

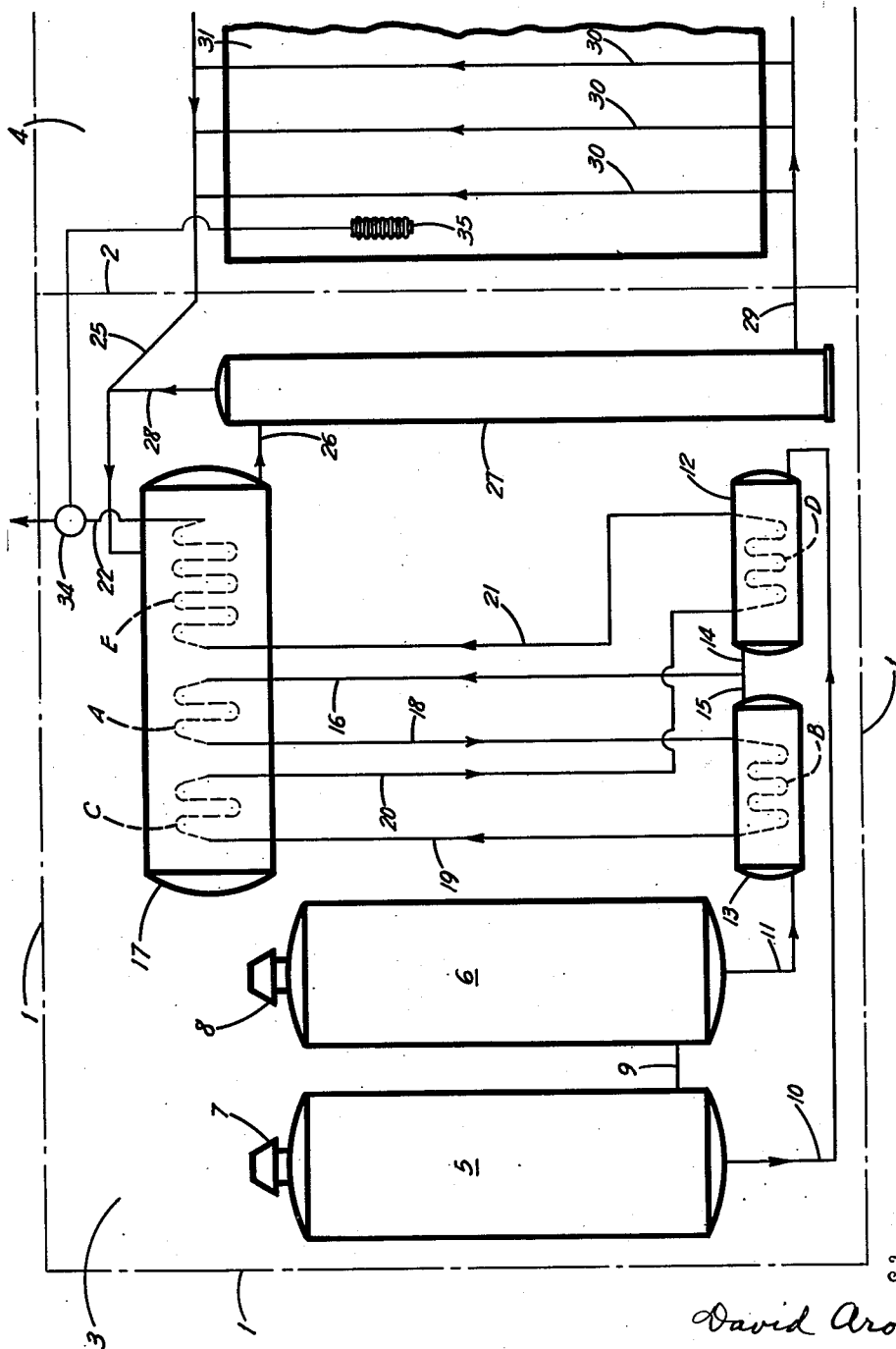
Aug. 30, 1949.

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2,480,693

REFRIGERATING APPARATUS

Filed July 2, 1947



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UNITED STATES PATENT OFFICE

2,480,693

REFRIGERATING APPARATUS

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Application July 2, 1947, Serial No. 758,612

9 Claims. (Cl. 62—92)

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This invention relates to a system of refrigeration in which a primary refrigerant having a very low boiling point, such as liquid air, is used to cool a secondary refrigerant that is a highly volatile fluid and that is circulated in a closed circuit as a heat transfer agent between the primary refrigerant and a refrigerator compartment.

