mode, the shut-off means then shut off the first cooling coil from the first circuit and divert the fluid to be chilled directly toward the evaporator, while the circulation of liquid in the second circuit is activated.

[0026] Essentially, the system exploits the presence of the first cooling coil, which would otherwise be quiescent in that operating mode, in order to exchange additional heat with the outdoor air.

[0027] Other features of the present invention are defined in the other claims.

[0028] Additional features and advantages of the invention will be more apparent from the description of preferred, but not exclusive, embodiments of the refrigeration system according to the invention, illustrated by way of non-restrictive example in the appended drawings, in which:

figure 1 shows the plumbing diagram of the system according to a first preferred embodiment of the invention in which the first cooling coil comprises only one liquid feed manifold (the arrows in the primary

cooling circuit indicate the path of the liquid in the free cooling and mixed operating modes);

figure 2 shows the plumbing diagram of the system according to a second preferred embodiment of the invention in which the first cooling coil comprises a number of feed manifolds which can be modified according to the operating regime (the arrows in the primary cooling circuit indicate the path of the liquid in the free cooling and mixed operating modes);

figure 3 shows the first cooling coil of figure 2 in the free cooling and mixed operating modes of the system (the arrows indicate the path of the liquid); figure 4 shows the first cooling coil of figure 2 in the chiller operating mode of the system (the arrows indicate the path of the liquid);

figures 5 and 6 and figure 7 respectively show a first and respectively a second variant of the secondary exchanger which in this case is integrated into the first cooling coil of a system according to a third preferred embodiment of the invention (the arrows indicate the path of the liquid and of the refrigerant fluid).

[0029] Equivalent parts of the various preferred embodiments will be indicated with the same numerical reference.

[0030] With reference to the figures, the free-cooling system for the refrigeration of a liquid suitable for circulating between at least one and in particular only one inlet 1 and at least one and in particular only one outlet 2 of a primary liquid cooling circuit 3, comprises at least one and in particular only one first air-cooled refrigeration unit 4 and at least one and in particular only one second refrigeration unit 5 with a cooling cycle having a refrigerant fluid circuit 16. The first refrigeration unit 4 has at least one and in particular only one first air-cooled cooling coil 6 inserted on the primary liquid cooling circuit 3. The second refrigeration unit 5 with a cooling cycle has at least one and in particular only one evaporator 7 inserted on the primary liquid cooling circuit 3 in cascade with the first air-cooled cooling coil 6.

[0031] The system includes means for shutting off the first air-cooled cooling coil 6 from the primary liquid cooling circuit 3.

[0032] The shut-off means preferably comprise a valve 8 with three passageways 8a, 8b, 8c inserted on the primary circuit 3, or an analogous device, e.g. two two-way valves that perform the same function.

[0033] The passageway 8a is connected to the feed inlet of the evaporator 7, the passageway 8b is connected to every manifold acting as a feed manifold 11 of the first air-cooled cooling coil 6 in the free-cooling and mixed operating modes, and the passageway 8c is connected to every manifold acting as an outlet manifold 12 of the first air-cooled cooling coil 6 in the free-cooling and mixed operating modes.

[0034] The system further comprises forced air ventilation means, in particular fans 9, designed to act both on at least the first air-cooled cooling coil 6 and on at

least one and in particular only one second air-cooled cooling coil 10 which is placed side by side with the first air-cooled cooling coil 6 and provided for at least one and in particular only one condenser of the second cooling unit 5 for condensing the refrigerant fluid operating in the cooling cycle.

[0035] The salient aspect of the invention consists in the fact of providing a secondary liquid circuit 13 on which the first air-cooled cooling coil 6 and at least one and in particular only one secondary exchanger 14 for subcooling the refrigerant fluid leaving the second air-cooled cooling coil 10 are inserted. In some applications, as is evident from the appended figures, in the secondary liquid circuit 13 there are also provided means for forced circulation of the liquid in the secondary circuit 13, in particular a circulation pump 15.

[0036] In the system according to the first preferred embodiment, the first cooling coil includes a single feed manifold 11 and a single outlet manifold 12.

[0037] It may also be advantageous to equip the first air-cooled cooling coil 6 with two or more feed manifolds 11.

[0038] In such a case in the secondary circuit 13 it is possible to provide valve means for modifying the number of feed manifolds 11 of the first air-cooled cooling coil 6 when it is shut off from the primary circuit 3.

