March 1, 1938. B. F. RANDEL 2,109,502

METHOD AND APPARATUS FOR REFRIGERATION

Filed Feb. 18, 1936 2 Sheets-Sheet 1

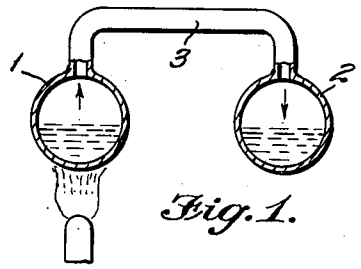

Fig. 1.

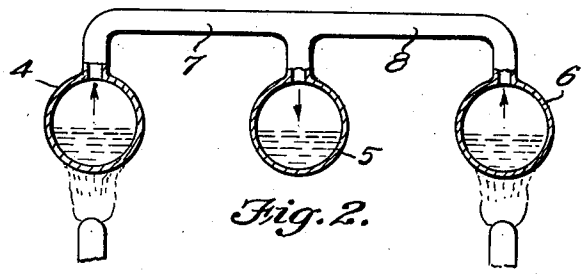

Fig. 2.

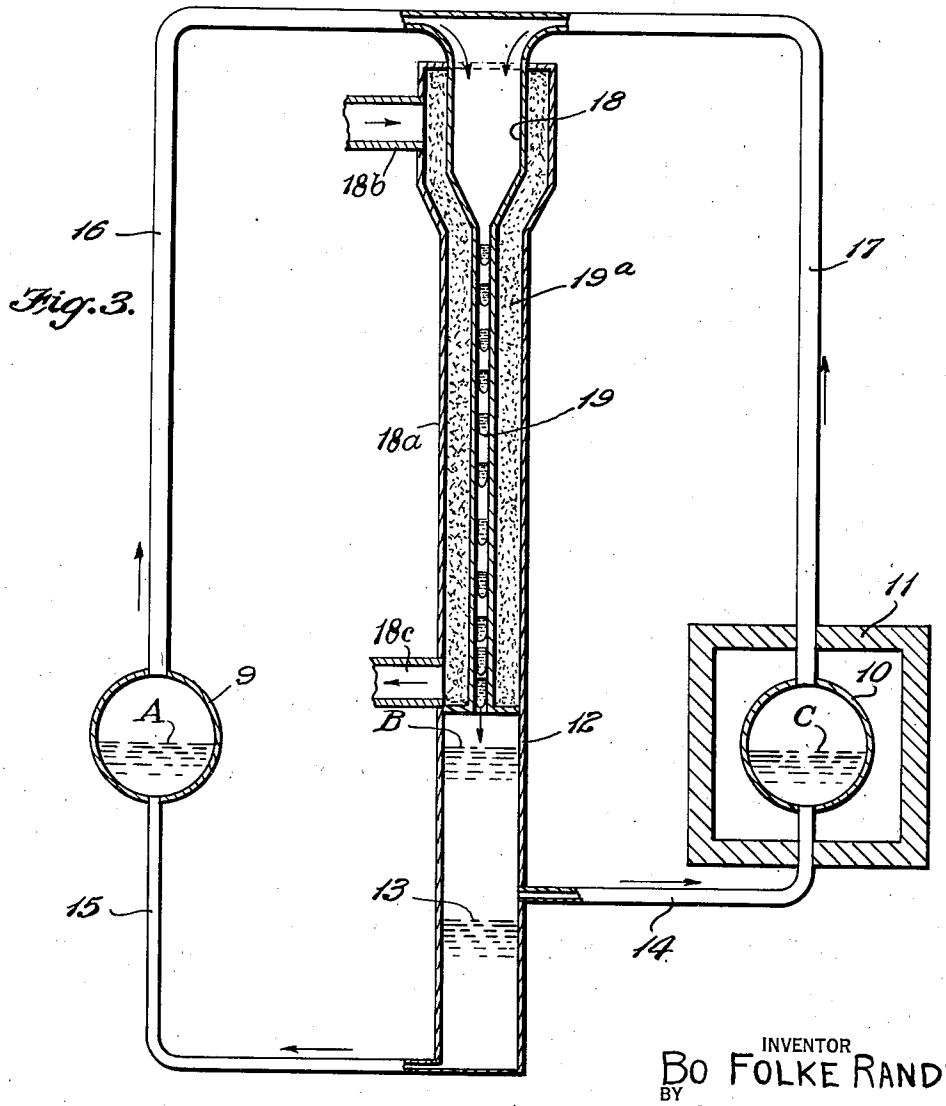

Fig. 3.