A refrigerating system of this type is particularly useful for preserving perishable products during shipment in railroad refrigerator cars, or other vehicles or vessels. It requires no external source of power, it has no moving parts, and it is capable of providing efficient refrigeration and close temperature control over a wide temperature range.

To obtain such efficient refrigeration and close temperature control, the secondary refrigerant should be a highly volatile fluid that continually undergoes a change of state as it circulates in a closed circuit between the primary refrigerant and the compartment to be cooled. In the liquid state, the fluid absorbs heat from cooling surfaces in the compartment and is evaporated without change in its temperature. In the vapor state, the fluid gives up heat to the primary refrigerant and is condensed to a liquid without change in its temperature. By so utilizing the latent heats of evaporation and condensation of a highly volatile fluid, it is possible to obtain high efficiency in the transfer of heat from the compartment to the primary refrigerant and to maintain the compartment at a uniform temperature determined by the characteristics of the fluid and its pressure.

In order to circulate a highly volatile fluid as a heat transfer agent without change in its temperature, two conditions must be substantially satisfied. First, the fluid must not be subcooled in its liquid state. Or stated another way, all of the heat that the fluid gives up to the primary refrigerant must be used to condense the fluid from a vapor to a liquid without cooling the latter below its condensation temperature. If the liquid is subcooled, it will absorb sensible heat (represented by a rise in its temperature) from the refrigerator compartment, and the cooling surfaces therein will not be kept at a uniform temperature. To avoid subcooling, apparatus must be so designed that no heat exchange takes place between this liquid and the primary refrigerant. Second, the fluid must not be superheated in its vapor state, which means that all of the heat absorbed by the fluid from the refrigerator compartment must be used to evap-

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orate the fluid from a liquid to a vapor without warming the latter above its evaporation temperature. If the vapor is superheated, it will absorb sensible heat (represented by a rise in its temperature) from the compartment, and again the cooling surfaces therein will not be kept at a uniform temperature. To avoid superheating, apparatus must be so designed that no heat exchange takes place between this vapor and the refrigerator compartment, that is, evaporation of liquid must take place throughout substantially all of the heat exchanging region in the refrigerator compartment.

It is difficult to satisfy both of these conditions when the required apparatus must be disposed within a vertically limited space, for example, in a railroad refrigerator car. Adequate storage capacity for liquid air, which is the preferred primary refrigerant, requires one or more storage tanks extending from near the floor of the car almost to the roof. As the liquid air is used up during the operation of the system, the liquid level in those tanks drops closer to the floor of the car. Accordingly, the liquid air is at all times readily available outside the tanks as a source of refrigeration only at, or below, the level of the bottoms of the tanks. While a pump could be used to raise the liquid air to a higher level, it would introduce moving mechanical parts which it is an object of this type of refrigerating system to avoid. As an alternative, the storage tanks could be sealed, so that heat leakage from outside would vaporize the liquid air and build up sufficient pressure to raise it to any required height. But this would introduce considerable hazards from possibly faulty pressure control equipment; and, even if adequate equipment could be provided, additional maintenance would be required.

Accordingly, the problem to be solved in devising a refrigerating system of this type for a railroad refrigerator car is how to utilize liquid air, which is available only near the floor of the car, as a source of refrigeration for condensing a highly volatile fluid without subcooling it and also to evaporate condensed fluid near the roof of the car in the refrigerator compartment.

One solution of this problem is disclosed in my copending patent application Serial No. 748,079, filed May 14, 1947, now Patent No. 2,452,711 granted November 2, 1948. In the apparatus there described, liquid air is vaporized near the floor of the car by heat exchange with the secondary refrigerant in the vapor state. To avoid subcooling in this case, the normal liquid level of

the secondary refrigerant must be very close to the floor of the car, and the liquid is raised to a higher level in the refrigerator compartment by means of evaporator tubes of special design. The present invention is directed to a different solution of the problem.

It is accordingly one of the objects of this invention to provide a method and apparatus in which a secondary refrigerant consisting of a highly volatile fluid is condensed, without being subcooled, by the cold vapor of a liquid primary refrigerant having a very low boiling point, in which the normal liquid level of the secondary refrigerant may be considerably higher than the liquid level of the primary refrigerant, and in which sufficient heat is transferred to the liquid primary refrigerant to vaporize it and make available its cold vapor for condensing the secondary refrigerant.