[0039] In the system according to the second preferred embodiment, the first air-cooled cooling coil 6 has two manifolds which act as liquid feed manifolds 11 and one manifold which acts as a liquid outlet manifold 12 in the free-cooling and mixed operating modes.

[0040] In this specific case, the valve means comprise a valve 17 with three passageways 17a, 17b, 17c, and a shut-off valve 18 applied on the manifold which acts as an outlet manifold 12 in the free-cooling and mixed operating modes.

[0041] In the system according to the third preferred embodiment, the secondary exchanger 14 is integrated with the first air-cooled cooling coil 6.

[0042] In such a case the secondary exchanger 14 can have pipes 19 for the refrigerant fluid embedded in pipes 20 for liquid provided for the first air-cooled cooling coil 6 (figure 5 and 6).

[0043] In this specific case there is also provided at least a three-way valve (not shown) inserted on the refrigerant fluid circuit 16 so as to divert the refrigerant fluid leaving the second air-cooled cooling coil 10 toward the refrigerant fluid pipes 19 when the first air-cooled cooling coil 6 is shut off from the first circuit 3.

[0044] Alternatively, the same pipes leaving the condensing coil 10 can pass through or exploit the finned surface of the free-cooling coil 6 and thus act as a secondary exchanger without an additional circulator being necessarily provided. Some pipes of the rows of the free-cooling coil 6 can thus be dedicated to the liquid refrigerant leaving the condenser coil 10, as illustrated in figure 7.

[0045] The system is designed with features such that

there cannot be any interference between the first and second circuits 3 and 13 in the chiller operating mode, even without it being necessary to provide specific separation valves.

[0046] Optionally, as shown, it is possible to provide one-way valves 23 in order to avoid interference between the liquid circulating in the primary circuit 3 and the liquid circulating in the secondary circuit 13 in the chiller operating mode. The system according to the first and second preferred embodiments operates in the following manner.

[0047] In the free-cooling and mixed operating modes, the system functions in the traditional manner, as described previously. The valve 8 is in a status in which the passageway 8b is closed and the passageways 8a and 8c are open.

[0048] In the chiller operating mode, the valve 8 changes status so as to divert the liquid toward the evaporator 7 (passageways 8a and 8b open, passageway 8c closed), and the circulation pump 15 is activated, causing the liquid present in the first air-cooled cooling coil 6 to circulate inside the secondary exchanger 14.

[0049] The liquid, preferably circulating countercurrent relative to the refrigerant fluid leaving the second cooling coil 10, subcools the refrigerant fluid and transfers the heat to the air in the first cooling coil 6.

[0050] This essentially serves to create additional rows in the second cooling coil 10 which better exploit the air delivered by the fans 9, which are already running in order to dissipate the condensation capacity of the second cooling unit 5. The flow of liquid delivered by the circulation pump 15 of the secondary circuit 13 is much lower than that delivered in the primary circuit 3 of the system, as the capacity to be dissipated is much lower.

[0051] In order to maintain the pumping expenses of the secondary circuit 13 low and simultaneously ensure that the velocity of the liquid is high enough to permit good exchange coefficients in the first cooling coil 6, it is preferable to use a system according to the second preferred embodiment.

[0052] This circuit solution decreases the number of feed manifolds of the first cooling coil 6 when it is included into the secondary circuit 13, in such a way as to increase the number of passages of the liquid through the first cooling coil 6. In this manner, both the exchange surface on the air side - unchanged - and the exchange coefficients on the water side are optimally exploited. Practically speaking, when the system works in the free-cooling or mixed mode the valve 17 has the passageways 17a and 17b open and the passageway 17c closed, whereas the shut-off valve 18 is open.

[0053] This status of the valves 17 and 18 attributes to two manifolds the function of feed manifolds 11 and to one manifold the function of outlet manifold 12.

[0054] In contrast, when the system works in the chiller mode the valve 17 has the passageways 17b and 17c open and the passageway 17a closed, whereas the shut-off valve 18 is closed.

[0055] This status of the valves 17 and 18 closes the manifold that acted as an outlet manifold in the previous status and attributes the function of outlet manifold 12 to one of the manifolds that acted as a feed manifold in the previous status.

[0056] The system according to the third preferred embodiment operates in the following manner.

[0057] Similarly to the previous case, when the system works in the chiller mode the three-way valve (not shown) on the cooling circuit 16 diverts the refrigerant fluid leaving the second cooling coil 10 inside the pipes 19.