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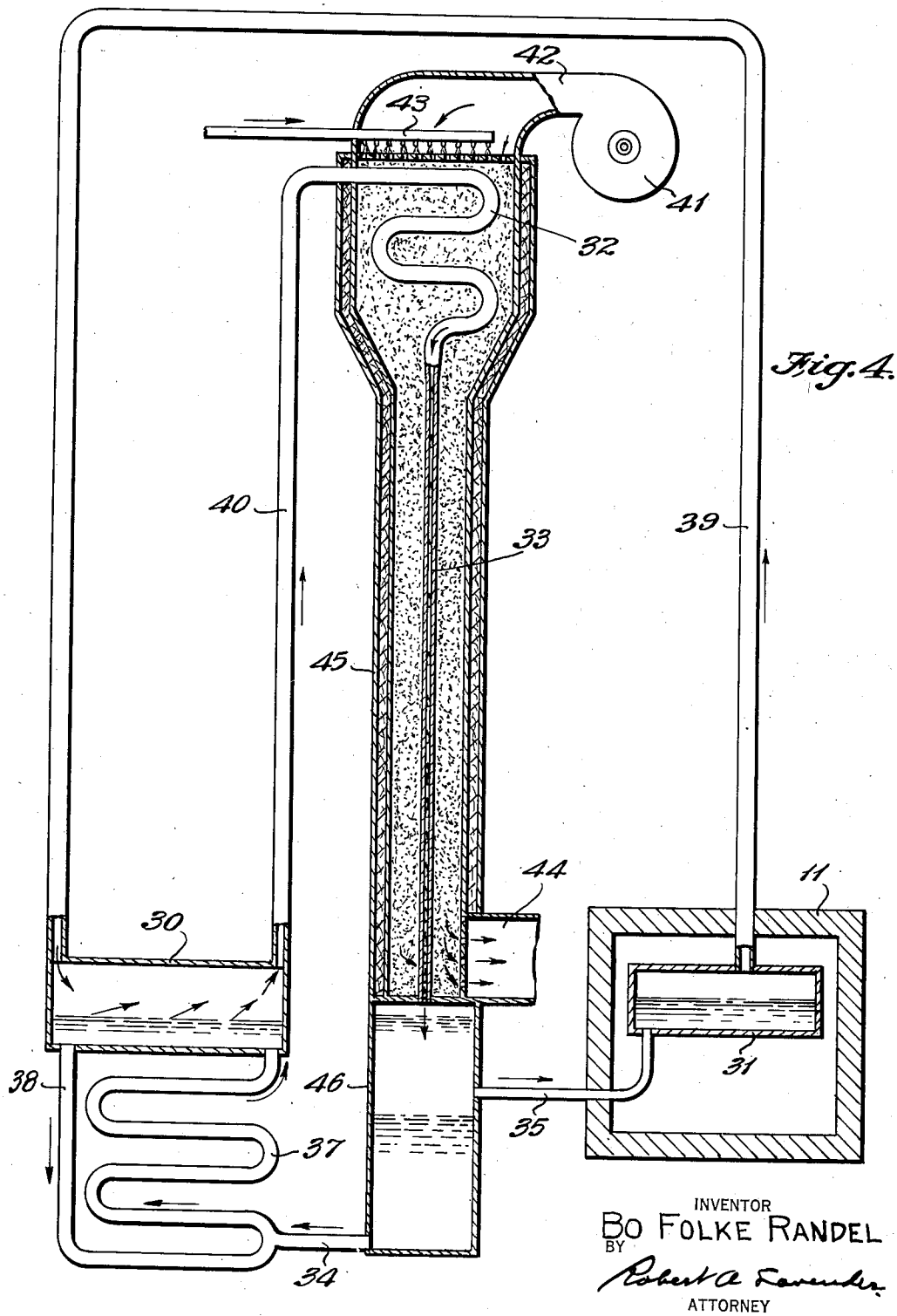

Fig. 4.

