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

(11) EP 3 232 138 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
18.10.2017 Bulletin 2017/42

(21) Application number: **17165891.7**

(22) Date of filing: **11.04.2017**

(51) Int Cl.:
F25B 7/00 *(2006.01)* ***F25B 25/00*** *(2006.01)*
F25B 40/02 *(2006.01)* ***F25B 41/00*** *(2006.01)*
F25D 16/00 *(2006.01)*

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

(30) Priority: **11.04.2016 IT IT20167146**

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(54) **REFRIGERATION SYSTEM OF THE "FREE COOLING" TYPE WITH SUB-COOLER OF THE REFRIGERANT**

(57) The refrigeration system of the "free cooling" type is equipped with a circuit for working fluid to be refrigerated, refrigeration circuits (16, 16') with refrigeration cycles, and a sub-cooling unit (14) having heat exchange means for sub-cooling, with the working fluid, the refrigerant circulating in the refrigeration circuits (16, 16'), the heat exchange means comprising a heat exchanger (14) shared by the refrigeration circuits (16, 16').

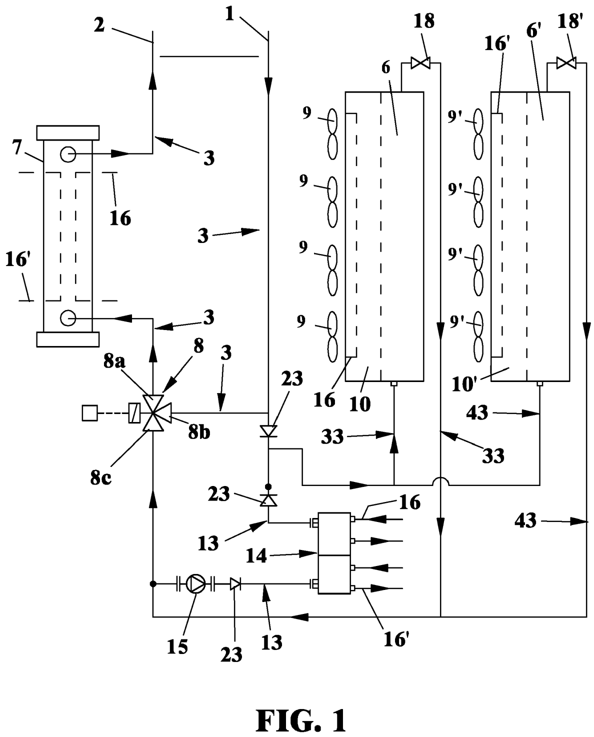

FIG. 1

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Printed by Jouve, 75001 PARIS (FR)

Description

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

[0002] The present invention particularly refers to a system commonly known as a "free-cooling" system that generally has a first air refrigeration unit having a first air cooling battery inserted on the working fluid cooling circuit, a second refrigeration unit with a refrigeration cycle and having an evaporator inserted on the working fluid cooling circuit in a cascade arrangement with respect to the first air cooling battery, valve means for excluding the first air cooling battery from the circuit for cooling the working fluid, and fans suitable for acting simultaneously on the first air cooling battery and on a second air cooling battery flanking the first cooling battery and equipped with a condenser of the second cooling unit for condensing the refrigerant operating in the refrigeration cycle.

[0003] When the temperature of the outside air is lower than the temperature of the liquid to be cooled, the "free-cooling" system facilitates independent cooling of the working fluid owing to direct heat exchange with the air.

[0004] The working fluid to be cooled generally consists of liquid water or a liquid solution of water and glycol, although the same concepts are applicable to any liquid.

[0005] Three different operating modes can be identified based on the temperature of the outside air with respect to the temperature to which one wishes to cool the working fluid, and the refrigeration load to be removed.

[0006] Let Tset-point be the "set point" temperature to which one wishes to cool the working fluid, Tair the air temperature, Toutfc the temperature of the working fluid exiting the first cooling battery, and Toutevap the temperature of the working fluid exiting the evaporator.

[0007] In the "free-cooling" operating mode, Tair < Toutfc = Toutevap = Tset-point.

[0008] When the air temperature is lower than the temperature to which one wishes to cool the working fluid (Tset-point), the valve means diverts the flow of working fluid towards the first cooling battery so that it is cooled by direct heat exchange with the outside air. If the air temperature is low enough to cool the working fluid to the "set point" temperature, the refrigeration cycle compressor will not begin operation and the system will substantially operate as a "dry cooler" with the sole use of the fans.

[0009] In the combined operating mode, the air temperature is lower than the temperature of the working fluid to be cooled, but Toutfc>Tset-point=Toutevap.

