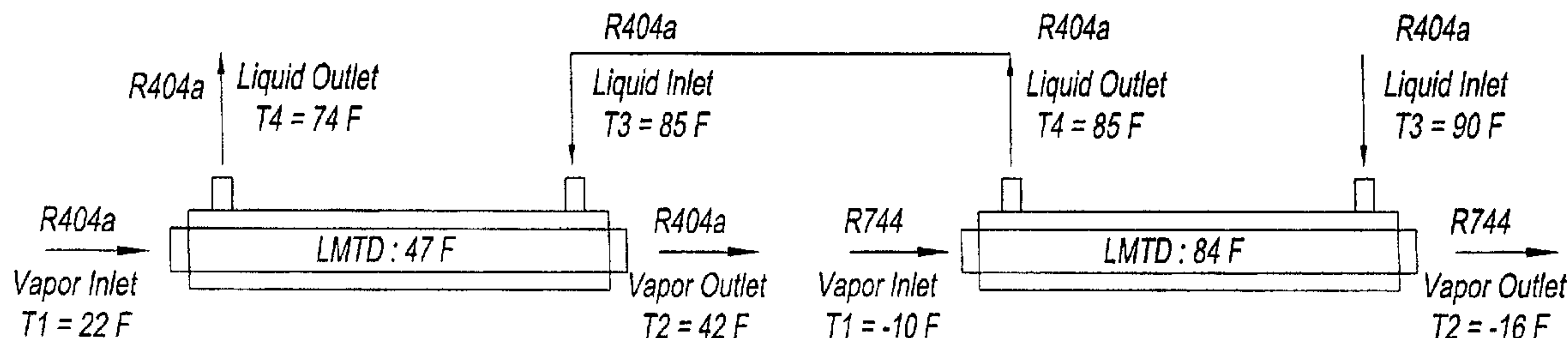




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(54) Titre : SYSTEME DE REFROIDISSEMENT EN CASCADE AVEC REFROIDISSEMENT A CYCLES INTERMEDIAIRES  
 (54) Title: CASCADE COOLING SYSTEM WITH INTERCYCLE COOLING



(57) **Abrégé/Abstract:**

A cascade refrigeration system, which comprises a top cycle that circulates a first refrigerant, a low cycle that circulates a second refrigerant, and a heat exchanger through which the two cycles interface. The system further comprises a second heat exchanger through which the second refrigerant is superheated by the first refrigerant, while the first refrigerant is simultaneously subcooled by the second refrigerant. The system further comprises a control system that can regulate the amount of superheating of the second refrigerant.

## ABSTRACT

A cascade refrigeration system, which comprises a top cycle that circulates a first refrigerant, a low cycle that circulates a second refrigerant, and a heat exchanger through which the two cycles interface. The system further comprises a second heat exchanger through which the second refrigerant is superheated by the first refrigerant, while the first refrigerant is simultaneously subcooled by the second refrigerant. The system further comprises a control system that can regulate the amount of superheating of the second refrigerant.

## CASCADE COOLING SYSTEM WITH INTERCYCLE COOLING

### CROSS-REFERENCE TO RELATED APPLICATION

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The present application claims priority to United States Provisional Application No. 61/126,276, filed on May 2, 2008.

### BACKGROUND OF THE DISCLOSURE

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#### 1. Field of the Disclosure

The present disclosure relates to cascade cooling systems, and in particular cascade cooling systems having inter-cycle cooling capacity.

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#### 2. Description of the Related Art

Cascade cooling systems can comprise a first, or top-side cooling cycle, and a second, or low-side cooling cycle. The two systems interface through a common heat  
20 exchanger, i.e. a cascade evaporator - condenser. Cascade cooling systems can be beneficial when there is a need for cooling to very low temperatures. They can also be necessary when equipment that can withstand very high pressures, which are required for the coolants used to provide cooling to these very low temperatures, is not available. There is a continuing need to improve the energy efficiency, system reliability, and  
25 safety of these systems.

### SUMMARY OF THE DISCLOSURE

The present disclosure addresses these needs with a cascade cooling system  
30 that utilizes intercycle cooling, e.g. an intercycle heat exchanger that simultaneously

subcools refrigerant leaving the condenser of the top-side cooling cycle, and further heats the vapor leaving the evaporator of the low-side cooling cycle.

In accordance with an aspect of the present invention, there is provided a  
5 refrigeration system, comprising:

a first cycle for circulating a first refrigerant;

a second cycle for circulating a second refrigerant;

a first heat exchanger, wherein said first refrigerant and said second  
refrigerant are in thermal communication with one another; and

10 a second heat exchanger, wherein said first refrigerant and said second  
refrigerant are also in thermal communication with one another,

wherein an expansion device expands said first refrigerant before it enters  
said first heat exchanger; and

wherein at least a portion of said first refrigerant is diverted from said first  
15 cycle to said second heat exchanger, before passing through said first heat  
exchanger;

wherein said second cycle comprises a receiver configured to receive fluid  
from the first heat exchanger, and a third heat exchanger configured to receive fluid  
from the receiver, wherein said second refrigerant passes through said third heat  
20 exchanger before entering said second heat exchanger.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a schematic drawing of the cascade cooling system of the  
25 present disclosure;

Fig. 2 shows a schematic drawing of the suction line heat exchangers of the  
system of Fig. 1,

30 Fig. 3 shows a schematic drawing of the suction line heat exchangers of Fig.  
2, when used in conjunction with the intercycle heat exchanger of Fig. 1;

Fig. 4 shows a graph comparing the temperature differences present in the suction line heat exchangers, and the intercycle cooling heat exchanger of the present disclosure;

5 Fig. 5 shows a schematic drawing of a cascade cooling system without intercycle cooling; and

Fig. 6 shows a schematic drawing of a second embodiment of a cascade cooling system without intercycle cooling.