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UNITED STATES PATENT OFFICE

2,109,502

METHOD AND APPARATUS FOR REFRIGERATION

Bo Folke Randel, San Diego, Calif.

Application February 18, 1936, Serial No. 64,472

15 Claims. (Cl. 62—115)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

This invention relates to refrigeration and is an improvement upon the invention disclosed in my companion Letters Patent of the United States No. 1,906,414, dated May 2, 1933.

The principal object of the present invention is the provision of a method of and apparatus for refrigeration in which the difference in temperature existing between wet and dry portions of the system in an atmosphere of less than 100 per cent humidity is utilized to supply the necessary energy in much the same manner as this principle is employed in the wet and dry bulb thermometer types of hygrometers. This difference in temperature may be augmented by the application of additional heat to the part in my system corresponding to the dry thermometer and by accelerating the rate of cooling by increased evaporation of the part in my system corresponding to the wet thermometer.

With these and other objects in view, as well as other advantages which may be incident to the use of the improvements, the invention consists of the parts and combinations thereof hereinafter set forth and claimed, with the understanding that the several necessary elements constituting the same may be varied in proportion and arrangement without departing from the nature and scope of the invention, as defined in the appended claims.

In order to make the invention more clearly understood, there are shown in the accompanying drawings means for carrying the invention into practical effect, without limiting the improvements in their useful application to the particular construction, which, for purposes of explanation, have been made the subject of illustration.

In the accompanying drawings:

Figs. 1 and 2 are diagrammatic views illustrating the physical theories upon which the present invention is based;

Fig. 3 is a diagrammatic view showing one form of apparatus for practicing the invention; and

Fig. 4 illustrates diagrammatically another embodiment of the invention.

Referring to the drawings, and particularly to Figs. 1 and 2 thereof, let it be assumed that two vessels 1 and 2, are interconnected by a tube 3. Each vessel is partially filled with a liquid such as water. Vessel 1 is heated, while 2 is cooled. Under these conditions the pressure in the two vessels will be the pressure in vessel 2 due to its temperature. If vessel 2 is cooled, to say 60 degrees F. temperature, the water vapor pressure will be 0.2562 lbs. absolute in both vessels. Increase of temperature outside vessel 1 will not increase the pressure but will increase the vaporizing capacity. As long as heat is supplied to vessel 1 and removed from vessel 2, the water will boil in 1 to condense in vessel 2, both vessels being under the same temperature and pressure.

Referring now to Fig. 2, we have three vessels, 4, 5, and 6 interconnected by pipes 7 and 8. We will assume that vessel 4 contains a substance which is a liquid at ordinary temperature and capable of being converted into a gas at an elevated temperature, and having a low vapor pressure-temperature gradient over the temperature range of operation. We will assume also, that vessel 6 contains a substance which is a liquid at ordinary temperatures and capable of being converted into a gas at an elevated temperature and having a high vapor pressure-temperature gradient over the temperature range of operation. The substances in the vessels 4 and 6 may, for example, be water and hexane, said substances being immiscible with one another when in liquid form and of different specific gravities. Also, the apparatus is an entirely closed and sealed system and the pressure therein is determined solely by the vapor pressures of the substances themselves. The vessels 4 and 6 and interconnecting pipes 7 and 8 may be evacuated by mechanical means or by vaporizing the substances so that their vapors will displace the air. We will also assume a constant heat supply to vessels 4 and 6, while vessel 5 is being cooled. Assuming that the temperature is sufficient to vaporize the substances in vessels 4 and 6 and that the temperature is low enough to condense the vapors in vessel 5, then a constant flow of vapors will occur from vessels 4 and 6 into vessel 5. While the two vapors will diffuse into each other and be present in all the vessels, at least at the start of the process, we will assume the flow to be of such velocity as to counteract the velocity of diffusion, so that the vapor in vessel 4 with connecting pipe 7 is water vapor only and vapor in vessel 6 with connecting pipe 8 is hexane vapor only. It is clear that the total pressure in all the three vessels must be equal. Thus the water vapor pressure in vessel 4, which equals the total pressure, will be the same as the hexane vapor pressure in vessel 6, and that in vessel 5 the vapor pressure will be composed of the partial vapor pressure on water and hexane, each vapor being reduced in pressure as it enters the vessel 5. If vessel 5 is kept at, say 60 degrees F. temperature, the vapor pressure on the water in this vessel will be 0.2562 lb. and the vapor pressure