[0058] The circulation pump 15 is activated, where provided, and serves to increase the exchange of heat between the refrigerant fluid, liquid and ambient air. As noted, in the embodiment of figure 7 no circulation pump 15 is provided.

[0059] When the system works in the free-cooling or mixed mode, in contrast, the three-way valve (not shown) takes on a status whereby the refrigerant fluid leaving the second cooling coil 10 cannot be fed to the pipes 19, and the circulation pump 15 is switched off.

[0060] The refrigeration system according to the invention has various advantages deriving from the subcooling of the condensed refrigerant fluid.

[0061] It increases the cooling yield of the second refrigeration unit 5 thanks to the higher enthalpy jump produced by the evaporator 7.

[0062] This consequently increases the efficiency at any given time and overall seasonal efficiency of the system, understood as the ratio between cooling capacity and input power.

[0063] The efficiency of the evaporator 7 increases, which means a higher evaporation temperature, the exchanged power being equal, thanks to the lower vapor quality it is fed.

[0064] The noise tied to fan operation is decreased, the cooling yield being equal, because the surface of exchange with the air is increased.

[0065] The refrigeration system and the method for controlling it thus conceived is susceptible of numerous modifications and variants, all falling within the scope of the inventive concept; moreover, all the details may be replaced with other technically equivalent elements.

[0066] In practice, the materials used, as well as the dimensions, can be any whatsoever according to need and the state of the art.

Claims

1. A system for the refrigeration of a liquid suitable for circulating between at least one inlet (1) and at least one outlet (2) of a primary liquid cooling circuit (3), comprising at least a first air-cooled refrigeration unit (4) having at least a first air-cooled cooling coil (6) inserted on the primary liquid cooling circuit (3), at least a second refrigeration unit (5) with a cooling cycle having a refrigerant fluid circuit (16) with at least

one evaporator (7) inserted on the primary liquid cooling circuit (3) in cascade with the first air-cooled cooling coil (6), means for shutting off the first air-cooled cooling coil (6) from the primary liquid cooling circuit (3) inserted on the primary circuit (3), **characterized in that** it comprises forced air ventilation means (9) suitable for acting on at least the first air-cooled cooling coil (6) and on at least a second air-cooled cooling coil (10) provided for at least one condenser of the second refrigeration unit (5) for condensing the refrigerant fluid operating in the cooling cycle, **in that** said first and second air-cooled cooling coils (6, 10) are side by side and share said forced ventilation means (9), and **in that** it includes a secondary liquid circuit (13) on which at least the first air-cooled cooling coil (6) and at least one secondary exchanger (14) for subcooling the refrigerant fluid leaving the second air-cooled cooling coil are inserted.

2. The liquid refrigeration system according to the preceding claim, **characterized in that** means for forced circulation of the liquid are inserted on said secondary liquid circuit (13).

3. The liquid refrigeration system according to any of the preceding claims, **characterized in that** in said secondary exchanger (14) the liquid and condensed refrigerant fluid leaving the second air-cooled cooling coil (10) circulate in countercurrent.

4. The liquid refrigeration system according to any of the preceding claims, **characterized in that** said means for shutting off the first air-cooled cooling coil comprise a three-way valve (8) or two two-way valves.

5. The liquid refrigeration system according to any of the preceding claims, **characterized in that** said first air-cooled cooling coil (6), when it is included into the primary circuit (3), has at least two liquid feed manifolds (11).

6. The liquid refrigeration system according to any of the preceding claims, **characterized in that** in the secondary circuit there are present valve means for decreasing the number of liquid feed manifolds (11) for the first air-cooled cooling coil (6) when it is shut off from the primary circuit (3).

7. The liquid refrigeration system according to the preceding claim, **characterized in that** said valve means comprise at least one three-way valve (17) and one shut-off valve (18).

8. The liquid refrigeration system according to any of the preceding claims, **characterized in that** said secondary exchanger (14) is integrated with said first

air-cooled cooling coil (6).