[0010] When the air temperature is lower than the temperature of the working fluid to be cooled, but the temperature of the working fluid leaving the first cooling battery has not yet reached the "set-point" temperature, the working fluid is further cooled in the evaporator, thanks to the refrigeration circuit of the second refrigeration unit. The efficiency of this design solution in this operating mode is linked to the fact that it exploits the air flow produced by the fans with a dual effect: cooling the working fluid in the first cooling battery and condensing the refrigerant in the second cooling battery.

[0011] In the "chiller" operating mode, the air temperature is higher than the temperature of the working fluid to be cooled.

[0012] When the outside air temperature is higher than the temperature of the working fluid to be cooled, operation in the "free-cooling" mode is not possible: the valve means switches, diverting the working fluid towards the evaporator, and the system operates cooling the working fluid owing solely to the refrigeration circuit of the second refrigeration unit.

[0013] With respect to a simple "chiller" of the same dimensions, the efficiency of a "free-cooling" system is much greater in the "free-cooling" and combined operating modes, whereas limitations are present in the "chiller" operating mode.

[0014] The main drawback of a traditional "free-cooling" system relates to the fact that when it is operating in the "chiller" operating mode, given that the temperature of the outside air is higher than the temperature of the working fluid to be cooled, the first cooling battery, even though it is inactive, increases air-side losses in load, decreasing the useful flow against the second cooling battery.

[0015] Stated in other terms, the first cooling battery flanking the second cooling battery causes a rise in the condensation temperature, to the detriment of the efficiency of the second refrigeration unit, the maximum cooling capacity that can be supplied and the operating limits of the system in terms of the maximum air temperature.

[0016] The presence of the first cooling battery limits the maximum number of rows that can be dedicated to the second cooling battery, for reasons related to the physical dimensions and so as to avoid an excessive increase in air-side losses in load, leading the fans to operate at an inefficient point of their characteristic curve.

[0017] With respect to a "chiller" of the same dimensions, a traditional "free-cooling" system thus generally exhibits lower refrigeration performance and efficiency.

[0018] In this "chiller" operating mode, employing a booster exchanger is often useful as a sub-cooler for the refrigerant.

[0019] Known booster heat exchangers for sub-cooling a refrigerant include just one refrigeration circuit.

[0020] This constitutes a limitation in the case in which the system comprises two or more refrigeration circuits, in that it imposes the realization of circuit solutions that are quite complex and costly, often to the detriment of the system's efficiency.

[0021] Moreover, owing to the need for compactness, booster heat exchangers used for sub-cooling a refrigerant are of the type having braze-welded plates.

[0022] This makes it impossible to carry out routine and non-routine maintenance on the heat exchanger, working fluid-side, to ensure the long life and constant efficiency of the system, and ultimately to guarantee that the energy-efficient performance levels are constantly kept at the designed levels.

[0023] Plate heat exchangers have significant losses in load on the working-fluid side and this requires the use of high pumping power.

[0024] The technical task of the present invention is therefore to realize a refrigeration system of the "free-cooling" type, equipped with a sub-cooling unit for sub-cooling the refrigerant and that makes it possible to eliminate the prior art technical drawbacks.

[0025] Within the scope of this technical task, an aim of the invention is to realize a refrigeration system of the "free-cooling" type, equipped with a sub-cooling unit for sub-cooling the refrigerant and that exhibits improved efficiency and refrigeration performance when operating in the "chiller" mode.

[0026] Not least in importance is also the aim of providing a "free-cooling" type of refrigeration system equipped with a sub-cooling unit for sub-cooling the refrigerant which proves to be simple and economical in terms of construction and which proves to be easy to inspect for routine and non-routine maintenance.

[0027] The technical task, as well as the latter and other aims, according to the present invention, are achieved by realizing a "free-cooling" type of refrigeration system equipped with a circuit for working fluid to be cooled, a first and at least a second refrigeration circuit with a refrigeration cycle, and a sub-cooling unit having heat exchange means for sub-cooling, with said working fluid, the refrigerant circulating in said refrigeration circuits, characterized in that said heat exchange means comprises a heat exchanger shared by said first and at least a second refrigeration circuit.

[0028] Said heat exchanger is preferably tubular.

[0029] Said tubular heat exchanger is preferably of the type comprising a shell and a tube bundle inserted in the shell.

[0030] Preferably, flow diverting partitions are provided inside said shell.

[0031] The tubes in said tube bundle are preferably shaped so as to be piggable.

[0032] In one embodiment of the invention, said working fluid is located tube-side and said refrigerant is located shell-side, said shell being divided into a first and at least a second chamber, respectively, for containing the refrigerant of said first and at least a second refrigeration circuit, respectively.

