Jan. 30, 1940. R. E. HOLMES 2,188,350

REFRIGERATING APPARATUS

Filed Aug. 24, 1935

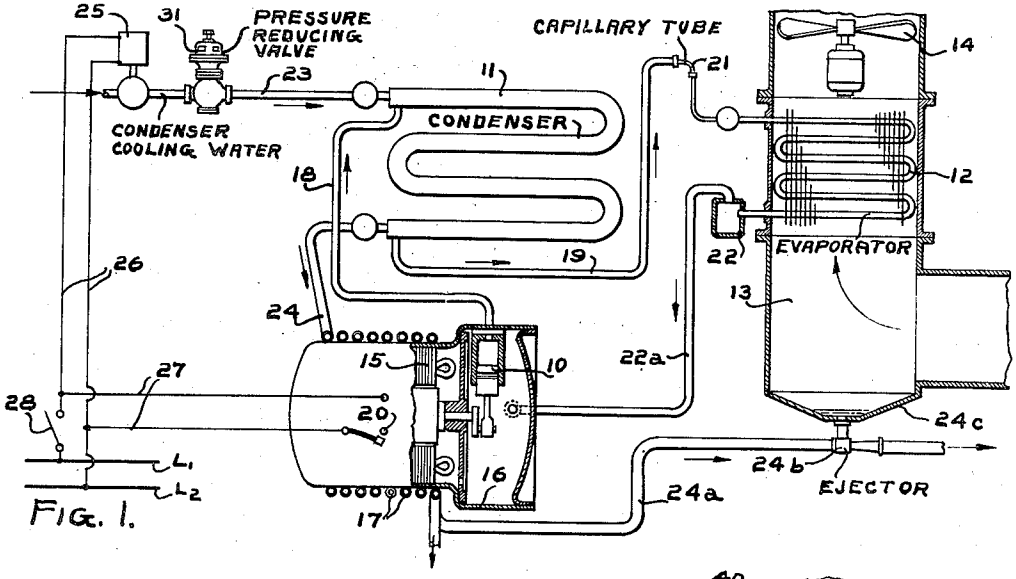


FIG. 1.

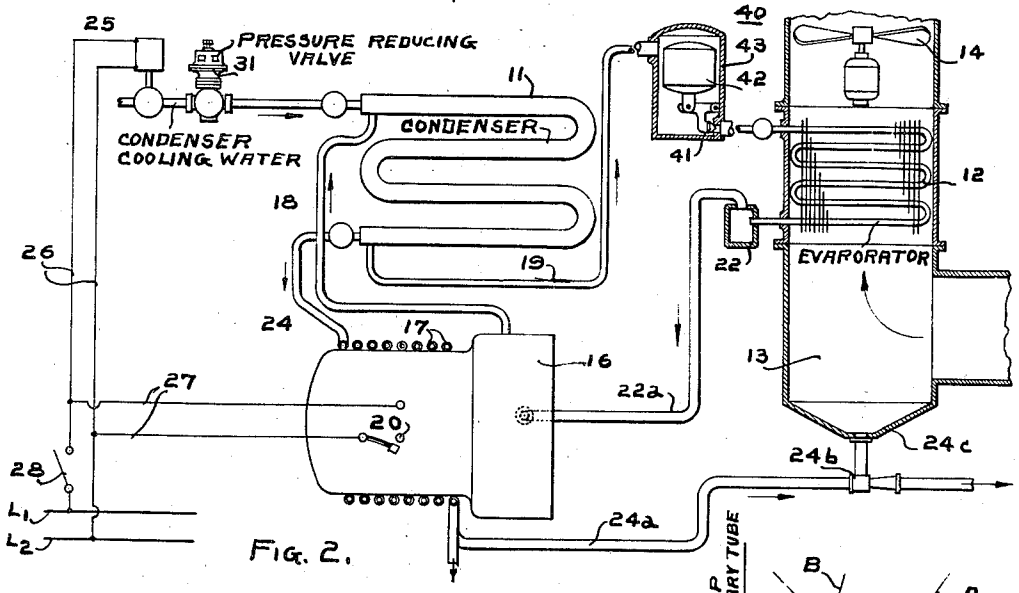


FIG. 2.