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#### DETAILED DESCRIPTION OF THE DISCLOSURE

Referring to Fig. 1, cascade system 10 is shown. Cascade system 10 has top cycle 20, low cycle 40, and intercycle heat exchanger 70. In intercycle heat  
15 exchanger

70, a first refrigerant leaving a condenser 24 of top cycle 20 is subcooled by a second refrigerant leaving evaporator 66 of low cycle 40, and the second refrigerant is superheated by the first refrigerant. Intercycle heat exchanger 70 provides a vastly improved efficiency of cascade system 10 over comparative systems currently available, especially when intercycle heat exchanger 70 is used exclusively or in conjunction with additional suction line heat exchangers (SLHXs), in the manner described below.

In some applications, it is desirable to control the amount of superheating completed by intercycle heat exchanger 70, to make sure that it is above a desired level, and because the design parameters of carbon dioxide compressors often require it, for reliability reasons. If not enough superheating is achieved, a designer has to add some sort of external or artificial heater, which will adversely affect the efficiency of the system. Thus, the present disclosure has advantageously provided control system 80 of cascade system 10, which can monitor and regulate the amount of intercycle subcooling performed in cascade system 10, in the manner discussed below. Control system 80 can provide for an easier control of the amount of superheating, when compared to presently available systems.

In top cycle 20, the first refrigerant is compressed to a high pressure and high temperature in compressor 22, and then passes through condenser 24 for a first amount of cooling. The first refrigerant can then pass through a conventional SLHX 28, wherein the first heat exchange takes place, resulting in subcooling of the first refrigerant. An SLHX can be used to provide subcooling or superheating of a refrigerant between a refrigerant exiting a condenser, and the same refrigerant exiting an evaporator, within the same cycle. These SLHXs can improve the efficiency of the overall system.

The subcooled first refrigerant exiting SLHX 28 then passes through the intercycle heat exchanger 70, where it exchanges heat with a second refrigerant in the manner discussed below, and undergoes further amount of cooling. The first refrigerant

is then passed through an expansion device 26, where it is expanded to a low-temperature, low-pressure vapor. The first refrigerant is then passed to main heat exchanger 30, where it again exchanges heat with the second refrigerant, in a manner discussed below. The refrigerant can then be returned to compressor 22, thus  
5 completing the cycle of top cycle 20.

As discussed above, in one embodiment, top cycle 20 can have SLHX 28. In SLHX 28, the first refrigerant, after being cooled and/or condensed in condenser 24, exchanges heat with the low temperature, low pressure first refrigerant that has passed  
10 through main heat exchanger 30, and is being returned to compressor 22. SLHX 28 and intercycle heat exchanger 70 cumulatively improve the efficiency of cascade system 10 in several ways. First, SLHX 28 provides further subcooling of the liquid refrigerant. In some cases, without SLHX 28, flash gas can form, which will decrease the capacity of main heat exchanger 30. Secondly, SLHX 28 can superheat the vapor  
15 of the first refrigerant leaving the main heat exchanger 30, thus evaporating remaining liquid, if any, that is in the stream of the first refrigerant. Liquid remaining within the refrigerant stream at this point could possibly damage compressor 22.

The heating and cooling that takes place within SLHX 28 as well as intercycle  
20 heat exchanger 70 increases the system refrigerating capacity, with beneficial increases in system efficiency and the coefficient of performance (COP) of the system. The selection and use of an SLHX can be very critical, as the benefits of an increase in refrigerating capacity can be negated by way of excessive sub-cooling, with significant pressure drops, that can adversely affect the system COP.

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The first refrigerant circulating in top cycle 20 can be any number of refrigerants. For example, the first refrigerant can be any hydrofluorocarbon (HFC) such as R404A, which is a blend of penta-, tetra-, and trifluoroethane.

30

Top cycle 20 interfaces with bottom cycle 40 through main heat exchanger 30. At main heat exchanger 30, the first refrigerant circulating through top cycle 20 is

evaporated by the second refrigerant passing through bottom cycle 40. At the same time, the second refrigerant is condensed by the first refrigerant.

In bottom cycle 40, the second refrigerant is compressed by compressor 42, and then passes through oil separator 44, which removes any compressor oil that has been carried by the second refrigerant. The second refrigerant then passes through main heat exchanger 30, where, as discussed above, it is condensed by thermal interaction with the first refrigerant. The second refrigerant can then be circulated to a separator 46, whose function is to serve as a reservoir and/or to separate the second refrigerant into vapor and liquid states. The vapor can be returned to main heat exchanger 30 via vapor return line 47.

The liquid portion of the second refrigerant within separator 46 can be routed to one of two locations. For medium-level cooling applications (for example, display cases, dairy cases, meat cases, and deli cases in supermarkets), the second refrigerant can be diverted through a medium temperature circuit 50. Circuit 50 comprises a pump 51, an optional flow control device 52, and an evaporator or series of evaporators 54, which provides cooling to the desired medium. Flow control device 52 can control the second refrigerant so that all or none of the second refrigerant passes to evaporator 54, or any amount in between. Circuit 50 also comprises a bypass line 53. If there is no demand for medium temperature cooling, flow control device 52 operates to terminate the flow of the second refrigerant to evaporator 54, and routes all of the second refrigerant through bypass line 53 back to separator 46. Alternately, to balance the system mass flow (in case the pump capacity is greater than the system requirement), the excess flow is diverted back to the separator through the bypass line 53. The excess pump energy flashes the liquid in the separator 46, thereby generating vapor that is separated and routed to heat exchanger 30 via vapor line 47. Another alternative (not shown), is to route the return from the medium temperature evaporator 54 directly to the heat exchanger 30 instead of returning to the separator 46.