on the hexane will be 1.92 lbs., or a total of 2.1762 lbs. The vapor pressure in vessels 4 and 6 will now be this total and the temperature required in vessel 4 to boil the water will be due to this total pressure, which will also be the case in vessel 6, or approximately 126 degrees in vessel 4 and 65 degrees in vessel 6. It is seen that the two liquids will boil or vaporize in their respective vessels, but under considerable difference in temperature. It is also seen that the pressure in vessel 6 is the greater part of the total pressure. If the vapor pressure in vessel 6 could be lowered, the temperature required in vessel 4 could also be lowered to vaporize the water. This can be done by limiting the inflow of heat to vessel 6 while maintaining an unlimited inflow of heat to vessel 4. The liquid in vessel 6 will cool by its own vaporization and thus lower its own vapor pressure. Under these conditions it will also be necessary to increase the partial pressure on the hexane vapor in vessel 5, in order to cause condensation and without increasing the total pressure in this same vessel. In Fig. 3 an apparatus is illustrated, wherein this is possible.

With reference to this figure, assume a vessel 9 containing water, a vassel 10 containing liquid hexane, kerosene or the like and a vessel 12 containing a mixture of both water and hexane, or kerosene, which due to their different specific weights will cause a division line 13 with the lighter hexane floating on top of the heavier water. The vessel 9 is connected with vessel 12 by pipe 15 and in such a manner as to cause the water to pass from vessel 12 to vessel 9, and vessel 10 is connected with vessel 12 by pipe 14 in such a manner as to allow the hexane to pass from vessel 12 to vessel 10.

Vessels 9 and 10 are connected by pipes 16 and 17 with a first condenser in the form of a vessel 18 located above the level of the vessels 9, 11 and 12 and which connects with the latter through a pipe 19 which functions as a second condenser in a manner presently to be described. The vessel 9 is provided with suitable heating means. The vessel 10 is enclosed in an insulated housing 11, preventing heat to reach same from the outside, or in a refrigerator if so desired. The vessel or first condenser 18 and the pipe or second condenser 19 are enclosed in a casing 18*a* containing a porous material 19*a*, as unglazed porcelain, and adapted to be saturated with water or packed in mineral wool or cloth. Air is caused to flow through the casing 18*a* and porous material 19*a* by any suitable means to cause the evaporation of the absorbed water and the resulting cooling of the vessel 18 and pipe 19. The pipe 19 may be lengthened if required by forming same into a coil, helix or other form. The vessel 18 and pipe 19 act as condensers, the cooling being caused by the evaporation of water from the surrounding material 19*a*. A fan or blower may be added to cause more rapid flow of air to cause this evaporation.

Let it now be assumed that the apparatus is at rest and in equilibrium and that the temperature surrounding all parts is 80 degrees F. We will also assume a relative humidity of 50 per cent. The equilibrium pressures will be, on hexane 3.1 and on the water 0.505 lb. Abs., or a total of 3.605 lbs. Abs. Both vapors will be diffused into each other throughout the apparatus. The liquid level will be at A, B and C in the different vessels. Actually, the level in vessels 10 and 12 will be higher than in vessel 9, due to the difference in specific weights of these media, but this is not shown for simplicity in presentation.

