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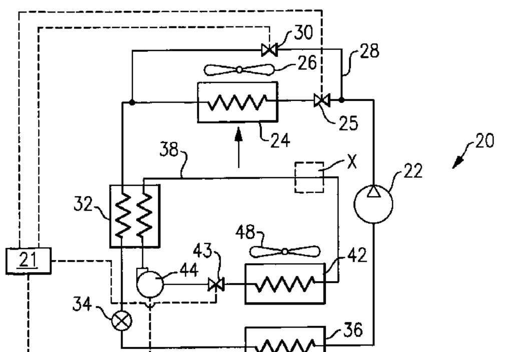
(54) **Title:** CLOSED-LOOP DEHUMIDIFICATION CIRCUIT FOR REFRIGERANT SYSTEM



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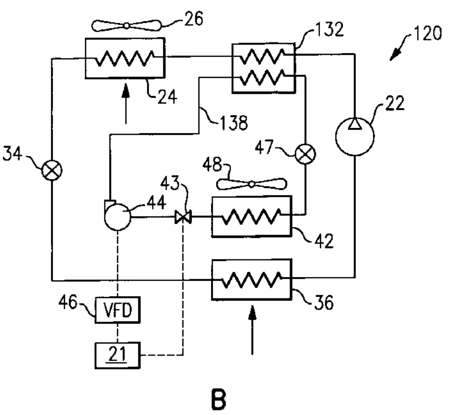

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(57) Abstract: A closed-loop reheat circuit decoupled from a main refrigerant circuit is provided as part of a refrigerant system. In the closed-loop reheat circuit refrigerant is flown through an auxiliary heat exchanger, at which it transfers heat to refrigerant in the main circuit, increasing its cooling and dehumidification potential prior to entering an evaporator. The closed-loop circuit also includes a reheat heat exchanger that is placed in the path of at least a portion of airflow having passed over an evaporator. The reheat heat exchanger reheats air supplied to a conditioned space to a desired temperature after sufficient amount of moisture has been removed from the air in the evaporator to provide a comfortable humidity level. By utilizing the closed-loop reheat circuit, a control for the overall refrigerant system becomes less complex and more flexible, and the refrigerant system operation turns out to be more reliable and satisfying a variety of environmental conditions and potential applications. Various features and options of the decoupled reheat circuit concept are also disclosed.

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CLOSED-LOOP DEHUMIDIFICATION CIRCUIT FOR REFRIGERANT SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to a refrigerant system wherein a closed-loop dehumidification circuit is incorporated into a system schematic.

Refrigerant systems are utilized to control the temperature and humidity of air in various indoor environments to be conditioned. In a typical refrigerant system operating in the cooling mode, a refrigerant is compressed in a compressor and delivered to a condenser (or an outdoor heat exchanger in this case). In the condenser, heat is exchanged between outside ambient air and the refrigerant. From the condenser, the refrigerant passes to an expansion device, at which the refrigerant is expanded to a lower pressure and temperature, and then to an evaporator (or an indoor heat exchanger in this case). In the evaporator, heat is exchanged between the refrigerant and the indoor air, to condition the indoor air. When the refrigerant system is operating, the evaporator cools the air that is being supplied to the indoor environment. In addition, as the temperature of the indoor air is lowered, moisture usually is also taken out of the air. In this manner, the humidity level of the indoor air can also be controlled.

In some cases, the temperature level, to which the air is brought to provide comfort in a conditioned space, may need to be higher than the temperature that would provide the ideal humidity level. This has presented challenges to refrigerant system designers. One way to address such challenges is to utilize various schematics incorporating reheat coils. In many cases, the reheat coils, placed in the indoor air stream behind the evaporator, are employed for the purpose of reheating the air supplied to the conditioned space after it has been cooled in the evaporator, and where the moisture has been removed.