It is another object of this invention to provide a method and apparatus for cooling a refrigerator compartment in a railroad refrigerator car, or other vehicle or vessel, in which a secondary refrigerant consisting of a highly volatile fluid is condensed, without being subcooled, by giving up heat to cold vaporized air that is then used to vaporize liquid air and in which the normal liquid level of the secondary refrigerant may be kept sufficiently high to permit liquid secondary refrigerant to flow by gravity to any desired level in the compartment from near the floor to close to the top of the compartment.

In accordance with this invention, a highly volatile fluid is circulated as a secondary refrigerant in a closed circuit, part of which (where the fluid is condensed) is in heat exchange relation to an intermediate refrigerant consisting of the cold vapor of a liquid primary refrigerant having very low boiling point, and another part of which (where the fluid is evaporated) is in heat exchange relation to a refrigerator compartment. The intermediate refrigerant, which is always in the vapor state, acts as a heat transfer agent between the secondary refrigerant and the liquid primary refrigerant. In condensing the secondary refrigerant, the cold vapor of the primary refrigerant is warmed and this warmed vapor is then brought into heat exchange relation to the liquid primary refrigerant, to which the vapor gives up some of its sensible heat, thereby causing some of the liquid primary refrigerant to boil and furnish more cold vapor for condensing the secondary refrigerant that circulates in the closed circuit. Since the amount of heat that, within practicable limits, can be transferred (from the secondary refrigerant) to a pound of liquid primary refrigerant by a pound of its cold vapor (the intermediate refrigerant) is less than the latent heat of evaporation of the former, it is essential that the vapor be at least twice warmed by indirect heat exchange with the secondary refrigerant and at least twice brought into heat exchange relation with the primary refrigerant in order to vaporize a sufficient amount of the latter to assure continued operation of the system. Practical considerations require that the vapor be once more warmed by indirect heat exchange with the secondary refrigerant before the vapor is discharged into the atmosphere. Otherwise, the available refrigeration in the cold vapor would be wasted.

By using the cold vapor of the primary refrigerant as an intermediate source of refrigeration, the two conditions previously mentioned can be substantially satisfied, even in a vertically

limited space, such as in a railroad refrigerator car where, as previously stated, the liquid primary refrigerant is available at all times only near the floor of the car. The secondary refrigerant may be condensed just below the roof of the car, and the normal level of the resulting liquid need be only slightly lower to avoid subcooling the liquid. There will then be a sufficient head of liquid secondary refrigerant to flow by gravity into a refrigerator compartment and flood evaporating apparatus therein extending almost to the roof of the car. In this way, substantially all of the heat absorbed from the compartment will be used to evaporate the secondary refrigerant, and the resulting vapor will not be appreciably superheated. Circulation of the vapor intermediate refrigerant as a heat transfer agent between the liquid primary refrigerant and the secondary refrigerant is assured by the pressure of the head of liquid primary refrigerant in the tanks where it is stored.

This invention, as applied to a railroad refrigerator car using liquid air as the primary refrigerant, is diagrammatically illustrated in the accompanying drawing. It is to be understood, however, that this invention is equally applicable to other installations, including motor vehicles and vessels, and to other refrigerants having a very low boiling point.

Referring to the drawing, the general outline of the interior of a railroad refrigerator car is roughly indicated by broken lines 1. A vertical partition 2, also indicated by a broken line, divides the car transversely into a refrigerant chamber 3 and a refrigerator compartment 4. The primary refrigerant, liquid air, is stored in one or more tanks in the refrigerant chamber. Two such tanks 5 and 6 are shown in the drawing. Each tank is provided with a vent 7 and 8, respectively, opening to the atmosphere, so that the liquid air will be at atmospheric pressure. The tanks may be connected near their bottoms by a pipe 9 to maintain the liquid in both at the same level. Liquid air flows by gravity from the bottoms of the tanks through pipes 10 and 11 to a vaporizer, which may consist of one or more conventional heat exchanger units having a plurality of separate passages, as hereinafter specified. In the embodiment shown, the vaporizer consists of two such units 12 and 13 connected in parallel. Each unit is shown for purposes of illustration as a cylinder surrounding a coil. The vaporizer is preferably lower than the bottom of the tank to assure the flow of liquid air when the tanks are nearly empty. Liquid air boils in each unit of the vaporizer, as explained below, and cold vaporized air at a temperature of about -310°F . is withdrawn therefrom through pipes 14 and 15, which are connected to a pipe 16. Pipe 16 conducts the cold vaporized air to a condenser 17, which is preferably just below the roof of the refrigerator car. Because of the very large difference in density between liquid and vaporized air (one foot of liquid air in the tanks will support approximately 250 feet of vaporized air), there is no difficulty in raising the vaporized air to this height.