Water will now be permitted to wet the porous material 19*a* surrounding the first and second condensers 18 and 19. These condensers will act as a wet bulb due to the evaporation of the water, and with an 80 degree dry bulb temperature and 50 per cent humidity, the wet bulb temperature will be approximately 67 degrees or 13 degrees below the dry bulb. A new pressure equilibruim due to this lower temperature will be established which, at say 70 degrees, will be as follows: On hexane 2.4 and on water 0.3626, or a total of 2.8226 lbs., a drop of 0.83 lb. absolute.

This drop of pressure in the vessel 12, pipe 19 and the vessel or first condenser 18 will cause a flow of vapors from vessels 10 and 9 to the condenser. This will also cause evaporation of liquids in the vessels 9 and 10, to supply additional vapors, and this evaporation will be accompanied with absorption of heat.

It will be seen that the vessel 9 is supplied with unlimited quantities of heat, being surrounded by an 80 degree atmosphere. The vessel 10, however, has no such unlimited supply of heat to draw from, but must draw from itself and the limited space surrounding it. As a result, while vapors are being continually generated in vessel 9, in vessel 10 the rate of generation decreases as the temperature in this vessel falls. It is assumed that the cooling in the condenser 18 also is unlimited, so that the vapors will continually condense to be separated in liquid form in vessel 12 and returned to 9 and 10.

The continued removal of heat by the wet bulb condenser, and the continued absorption of heat by the hexane liquid in vessel 10 will finally bring down the temperature in the vessel 10 and the vapor pressure on the hexane to the point at which the wet bulb temperature is insufficient to condense same, and this point will be reached when the temperature in vessel 10 equals this wet bulb temperature. However, water vapor will continue to flow from vessel 9 to vessel 18 as long as there is a higher temperature surrounding the former than surrounding the latter. By withdrawing practically all the heat from the upper part of the condenser 18, the water vapor will condense in this vessel to form drops or slugs of liquid which will descend through pipe 19 under the action of gravity. These slugs will pull uncondensed hexane vapor downwardly in the same manner as condensate return water from a radiator will draw uncondensable gases downwardly back to the boiler.

While the pressure is insufficient in condenser 18 to condense the hexane vapor, a point will be reached in the descending column where this pressure will be sufficient, provided the pipe 19 is of proper length. The hexane vapor will therefore liquefy and separate itself from the water and flow back to the vessel 10. During this action heat is constantly removed from the vessel 10 constantly lowering the vapor pressure in this vessel.

While at the start of the operation the two different vapors were diffused into each other all throughout the apparatus, due to the motion of the vapors, the vessel 9 will soon contain only water vapor, and the vessel 10 will contain only hexane vapor. The vapor pressure in vessel 9 will also equal the vapor pressure in vessel 10, and the vapor pressure in vessel 18 will be the total of the partial pressures on the water and the hexane and this total will of course equal the pressures

in either vessel 10 or vessel 9. If it is assumed that the temperature in vessel 9 is 76° F. with an outside temperature of 80° F. and in vessel 12 is 72° F. with an outside temperature of 67° F., then the equilibrium will be as follows: Vapor pressure on the water and also on the hexane will be 0.45 lb. absolute. The evaporating temperature of the hexane in the vessel 10 will be 14 degrees F. Partial vapor pressure on the water in the vessel 18 will be 0.40 lb. and on hexane vapor 0.05 lb. To liquefy hexane at 72 degrees F. will require a pressure of 2.55 lbs. or a water column approximately 5.10 feet, assuming a solid column. With vapor and liquid mixed in this column to, say 50 per cent each, the height will have to be at least ten feet.

The pressure in vessel 9 is dependent on the pressure in vessel 10, or on the temperature on hexane liquid. If this temperature rises the pressure in vessel 9 will rise, requiring a higher temperature to vaporize the water. Also, the vapor generated in vessel 9 will cover the surface as a film, so that before the temperature in vessel 10 is brought down sufficiently to bring down the pressure in vessel 9, to enable vaporization by an outside temperature of 80 degrees F., it will be necessary to supply other heat to vessel 9. After the temperature in vessel 10 is down, the ordinary room temperature of 80 degrees F. will be sufficient to operate the apparatus.