9. The liquid refrigeration system according to the preceding claim, **characterized in that** said secondary exchanger (14) has pipes (19) for the refrigerant fluid embedded in pipes (20) for liquid provided for said first air-cooled cooling coil (6). 5
10. The liquid refrigeration system according to either of claims 8 and 9, **characterized in that** it comprises at least one three-way valve inserted on the refrigerant fluid circuit for diverting the refrigerant fluid leaving the second air-cooled cooling coil (10) toward said refrigerant fluid pipes (19) when the first air-cooled cooling coil (6) is shut off from the primary circuit (3). 10 15
11. A method for controlling a refrigeration system for liquid circulating between at least one inlet (1) and at least one outlet (2) of a primary liquid cooling circuit (3), said system comprising at least a first air refrigeration unit (4) having at least a first air-cooled cooling coil (6) inserted on the primary liquid cooling circuit (3), at least a second cooling-cycle refrigeration unit (5) having at least one evaporator (7) inserted on to the primary liquid cooling circuit (3) in cascade with the first air-cooled cooling coil (6), means for shutting off the first air-cooled cooling coil (6) from the primary liquid cooling circuit (3), forced air ventilation means suitable for acting on at least the first air-cooled cooling coil (6) and on at least a second air-cooled cooling coil (10) provided for at least one condenser of the second refrigeration unit (5) for condensing the refrigerant fluid operating in the cooling cycle, **characterized in that** the first cooling coil (6), when it is shut off from the primary circuit (3), is included into a secondary liquid circuit (13) to which there is also included at least one secondary exchanger (14) for subcooling the refrigerant fluid leaving the second air-cooled cooling coil (10), and the circulation of liquid in the secondary circuit (13) is activated. 20 25 30 35 40
12. The method for controlling a liquid refrigeration system according to the preceding claim, **characterized in that** in said secondary exchanger (14), said liquid and said refrigerant fluid circulate in countercurrent. 45
13. The method for controlling a liquid refrigeration system according to either of claims 11 and 12, **characterized in that** it establishes a lower liquid flow rate in the secondary circuit (13) than in the primary circuit (3). 50
14. The method for controlling a liquid refrigeration system according to the preceding claim, **characterized in that** it decreases the number of feed manifolds (11) of the first cooling coil (6) when it is included 55

into the secondary circuit (13), in such a way as to increase the number of passages of liquid through the first cooling coil (6).