[0033] In a different embodiment of the invention, said working fluid is located shell-side and said refrigerant is located tube-side.

[0034] The working fluid preferably flows counter-current to said refrigerant in said heat exchanger.

[0035] In other embodiments of the invention, said heat exchanger is a plate heat exchanger having two or more refrigerant-side circuits and one working fluid-side circuit.

[0036] Further characteristics and advantages of the invention will become more apparent from the description of preferred, but not exclusive, embodiments of the refrigeration system according to the invention, which is illustrated by way of approximate and non-limiting example in the attached drawings, of which:

Figure 1 is a hydraulic circuit diagram of the refrigeration system.

Figures 2a and 2b show an elevation view and a front view of the sub-cooling heat exchanger with a tube bundle in a version with working fluid tube-side and pure counter-current with respect to the flow of refrigerants.

Figures 3a and 3b show an elevation view and a front view of the sub-cooling heat exchanger with a tube bundle in a version with working fluid tube-side and not pure counter-current with respect to the flow of refrigerants.

Figures 4a and 4b show an elevation view and a front view of the sub-cooling heat exchanger with a tube bundle in a version with working fluid shell-side and pure counter-current with respect to the flow of refrigerants.

Figures 5a and 5b show an elevation view and a front view of the sub-cooling heat exchanger with a tube bundle in a version with working fluid shell-side and not pure counter-current with respect to the flow of refrigerants.

[0037] Equivalent parts in the various preferred embodiments are indicated using the same reference number.

[0038] With reference to the figures, a "free-cooling" type of refrigeration system is illustrated and indicated by the reference number 1; the system serves for refrigerating a working liquid circulating between an inlet 1 and an outlet 2 of a circuit 3, 13, 33, 43 for the working fluid which for example, but not necessarily, consists of liquid water or a liquid mixture of glycol and water.

[0039] The refrigeration system 1 comprises a first refrigeration circuit 16 with a refrigeration cycle, and a second refrigeration circuit 16' with a refrigeration cycle. In an unillustrated embodiment, three or more refrigeration circuits with a refrigeration circuit are provided.

[0040] The refrigeration system 1 also has a first air cooling battery 6 and a second air cooling battery 6', both of which are inserted on sections 33, 43 set in parallel of the working fluid circuit 3, 13, 33, 43.

[0041] The first air cooling battery 6 is flanked by a third air cooling battery 10 that acts as a condenser in the first refrigeration circuit 16.

[0042] The first air cooling battery 6 and the third air cooling battery 10 share forced ventilation means 9.

[0043] Similarly, the second air cooling battery 6' is flanked by a fourth air cooling battery 10' that acts as a condenser in the second refrigeration circuit 16'.

[0044] The second air cooling battery 6' and the fourth air cooling battery 10' share forced ventilation means 9'.

[0045] The first refrigeration circuit 16 and the second refrigeration circuit 16' share an evaporator 7.

[0046] The refrigeration system 1 further comprises valve means for distribution of the working fluid among the sections 3, 13, 33, 43 of the working fluid circuit.

[0047] For example, this valve means comprises a three-way valve 8 with three ports 8a, 8b, 8c.

[0048] The refrigeration system 1 has a sub-cooling unit equipped with heat exchange means for sub-cooling, with the working fluid, the refrigerant circulating in the refrigeration circuits 16, 16'.

[0049] The sub-cooling unit comprises a heat exchanger 14 and a circulation pump 15 dedicated to the latter.

[0050] The heat exchanger 14 is tubular in the illustrated solution.

[0051] Other applications in which the heat exchanger 14 is a plate type of heat exchanger are not excluded.

[0052] In particular, the heat exchanger 14 comprises a shell 24 and a tube bundle inserted in the shell 24.

[0053] Flow diverting partitions 27 are also provided inside the shell 24.

[0054] Advantageously, the tubes in the tube bundle are piggable.

[0055] As illustrated in Figures 2a and 2b, in one embodiment of the invention, the working fluid is located tube-side, whereas the refrigerant is located shell-side. In this case, by means of a partition wall 28, the shell 24 is divided into a first chamber 29 for containing the refrigerant of first refrigeration circuit 16 and a second chamber 30 for containing the refrigerant of the second refrigeration circuit 16'.The exchanger 14 is configured for pure counter-current exchange, and therefore the inlet ends of all the tubes for the working fluid communicate with a manifold 31 located at one end of the shell 24 and the outlet ends communicate with a manifold 32 located at the opposite end of the shell 24.