The condenser, like the vaporizer, may consist of any conventional heat exchanger unit or units having a plurality of separate passages, as hereinafter specified. In the embodiment shown, for the sake of illustration only, this condenser consists of only one unit in the form of a cylinder surrounding three separate coils.

When liquid air enters the vaporizers 12 and 13

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from the tanks 5 and 6, it comes into contact with the coils B and D, respectively. These coils, and the air within them, are at a temperature higher than the boiling point of the liquid air, either because of heat leakage over a period of time (as when the system is first put into operation) or because of the heat transferred, as hereinafter described, from a secondary refrigerant that is at a much higher temperature. In either case, some of the liquid air in the vaporizers boils; and the cold vaporized air that results is led through pipes 14 and 15 to a pipe 16, which conducts it to a coil A in condenser 17. The cold air is there warmed to about -65°F . by heat absorbed from a secondary refrigerant in the vapor state surrounding coil A. The cold air that has been warmed in coil A is delivered by a pipe 18 to coil B in unit 13 of the vaporizer, where the air is cooled to about -245°F . by giving up some of its sensible heat to the liquid air in that unit. The heat absorbed by the liquid air causes more of it to boil, which allows more cold vapor to flow into pipe 16 due to the head of liquid air in the tanks 5 and 6. This head of liquid air produces the pressure necessary to move vaporized air through pipe 16, through coil A, coil B, and the other coils hereinafter mentioned. Since the liquid air in the vaporizer units and the vaporized air in coil B (and in coil D mentioned below) are at substantially the same pressure, the vaporized air in these coils cannot condense to a liquid. Even if its temperature were lowered to the temperature of the liquid air surrounding the coils (i. e., under conditions of perfect heat exchange), the vapor would undergo no change of state in the absence of some external force that was applied to increase its pressure. The air cooled in coil B is then led back to the condenser 17 by a pipe 19 and flows through coil C to be again warmed to about -65°F . by heat absorbed from the fluid in the condenser. This warmed air is withdrawn from coil C by a pipe 20 and led to coil D in unit 12 of the vaporizer, where it gives up heat to and boils some of the liquid air in that vaporizer and is again cooled to about -245°F . To take advantage of the air cooled in coil D as a source of refrigeration, the air is withdrawn from coil D by a pipe 21 and conducted to coil E, where it is once more warmed by the secondary refrigerant in the vapor state in the condenser. This thrice-warmed air is finally discharged to the atmosphere through a pipe 22 at a temperature around -20°F .

To avoid subcooling the secondary refrigerant that is condensed from a vapor to a liquid in the condenser, the coils A, C, and E are preferably spaced above the bottom of the condenser to avoid contact with the liquid collecting there. For the same reason, all of the pipes 18 to 21, inclusive, which are connected to those coils, preferably enter or leave the condenser through its side and not through its bottom.

It is an important feature of this invention that warmed vaporized air is brought into indirect heat exchange with liquid air at least twice, either by a single pass through each unit of a multiple unit vaporizer as illustrated or by successive passes through at least two separate passages in a one unit vaporizer. It is not otherwise practicable to obtain sufficient heat from a given weight of vaporized air to boil an equal weight of liquid air, because the latent heat of the latter is greater than the available sensible heat in the former. The temperatures, previously mentioned herein, to which the vaporized air is

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alternately warmed and cooled are those which yield a theoretical thermal balance between the latent heat of the liquid air and the sensible heat of the vaporized air. Sufficient heat transfer surface must accordingly be provided in both the vaporizer and the condenser to lower and raise the temperature of the vaporized air at least as low and as high as the temperatures indicated.