30

For applications that require a greater degree of cooling (for example, glass door reach-in freezers, open coffin style freezers, frozen food display cases, etc.), the liquid portion of the second refrigerant from separator 46 can be routed to a low temperature circuit 60. Circuit 60 can comprise an optional second SLHX 62, an expansion device 5 64, and an evaporator 66. The second refrigerant passes through expansion device 64, where it is expanded to a low temperature and low pressure state, and then the liquid undergoes a phase change in the evaporator 66, to provide the desired cooling. SLHX 62 functions in a similar manner to SLHX 28 of top cycle 20, namely that it provides additional cooling and evaporation for the second refrigerant upstream and downstream 10 of evaporator 66, respectively.

In one embodiment, the second refrigerant can be carbon dioxide. However, other candidates for the second refrigerant are considered by the present disclosure, such as ammonia.

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Vapor exiting SLHX 62 is then circulated to intercycle heat exchanger 70, where it is in thermal communication with the first refrigerant of top cycle 20. As discussed above, this configuration provides significant benefits for the COP of system 10. As can be seen in the data below, intercycle heat exchanger 70 can provide significantly better 20 performance than standard cascade cooling systems.

Referring to Figs. 2-3, the advantages of system 10 of the present disclosure are illustrated more clearly. The temperatures used in Figs. 2-3 are not meant to be limiting of system 10, but are merely used to show the difference between system 10 and 25 conventional cooling systems. In the HFC (e.g., R-404A) cycle shown in Fig. 2, refrigerant liquid exiting the top cycle condenser 24 at 90° F (degrees Fahrenheit) exchanges heat with refrigerant vapor exiting the top cycle evaporator 30 at 22° F. In one example, the liquid HFC is subcooled to a temperature of 78.6° F, while the HFC vapor is heated to a temperature of 42° F. In the carbon dioxide (e.g., R744) cycle, 30 refrigerant carbon dioxide exiting the low cycle condenser 30 at 20° F exchanges heat with the carbon dioxide vapor leaving the low cycle evaporator 66 at -10° F. The R744

may act at a saturation temperature of  $-15^{\circ}\text{F}$ , and undergo additional superheating while still disposed within evaporator 66, bringing the temperature to  $-10^{\circ}\text{F}$ . In one example, the carbon dioxide liquid is cooled to a temperature of  $13^{\circ}\text{F}$ , while the carbon dioxide vapor is superheated to a temperature of  $4.4^{\circ}\text{F}$ , for a superheat amount of 5  $19.4^{\circ}\text{F}$ , i.e. from  $-15^{\circ}\text{F}$  to  $4.4^{\circ}\text{F}$ . Even with a heat exchanger having a close to ideal effectiveness of 0.8 (SLHXs such as the one shown in Fig. 2 typically have effectiveness on the order of 0.3), the maximum amount of superheating of the carbon dioxide vapor, attainable without using any external heating device, would be  $29^{\circ}\text{F}$ . This is not enough superheating for many carbon dioxide compressors, which often 10 require superheating of more than  $36^{\circ}\text{F}$ .

Referring to Fig. 3, another configuration of the present disclosure is shown. In this example, a top cycle refrigerant, such as R404A, leaves a condenser, such as condenser 24, at  $90^{\circ}\text{F}$ , and exchanges heat with R404A refrigerant leaving the main 15 heat exchanger 30 at  $22^{\circ}\text{F}$ , within SLHX 28. As with the SLHX shown in Fig. 2, the R404A liquid can be cooled to a temperature of  $78.6^{\circ}\text{F}$ . This liquid can then be circulated through intercycle heat exchanger 70, where it can provide superheating to R744 exiting evaporator 66 or SLHX 62 of low cycle 40 at  $-10^{\circ}\text{F}$ . As shown, the amount of superheating provided to the carbon dioxide vapor of the low cycle using 20 intercycle heat exchanger 70 is  $47.5^{\circ}\text{F}$  (i.e. from  $-15^{\circ}\text{F}$  to  $32.5^{\circ}\text{F}$ ), which is much greater than in the systems of the prior art. Again, this data was calculated at an intercycle heat exchanger efficiency of 0.3. With a close to ideal heat exchanger having an effectiveness of 0.8, the superheating can be as much as  $76^{\circ}\text{F}$ . This number was calculated based on the log mean temperature difference (LMTD) between the two 25 refrigerant streams within and along the length of the heat exchanger.

Referring to Fig. 4, a plot showing the temperature difference along the length of intercycle SLHX 70, as compared to conventional SLHXs, based on the numbers shown in Figs. 2 and 3, is shown. As can be seen from the graph, the temperature difference 30 along the intercycle heat exchanger 70 is much greater than in conventional SLHXs.

Control system 80 further adds to the efficiency of cascade system 10. As stated above, it is often desirable to maintain the superheating of the second refrigerant above a certain value. A device, such as a controller 81, can measure the temperature of the second refrigerant as it exits intercycle heat exchanger 70, and determine the amount of superheating. Controller 81 can then control a motor 82, which can in turn regulate a flow control device 83. Flow control device 83 is disposed on a bypass line 84. When a greater amount of superheating of the second refrigerant is required, controller 81 can control flow control device 83 so that all, or at least a portion, of the first refrigerant is circulated through intercycle heat exchanger 70.

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Alternatively, when there is less demand for superheating of the second refrigerant, flow control device 83 can be controlled so that all, or at least a portion of, the first refrigerant can be circulated directly through bypass line 84 and expansion device 26, without passing through intercycle heat exchanger 70. Intercycle heat exchanger 70 is thereby utilized as needed to maintain superheat within comfortable margins. Thus, control system 80 provides a great deal of flexibility in controlling the amount of superheating that occurs in cascade system 10.