[0056] A different embodiment of the invention is illustrated in Figures 3a and 3b. In this case as well, the working fluid is located tube-side and the refrigerant is located shell-side. Here again, by means of a partition wall 28, the shell 24 is divided, into a first chamber 29 for containing the refrigerant of first refrigeration circuit 16 and a second chamber 30 for containing the refrigerant of the second refrigeration circuit 16'.However, in this case the exchanger 14 is configured for not pure counter-current exchange, and therefore all the tubes 45 for the working fluid are U-shaped so as to position both the inlet end and the outlet end at a manifold 34 located at one end of the shell 24.

[0057] A different embodiment of the invention is illustrated in Figures 4a and 4b. The working fluid is located shell-side, whereas the refrigerant is located tube-side. In this case, the tube bundle is divided into a first sub-bundle of tubes 35 for circulation of the refrigerant in the first refrigeration circuit 16 and a second sub-bundle of tubes 36 for circulation of the refrigerant in the second refrigeration circuit 16'.The exchanger 14 is configured for pure counter-current exchange, and therefore the inlet ends of all the tubes 35 and 36, respectively, for the refrigerant of the first refrigeration circuit 16 and the second refrigeration circuit 16', respectively, communicate with a respective inlet manifold 37, 37' located at one end of the shell 24 and the outlet ends communicate with a respective outlet manifold 38, 38' located at the opposite end of the shell 24.

[0058] A different embodiment of the invention is illustrated in Figures 5a and 5b. In this case as well, the working fluid is located shell-side and the refrigerant is located tube-side. In this case, the tube bundle is again divided into a first sub-bundle of tubes 55 for circulation of the refrigerant in the first refrigeration circuit 16 and a second sub-bundle of tubes 56 for circulation of the refrigerant in the second refrigeration circuit 16'.However, in this case the exchanger 14 is configured for not pure counter-current exchange, and therefore all the tubes 55, 56 are U-shaped so that all the manifolds, that is, the inlet manifolds 57, 57' and the outlet manifolds 58, 58' are positioned at one end of the shell 24.

[0059] Lastly, the system comprises one-way valves 23 for properly directing the working fluid in the various operating modes.

[0060] The refrigeration system operates as follows.

[0061] In the "free-cooling" operating mode, the valve 8 is in a state in which the port 8b is closed and the ports 8a and 8c are open, the circulation pump 15 is off and the compressor for the refrigeration circuits is off.

[0062] Only the forced ventilation means 9, 9' are operative to supply a flow of air on the air cooling batteries 6, 6' in which the working fluid is circulating.

[0063] In the "combined" operating mode as well, the valve 8 is in the state in which the port 8b is closed and the ports 8a and 8c are open, the circulation pump 15 is off and the compressor for the refrigeration circuits is off.

[0064] Cooling of the working fluid is carried out in a cascaded process by the forced ventilation means 9, 9' for ventilating the air cooling batteries 6, 6' and by the evaporator 7.

[0065] In the "chiller" operating mode, the valve 8 switches into a state in which the port 8b is open, the port 8a is open and the port 8c is closed, the circulation pump 15 is on, and the compressor for the refrigeration circuits is on.

[0066] Primary circulation of working fluid is established in the section 3 of the working fluid circuit comprising the evaporator 7, and secondary circulation of working fluid is established in the sections 33, 43, 13 of the working fluid circuit comprising the air cooling batteries 6, 6' and the sub-cooling exchanger 14.

[0067] The temperature of the working fluid circulating in the exchanger 14 is always lower than that of the condensed refrigerants and therefore the working fluid removes heat from the latter.

[0068] Owing to the sub-cooling of the refrigerant, the refrigeration performance of the system is enhanced by virtue of the higher enthalpy jump produced by the evaporator 7.

[0069] As a result, the punctual and seasonal efficiency of the system, intended as a ratio of refrigeration power to power consumption, increases.

[0070] The efficiency of the evaporator 7 improves, which leads to a higher evaporation temperature, with the power exchanged being equal, owing to the lower concentration with which it is supplied.

[0071] With the refrigeration performance being equal, ventilation-related noise decreases because the exchange surface with the air is exploited to a greater degree.

[0072] The advantages derived from the adoption of a sole cooling exchanger shared by the refrigeration circuits are as follows: with respect to the use of a number of single exchangers in parallel, this solution prevents the mixing of working fluid at different temperatures when for example not all the refrigeration circuits are in operation at the same time.

[0073] Moreover, if this cooling exchanger is a tubular-type exchanger, the following additional advantages are present: the tubes are piggable, thus making it possible to carry out maintenance and cleaning procedures needed to ensure efficient heat exchange over time and therefore, ultimately, ensuring high efficiency levels. With respect to a braze-welded plate heat exchanger, this solution offers lower load losses on working fluid-side, resulting in savings in the pumping power to be used. The refrigeration circuits can have the same exchange surface or even different exchange surfaces.