The secondary refrigerant is a highly volatile fluid that flows in a closed circuit as described below. In one part of the circuit it is a liquid and in another part it is a vapor, continually passing from one state to the other at a rate determined by the amount of heat that it absorbs from or gives up to its environment in a given time. One of the most suitable fluids for supplying refrigeration over a wide temperature range is dichloro-difluoro-methane which at a pressure of 24 pounds absolute boils at 0°F . However, other well known refrigerants may be used that have a boiling point between that of the primary refrigerant and the temperature that it is desired to maintain in the refrigerator compartment. The fluid enters the top condenser 17 through a pipe 25 as a vapor and, as previously described, gives up heat to cold vaporized air flowing through coils A, C, and E, and is thereby condensed to a liquid. This liquid flows from the bottom of the condenser through a pipe 26 to a surge tank 27, which acts as a liquid reservoir. The normal level of liquid in the surge tank is lower than the bottoms of the coils in the condenser, so that the liquid will not be subcooled by the cold vaporized air flowing through those coils. As a result, any heat that is absorbed by the liquid is used to change it to a vapor without change in temperature. Since some heat will inevitably leak into the surge tank and some evaporation will there take place, a pipe 28 is provided to conduct the resulting vapor to pipe 25, which leads it back to the condenser. Liquid is withdrawn from the bottom of the surge tank by a pipe 29 near the floor of the car and is conducted into the refrigerator compartment and delivered to any suitable evaporator for evaporating it by indirect heat exchange with the air in the compartment. While many different types of evaporating apparatus may be used, the apparatus shown in the drawing for purposes of illustration only consist of a plurality of upwardly extending evaporator tubes 30 along one or more side walls of the compartment. Pipe 29 is connected to the lower ends of those tubes.

Since the normal level of liquid in the surge tank 27 can be maintained at least as high as the bottom of the condenser without subcooling the liquid, there is a sufficient head of liquid to flood the evaporator tubes 30 (or any other evaporating apparatus that is used, provided such apparatus is spaced slightly below the top of the compartment) throughout substantially their entire length. The liquid in those tubes is evaporated by heat absorbed from the compartment, and the resulting vapor is withdrawn from the upper ends of the tubes by pipe 25 and led back to the condenser, where it is recondensed. Circulation of the secondary refrigerant is maintained without a pump by the difference in density between its liquid and vapor states.

To increase the area of cooling surface in the compartment when using evaporator tubes of the type described herein, it is desirable to provide a metal plate 31 engaging those tubes. This plate

and the tubes constitute the major cooling surfaces within the compartment, and the temperature of those surfaces will correspond to that of the secondary refrigerant in the tubes. Since substantially all of the heat absorbed by that refrigerant from the compartment is used to change it from a liquid to a vapor state, both the secondary refrigerant and these cooling surfaces remain at a substantially uniform temperature. That temperature is determined by the boiling point of the secondary refrigerant.

The boiling point of the secondary refrigerant varies, as previously stated, in accordance with its physical characteristics and its pressure. In using dichloro-difluoro-methane as the secondary refrigerant, the pressure in the system that is required to provide suitable refrigeration over the usual temperature range is about 85 pounds per square inch absolute when the fluid (entirely in the vapor state) is at a temperature of 70° F. As part of the vapor is condensed, the pressure of the remaining vapor and the boiling point of the liquid are lowered and a state of equilibrium is reached in which liquid evaporates in the evaporator tubes at the same rate as vapor is condensed in the condenser.

When the flow of liquid air to the vaporizers is increased, more of the secondary refrigerant is condensed in a given time, thereby reducing the pressure of the circulating fluid and lowering its boiling point until equilibrium is again restored by increased evaporation of the liquid in the evaporator tubes. The temperature within the compartment may accordingly be regulated within desired limits by controlling the flow of liquid air to the vaporizers. That flow may be conveniently controlled by a valve 34, preferably placed in pipe 22, through which vaporized air from the vaporizer is discharged into the atmosphere. This valve may be connected to a temperature responsive device 35 in the refrigerator compartment. When the temperature in the compartment drops below a predetermined level, valve 34 begins to close and allows less liquid air to enter the vaporizer. As a result, the rate of condensation and evaporation of the secondary refrigerant is decreased and its temperature is slightly raised. If the temperature in the compartment continues to decline, the flow of liquid air is entirely cut off. When the temperature in the compartment rises above a predetermined level, valve 34 opens and permits more liquid air to enter the vaporizer, thereby increasing the amount of cold vaporized air flowing to the condenser. As a result, the rate of condensation and evaporation of the secondary refrigerant is increased and its temperature is slightly lowered.

According to the provisions of the patent statutes, I have explained the principle of my invention and have illustrated and described what I now consider to represent its best embodiment. However, I desire to have it understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically illustrated and described.