Referring to Figs. 5-6, another cascade cooling system 105 according to the present disclosure is shown. The system comprises primary system 110, secondary system 120, and evaporator/condenser 130. Cascade cooling system 105 can also have third or emergency system 140.

Primary system 110 comprises compressor 111, condenser 112, receiver 113, and expansion device 114. Refrigerant vapor, i.e. a hydrofluorocarbon (HFC), is compressed by compressor 111 and is discharged as a high pressure, superheated vapor. Oil from compressor 111 that dissolves in the superheated vapor can be removed by separator 117. After the superheated vapor exits compressor 111, it is then condensed to a high pressure liquid by condenser 112. The high pressure liquid is then stored in receiver 113, and is withdrawn as needed to satisfy the load on evaporator/condenser 130. The liquid feed to the evaporator passes through expansion

device 114, where the outlet pressure is lower, resulting in "flashing" of the liquid to a liquid/vapor state, which is at a lower pressure and temperature. The refrigerant absorbs heat in evaporator/condenser 130, and, as a result, the remaining liquid is boiled off into a low pressure vapor or gas. The gas then returns back to the inlet of compressor 111, where the compression cycle starts over again. In one embodiment, suction/liquid heat exchanger 115 can be used, to subcool the liquid prior to entering the evaporator, and which utilizes the lower temperature outlet gas of the evaporator to achieve the desired subcooling.

Secondary system 120 comprises compressor 121, receiver 123, one or more evaporators 122, and one or more expansion devices 124. In the shown embodiment, carbon dioxide is used as a refrigerant in secondary system 120. Secondary system 120 follows a similar vapor-compression cycle as that of primary system 110. Vapor is compressed by the compressor 121, and separator 127 can remove any oil that is dissolved in the vapor. The vapor is passed to evaporator/condenser 130, where it is condensed to a high pressure liquid. The liquid is then passed to receiver 123, where it is withdrawn as needed. For a low temperature cycle, this liquid carbon dioxide flows from receiver 123 through one or more expansion devices 124, and into one or more evaporators 122, where it can exchange heat with an environment that requires cooling. The refrigerant exits these low temperature evaporators 122 as a low pressure gas, and is then fed back to compressor 121.

Secondary system 120 also comprises a medium temperature cycle. Liquid exiting receiver 123 can be circulated by pump 128, through one or more flow valves 129 to one or more evaporators 122. Valves 129 can either be open/close valves, or flow regulating valves. The exiting state of the refrigerant in this medium temperature cycle is a high pressure, liquid/vapor mixture. This mixture is then mixed with the vapor exiting compressor 121, and is routed to evaporator/condenser 130, where the vapor is condensed out of the mixture.

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Accumulators 116 and 126 help to ensure that liquid does not reach the compressors. Whether or not they are necessary will depend on the particular parameters of the user's system.

5           The use of third system 140 will depend upon the particular parameters of the user's system, and how emergency power is supplied in a particular application of system 105. Much like primary system 110 and secondary system 120, third system 140 can comprise a compressor 141, condenser 142, and expansion device 144. Third system 140 will maintain the temperature/pressure of the carbon dioxide liquid below a  
10 relief setting, that is set to release carbon dioxide to the atmosphere when the pressure becomes too great for second system 120 to withstand. This can happen, for example, during a power failure, and results in loss of carbon dioxide refrigerant, and cooling ability when the system is back on-line. Thus, third cooling system 140 can cool a vapor carbon dioxide within receiver 123 by heat exchange through emergency  
15 condenser/evaporator 150. Third cooling system 140 can also have its own power supply 148.

Referring to Fig. 6, a second embodiment of cascade system 105 is shown. This system is identical to that of Fig. 5, with the exception that the liquid/gas carbon dioxide  
20 mixture exiting evaporators 122 of the medium temperature cycle is diverted to receiver 123, where the liquid and vapor will separate. The vapor portion will be piped back to the evaporator/condenser 130 through a thermal siphon, and mixed with the vapor exiting compressor 121, in order to condense the vapor to a liquid.

25           While the present disclosure has been described with reference to one or more exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the present disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the disclosure  
30 without departing from the scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiment(s) disclosed as the best mode

contemplated for carrying out this disclosure, but that the disclosure will include all embodiments falling within the scope of the claims.

## WHAT IS CLAIMED IS:

1. A refrigeration system, comprising:
  - a first cycle for circulating a first refrigerant;
  - 5 a second cycle for circulating a second refrigerant;
  - a first heat exchanger, wherein said first refrigerant and said second refrigerant are in thermal communication with one another; and
  - a second heat exchanger, wherein said first refrigerant and said second refrigerant are also in thermal communication with one another,
  - 10 wherein an expansion device expands said first refrigerant before it enters said first heat exchanger, and
  - wherein at least a portion of said first refrigerant is diverted from said first cycle to said second heat exchanger, before passing through said first heat exchanger;
  - 15 wherein said second cycle comprises a receiver configured to receive fluid from the first heat exchanger, and a third heat exchanger configured to receive fluid from the receiver, wherein said second refrigerant passes through said third heat exchanger before entering said second heat exchanger.
- 20 2. The refrigeration system of claim 1, wherein within said first heat exchanger, said first refrigerant cools said second refrigerant, said second refrigerant heats said first refrigerant, or a combination of the two.
3. The refrigeration system of claim 1, wherein within said second heat exchanger,  
25 said second refrigerant cools said first refrigerant, said first refrigerant heats said second refrigerant, or a combination of the two.
4. The refrigeration system of claim 1, further comprising a device that that controls  
30 an amount of cooling of said first refrigerant, an amount of heating of said second refrigerant, or a combination of the two.