[0074] The refrigeration system and the relative control method thus conceived are susceptible to numerous modifications and variants, all of which falling within the scope of the inventive concept. Moreover, all details may be replaced with other technically equivalent elements.

[0075] The materials used, as well as the dimensions, may in practice be of any type, according to needs and the state of the art.

Claims

1. A refrigeration system of the "free cooling" type, equipped with a circuit for working fluid to be cooled, a first (16) and at least a second (16’) refrigeration circuit with a refrigeration cycle, and a sub-cooling unit (14) having heat exchange means for sub-cooling, with said working fluid, the refrigerant circulating in said refrigeration circuits (16, 16’), **characterized in that** said heat exchange means comprises a heat exchanger (14) shared by said first and at least a second refrigeration circuit (16, 16’).

2. The refrigeration system of the "free cooling" type, according to claim 1, **characterized in that** it comprises a first (6) and at least a second (6’) air cooling battery, both inserted on sections set in parallel of said working fluid circuit.

3. The refrigeration system of the "free cooling" type, according to the preceding claim, **characterized in that** said first and at least a second air cooling battery (6, 6’), respectively, are flanked by a respective condenser (10, 10’) provided in said first and at least a second refrigeration circuit (16, 16’), respectively, and **in that** a first forced ventilation means (9) is provided and shared by said first air cooling battery (6) and said condenser (10) of said first refrigeration circuit (16’) and at least a second forced ventilation means (9’) shared by said at least a second air cooling battery (6’) and said condenser (10’) of said second refrigeration circuit (16’).

4. The refrigeration system of the "free cooling" type, according to the preceding claim, **characterized in that** it has a shared evaporator (7) for said first and at least a second refrigeration circuit (16, 16’).

5. The refrigeration system of the "free cooling" type, according to any one of the preceding claims, **characterized in that** said heat exchanger (14) has a number of refrigerant-side circuits and only one working fluid-side circuit.

6. The refrigeration system of the "free cooling" type, according to any one of the preceding claims, **characterized in that** said heat exchanger (14) is tubular.

7. The refrigeration system of the "free cooling" type, according to the preceding claim, **characterized in that** said heat exchanger (14) comprises a shell (24) and a tube bundle (25, 45, 35, 36, 55, 56) inserted in the shell (24).

8. The refrigeration system of the "free cooling" type, according to the preceding claim, **characterized in that** flow diverting partitions (27) are provided inside said shell (24).

9. The refrigeration system of the "free cooling" type, according to claim 7 or 8, **characterized in that** the tubes (25, 45, 35, 36, 55, 56) in said tube bundle are piggable.

10. The refrigeration system of the "free cooling" type, according to any one of claims 7 to 9, **characterized in that** said working fluid is located tube-side and said refrigerant is located shell-side, said shell (24) being divided in a first and at least a second chamber (29, 30), respectively, for containing the refrigerant of said first and at least a second refrigeration circuit (16, 16’), respectively.

11. The refrigeration system of the "free cooling" type, according to any one of claims 6 to 10, **characterized in that** said working fluid is located shell-side and said refrigerant is located tube-side.

12. The refrigeration system of the "free cooling" type, according to any one of claims 6 to 10, **characterized in that** said working fluid flows counter-current to said refrigerant in said heat exchanger (14).

13. The refrigeration system of the "free cooling" type according to any one of claims 1 to 5, **characterized in that** said heat exchanger (14) is a plate heat exchanger.