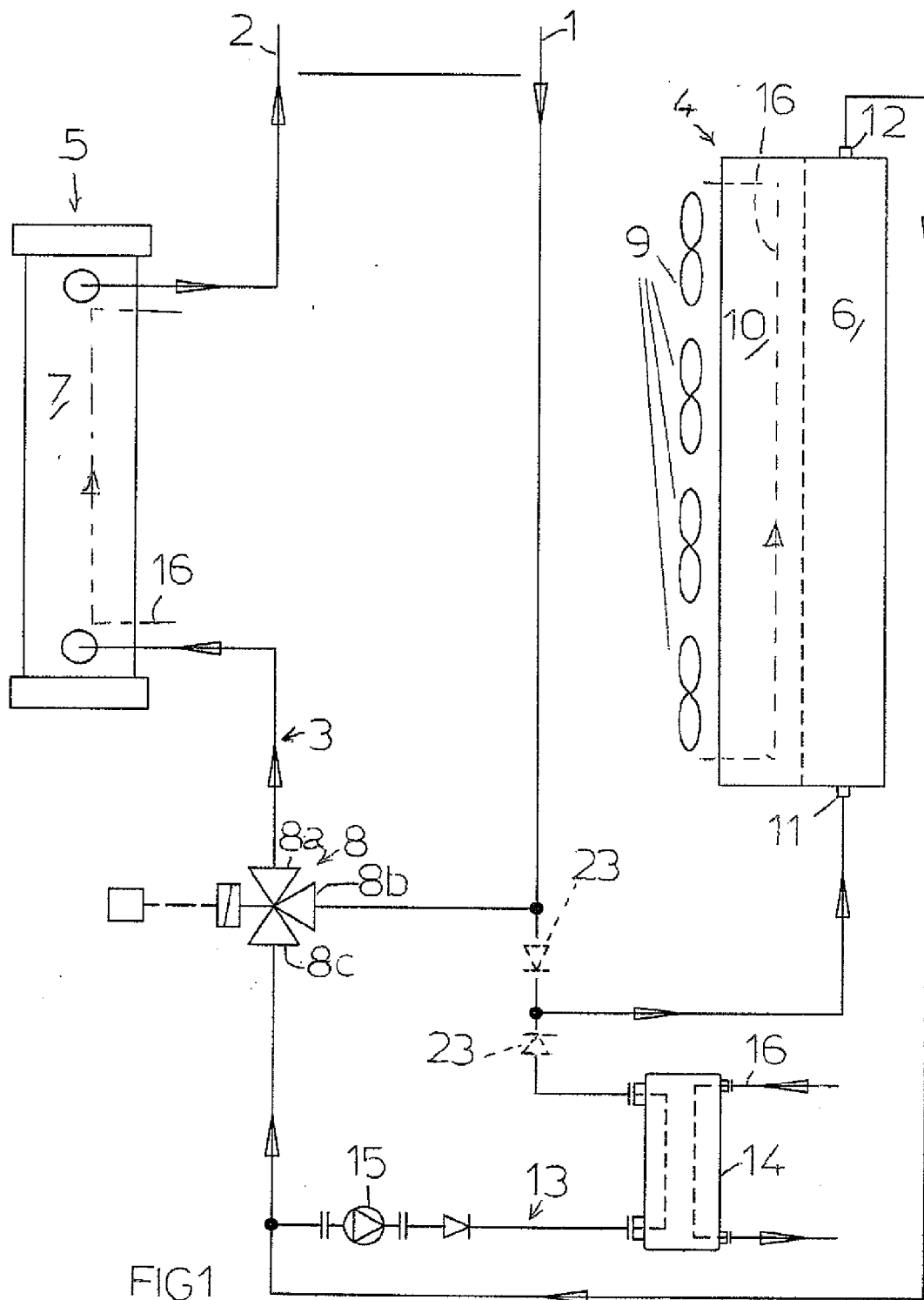
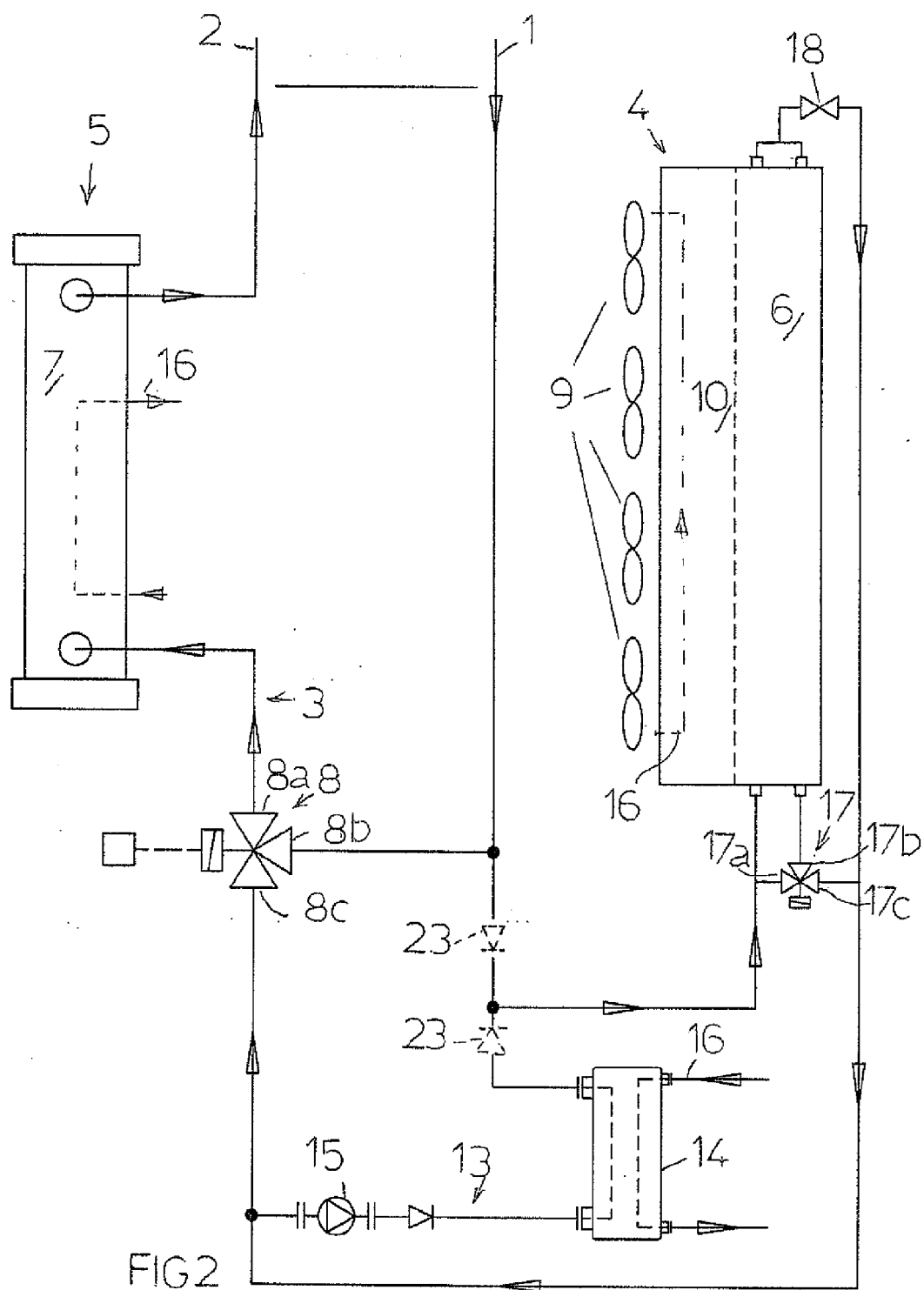