5. The refrigeration system of claim 4, wherein said device measures a temperature of said second refrigerant after it exits said second heat exchanger, and comprises a flow control device that controls a flow of said first refrigerant to said second heat exchanger, based on said temperature of said second refrigerant.

5

6. The refrigeration system of claim 1, wherein said first cycle further comprises a condenser and a third heat exchanger, wherein a portion of said first refrigerant exiting said condenser is in thermal communication with a portion of said first refrigerant exiting said first heat exchanger.

10

7. The refrigeration system of claim 1, wherein said second cycle further comprises an evaporator, a third heat exchanger, and a receiver, and

said second refrigerant exits said first heat exchanger and passes to said receiver, wherein a portion thereof further passes through said third heat exchanger, where it is in thermal communication with a portion of said second refrigerant exiting said evaporator.

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8. The refrigeration system of claim 1, wherein said second cycle further comprises an evaporator positioned to receive fluid output from the third heat exchanger, wherein the third heat exchanger is configured to receive fluid output from the evaporator.

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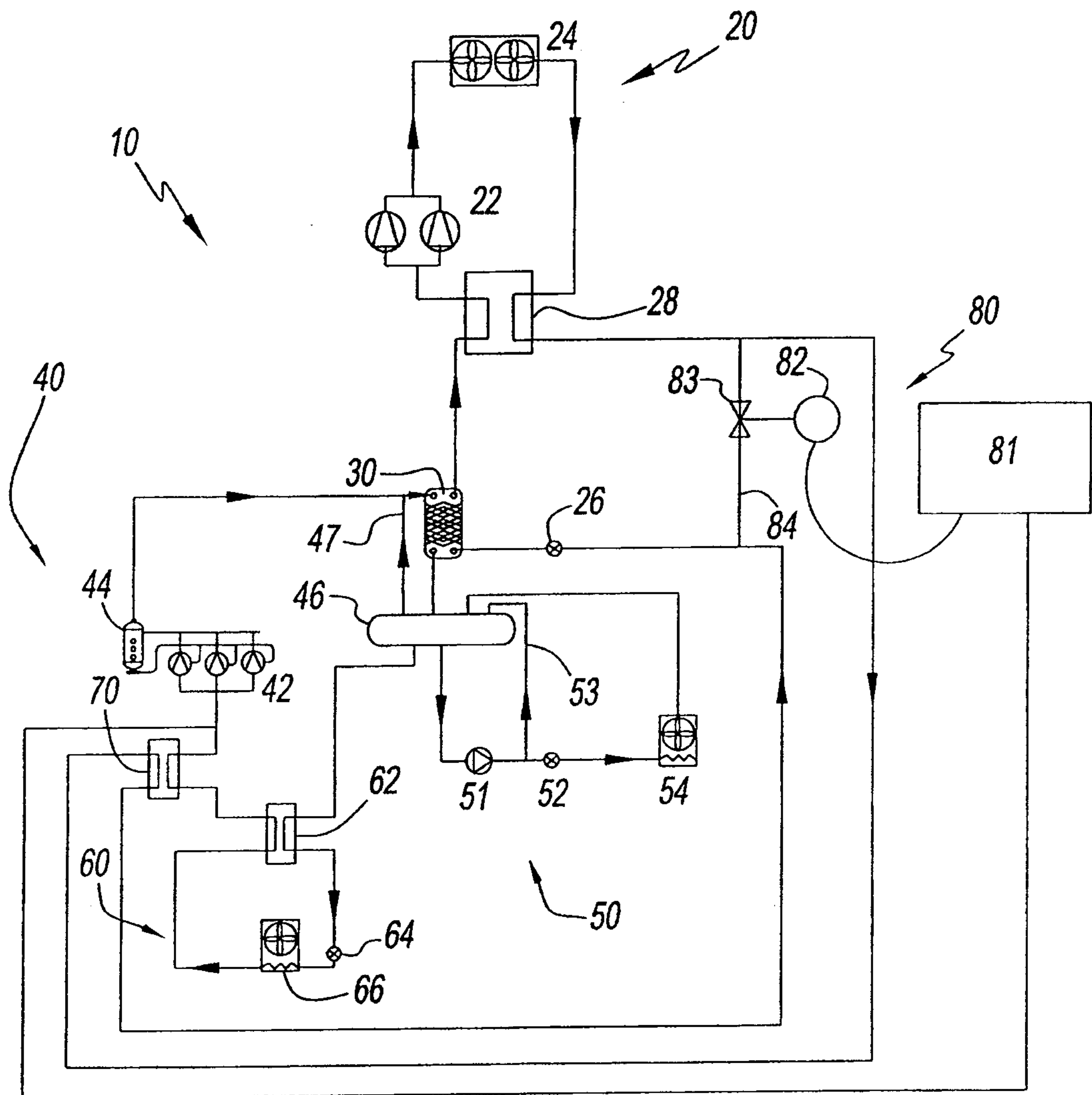
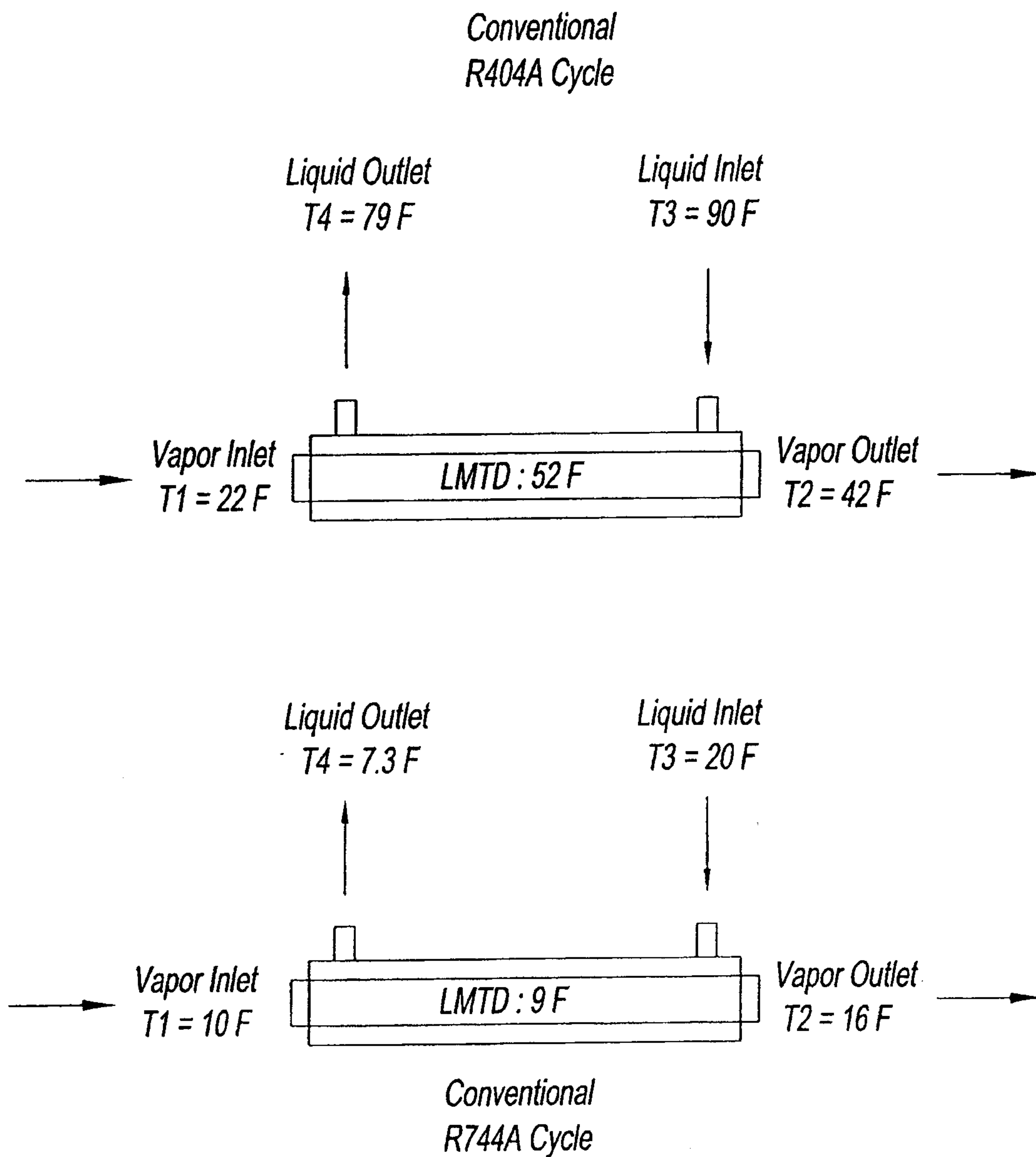