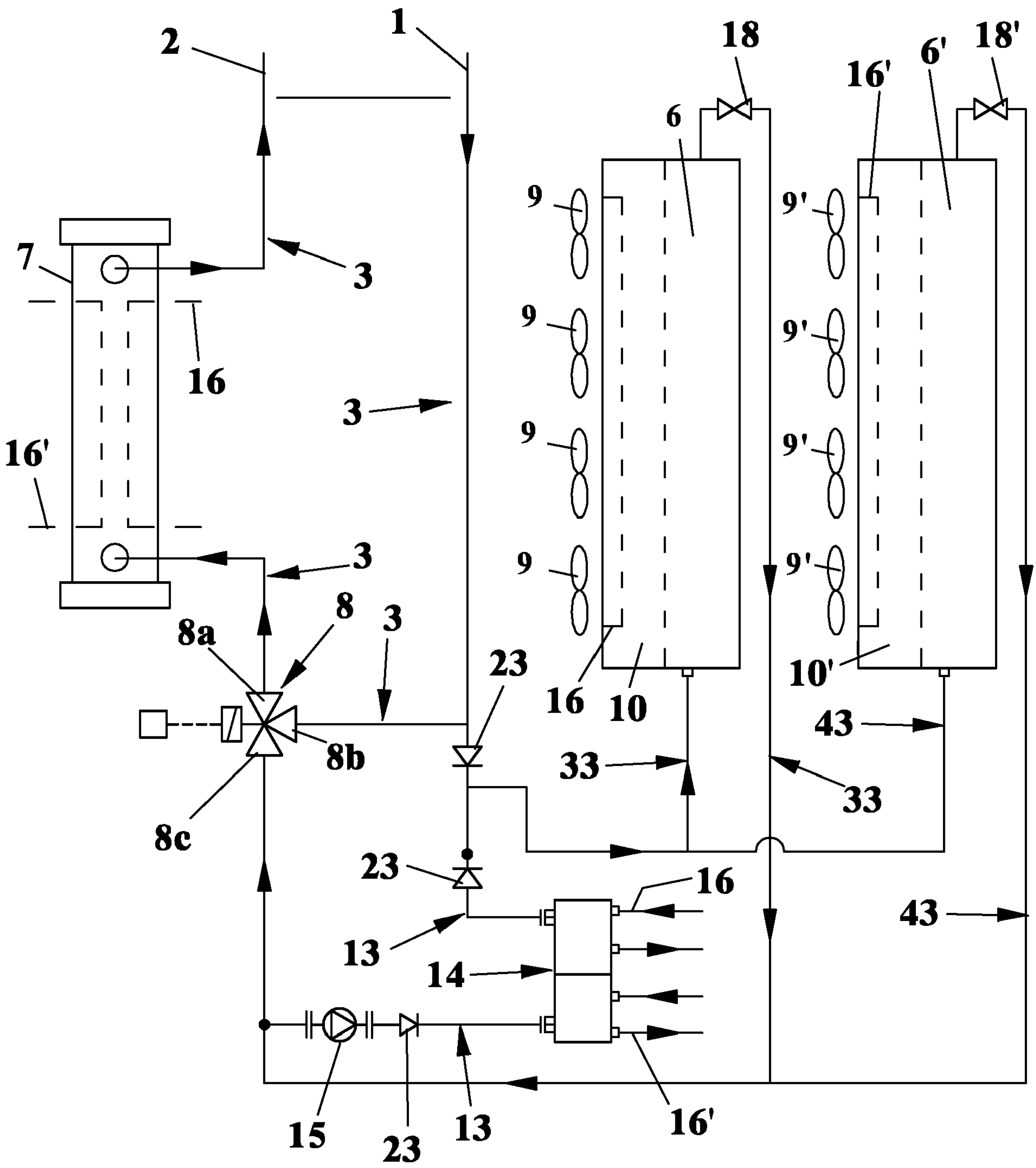
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FIG. 1