One challenge with integrating these reheat circuits into refrigerant systems is that the reheat circuits require connections to the main refrigerant loop associated with specific flow control devices. These flow control devices, such as three-way valves, check valves or other valve systems, may need additional control functionality and frequently present reliability and refrigerant migration issues. For instance, as known, the refrigerant would migrate to a coldest spot within a refrigerant system. The coldest spot will change depending on the mode of operation. In the conventional cooling mode, the refrigerant would naturally migrate to the non-functioning reheat coil and, in a reheat mode, the opposite phenomenon would typically take place. This refrigerant re-distribution within the refrigerant system affects amount of the refrigerant flowing through the main refrigerant loop that in turn may cause serious system malfunctioning and reliability issues. Moreover, since a reheat loop is closely coupled to a main refrigerant circuit the system control for both the reheat function and conventional cooling becomes more complicated than would be desirable. In other words, this complexity arises from the fact that the refrigerant is essentially shared between the main refrigerant loop and the reheat circuit. Another issue related to the reheat concepts employing main circuit refrigerant is associated with the fact that refrigerant system operational flexibility is compromised. Consequently, it becomes extremely difficult to satisfy a wide range of operational and environmental conditions and potential applications.

Separate closed-loop refrigerant circuits have been utilized for various purposes in the past, however, they have not been utilized in combination with a refrigerant system and to provide dehumidification. Thus, there is a need in a reliable refrigerant system with a decoupled refrigerant circuit to satisfy market requirements and to provide operational flexibility.

SUMMARY OF THE INVENTION

In the present invention, a closed-loop reheat circuit is utilized in conjunction with a main refrigerant system. The closed-loop reheat circuit includes a pair of heat exchangers, with a reheat heat exchanger providing an effective reheat function by being placed in the path of at least a portion of the airflow having passed over the evaporator. As is known, this reheat heat exchanger will tend to reheat the air, such that the air can be cooled below its desired comfort temperature in the evaporator to remove an adequate amount of moisture and thus to provide a comfortable humidity level. The air then passes over the reheat heat exchanger, at which its temperature is increased to achieve a desired temperature set by an occupant of an environment to be conditioned. As known, in the reheat heat exchanger, heat is transferred from refrigerant to air to reheat the air.

The other heat exchanger is an auxiliary heat exchanger where, due to heat transfer interaction, the refrigerant in the closed-loop reheat circuit cools the refrigerant in the main refrigerant circuit. In other words, in the auxiliary heat exchanger heat is transferred from the main circuit refrigerant to the refrigerant circulating through the reheat loop. Therefore, the refrigerant in the closed-loop reheat circuit is heated, while the refrigerant in the main refrigerant circuit will have an increased cooling potential when it reaches the evaporator. The refrigerant in the closed-loop reheat circuit leaves the auxiliary heat exchanger and returns to the reheat heat exchanger.

In one disclosed embodiment, a liquid pump is included to drive the refrigerant through the closed-loop reheat circuit. Further, the liquid pump may be provided with a variable speed drive or an external flow control device such as an adjustable valve can be used to achieve variable refrigerant flow and consequently variable capacity in the reheat heat exchanger.

In another embodiment, the invention may be utilized with the option of bypassing at least a portion of refrigerant around the condenser to achieve a variable cooling potential in the evaporator. This control feature may be employed separately or in conjunction with a variable speed liquid pump or/and with adjustable reheat circuit valve.

In still another embodiment, a refrigerant different from the refrigerant circulating through the main circuit is used in the closed-loop reheat circuit. Further, the refrigerant composition in the reheat circuit can be formulated to sustain a liquid phase throughout the circuit or to change phases from vapor to liquid in the reheat heat exchanger and back from liquid to vapor in the auxiliary heat exchanger.

In yet another embodiment, a natural convection or thermosiphon is employed for refrigerant circulating through the reheat circuit in place of a forced fluid flow by the liquid pump. Obviously, in this embodiment refrigerant phase change would be required.

These and other features of the present invention can be best understood from the following specification and drawings, the following of which is a brief description.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A shows a first schematic of the present invention.

Figure 1B shows an alternate schematic of the Figure 1A schematic.

Figure 2A shows a second schematic of the present invention.