Fig. 1

2/6



*Fig. 2  
(Prior Art)*

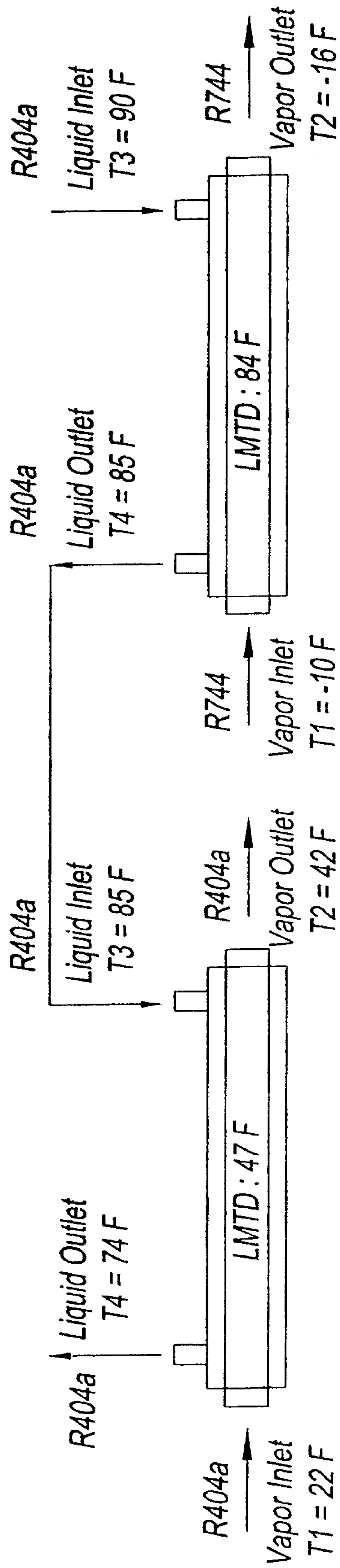


Fig. 3



Plot of TD Between Inlet and Outlet of Conventional SLHX  
Intercycle Heat Exchanger