I claim:

1. Refrigerating apparatus comprising a tank for storing a liquid primary refrigerant having a very low boiling point, a vaporizer having a plurality of separate passages therethrough including a first passage connected to the tank for receiving and vaporizing liquid primary refrigerant and at least two cooling passages in heat exchange relation to the first passage, a condenser having a plurality of separate passages there-

through including a first passage adapted to receive and condense a highly volatile secondary refrigerant from a refrigerator compartment and at least three warming passages in heat exchange relation to the first passage, conduits connecting the warming passages in the condenser and the cooling passages in the vaporizer alternately in series, and a conduit connecting the first passage in the vaporizer to a warming passage at one end of said series so that vaporized primary refrigerant withdrawn from the first passage in the vaporizer will be alternately and successively warmed at least three times in different warming passages in the condenser by absorbing heat from the secondary refrigerant in the first passage of the condenser and cooled at least twice in different cooling passages in the vaporizer by giving up heat to the liquid primary refrigerant in the first passage of the vaporizer, whereby the secondary refrigerant in the condenser will be condensed and the primary refrigerant in the vaporizer will be vaporized.

2. Refrigerating apparatus for condensing, without subcooling, a highly volatile secondary refrigerant by indirect heat exchange with a liquid primary refrigerant having a very low boiling point, said apparatus comprising a tank for storing the liquid primary refrigerant, a vaporizer located at a lower level than the tank and having a plurality of separate passages therethrough including a first passage connected to the tank for receiving and vaporizing liquid primary refrigerant and at least two cooling passages in heat exchange relation to the first passage, a condenser located at a higher level than the vaporizer and having a plurality of separate passages therethrough including a first passage adapted to receive and condense a highly volatile secondary refrigerant from a refrigerator compartment and at least three warming passages in heat exchange relation to the first passage, conduits connecting the warming passages in the condenser and the cooling passages in the vaporizer alternately in series, a conduit connecting the first passage in the vaporizer to a warming passage at one end of said series so that vaporized primary refrigerant withdrawn from the first passage in the vaporizer will be alternately and successively warmed at least three times in different warming passages in the condenser by absorbing heat from the secondary refrigerant in the first passage of the condenser and cooled at least twice in different cooling passages in the vaporizer by giving up heat to the liquid primary refrigerant in the first passage of the vaporizer, whereby the secondary refrigerant will be condensed to a liquid and the liquid primary refrigerant will be vaporized, and a conduit for withdrawing liquid secondary refrigerant from the first passage in the condenser as a liquid at its condensing temperature.

3. Refrigerating apparatus for circulating a highly volatile secondary refrigerant at a substantially uniform temperature in a closed circuit that is in heat exchange relation to a liquid primary refrigerant having a very low boiling point and to a refrigerator compartment, said apparatus comprising a tank for storing the liquid primary refrigerant, a vaporizer located at a lower level than the tank and having a plurality of separate passages therethrough including a first passage connected to the tank for receiving and vaporizing liquid primary refrigerant and at least two cooling passages in heat exchange relation to the first passage, a condenser located at a higher

vel than the vaporizer and having a plurality of separate passages therethrough including a first passage adapted to receive and condense a highly volatile secondary refrigerant from the refrigerator compartment and at least three warming passages in heat exchange relation to the first passage, conduits connecting the warming passages in the condenser and the cooling passages in the vaporizer alternately in series, a conduit connecting the first passage in the vaporizer to a warming passage at one end of said series so that vaporized primary refrigerant withdrawn from the first passage in the vaporizer will be alternately and successively warmed at least three times in different warming passages in the condenser by absorbing heat from the secondary refrigerant in the first passage of the condenser and cooled at least twice in different cooling passages in the vaporizer by giving up heat to the liquid primary refrigerant in the first passage of the vaporizer, whereby the secondary refrigerant will be condensed to a liquid and the liquid primary refrigerant will be vaporized, a liquid conduit for receiving liquid secondary refrigerant withdrawn from the first passage in the condenser and conducting it to the refrigerator compartment, an evaporator in the refrigerator compartment connected to the liquid conduit for receiving liquid secondary refrigerant therefrom and evaporating it, and a vapor conduit connected to the evaporator for withdrawing evaporated secondary refrigerant therefrom and conducting it back to the first passage in the condenser where it is recondensed.