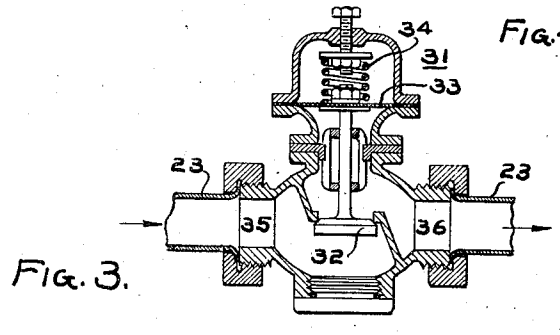


FIG. 3.

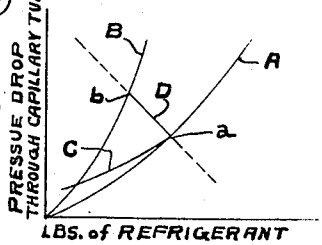


FIG. 4.

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REFRIGERATING APPARATUS

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Application August 24, 1935, Serial No. 37,668

15 Claims. (Cl. 62—115)

My invention relates to refrigerating apparatus and more particularly to refrigerating apparatus used in air conditioning applications, and it has for an object to provide improved apparatus of this kind.

An object of my invention is to provide refrigerating apparatus which is simple, reliable, and inexpensive to construct and maintain.

A particular object is to vary the difference between the condenser and evaporator pressures more nearly in accordance with the pressure difference required to effect the desired flow of liquid refrigerant through a capillary tube or fixed flow resistance passage.

A further object of my invention is to provide an improved refrigerating system having a water cooled condensing unit and which may be operated at various loads without tapping into refrigerant lines for control purposes.

Another object is to provide earlier resumption of refrigerating service after an interruption of electric current to the compressor motor in response to excess temperature thereof.

A still further object is to provide a control of condenser cooling water that is suitable for the use of such water in an ejector for removing moisture condensed by the evaporator.

Heretofore, it has been the practice to provide a thermostatic expansion valve for controlling the flow of liquid refrigerant to the evaporator. Such a valve is costly, and often requires considerable servicing in operation. It has also been the practice to provide a valve for controlling the supply of cooling water to the condenser in accordance with the condenser pressure. Such a valve is also costly and it is necessary to tap into the refrigerant line to obtain the condenser pressure for control.

In apparatus embodying my invention, there is provided a capillary tube or fixed flow resistance passage as an expansion device or restrictor, through which flow of liquid refrigerant from the high side to the low side of the system is effected. Such a device is simple and has no moving parts, so that it is inexpensive. For the same reasons it is reliable in operation and requires very little, if any, servicing. The flow of liquid refrigerant through such an expansion device varies substantially as the square root of the pressure difference. If the flow of cooling water is controlled so as to maintain a constant condenser pressure, then the pressure difference across the capillary tube increases with a decrease in load, as hereinafter explained, whereas, a decrease in pressure difference is desired for effecting decreased flow of refrigerant therethrough.

In accordance with my invention, I provide a pressure reducing valve to control the supply of cooling water to the condenser. Such valves are sold as a standard article, and are inexpensive and reliable in operation. They control the flow of water so that the water supplied to the condenser is at a constant pressure. Since the resistance to flow through the condenser and any further parts through which it flows is substantially constant, the rate of flow of cooling water is substantially constant. With constant flow of cooling water, as the refrigeration load decreases, the condenser pressure decreases, thereby effecting decreased pressure difference across the capillary tube with decrease in load, or increased pressure difference with increase in load. With this arrangement, more nearly the desired pressure difference at various loads is provided for obtaining the required flow of liquid refrigerant to the evaporator. Undesirable flow of vaporous refrigerant through the capillary tube at low load is reduced to a minimum.

Control mechanism is provided for initiating the flow of cooling water when the compressor is conditioned for operation; the arrangement being such that the flow of cooling water continues in an uninterrupted manner until the compressor is normally stopped. If the compressor slows down or stops due to some abnormal condition, the flow of cooling water continues at the given rate so that the head pressure is quickly reduced and, when normalcy is restored, the compressor starts against a reduced head pressure. The compressor may be driven by an electric motor and the cooling water used to cool the motor after it leaves the condenser. In such case, the flow of cooling water is preferably effected simultaneously with the supply of electrical current to the motor. In the event of the motor slowing down or stalling while current is supplied thereto, the flow of cooling water continues to cool the motor.