Figure 2B shows an alternate schematic of the Figure 2A schematic.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1A shows a refrigerant system 20 incorporating a compressor 22, compressing refrigerant and delivering it through a condenser 24. A fan 26 moves air over the condenser 24. Refrigerant flow through a bypass line 28 is controlled by a flow control device such as a valve 30. Another optional valve 25 may be positioned upstream of the condenser 24 (but downstream of the diversion point of the bypass line 28) to assist in refrigerant routing through the condenser 24 and bypass line 28. A control 21 can control the valves 30 and 25 to selectively bypass at least a portion of the refrigerant around the condenser 24. Such a bypass will typically be utilized when full cooling capacity of the refrigerant system 20 in the reheat mode of operation is not required. The two refrigerant flows mentioned above are combined downstream of the condenser 24. Of course, the control 21 controls other components of the refrigerant system 20 such as the compressor 22 and fans 26 and 48.

An auxiliary heat exchanger 32 is positioned on a liquid refrigerant line downstream of the condenser 24. An expansion device 34 is positioned downstream of the auxiliary heat exchanger 32, and an evaporator 36 is located downstream of the expansion device 34. The refrigerant in the main circuit of the refrigerant system 20 flows through the auxiliary heat exchanger 32, through the expansion device 34 to the evaporator 36 and then is returned to the compressor 22.

A closed-loop reheat circuit 38 is also incorporated into the refrigerant system 20. The refrigerant in the closed-loop reheat circuit flows through a reheat heat exchanger 42. As shown, a fan 48 blows air over the evaporator 36, and then over the reheat heat exchanger 42. As is known, a reheat function allows the evaporator to be controlled to cool the air to a lower temperature than would be desired by an environment into which the air is being delivered. This permits the removal of an adequate amount of moisture (significantly more than might otherwise be available given the desired temperature) and thus to provide a comfortable humidity level in an environment to be conditioned. Once the air has passed over the evaporator 36, it next encounters the reheat heat exchanger 42. The refrigerant in the reheat heat exchanger 42 reheats this air, such that when the air approaches the environment to be conditioned, it will be at the desired temperature. During this heat transfer interaction in the reheat heat exchanger 42, the heat is transferred from the refrigerant in the reheat loop to the conditioned air.

A liquid pump 44 circulates the refrigerant through the closed-loop reheat circuit 38 from the reheat heat exchanger 42, through an optional flow control device such as valve 43, through the auxiliary heat exchanger 32 and then returns it back to the reheat heat exchanger 42. In the reheat heat exchanger 42 the heat is transferred from the refrigerant in the reheat circuit to the conditioned air and in the auxiliary heat exchanger 32 the heat is transferred from the refrigerant in the main circuit to the refrigerant in the reheat circuit (in this case, to cool the refrigerant in the main circuit). It has to be pointed out that the preferred flow configuration in the auxiliary heat exchanger 32 is a counterflow arrangement.

Since the reheat circuit 38 is physically decoupled from the main circuit (the communication between the circuits is conducted through direct and indirect heat transfer interactions in the heat exchangers 32 and 42 respectively), the refrigerant flow in the reheat circuit can be controlled independently by the system control 21 through the adjustable valve 43 or by a variable speed drive 46 for the liquid pump 44. Therefore, the reheat capacity can be controlled. A variable flow of the reheat circuit refrigerant circulating through the heat exchangers 32 and 42 can be utilized in conjunction with the control 21 controlling the bypass valve 30 and valve 25 to achieve a desired temperature of the air leaving the reheat heat exchanger 42 and supplied to the conditioned space. The valves 30 and 25 will control the amount of sub-cooling of the refrigerant entering the auxiliary heat exchanger 32 and consequently, to a great extent, its cooling potential in the downstream evaporator.

For instance, if humidity control with lower cooling is desired, then, as is known, the amount of refrigerant bypassing the condenser 24 is increased. The reheat circuit subsystem consisting of the liquid pump 44 and upstream valve 43 could be also placed upstream of the reheat heat exchanger 42 (downstream of the auxiliary heat exchanger 32). In this case, the refrigerant flowing through the entire reheat circuit 38 has to be in a liquid phase. This position is illustrated in phantom at X.

