Aug. 15, 1950 E. W. ZEARFOSS, JR. 2,518,587

REFRIGERANT FLOW CONTROL

Filed April 11, 1947 2 Sheets-Sheet 1

FIG. 1.

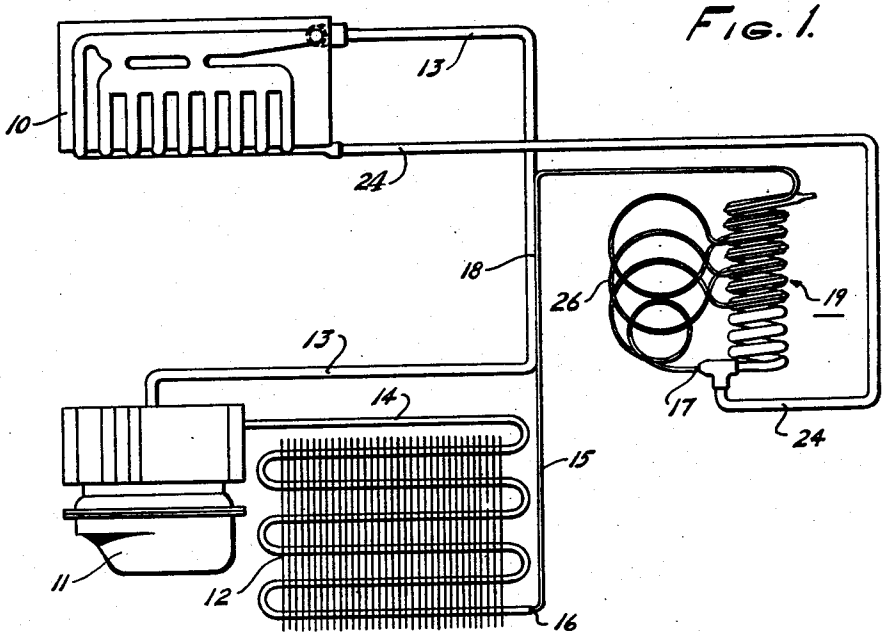
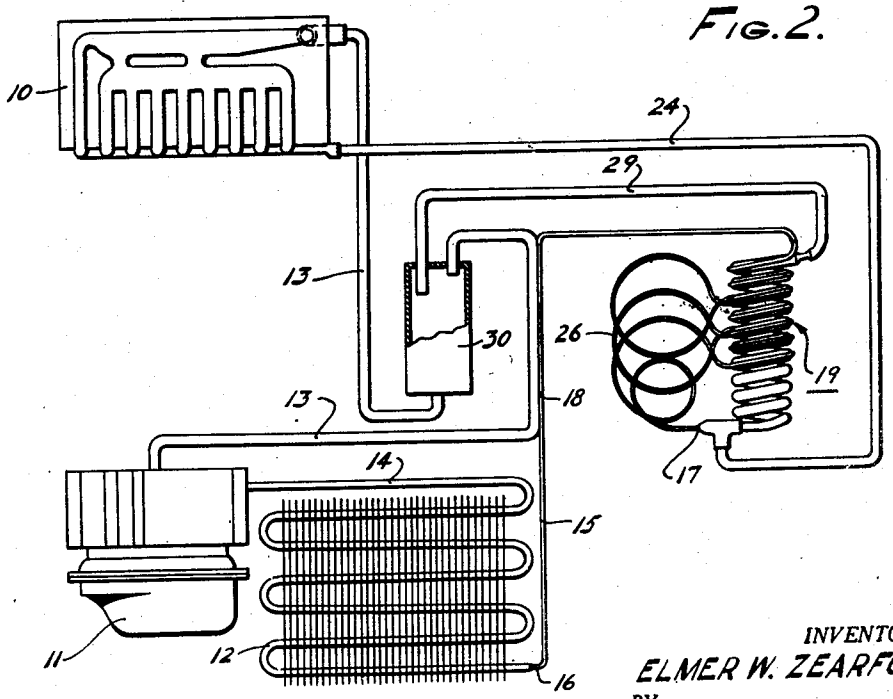


FIG. 2.



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Filed April 11, 1947 2 Sheets-Sheet 2

FIG. 3.