These and other objects are effected by my invention as will be apparent from the following description and claims taken in connection with the accompanying drawing, forming a part of this application, in which:

Fig. 1 is a diagrammatic view of a refrigerating system arranged in accordance with my invention;

Fig. 2 is a view similar to Fig. 1 of a modified system;

Fig. 3 is a view of a detail employed in the systems of Figs. 1 and 2; and

Fig. 4 is a graph illustrating characteristics of the capillary tube of Fig. 1.

Reference will now be had to the drawing, in which I have disclosed my improved refrigerating system in an air cooling application.

In Fig. 1 of the drawing, a refrigerant compressor 10 shown, by way of example, as a hermetically sealed, water-cooled machine, serves to circulate refrigerant through a water-cooled condenser 11 and an evaporator 12. The latter is arranged for cooling the air for a room or enclosure (not shown) and is disposed in a duct 13 connected to the enclosure. It is preferably of the dry type, and may comprise one or more cross-finned coils. A fan 14 may be employed for translating the air to be cooled over the evaporator 12 and then to the point of use.

The compressor 10 is driven by an electric motor 15, and both are enclosed in a hermetically-sealed casing 16. A coil 17 for cooling water is preferably arranged in heat exchanging relation with the casing 16 for abstracting therefrom the heat of the motor 15 and the compressor 10. A normally closed, thermally operated switch 20 may be fixed to the casing 16 for interrupting the supply of electric current upon an abnormal temperature of the casing 16 and the motor 15.

Upon operation of the compressor 10, refrigerant vapor withdrawn from the evaporator 12 is compressed and delivered by the compressor to the condenser 11 by means of a conduit 18. Condensation of the vapor is effected in the condenser 11 at relatively high pressure and the liquid refrigerant flows therefrom through a conduit 19 to an expansion device 21 preferably of the capillary tube type. The latter has a fixed flow resistance passage for the liquid refrigerant which effects a drop in pressure as the liquid passes therethrough. Evaporation of the liquid is effected in the evaporator at relatively low pressure, heat being thereby abstracted from the air flowing over the evaporator. The refrigerant passes from the evaporator to a liquid separator and accumulator 22, in which any liquid refrigerant is retained. The vaporous refrigerant passes through a conduit 22*a* to the compressor 10. The cycle of operation continues as long as the compressor is operated.

Water for cooling the condenser 11, obtained from any suitable source, is conveyed thereto through a conduit 23 and is discharged from the condenser into a conduit 24. The latter is preferably connected to the coil 17, so that the cooling water flows in series through the condenser 11 and coil 17. It is then conveyed through a conduit 24*a* to an ejector 24*b*, which is motivated thereby and removes the moisture condensed from the air by the evaporator 12 and collecting in a sump 24*c*. A solenoid valve 25 may be connected in the conduit 23, said valve being opened upon energization of the solenoid to permit cooling water to flow in the conduit 23.

An electrical circuit 26 is connected to the solenoid valve 25 and is in parallel with a circuit 27 of the motor 15. Both circuits 26 and 27 are connected to a source of electric current through conductors L_1 and L_2 and may be controlled by a single switch 28, adapted to be operated either manually or automatically in any suitable manner known in the art. The thermally operated switch 20 is in the motor circuit 27 and exercises no control over the solenoid valve circuit 26. Closure of the switch 28 energizes both circuits 26 and 27 and operation of the motor 15 and flow of cooling water through the condenser 11 and coil 17 are initiated. Opening the switch 28 terminates operation of the motor 15 and flow of cooling water. If, due to an abnormal condition such as, for example, a low voltage condition, the motor 15 heats sufficiently to open the thermally operated switch 20, its operation is discontinued but cooling water continues to flow to cool the condenser 11, the motor 15, and the compressor 10. The head pressure is, therefore, reduced substantially so that the compressor 10 is started against a reduced pressure when conditions become normal and the switch 20 closes.