Further, in the schematic shown in Figure 1A, the refrigerant in the reheat circuit can undergo phase transformation and change from liquid to vapor in the auxiliary heat exchanger 32 and from vapor to liquid in the reheat heat exchanger 42. In this case, (as explained below) an additional expansion device may be required, and the cavitation conditions at the entrance to the liquid pump 44 should be prevented to ensure reliable operation.

Moreover, since the reheat circuit is physically decoupled from the main circuit, the refrigerant in the reheat circuit may be different in nature, have different constituents and/or composition and may have substantially different operating parameters (such as pressure, controlled by the refrigerant charge).

Another schematic 120 shown in Figure 1B has the auxiliary heat exchanger 132 positioned upstream of the condenser 24 in the main refrigerant circuit. In this case, heat transfer interaction in the auxiliary heat exchanger 132 is between the refrigerant in the reheat circuit 138 and a discharge line refrigerant vapor (in comparison to a liquid line refrigerant in Figure 1A). As mentioned before, a reheat circuit expansion device 47 may be required if the reheat circuit refrigerant changes phases (between liquid and vapor), and a liquid refrigerant state is to be maintained at the entrance of the liquid pump 44 to prevent cavitation. In all other aspects this embodiment is identical to the Figure 1A embodiment.

Another embodiment 50 is shown in Figure 2A, wherein the forced flow of refrigerant in the reheat circuit 38 provided by the liquid pump 44 of Figures 1A and 1B is substituted by the natural convection phenomenon or so-called thermosiphon action. Therefore, in this case, a liquid pump 44 is not anymore required, but, for this concept to function properly, the refrigerant in the reheat circuit should change phases between liquid and vapor. In this embodiment, a closed-loop reheat circuit 52 incorporates a shutoff valve 54, the auxiliary heat exchanger 32, and a reheat heat exchanger 58. As before, the reheat heat exchanger 58 is placed in the path of at least a portion of airflow blown by a fan 56 over the evaporator 36. The refrigerant within the reheat circuit 52 circulates due to the force of gravity. The refrigerant condenses in the reheat heat exchanger 58 and naturally flows down due to the force of gravity. This refrigerant then gets drawn to the auxiliary heat exchanger 32 where it evaporates and raises due to the density difference. Then the refrigerant, once again, enters the reheat heat exchanger 58 and the cycle repeats itself. In this manner, natural circulation is accomplished throughout the reheat circuit 52.

Another embodiment 150 is shown in Figure 2B. This embodiment is analogous to the embodiment 50, with the exception that the reheat heat exchanger 158 utilizes refrigerant vapor in the discharge line of the main circuit as a source of heat for the refrigerant in the reheat circuit 152.

The present invention provides the reheat function as a separate closed–loop circuit decoupled form the main refrigerant circuit. A control of such a system is less complex and more flexible than the control for a refrigerant system that selectively taps refrigerant from the main refrigerant circuit to provide the reheat function. The control and operation of the known systems is less reliable and frequently needs additional components due to changing environmental conditions and refrigerant migration issues. By utilizing the separate closed-loop reheat circuit, these concerns are eliminated, and the system is better suited for a variety of environments and potential applications.

A worker of ordinary skill in the art would recognize that certain modifications would come within the scope of this invention. For that reason, the following claims should be studied to determine the true scope and content of this invention.

CLAIMS

We claim:

1. A refrigerant system comprising:

a main refrigerant circuit including a compressor, a condenser, an auxiliary heat exchanger, an expansion device, and an evaporator;

a closed-loop reheat circuit, said closed-loop reheat circuit passing a refrigerant through said auxiliary heat exchanger and a reheat heat exchanger;

an air-moving device moving air over said evaporator; and

said reheat heat exchanger being positioned such that at least a portion of air having passed over said evaporator then passes over said reheat heat exchanger.

2. The refrigerant system as set forth in claim 1, wherein said auxiliary heat exchanger is positioned downstream of the condenser.