In Fig. 4 a modification is shown in which this fact is provided for and the arrangement so constructed that at no time is any other outside temperature required besides the ordinary room temperature, this eliminating the necessity for additional heat. This particular construction embodies a water boiler 30, and a hexane evaporator 31, connected with a liquid separator 46 by pipes 34 and 35. A wet bulb or first condenser 32 is located above the level of the boiler 30 and evaporator 31 and communicates with the separator through a pipe 33 which functions as a second condenser and in which the hexane vapor is liquefied as before. In this construction provision is made to permit the vapor from the hexane evaporator to sweep across the water in the boiler 30 and carry the water vapor commingled therewith through pipe 40 to the condenser 32.

The boiler 30 is provided with a coil 37, one end of which communicates directly with the boiler and the other end of which communicates therewith through a pipe 38 to assist in transferring the heat to the water by causing circulation of this water. A fan or blower 41 is also provided to pass air through a conduit 42 and over the condenser coils 32 enclosed in porous material and insulated by insulation material 45. Water is allowed to drip over the porous material from a suitable sprinkler 43. The saturated air escapes from the condenser through a conduit 44. Provision may be made to allow the air before it is passed to the condenser to pass over the heating coil 37 and boiler 30 to accelerate the evaporation at this point.

It will be seen that this arrangement will permit a considerably lower temperature in boiler 30, as the water vapor pressure is now a partial pressure and not a total pressure. Hexane vapor will always be present in boiler 30 and diffused with the water vapor therein. The partial water pressure will be the same in boiler 30 as in condenser 32, so that as long as the outside temperature surrounding boiler 30 is higher than the temperature surrounding the condenser 32, evaporation will occur in the boiler 30 and condensation in condenser 32. This action will cause a flow of hexane vapors from evaporator 31 through the pipe 39 to boiler 30, and thence to the first condenser 32 where the water vapors are liquefied. From the condenser 32 the mixture of water of condensation and hexane vapors will be drawn downwardly through the pipe 33, where the latter are condensed. In other respects, the apparatus will operate similarly to the other apparatus described.

Water is mentioned as the motive medium, but other mediums may be used, and the invention includes the use of any and all mediums which may be suitable. Hexane is mentioned as refrigerant, that is to say, normal hexane (hexane boiling at +71° C. at 760 mm.). The term "kerosene", as herein used, refers to a mixture of nonane and decane (normal) and of a density of approximately .791 to .824. In the present apparatus normal hydrocarbons from hexane to decane as well as others with like characteristics would operate satisfactorily. Other refrigerants may be used and are contemplated in the invention. A wet bulb condenser is described, but other means may be employed to cool the condenser.

Other modifications and changes in the proportions and arrangement of the parts may be made by those skilled in the art, without departing from the nature and scope of the invention as defined in the appended claims.

The invention described herein may be manufactured and used by or for the Government of the United States for governmental purposes without the payment of any royalties thereon or therefor.

I claim:

1. The method of refrigeration, comprising vaporizing a liquid motive medium; vaporizing a liquid refrigerant; passing the two vapors to a first condenser, liquefying the vapor of the motive medium in said first condenser and allowing the liquid to descend by gravity through a second condenser in a series of separated slugs, entraining the vaporized refrigerant between the descending slugs of liquefied motive medium, thus subjecting this vapor to compression sufficient to liquefy the same in said second condenser, separating the two liquids and returning each to its point of vaporization.

2. The method of refrigeration, comprising vaporizing a liquid motive medium having a predetermined density and a predetermined boiling point; vaporizing a liquid refrigerant having a less density and a lower boiling point than said liquid motive medium; passing the two vapors to a first condenser, liquefying the vapor of the motive medium in said first condenser and allowing the liquid to descend by gravity through a second condenser in a series of separated slugs, entraining the vaporized refrigerant between the descending slugs of liquefied motive medium, thus subjecting this vapor to compression sufficient to liquefy the same in said second condenser, separating the two liquids by the levitation of the liquid refrigerant and returning each to its point of vaporization.