A pressure reducing valve 31 is connected in the conduit 23 for controlling the flow of water to the condenser 11 and the coil 17. As shown in Fig. 3, this device may include a valve 32 actuated by a diaphragm 33 which is subjected on the under side to the pressure of the water on the downstream side of the valve 32. The diaphragm 33 is biased in opposition to the water pressure by an adjustable spring 34 and by atmospheric pressure. Water flowing in the conduit 23 enters the valve 32 at 35 and leaves at 36 as shown by the arrows. The pressure at 36 is determined by the adjustment of the spring 34. An increase in pressure at 36 effects an upward movement of the diaphragm 33 and the valve 32 moves in a closing or throttling direction. Conversely, a drop in pressure at 36 results in an opening movement of the valve 32 to permit additional water to flow. The pressure reducing valve 31 thereby operates to maintain the pressure of the water supplied to the condenser substantially constant. Inasmuch as the resistance to flow beyond said valve is constant, the rate of flow will be constant, notwithstanding variations in pressure of the water from the source.

The amount of water passing through the condenser 11 and coil 17 is thus maintained constant at a desired value by the valve 31, which is so set that, when the load on the compressor, which is represented in this case by the temperature of the air being cooled, and the temperature of the cooling water are at maximum values, the discharge or head pressure will be as high as is advisable from an efficiency standpoint. When operating under lower loads, as when the air being cooled is at a temperature below said maximum value, the refrigerant in the evaporator is not heated by said air to as high a temperature, hence its pressure and density are lower. Consequently, the compressor delivers less refrigerant, by weight, to the condenser. A lesser temperature rise of the cooling water is required to condense the smaller quantity of refrigerant, so that a lower temperature and pressure of the refrigerant in the condenser are effected. The head pressure, therefore, rises and falls with the load or the temperature of the air being cooled.

The amount of refrigerant delivered to the evaporator 12 by the capillary tube 21 is responsive to the difference in pressures in the condenser and the evaporator. As the head or condenser pressure rises and falls with increases and decreases in load, more refrigerant is delivered to the evaporator 12 at high load than at a lower load. In this connection, the pressure in the evaporator 12 also rises and falls with increases and decreases in the load or the temperature of the air being cooled but the change in evaporator pressure is at a lower rate than the change in condenser or head pressure. There-

fore, the difference between the pressures in the condenser and evaporator increases and decreases with increases and decreases in load, respectively, so that more refrigerant is delivered to the evaporator at high load than at low load.

The head pressure also varies with the temperature of the cooling water, since, the quantity thereof being constant, a higher pressure of the compressed refrigerant is necessary to effect condensation when the temperature of the cooling water increases. In general, such increased water temperature occurs in hot weather when the refrigeration load is greatest, so that the resultant increase in head pressure provides increased flow of refrigerant to the evaporator at that time.

The refrigerating system is charged with such quantity of refrigerant that there will be liquid refrigerant throughout substantially the entire length of the evaporator 12 at all times. Under variable conditions, such as lower density of the refrigerant vapor in the condenser and the evaporator, the surplus refrigerant is retained in the accumulator 22 in the form of liquid refrigerant.

The characteristics of the capillary tube are graphically illustrated in Fig. 4. The curve A shows the variation in pressure drop across the capillary tube which is necessary to maintain various rates of flow of liquid refrigerant into the capillary tube. Curve B shows the variation in pressure drop for refrigerant in the vaporous state. The refrigerating system of Fig. 1 is so designed and the valve 31 is so set that, under maximum load and maximum seasonal water temperature, the pressure difference and refrigerant flow obtained are represented by the point *a* on the line A, that is, the pressure difference is just sufficient to provide a solid column of liquid refrigerant entering the capillary tube.

When the cooling load decreases, the amount of refrigerant circulated also decreases. This is inherently due to the fact that as the evaporator temperature decreases, the pressure and density of the refrigerant also decrease, so that a reduced mass of refrigerant is circulated by the constant displacement of the compressor 10. To obtain the reduced flow of liquid refrigerant under optimum conditions, the pressure difference should be reduced in accordance with the curve A, since any greater pressure difference at a given refrigerant flow results in the entrance of vaporous refrigerant into the capillary tube. Such flow of uncondensed refrigerant is undesirable, since it tends to raise the pressure of the evaporator without doing any appreciable amount of cooling.