3. The refrigerant system as set forth in claim 1, wherein said auxiliary heat exchanger is positioned upstream of the condenser.

4. The refrigerant system as set forth in claim 1, wherein a liquid pump is included in said closed-loop circuit to drive refrigerant.

5. The refrigerant system as set forth in claim 4, wherein a variable speed drive is provided for said liquid pump.

6. The refrigerant system as set forth in claim 4, wherein an expansion device is included in said closed-loop circuit.

7. The refrigerant system as set forth in claim 1, wherein a flow control device is included in said closed-loop reheat circuit.

8. The refrigerant system as set forth in claim 1, wherein a bypass line allows selective bypass of at least a portion of refrigerant in said main refrigerant circuit around said condenser.

9. The refrigerant system as set forth in claim 1, wherein refrigerant in said main circuit and refrigerant in said reheat circuit are different.

10. The refrigerant system as set forth in claim 1, wherein refrigerant in said main circuit and refrigerant in said reheat circuit have identical constituents.

11. The refrigerant system as set forth in claim 1, wherein refrigerant in said reheat circuit remains in a liquid state throughout the circuit.

12. The refrigerant system as set forth in claim 1, wherein refrigerant in said reheat circuit undergoes phase transformation between liquid and vapor phases.

13. A method of refrigerant system comprising:

compressing a refrigerant at a compressor and delivering the refrigerant to a downstream condenser through a main flow line;

providing an auxiliary heat exchanger, and an evaporator downstream of said auxiliary heat exchanger;

compressed refrigerant in said main flow line passing to said condenser, to said auxiliary heat exchanger, to said evaporator, and back to said compressor;

providing a closed-loop reheat circuit, said closed-loop reheat circuit passing a refrigerant through said auxiliary heat exchanger, and then to a reheat heat exchanger;

an air-moving device moving air over said evaporator; and

said reheat heat exchanger being positioned such that at least a portion of air having passed over said evaporator then passes over said reheat heat exchanger.

14. The method as set forth in claim 13, wherein a liquid pump drives refrigerant through said closed-loop circuit.

15. The method as set forth in claim 14, wherein a variable speed drive varies the speed of said liquid pump.

16 The method as set forth in claim 13, wherein a flow control device is included in said closed-loop reheat circuit.

17. The method as set forth in claim 13, wherein a bypass line selectively bypasses refrigerant from said main refrigerant line around said condenser.

18. The method as set forth in claim 13, wherein said auxiliary heat exchanger is positioned downstream of the condenser.

19. The method as set forth in claim 13, wherein said auxiliary heat exchanger is positioned upstream of the condenser.

20. The method as set forth in claim 15, wherein an expansion device is included in said closed-loop reheat circuit.

21. The method as set forth in claim 13, wherein refrigerant in said main circuit and refrigerant in said closed-loop reheat circuit are different.

22. The method as set forth in claim 13, wherein refrigerant in said main circuit and refrigerant in said closed-loop reheat circuit have identical constituents.

23. The method as set forth in claim 13, wherein refrigerant in said closed-loop reheat circuit remains in a liquid state throughout the circuit.

24. The method as set forth in claim 13, wherein refrigerant in said closed-loop reheat circuit undergoes phase transformation between liquid and vapor phases.