FIG1



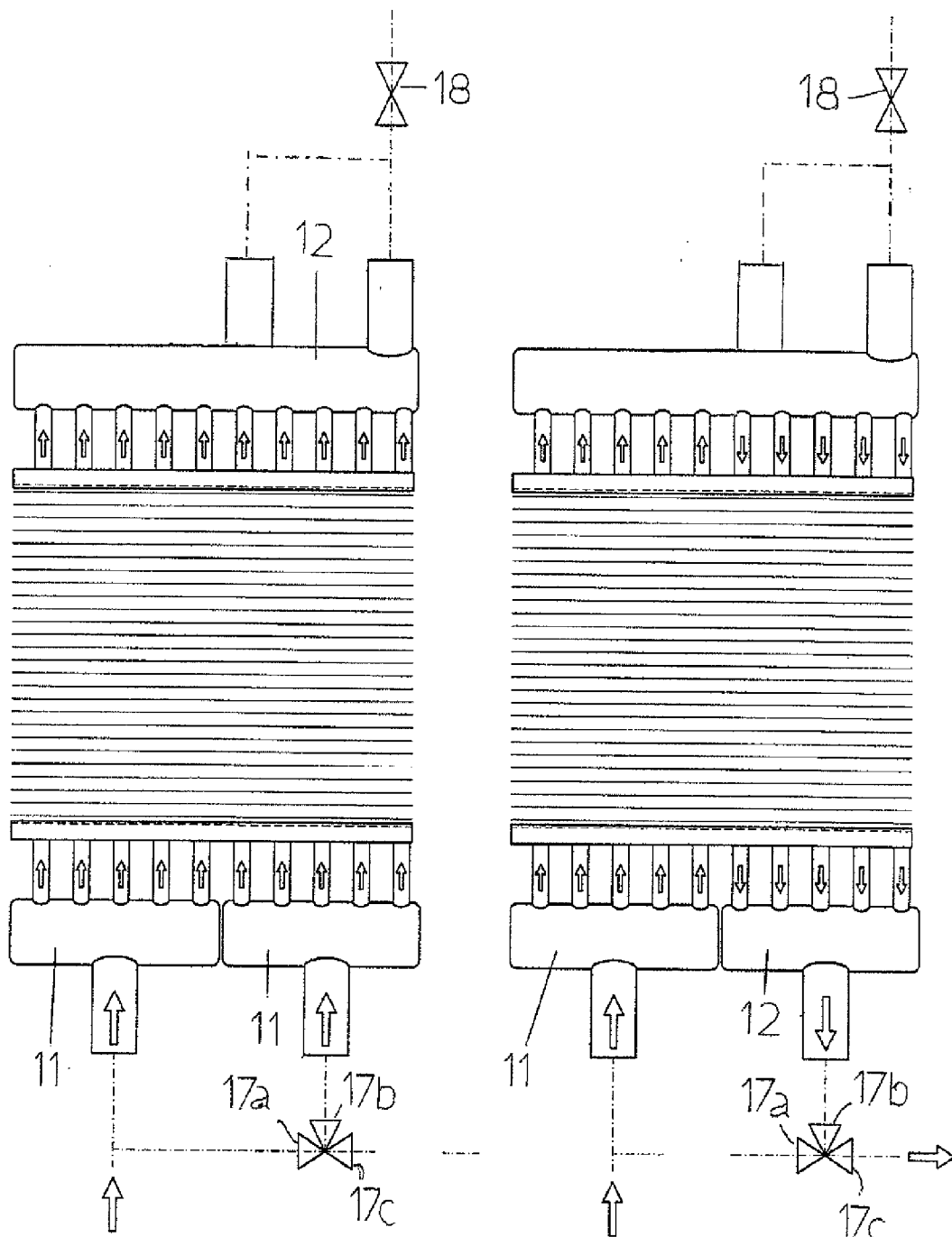