With apparatus as constructed in accordance with my invention, I find that the pressure variation characteristic is such as represented by the line C. Upon decrease in cooling load from the point represented by *a*, the condenser pressure decreases, due to the fact that a smaller quantity of compressed refrigerant is condensed. It will be noted that the line C diverges upwardly from the line A to a slight extent upon decrease in load so that the pressure difference is more than the optimum value and a small amount of uncondensed or vaporous refrigerant passes through the capillary tube. However, the line C approaches the line A sufficiently close to obtain very desirable operating characteristics.

If the condenser pressure were maintained constant, in accordance with conventional practice, then the pressure variation characteristic or variation in refrigerant flow would be represented by the line D. Upon reduction in cooling load, the pressure difference would increase, for the reason that the evaporator pressure would decrease while the condenser pressure remained constant. That is, as the refrigerant flow decreased with decrease in load, the pressure difference would increase as represented by the line D, so that an increasing amount of uncondensed vaporous refrigerant would enter the capillary tube, until the point *b* on the line B were reached, at which point only vaporous refrigerant would enter the tube.

It will thus be seen that my improved refrigerating system inherently operates to increase the rate of flow of refrigerant to the evaporator under conditions of increased load, and vice versa. Furthermore, it is not necessary to tap into refrigerant lines for control purposes.

In Fig. 2, I show an embodiment of my invention in which I have applied the pressure reducing valve 31 to a refrigerating system embodying a high side float valve, shown at 40. Except for the substitution of the float valve for the capillary tube 21, the refrigerating system of Fig. 2 is similar to that of Fig. 1. The float valve 40 includes a casing 43 into which the conduit 19 delivers the condensed refrigerant. Within the casing 43 is a float member 42 actuating a valve 41, the latter controlling the flow of liquid refrigerant from the casing 43 to the evaporator 12. The float member 42 moves the valve 41 in opening direction upon rise of liquid level in the casing, and moves the same in closing direction upon drop in level. The float valve mechanism thus operates to admit liquid refrigerant to the evaporator 12 as rapidly as it is condensed, only a relatively small and constant quantity of refrigerant being retained in the casing 43 to actuate the float member 42.

The pressure reducing valve 31, as in the first embodiment, operates to maintain a constant pressure and a constant flow of cooling water. It is adjusted so that, with maximum seasonal temperature of the cooling water and maximum temperature of the air flow over the evaporator 12, the head pressure is at the highest value at which it is desired to operate. At lower cooling water temperatures and lower air temperatures, the head pressure is reduced. Condensed refrigerant as it is liquefied is all admitted at the liquefying rate to the evaporator, and the rate is not substantially changed by variations in head pressure as is the case with a capillary tube.

The advantages of the pressure reducing valve in this embodiment are: reduced cost of the valve, and the elimination of the necessity for tapping into the refrigerant line.

The above described control for flow of cooling water is particularly suitable for the use of the ejector 24*b*. An ejector requires motivating fluid of constant pressure for best operation, and with the above-described control, such constant pressure of motivating fluid is supplied.

While I have shown my invention in two forms, it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various other changes and modifications without departing from the spirit thereof, and I desire, therefore, that only such limitations shall be placed thereupon as are imposed by the prior art or as are specifically set forth in the appended claims.

What I claim is:

1. In refrigerating apparatus of the compressor-condenser-expander type, the combination of a water-cooled condenser, an evaporator, a compressor for circulating refrigerant through the

condenser and the evaporator, means responsive to increase and decrease in the pressure difference obtaining between the condenser and the evaporator for increasing and decreasing, respectively, the flow of refrigerant therebetween, and regulating means for supplying water at a substantially constant rate to the condenser such that the condenser pressure and the pressure difference between the condenser and the evaporator increase and decrease upon increase and decrease, respectively, in the refrigerating load.

2. In refrigerating apparatus of the compressor-condenser-expander type, the combination of a water-cooled condenser, an evaporator, a compressor for circulating refrigerant through the condenser and the evaporator, an expansion device having a fixed flow resistance passage interposed between the condenser and the evaporator, whereby the flow of refrigerant from the former to the latter increases and decreases as the pressure difference obtaining therebetween rises and falls, respectively, and means for supplying water to the condenser at a substantially constant rate regardless of the compressor load so that the discharge pressure of the compressor increases as its suction pressure rises and at a higher rate, thereby effecting increased pressure difference with corresponding increased flow of refrigerant between the condenser and the evaporator upon increase in refrigeration load.