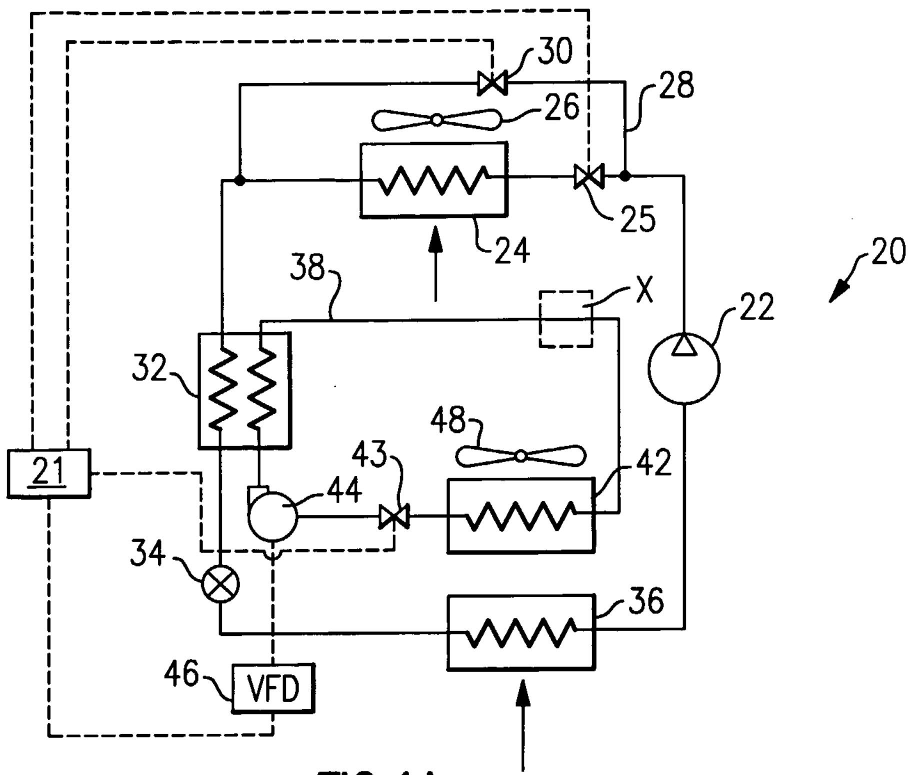
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FIG.1A

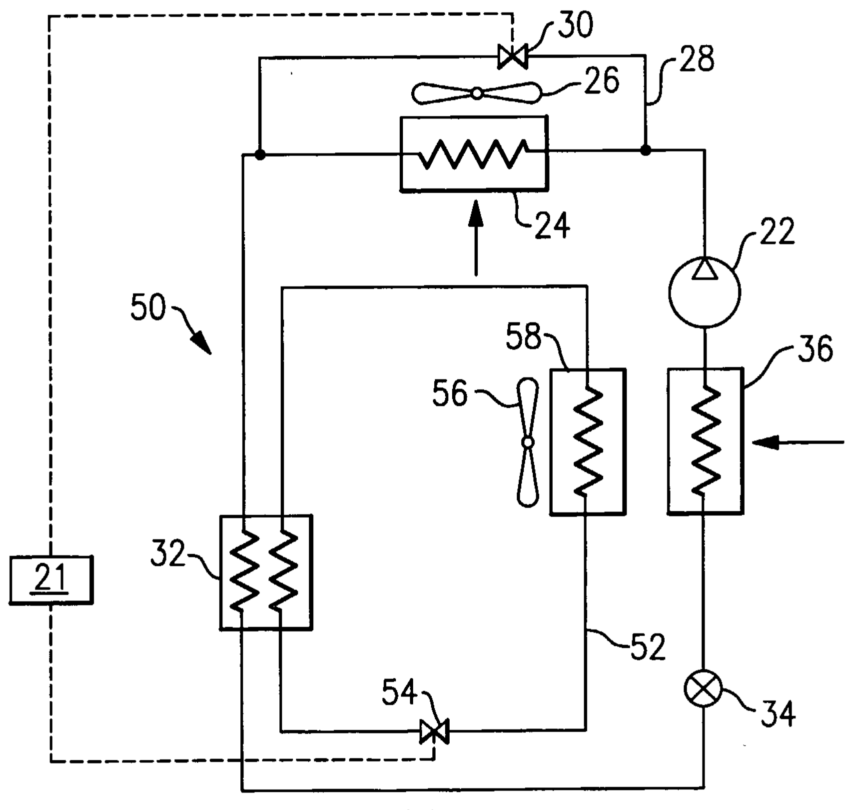
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FIG.2A