3. The method of refrigeration, comprising vaporizing a liquid motive medium consisting of water; vaporizing a liquid refrigerant consisting of a hydrocarbon of the methane series; passing the two vapors to a first condenser, liquefying the vapor of the motive medium in said first condenser and allowing the liquid to descend by grav-

ity through a second condenser in a series of separated slugs, entraining the vaporized refrigerant between the descending slugs of liquefied motive medium thus subjecting this vapor to compression sufficient to liquefy the same in said second condenser, separating the two liquids by the levitation of the liquid refrigerant and returning each to its point of evaporation.

4. The method of refrigeration, comprising vaporizing a liquid motive medium consisting of water; vaporizing a liquid refrigerant consisting of hexane or hexylene; passing the two vapors to a first condenser, liquefying the vapor of the motive medium in said first condenser and allowing the liquid to descend by gravity through a second condenser in a series of separated slugs, entraining the vaporized refrigerant between the descending slugs of liquefied motive medium, thus subjecting this vapor to compression sufficient to liquefy the same in said second condenser, separating the two liquids by the levitation of the liquid refrigerant and returning each to its point of evaporation.

5. The method of refrigeration, comprising vaporizing a liquid motive medium consisting of water; vaporizing a liquid refrigerant consisting of kerosene; passing the two vapors to a first condenser, liquefying the vapor of the motive medium in said first condenser and allowing the liquid to descend by gravity through a second condenser in a series of separated slugs, entraining the vaporized refrigerant between the descending slugs of liquefied motive medium, thus subjecting this vapor to compression sufficient to liquefy the same in said second condenser, separating the two liquids by the levitation of the liquid refrigerant and returning each to its point of vaporization.

6. A refrigerating apparatus comprising an evaporator for a liquid motive medium; an evaporator for a liquid refrigerant; a receptacle for containing a supply of both liquid motive medium and refrigerant and in liquid communication with each of said evaporators, a condenser located at a level higher than said evaporators and receptacle and in vapor communication with each of said evaporators for liquefying the vaporized motive medium; and means communicating with said condenser and said receptacle for conducting liquid motive medium liquefied by said condenser in a series of separated slugs and vaporized refrigerant entrained between said slugs from said condenser to said receptacle under the action of gravity, thus to subject said vaporized refrigerant to sufficient pressure to liquefy the same during its passage through said conducting means.

7. A refrigerating apparatus comprising an evaporator for a liquid motive medium having a predetermined density and a predetermined boiling point; an evaporator for a liquid refrigerant having a less density and lower boiling point than said liquid motive medium; a receptacle for containing a supply of both liquid motive medium and refrigerant in a superimposed stratum and in liquid communication with each of said evaporators, a condenser located at a level higher than said evaporators and receptacle and in vapor communication with each of said evaporators for liquefying the vaporized motive medium; and means communicating with said condenser and said receptacle for conducting liquid motive medium liquefied by said condenser in a series of separated slugs and vaporized refrigerant entrained between said slugs from said condenser to said receptacle under the action of gravity, thus to subject said vaporized refrigerant to sufficient pressure to liquefy the same during its passage through said conducting means.

8. A refrigerating apparatus comprising an evaporator for water; an evaporator for a refrigerant consisting of a hydrocarbon of the methane series; a receptacle for containing a supply of both water and refrigerant in a superimposed stratum and in liquid communication with each of said evaporators, a condenser located at a level higher than said evaporators and receptacle and in vapor communication with each of said evaporators for condensing the vaporized water; and means communicating with said condenser and said receptacle for conducting water condensed by said condenser in a series of separated slugs and vaporized refrigerant entrained between said slugs from said condenser to said receptacle under the action of gravity, thus to subject said vaporized refrigerant to sufficient pressure to liquefy the same during its passage through said conducting means.

9. A refrigerating apparatus comprising an evaporator for water; an evaporator for a liquid refrigerant consisting of hexane or hexylene; a receptacle for containing a supply of both water and the refrigerant in a stratum superimposed thereupon and in liquid communication with each of said evaporators, a condenser located at a level higher than said evaporators and receptacle and in vapor communication with each of said evaporators for condensing the vaporized water; and means communicating with said condenser and said receptacle for conducting water condensed by said condenser in a series of separated slugs and vaporized refrigerant entrained between said slugs from said condenser to said receptacle under the action of gravity, thus to subject said vaporized refrigerant to sufficient pressure to liquefy the same during its passage through said conducting means.