4. Refrigerating apparatus for circulating a highly volatile secondary refrigerant at a substantially uniform temperature in a closed circuit that is in heat exchange relation to a liquid primary refrigerant having a very low boiling point and to a refrigerator compartment, said apparatus comprising a tank for storing the liquid primary refrigerant, a vaporizer located at a lower level than the tank and having a plurality of separate passages therethrough including a first passage connected to the tank for receiving and vaporizing liquid primary refrigerant and at least two cooling passages in heat exchange relation to the first passage, a condenser located at a higher level than the vaporizer and having a plurality of separate passages therethrough including a first passage adapted to receive and condense a highly volatile secondary refrigerant from the refrigerator compartment and at least three warming passages in heat exchange relation to the first passage, conduits connecting the warming passages in the condenser and the cooling passages in the vaporizer alternately in series, a conduit connecting the first passage in the vaporizer to a warming passage at one end of said series so that vaporized primary refrigerant withdrawn from the first passage in the vaporizer will be alternately and successively warmed at least three times in different warming passages in the condenser by absorbing heat from the secondary refrigerant in the first passage of the condenser and cooled at least twice in different cooling passages in the vaporizer by giving up heat to the liquid primary refrigerant in the first passage of the vaporizer, whereby the secondary refrigerant will be condensed to a liquid and the liquid primary refrigerant will be vaporized, a surge tank for receiving liquid secondary refrigerant from the first passage in the condenser and in which the normal level of the liquid secondary refrigerant is below the level of the warming

passages in the condenser, a liquid conduit for withdrawing liquid secondary refrigerant from near the bottom of the surge tank and conducting it to the refrigerator compartment, an evaporator in the refrigerator compartment connected to the liquid conduit for receiving liquid secondary refrigerant therefrom and evaporating it, and a vapor conduit connected to the evaporator for withdrawing evaporated secondary refrigerant therefrom and conducting it back to the first passage in the condenser where it is recondensed.

5. Refrigerating apparatus for circulating a highly volatile secondary refrigerant at a substantially uniform temperature in a closed circuit that is in heat exchange relation to a liquid primary refrigerant having a very low boiling point and to a refrigerator compartment, said apparatus comprising a tank for storing the liquid primary refrigerant, a vaporizer located at a lower level than the tank and having a plurality of separate passages therethrough including a first passage connected to the tank for receiving and vaporizing liquid primary refrigerant and at least two cooling passages in heat exchange relation to the first passage, a condenser located at a higher level than the vaporizer and having a plurality of separate passages therethrough including a first passage adapted to receive and condense a highly volatile secondary refrigerant from the refrigerator compartment and at least three warming passages in heat exchange relation to the first passage, conduits connecting the warming passages in the condenser and the cooling passages in the vaporizer alternately in series, a conduit connecting the first passage in the vaporizer to a warming passage at one end of said series so that vaporized primary refrigerant withdrawn from the first passage in the vaporizer will be alternately and successively warmed at least three times in different warming passages in the condenser by absorbing heat from the secondary refrigerant in the first passage of the condenser and cooled at least twice in different cooling passages in the vaporizer by giving up heat to the liquid primary refrigerant in the first passage of the vaporizer, whereby the secondary refrigerant will be condensed to a liquid and the liquid primary refrigerant will be vaporized, a surge tank for receiving liquid secondary refrigerant condensed in the first passage of the condenser and in which the normal level of said liquid is lower than the level of the warming passages in the condenser, a liquid conduit for withdrawing liquid secondary refrigerant from near the bottom of the surge tank and conducting it to the refrigerator compartment, an evaporator in the refrigerator compartment connected to the liquid conduit for receiving liquid secondary refrigerant therefrom and evaporating it, a vapor conduit connected to the evaporator for withdrawing evaporated secondary refrigerant therefrom and conducting it back to the first passage in the condenser where it is recondensed, a conduit connecting the top of the surge tank with the vapor conduit so that any secondary refrigerant evaporated in the surge tank will be conducted back to the first passage in the condenser, and a valve adapted to respond to the temperature in the refrigerator compartment for controlling the flow of liquid primary refrigerant to the first passage in the vaporizer in accordance with that temperature.