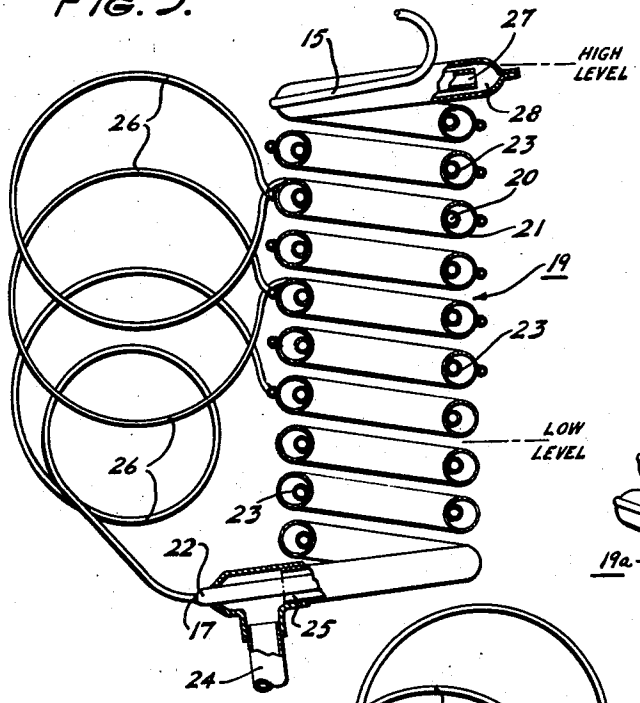


FIG. 4.

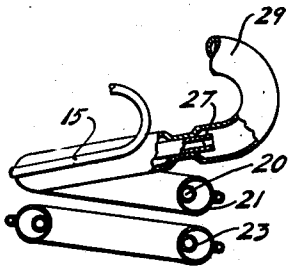


FIG. 7.

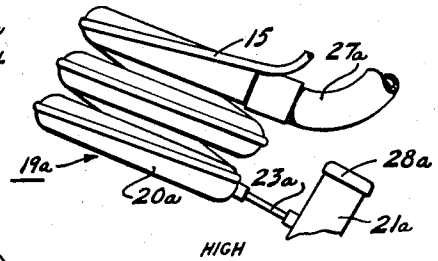
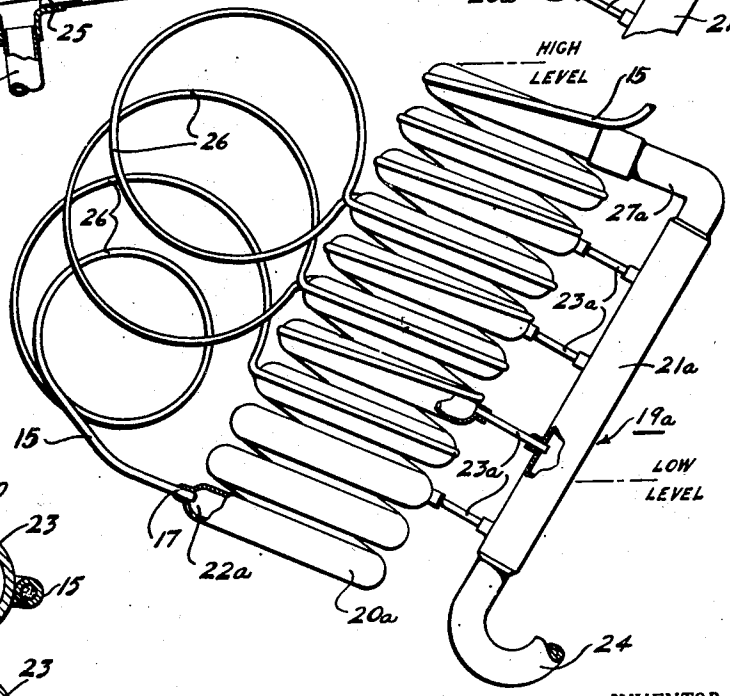


FIG. 6.



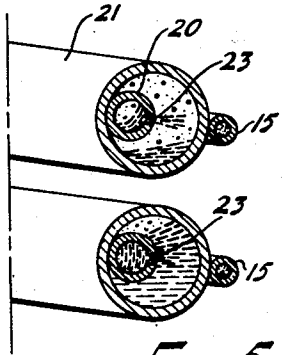


FIG. 5.

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REFRIGERANT FLOW CONTROL

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6 Claims. (Cl. 62—8)

1

The present invention relates to refrigeration and, particularly, to refrigerating systems of the capillary tube variety. More specifically, the invention has to do with the problem of controlling the flow of refrigerant between the high-pressure side and the low-pressure side of refrigerating systems of the general kind above mentioned.