10. A refrigerating apparatus comprising an evaporator for water; an evaporator for a liquid refrigerant consisting of kerosene; a receptacle for containing a supply of both water and the refrigerant in a stratum superimposed thereupon and in liquid communication with each of said evaporators, a condenser located at a level higher than said evaporators and receptacle and in vapor communication with each of said evaporators for condensing the vaporized water; and means communicating with said condenser and said receptacle for conducting water condensed by said condenser in a series of separated slugs and vaporized refrigerant entrained between said slugs from said condenser to said receptacle under the action of gravity, thus to subject said vaporized refrigerant to sufficient pressure to liquefy the same during its passage through said conducting means.

11. A refrigerating apparatus comprising an evaporator for a liquid motive medium; an evaporator for a liquid refrigerant; a receptacle for containing a supply of both liquid motive medium and refrigerant and in liquid communication with each of said evaporators, a condenser located at a level higher than said evaporators and receptacle and in vapor communication with each of said evaporators for liquefying the vaporized motive medium; and means for conducting increments of said motive medium liquefied by said condenser in a series of separated slugs separated by interposed increments of said vaporized refrigerant from said condenser to said receptacle

under the action of gravity, thus to subject said vaporized refrigerant to sufficient pressure to liquefy the same during its passage through said conducting means.

12. A refrigerating apparatus comprising an evaporator for a liquid motive medium; an evaporator for a liquid refrigerant; a receptacle for containing a supply of both liquid motive medium and refrigerant and in liquid communication with each of said evaporators, a condenser located at a level higher than said evaporators and receptacle and in vapor communication with each of said evaporators for liquefying the vaporized motive medium; and a tube for conducting increments of said motive medium liquefied by said condenser and separated by interposed increments of said vaporized refrigerant from said condenser to said receptacle under the action of gravity, thus to subject said vaporized refrigerant to sufficient pressure to liquefy the same during its passage through said tube.

13. A refrigerating apparatus comprising an evaporator for a liquid motive medium; an evaporator for a liquid refrigerant; a receptacle for containing a supply of both liquid motive medium and refrigerant and in liquid communication with each of said evaporators; a condenser located at a level higher than said evaporators and receptacle and in vapor communication with each of said evaporators for liquefying the vaporized motive medium; and a bubble column for conducting increments of said motive medium liquefied by said condenser and separated by interposed increments of said vaporized refrigerant from said condenser to said receptacle under the action of gravity, thus to subject said vaporized refrigerant to sufficient pressure to liquefy the same during its passage through said bubble column.

14. A refrigerating apparatus comprising an evaporator for a liquid motive medium; an evaporator for a liquid refrigerant; a receptacle for containing a supply of both liquid motive medium and refrigerant and in liquid communication with each of said evaporators, a condenser located at a level higher than said evaporators and receptacle and in vapor communication with each of said evaporators for liquefying the vaporized motive medium; and a tube for conducting increments of said motive medium liquefied by said condenser and in capillary contact with the walls of said tube and separated by interposed increments of said vaporized refrigerant from said condenser to said receptacle under the action of gravity, thus to subject said vaporized refrigerant to sufficient pressure to liquefy the same during its passage through said tube.

15. A refrigerating apparatus comprising an evaporator for a liquid motive medium; an evaporator for a liquid refrigerant; a receptacle for containing a supply of both liquid motive medium and refrigerant and in liquid communication with each of said evaporators; a condenser located at a level higher than said evaporators and said receptacle and in vapor communication with each of said evaporators for liquefying the vaporized motive medium; and means for conducting increments of said motive medium liquefied by said condenser and increments of said vaporized refrigerant trapped therebetween, from said condenser to said receptacle under the action of gravity, thus to subject said vaporized refrigerant to sufficient pressure to liquefy the same during its passage through said conducting means.

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