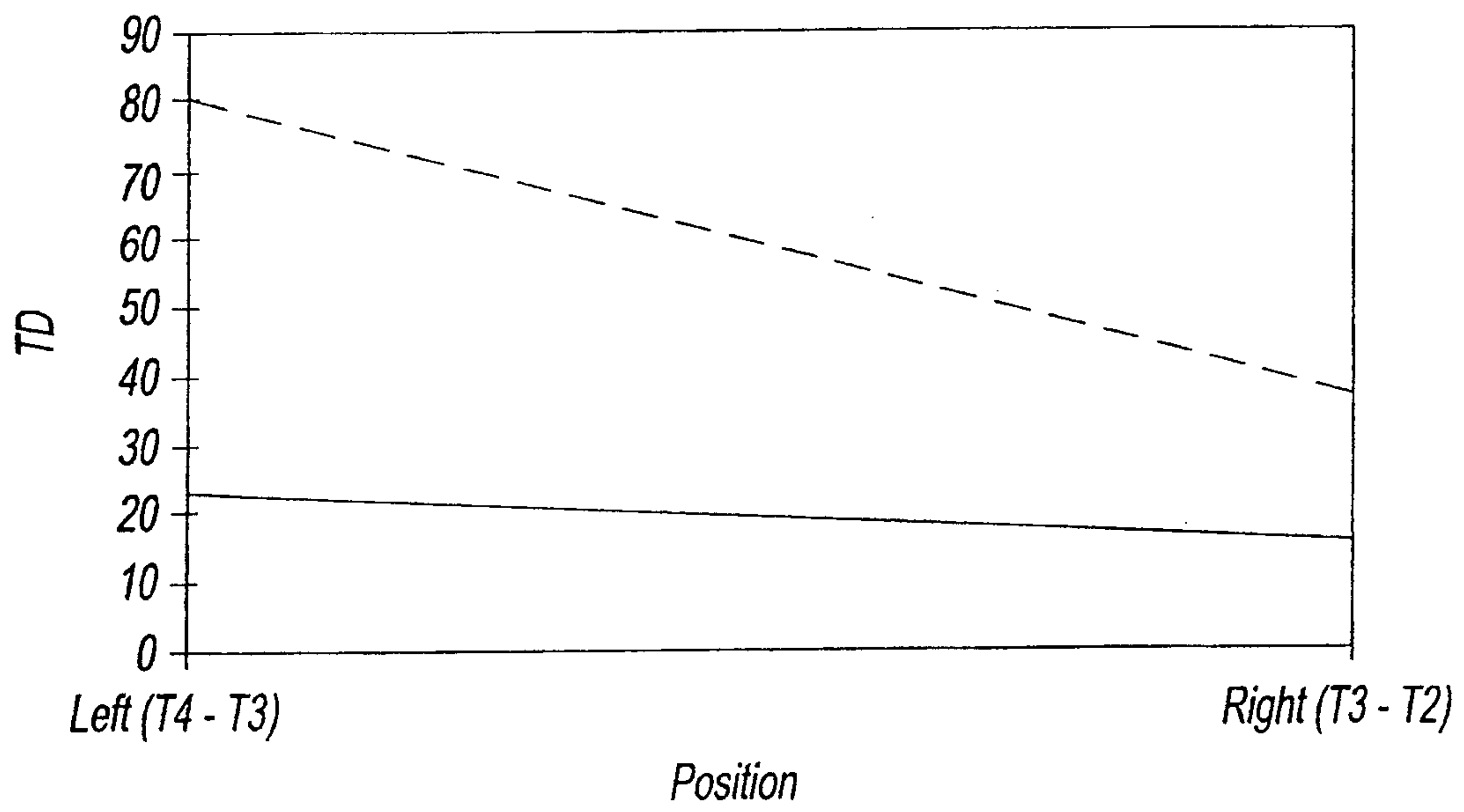


Fig. 4

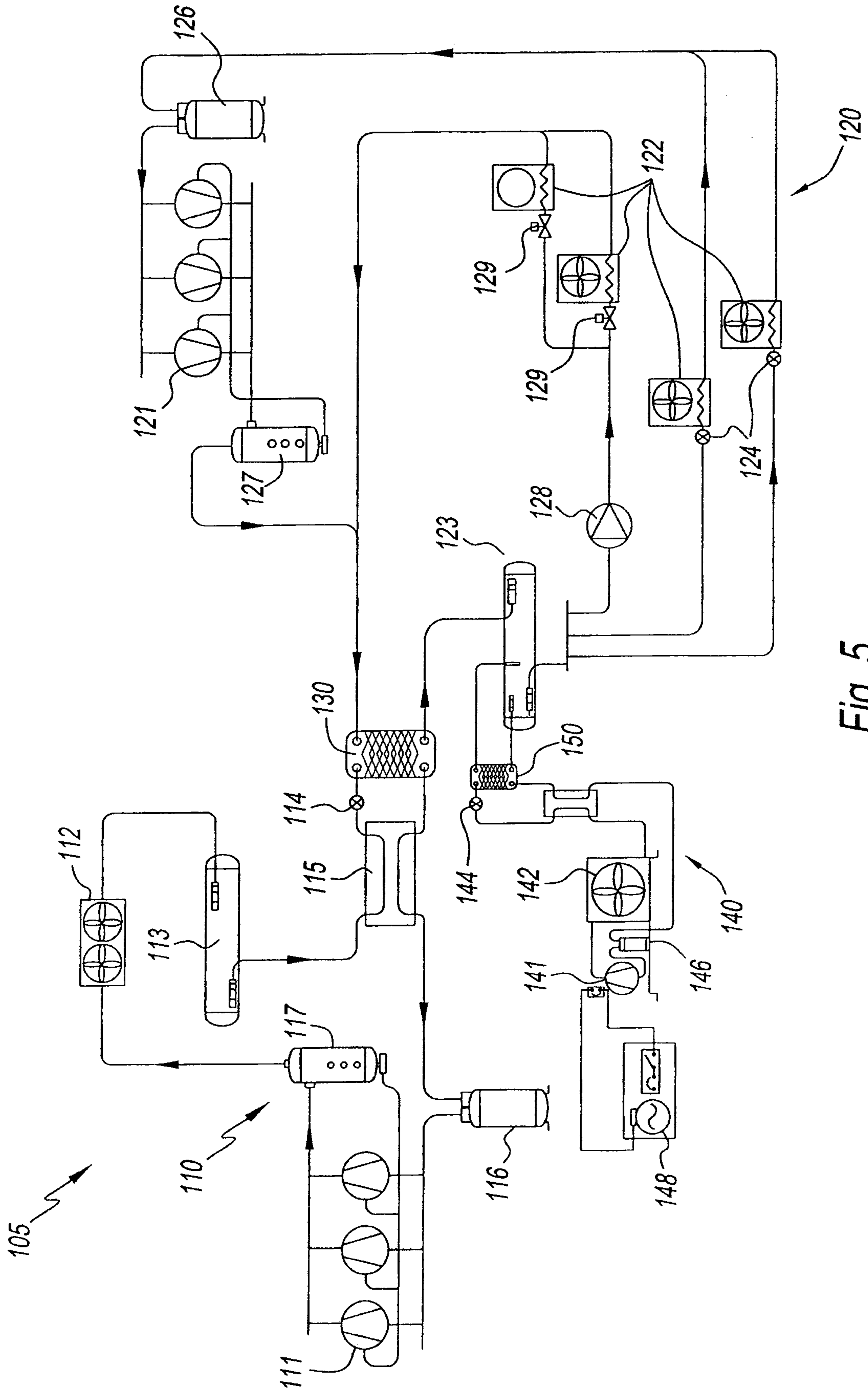