In systems of that kind, the capillary tube is interposed between the condenser and the evaporator, and its function is to restrict the flow of refrigerant by creating frictional resistance or impedance to the flow of refrigerant as it passes from the condenser to the evaporator. In this manner, the tube effects a gradual reduction in pressure from the high or condensing pressure to the low or evaporating pressure. The rate of flow of refrigerant through the capillary tube is determined by the length and internal diameter of the tube. However, because the inlet end of the tube is exposed to high or condensing pressure, and the outlet of the tube is exposed to low or evaporating pressure, the rate of flow through the capillary tube depends largely upon the pressure difference between these two pressures. Optimum rate of flow is said to exist when 100% liquid, at saturation temperature, is delivered 100% of the time at the inlet of the tube. In this ideal condition, the liquid at the entrance of the capillary tube, is at condensing pressure and, as the liquid travels through the capillary tube, the impedance or frictional resistance of the tube to the flow of refrigerant progressively reduces the refrigerant pressure. This progressive reduction in pressure continually causes some liquid to flash into gas. In this manner, the refrigerant, as it travels along the tube, is maintained at saturation temperature with respect to the existing and progressively decreasing pressure, so that by the time the refrigerant reaches the outlet of the tube, the liquid and accumulated flash gas are substantially at evaporator or suction pressure and temperature.

All of these factors are taken into consideration when designing a capillary tube system and, therefore, it is customary to provide the system with a capillary tube of such a length and internal diameter that refrigerant will flow at the optimum rate for a given difference in pressure between the inlet and outlet ends of the tube. Unfortunately, the ideal condition for which the system is designed, is most unstable, firstly, because the pressure in the condenser and in the evaporator is ever subject to change with variations in the temperature of the ambient air, and secondly, because changes in the difference in

2

pressure at the ends of the tube deleteriously affects the rate of flow of refrigerant through the tube with detriment to the efficient operation of the system.

Attempts have heretofore been made to overcome the above noted objections by varying the flow restricting effect of the capillary tube in response to changes in condensing pressure and/or evaporating pressure. However, most of the known proposals which have been devised as a solution for the problem, proceed from the theory that refrigerant will flow more freely through the capillary tube if less flash gas is present, and refrigerant will flow less freely through the tube if more flash gas is present. Accordingly, many of the known arrangements include means purposely designed to produce additional or to increase the quantity of flash gas when more restriction is required. Arrangements of that kind are in opposition to the thermodynamic laws for maximum efficiency of the refrigerating system, because the additional or increased quantity of flash gas must pass through the evaporator, not only without doing any useful work, but also taking up valuable liquid refrigerant space in the evaporator; thereby reducing its effective heat absorbing capacity. Furthermore, known arrangements of the general type above referred to, preclude the use of ideal or optimum capillary impedance, because improper impedance must first be intentionally provided before compensation for pressure changes can be obtained and, hence, a periodic or cycling deviation from the ideal or optimum condition, is necessary if the purpose of such known arrangements is to be realized.

In contradistinction to these previously known arrangements, the present invention is based upon the fact that optimum rate of flow of refrigerant, for any predetermined difference between condensing pressure and evaporating pressure, can be obtained if a capillary tube of proper length is employed for that predetermined condition. In line with this fact, the present invention recognizes that, if the difference in pressure between the ends of the capillary tube decreases, a corresponding reduction in the flow rate takes place with the result that liquid refrigerant accumulates in the condenser and thereby interferes with the efficient operation of the system; but, if the difference of pressure between the ends of the capillary tube increases, a corresponding increase in the refrigerant flow occurs with the result that uncondensed refrigerant passes through the evaporator and thereby also inter-

feres with the efficient operation of the system. The invention therefore, realizes that, in order to overcome these undesirable results and to do so adequately (that is to say, in accordance with the applicable thermodynamic laws and without interference with the efficient operation of a set-up of predetermined capacity), the impedance of the capillary tube should be low when the flow rate is high, and the impedance of the capillary should be high when the flow rate is low. Otherwise, the proper ratio of liquid to gas is off balance and the previously mentioned optimum rate of flow of refrigerant is lost.