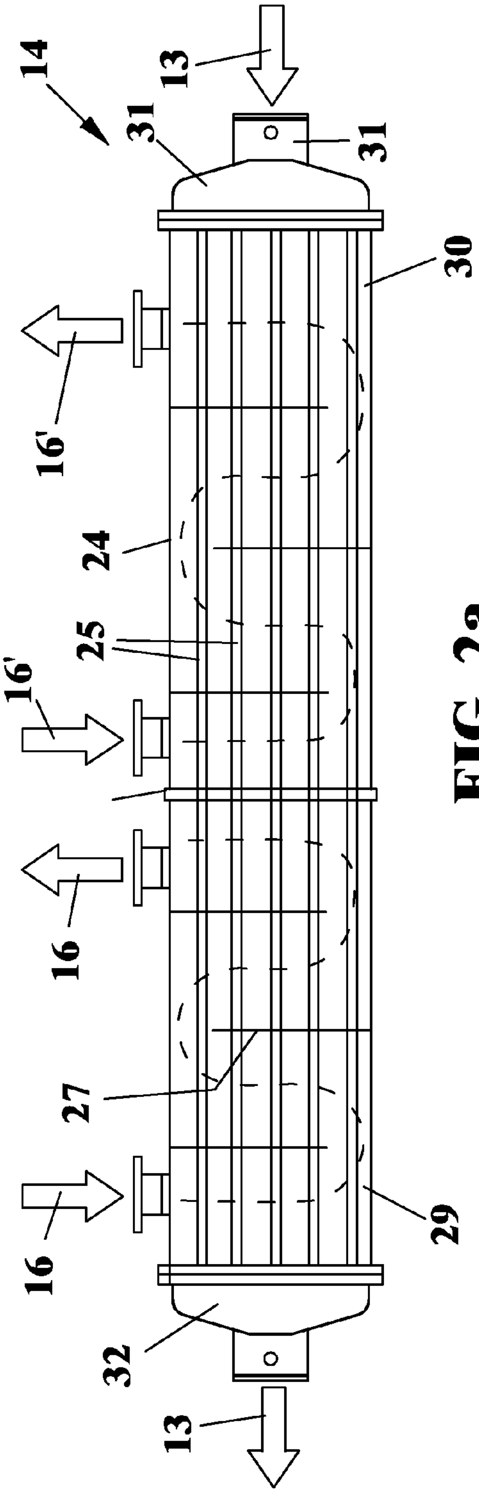

FIG. 2a

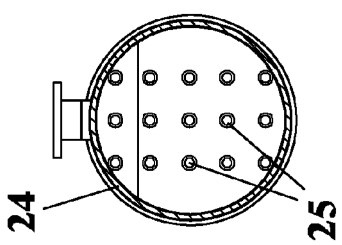

FIG. 2b

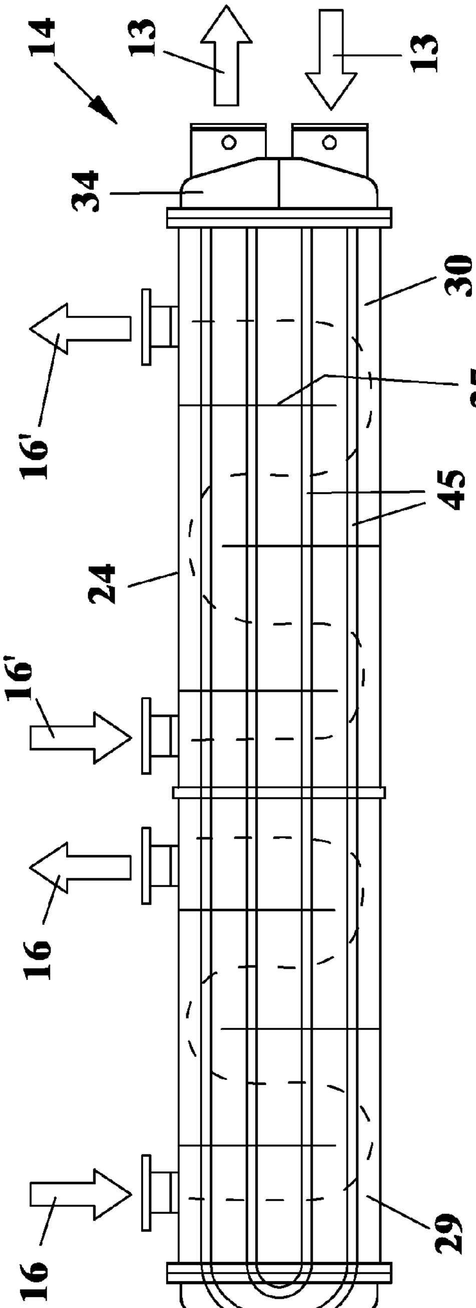

FIG. 3a

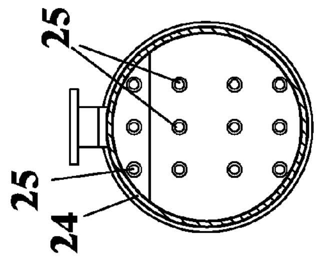

FIG. 3b

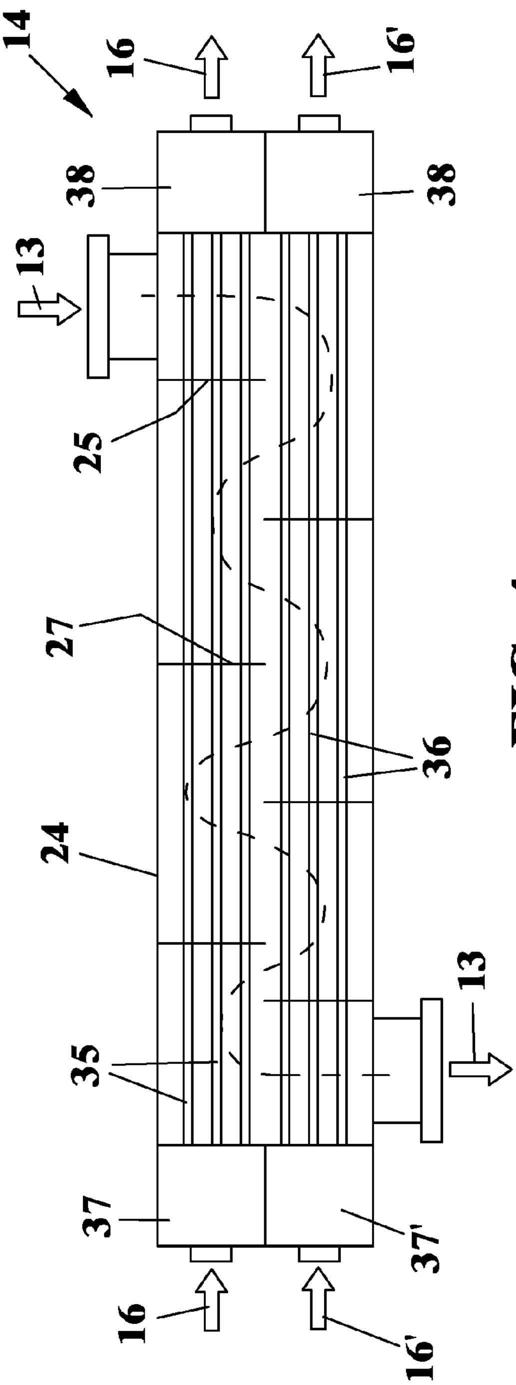

FIG. 4a

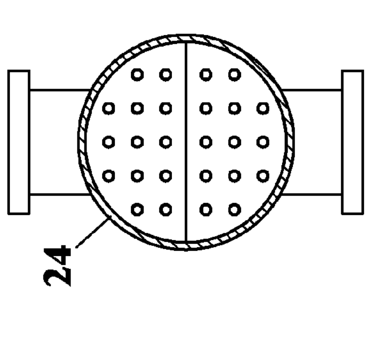

FIG. 4b

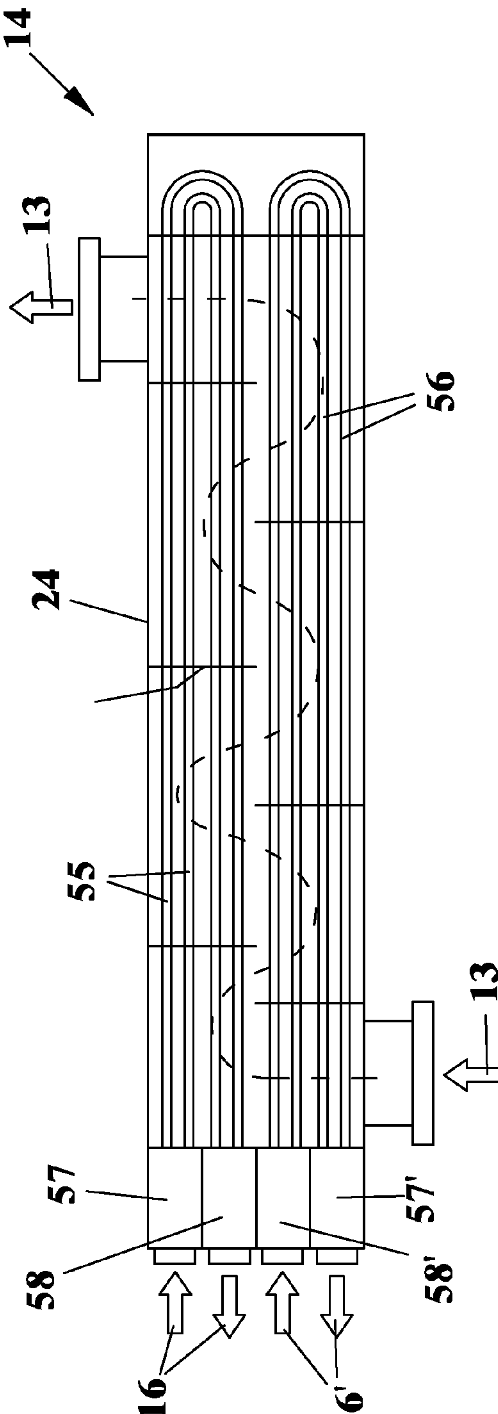

FIG. 5a

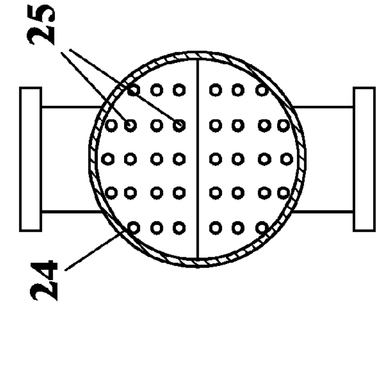

FIG. 5b

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EUROPEAN SEARCH REPORT

Application Number
EP 17 16 5891

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TECHNICAL FIELDS SEARCHED (IPC)

F25B
F25D
F28D

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	6 September 2017	Lucic, Anita

CATEGORY OF CITED DOCUMENTS

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EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 17 16 5891

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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