Fig. 5

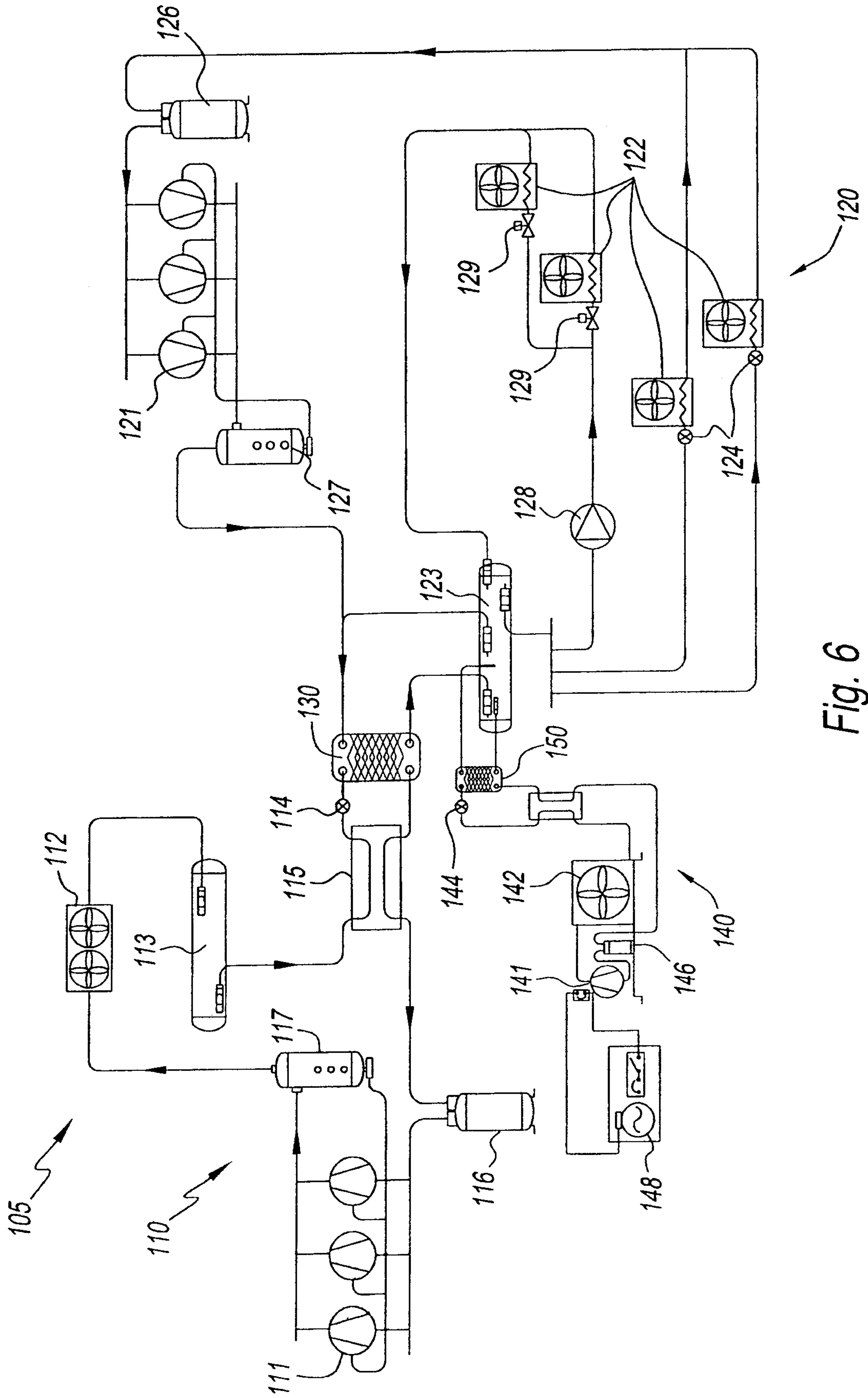


Fig. 6