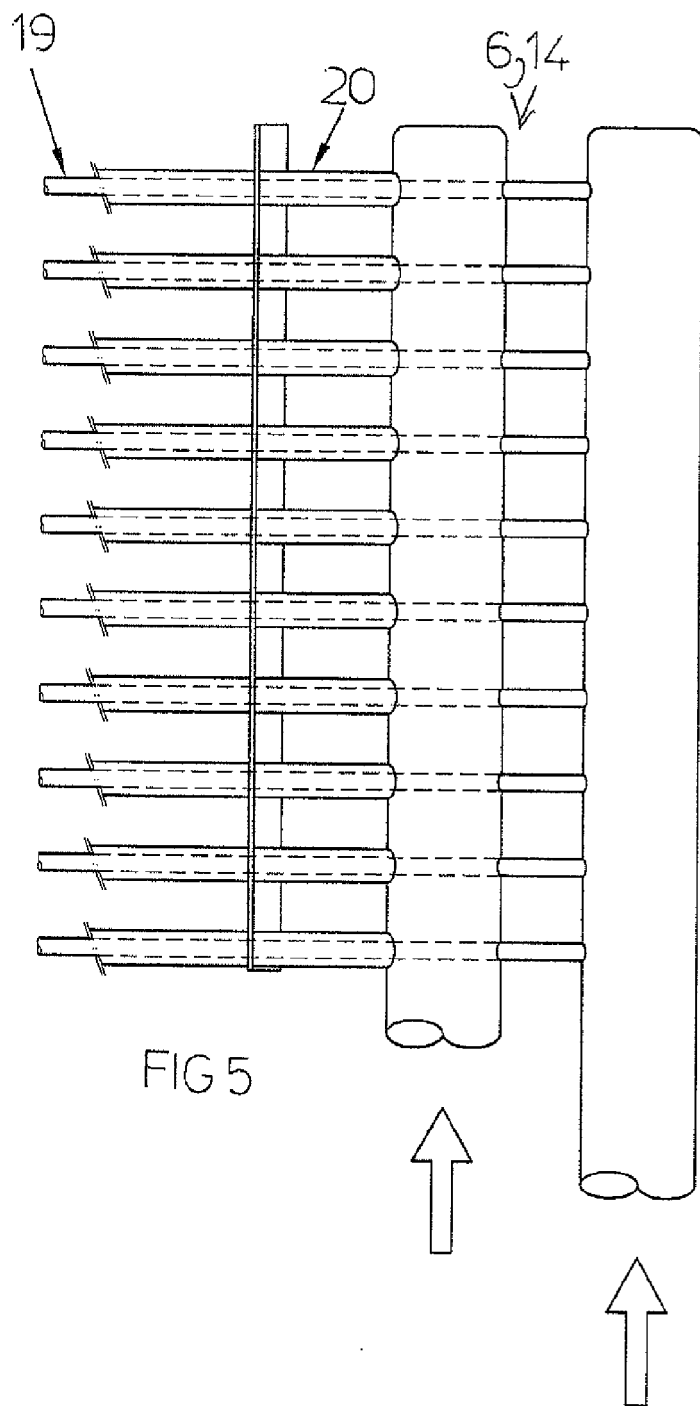
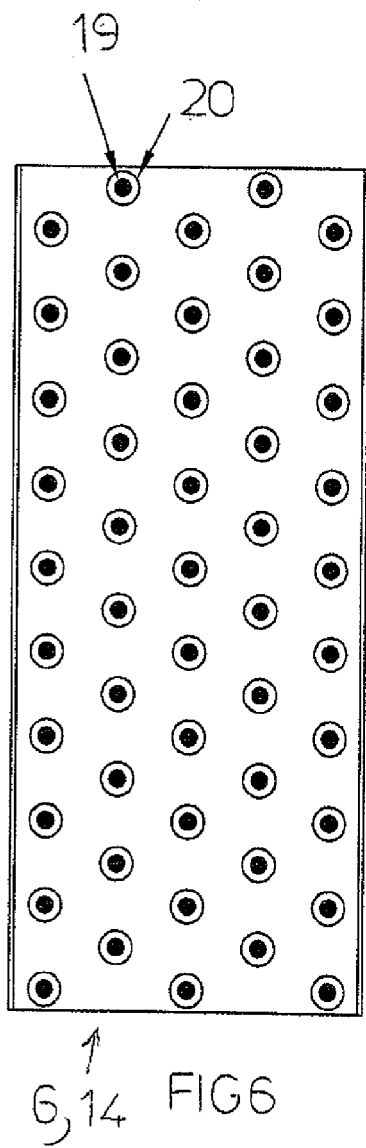