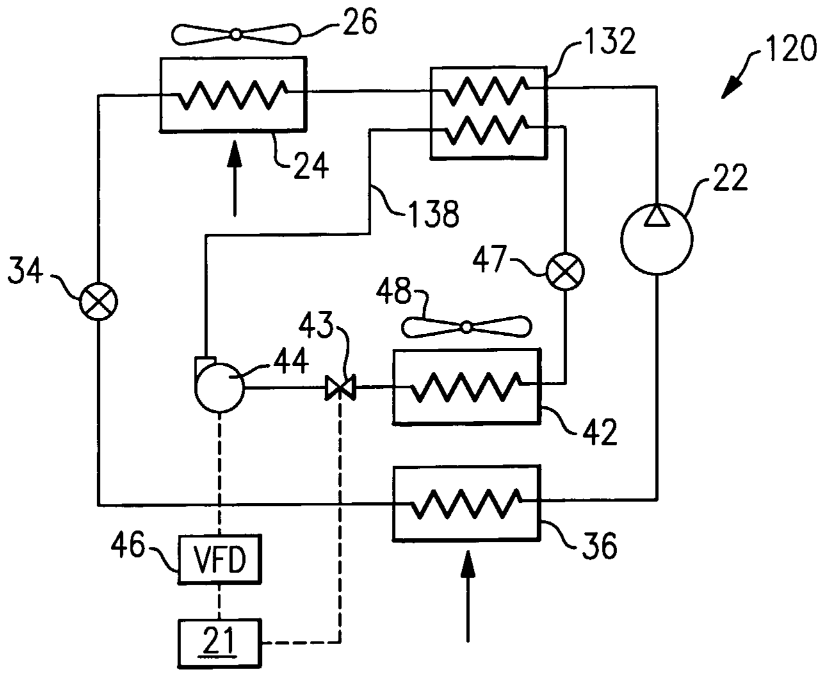
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FIG.1B

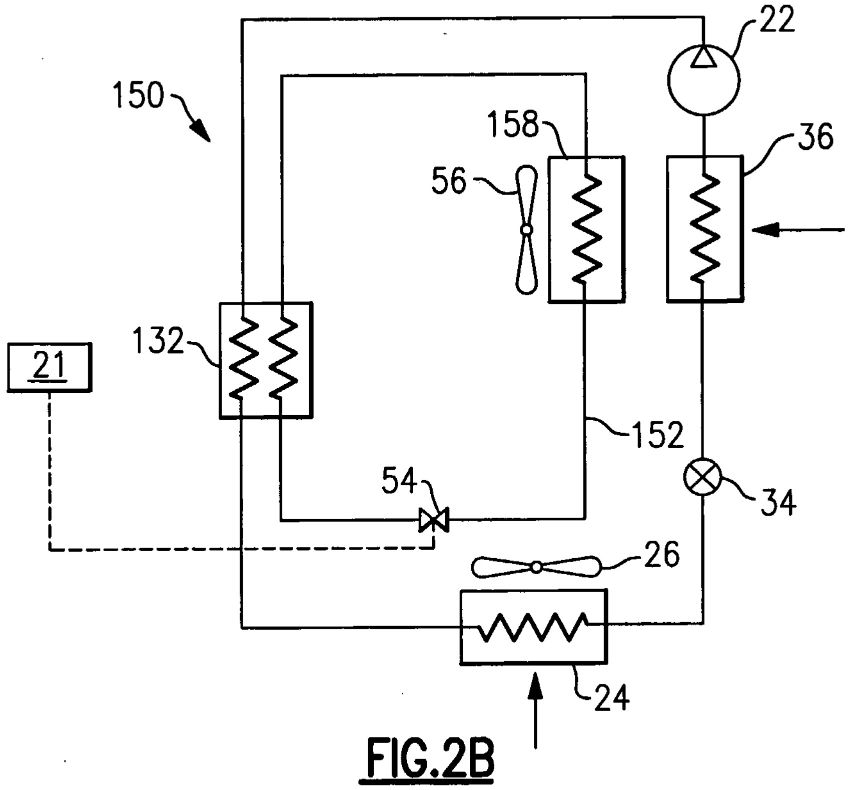
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FIG.2B