6. Apparatus for cooling a refrigerator compartment in a railroad refrigerator car by utiliz-

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ing liquid air as a primary refrigerant and a highly volatile fluid as a secondary refrigerant, comprising an evaporator within the compartment for receiving secondary refrigerant in a liquid state and evaporating it by heat absorbed from the compartment, a vapor conduit for withdrawing the secondary refrigerant in a vapor state from the evaporator and conducting it outside the compartment, a condenser near the roof of the car having a plurality of separate passages therethrough including a first passage connected to the vapor conduit for receiving and condensing secondary refrigerant and at least three warming passages in heat exchange relation to the first passage, a storage tank for receiving liquid air, a vaporizer located at a lower level than the tank and having a plurality of separate passages therethrough including a first passage connected to the tank for receiving and vaporizing liquid air and at least two cooling passages in heat exchange relation to the first passage, conduits connecting the warming passages in the condenser and the cooling passages in the vaporizer alternately in series, a conduit connecting the first passage in the vaporizer to a warming passage at one end of said series so that vaporized air withdrawn from the first passage in the vaporizer will be alternately and successively warmed at least three times in different warming passages by absorbing heat from the secondary refrigerant in a vapor state in the first passage of the condenser and cooled at least twice in different cooling passages by giving up heat to liquid air in the first passage of the vaporizer, whereby the secondary refrigerant will be condensed to a liquid and the liquid air will be vaporized to form said vaporized air, and a liquid conduit for receiving secondary refrigerant in a liquid state withdrawn from the first passage in the condenser and conducting it to the evaporator in the compartment.

7. The combination with a railroad refrigerator car compartment of apparatus for cooling the compartment by means of a highly volatile secondary refrigerant that is alternately condensed and evaporated as it is circulated in a closed circuit, said apparatus comprising upwardly extending evaporator tubes spaced along at least one of the side walls of the compartment for receiving at their lower ends secondary refrigerant in a liquid state and evaporating it by heat absorbed from the compartment, a metal plate extending along a side wall of the compartment and engaging the evaporator tubes to increase the cooling surface within the compartment, a vapor conduit for withdrawing secondary refrigerant in a vapor state from the upper ends of the evaporator tubes and conducting it outside the compartment, a condenser near the roof of the car having a plurality of separate passages therethrough including a first passage connected to the vapor conduit for receiving and condensing secondary refrigerant and three warming passages in heat exchange relation to the first passage, a storage tank for receiving liquid air, a vaporizer located at a lower level than the tank and having a plurality of separate passages therethrough including a first passage connected to the tank for receiving and vaporizing liquid air and two cooling passages in heat exchange relation to the first passage, conduits connecting the

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three warming passages in the condenser and the two cooling passages in the vaporizer alternately in series, a conduit connecting the first passage in the vaporizer to a warming passage at one end of said series so that vaporized air withdrawn from the first passage in the vaporizer will be alternately and successively warmed three times in different warming passages by absorbing heat from the secondary refrigerant in a vapor state in the first passage of the condenser and cooled twice in different cooling passages by giving up heat to liquid air in the first passage of the vaporizer, whereby the secondary refrigerant will be condensed and the liquid air will be vaporized to form said vaporized air, a surge tank for receiving secondary refrigerant in a liquid state from the first passage in the condenser and in which the normal liquid level of the secondary refrigerant is lower than the warming passages in the condenser but high enough to flood by gravity the evaporator tubes in the compartment throughout most of their length, a liquid conduit for withdrawing secondary refrigerant in a liquid state from near the bottom of the surge tank and conducting it to the lower ends of the evaporator tubes in the compartment, a conduit connecting the top of the surge tank with the vapor conduit so that any secondary refrigerant evaporated in the surge tank will be conducted back to the first passage in the condenser and recondensed, and a valve adapted to respond to the temperature in the compartment for controlling the flow of liquid air from the storage tank to the first passage in the vaporizer in accordance with that temperature.

8. A method of refrigerating that comprises vaporizing a liquid primary refrigerant having a very low boiling point and condensing a highly volatile secondary refrigerant having a higher boiling point by bringing vapor of the liquid primary refrigerant alternately and successively into indirect heat exchange at least three times with the secondary refrigerant and at least twice with the liquid primary refrigerant, whereby said vapor will absorb heat from and condense the secondary refrigerant and will give up heat to and vaporize the liquid primary refrigerant to form said vapor, and utilizing the condensed secondary refrigerant to absorb heat from a refrigerator compartment.

9. A method of refrigerating a compartment in a railroad refrigerator car that comprises vaporizing near the floor of the car a liquid primary refrigerant having a very low boiling point and condensing near the roof of the car a highly volatile secondary refrigerant by bringing vapor of the liquid primary refrigerant alternately and successively into indirect heat exchange at least three times with the secondary refrigerant in a vapor state and at least twice with the liquid primary refrigerant, whereby said vapor will absorb heat from and condense the secondary refrigerant without subcooling it and will give up heat to and vaporize the liquid primary refrigerant to form said vapor, and evaporating the condensed secondary refrigerant by heat absorbed from the compartment.

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No references cited.