3. Refrigerating apparatus as specified in claim 2, wherein the means for supplying water to the condenser at a substantially constant rate comprises a pressure reducing valve operating in response to the pressure of the water on the discharge side of the valve to maintain the same substantially constant.

4. In apparatus for cooling the air in an enclosure, the combination of an evaporator, means for translating air for the enclosure in heat exchanging relation with the evaporator, a water cooled condenser, a compressor for withdrawing refrigerant vapor from said evaporator and for translating it to said condenser at a relatively high pressure, means responsive to increase in and decrease in the difference between the pressures obtaining in the condenser and the evaporator for increasing and decreasing, respectively, flow of refrigerant from the former to the latter, means for supplying water to the condenser at a substantially constant rate such that the condenser pressure and the pressure difference between the condenser and the evaporator increase and decrease upon increase and decrease, respectively, in the refrigerating load, and means for simultaneously initiating and terminating operation of the compressor and flow of cooling water.

5. In apparatus for cooling the air in an enclosure, the combination of an evaporator, means for translating air for the enclosure in heat exchanging relation with the evaporator, a water cooled condenser, a compressor for withdrawing refrigerant vapor from said evaporator and for translating it to said condenser at a relatively high pressure, means responsive to the difference between the pressures obtaining in the condenser and the evaporator for controlling flow of refrigerant from the former to the latter, means for supplying water to the condenser at a substantially constant rate and including a valve for controlling the flow of cooling water to the condenser, means responsive to the pressure of the water delivered to the condenser for actuating said valve, and means for simultaneously initiating and terminating operation of the compressor and flow of cooling water.

6. In refrigerating apparatus, the combination of an evaporator, a compressor, a water cooled condenser, a fixed flow resistance passage for flow of refrigerant from the condenser to the evaporator, and means for circulating cooling water at a substantially constant rate in heat exchange relation with said condenser, whereby the pressure in the condenser decreases with decrease in cooling load and vice versa, said flow resistance passage being of such dimensions and the flow of cooling water being such that, with maximum seasonal temperature of said cooling water and maximum cooling load, the difference between the condenser and the evaporator pressure is substantially that required to effect flow of liquid refrigerant at the same rate that refrigerant is circulated by the compressor.

7. Apparatus for effecting comfort cooling of air for an enclosure occupied by people comprising an evaporator, means for effecting forced circulation of air over said evaporator and into the enclosure, a compressor for withdrawing refrigerant vapor from said evaporator and for compressing it, a water cooled condenser for condensing the compressed refrigerant, an expansion device interposed between the condenser and the evaporator, said expansion device comprising a fixed flow resistance passage whereby the flow of refrigerant from the condenser to the evaporator increases and decreases as the difference between the pressures therein rises and falls, respectively, and means for supplying cooling water to the condenser at a substantially constant rate independently of the pressure in the condenser so that the condenser pressure increases as the evaporator pressure rises and at a higher rate, thereby effecting increased pressure difference with corresponding increased flow of refrigerant between the condenser and the evaporator upon increase in cooling load, the last-mentioned means comprising a pressure reducing valve operating in response to the pressure on the discharge side of the valve to maintain the same substantially constant.

8. The method of operating a water cooled refrigerating system of the compressor-condenser-expander type which includes increasing and decreasing the flow of condensed refrigerant to be evaporated upon increase and decrease, respectively, in pressure difference between the condensed and the evaporated refrigerant, and supplying cooling water for condensing the refrigerant at a substantially constant rate at all loads such that the pressure of the condensed refrigerant and the pressure difference between the condensed and the evaporated refrigerant increase and decrease upon increase and decrease, respectively, in the refrigerating load.