FIG 3

FIG 4



6, 14

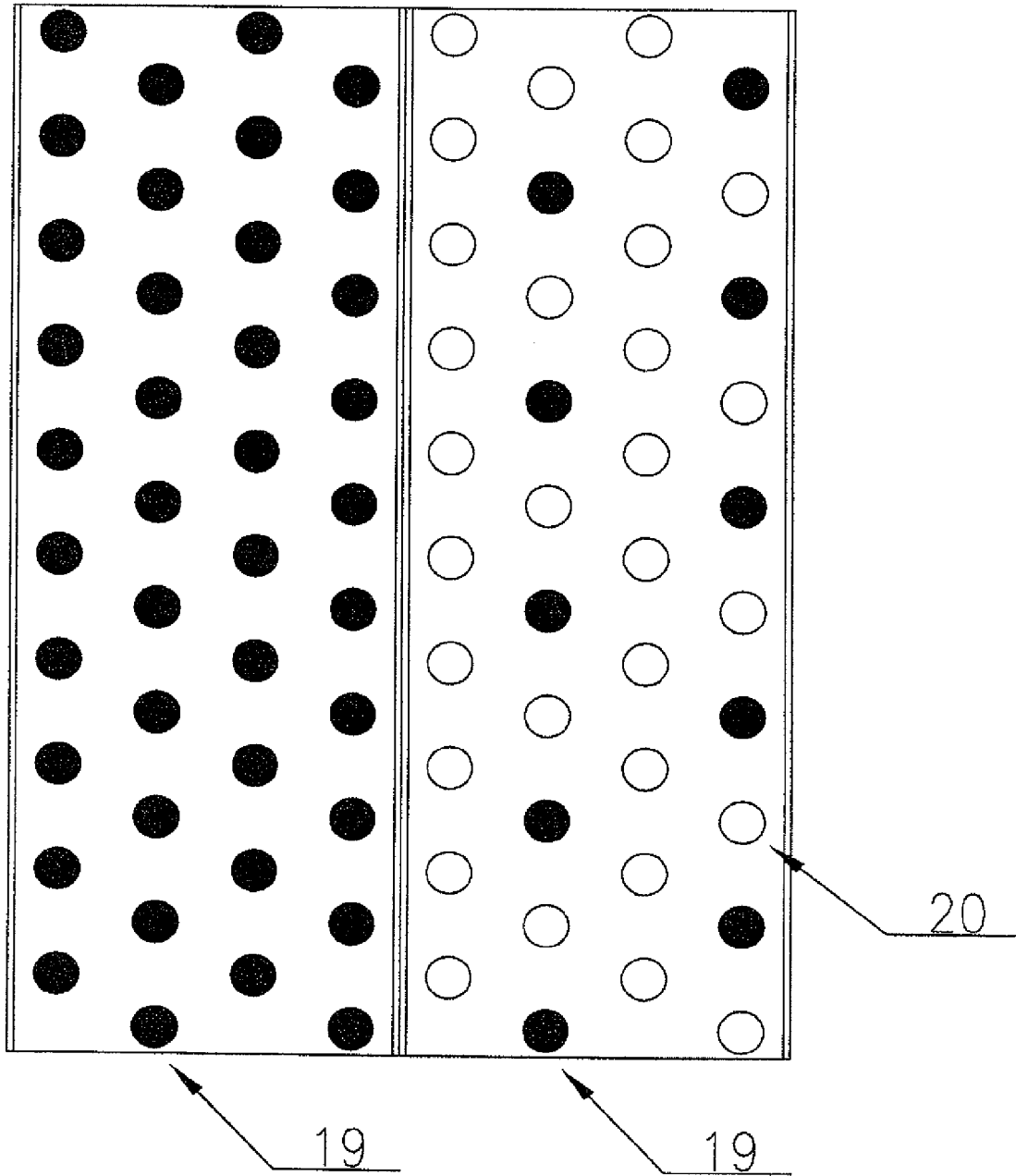


FIG 7