9. A refrigerating system comprising a condenser, an evaporator of the type known as a dry evaporator and comprising an elongated once-through passage through which refrigerant flows at substantial velocity, a compressor, means for conveying refrigerant from the condenser to the evaporator and for reducing the pressure thereof comprising a fixed elongated passage of restricted flow area, and means for conveying vaporous refrigerant from the outlet of the evaporator to the inlet of the compressor including a separating chamber or reservoir for retaining therein surplus liquid refigerant occasioned by variation in operating conditions, the dimensions of said restricted passage, said evaporator passage

and said condenser being proportioned so that throughout a substantial portion of the normal range of variable conditions under which the system operates, sufficient liquid refrigerant flows through said restricted passage so that liquid refrigerant extends throughout substantially the entire length of the evaporator passage and some vaporous refrigerant also enters the inlet of the restricted passage, and the refrigerating system being arranged so that all the refrigerant flowing through the evaporator passage is returned to the compressor before being again circulated through the evaporator passage.

10. In air conditioning apparatus, the combination of an evaporator of the dry type comprising one or more cross-finned serpentine coils each providing an elongated refrigerant passage, duct means within which said evaporator is disposed, a fan effecting flow of air through said duct means and in contact with said evaporator, a compressor, a condenser, means for conveying refrigerant from the condenser to the evaporator including expansion means of constant restriction permitting sufficient flow of refrigerant so that there may be liquid refrigerant leaving the evaporator, said expansion means including a tube of restricted bore, and means for conveying vaporous refrigerant from the outlet of the evaporator to the inlet of the compressor including a separating chamber or reservoir for retaining therein surplus liquid refrigerant occasioned by variation in operating conditions, the dimensions of said expansion means, said evaporator and said condenser being proportioned so that throughout a substantial portion of the normal range of variable conditions under which the apparatus operates, sufficient liquid refrigerant flows through said expansion means so that liquid refrigerant extends throughout substantially the entire length of the evaporator passage or passages and some vaporous refrigerant also enters the inlet of said tube of restricted bore, and the refrigerating system being arranged so that all the refrigerant flowing through the evaporator passage is returned to the compressor before being again circulated through the evaporator passage.

11. A refrigerating system comprising a condenser, an evaporator coil of the dry type and comprising substantially horizontal runs through which refrigerant flows in series, a compressor, means for conveying refrigerant from the condenser to the evaporator including expansion means for reducing the pressure of the refrigerant from condenser pressure to evaporator pressure, said expansion means providing a constant restriction and comprising a passage of restricted flow area and considerable length, and means for conveying vaporous refrigerant from the outlet of the evaporator coil to the inlet of the compressor including a separating chamber or reservoir for retaining therein surplus liquid refrigerant occasioned by variation in operating conditions, the expansion means being of such dimensions, in relation to the evaporator and the condenser, that throughout a substantial portion of the normal range of variable conditions under which the system operates, it permits sufficient flow so that liquid refrigerant extends throughout substantially the entire length of the evaporator coil and some vaporous refrigerant also enters the inlet of the expansion means, and the refrigerating system being arranged so that substantially all the refrigerant flowing through the evaporator coil is returned to the compressor before being again circulated through the evaporator coil.

12. A refrigerating system as set forth in claim 11 wherein each successive run of the evaporator coil is disposed at least as low as the preceding run and wherein said separating chamber or reservoir is disposed at least as low as the last run.

13. A refrigerating system as set forth in claim 11 wherein the evaporator coil is arranged to provide refrigerant drainage in a direction from the inlet to the outlet and thence to said separating chamber or reservoir.

14. In a refrigerating system, the combination of an evaporator coil of the dry type and comprising substantially horizontal runs through which refrigerant flows in series, a compressor, a condenser, means for conveying refrigerant from the condenser to the evaporator including expansion means for reducing the pressure of the refrigerant from condenser pressure to evaporator pressure, said expansion means providing a constant restriction and including a capillary tube, said expansion means permitting sufficient flow of refrigerant so that there may be liquid refrigerant leaving the evaporator under some conditions, and means for conveying vaporous refrigerant from the outlet of the evaporator to the inlet of the compressor including a separating chamber or reservoir for retaining therein surplus liquid refrigerant occasioned by variation in operating conditions, said separating chamber being connected and formed to trap liquid refrigerant and to prevent its return to said evaporator coil by gravity flow, the refrigerating system being arranged so that substantially all of the refrigerant flowing through the evaporator coil is returned to the compressor before being again circulated through the evaporator coil.

15. A refrigerating system as set forth in claim 14 wherein each successive run of the evaporator coil is disposed at least as low as the preceding run and wherein said separating chamber or reservoir is disposed at least as low as the last run.

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