Accordingly, it is the primary object of this invention to provide an arrangement by means of which the effective flow restricting length of capillary tube is, in effect, decreased or increased in response to flow rate variations which arise from changes in the difference in pressure between the intake and discharge ends of the tube. In this manner, the optimum rate of flow of refrigerant for the particular pressure difference which occurs at any one time, is efficiently obtained. To accomplish this object, the invention provides means whereby the full length of the capillary tube is available to impose its flow restricting effect on the refrigerant, when the rate of flow through the tube is at its lowest level, and whereby a considerably shortened length of capillary tube is made available to restrict the flow, when the rate of flow through the tube is at its highest level. Between these two extremes, the arrangement functions to increase or to decrease the effective flow restricting length of the capillary tube, progressively and proportionately to diminutions or augmentations in the rate of flow of refrigerant through the tube. The advantages derived from the use of an arrangement of a kind above stated, are that the control of the flow rate is instantaneously and spontaneously responsive to changes in pressure conditions at the opposite ends of the tube, and the control does not require the use of movable or adjustable parts to secure the desired effects.

It is also an object of the invention to control the rate at which refrigerant flows through the capillary tube, and to utilize, for that purpose, liquid refrigerant which is discharged through the tube. To that end, the invention employs means adapted to receive the mixture of gaseous and liquid refrigerant passed by the tube, to induce separation of the liquid from the flash gas, and to circulate the liquid in heat exchange relationship with various lengths of the tube, depending upon the quantity of liquid which the tube passes, the quantity of liquid passed, in turn, depending upon the difference in pressure at the ends of the tube. This feature of the invention makes it possible, as conditions demand, to place liquid refrigerant which has passed out of the tube, in intimate heat exchange relationship with refrigerant which is passing through certain portions of the tube, so that the refrigerant passing through said portions is rapidly subcooled with the result that the flow restricting effect of these portions is nullified.

Another object of the invention is to maintain the proper relationship between the condensing pressure and the rate of flow of refrigerant in a refrigerating system in which a capillary tube is utilized to control the passage of refrigerant from the condenser to the evaporator. Basically, this object of the invention is obtained by increasing the restriction of the capillary tube, when a reduced quantity of liquid refrigerant flows through the tube, and by decreasing the restriction of the capillary tube, when an increased quantity of liquid refrigerant flows through the tube. To realize this feature of the invention, the capillary tube is associated with a device which, in order to obtain increased reduction, is adapted to provide for low heat exchange when the quanty of liquid flowing through the tube is low, and, in order to obtain decreased restriction, is adapted to provide for high heat exchange when the quantity of liquid flowing through the tube is high.

A further and more specific object of the invention is to control the rate of flow of refrigerant during a pull-down cycle, so as to reduce the load imposed upon the motor-compressor unit during such a cycle. Usually, in order to take care of the extra work required during pull-down periods, the motor-compressor employed is much larger and more powerful than is needed for efficient operation during normal cycling periods. The invention, by providing means including a capillary tube and heat exchanging device arrangement of the above-mentioned character, makes it possible to use a motor-compressor unit which need be no larger nor more powerful than is required for adequate normal operation.

These and other objects of the invention, and the manner in which they are obtained, will be more fully understood from the following description based on the accompanying drawings, in which:

Figure 1 is a diagrammatic view of a refrigerating system embodying the invention;

Figure 2 is a view similar to Figure 1, showing a modified system including the invention;

Figure 3 is an elevational cross-sectional view, on an enlarged scale, of a heat exchanging device constructed in accordance with the invention;

Figure 4 is a view of a portion of the device as shown in Figure 3, and illustrates a modification in the structure of said device to adapt the same to the system shown in Figure 2;

Figure 5 is an enlarged view of a detail of the heat exchanging device;

Figure 6 is a side elevational view, with parts in section, illustrating a slightly modified form of the heat exchanging device; and,

Figure 7 is a view of a portion of the device as shown in Figure 6, and illustrates a modification in the structure of said device to adapt the same to the system shown in Figure 2.

With more particular reference to the drawings, the system, as shown in either Figure 1 or Figure 2, includes an evaporator 10 and a condensing unit, the latter comprising a motor-compressor 11 and a condenser 12. According to the customary practice, the evaporator is adapted to be mounted within an insulated compartment of a refrigerator cabinet (not shown), and the condensing unit is adapted to be mounted in a machinery compartment, usually provided in such a cabinet, outside the insulated compartment thereof. The motor-compressor is adapted to withdraw heat-laden vaporized refrigerant from the evaporator, through suction line 13, and to discharge compressed refrigerant vapor into the condenser, through duct 14. In the condenser, the vapor gives up its heat to the ambient air and is thereby reconverted to liquid state for feeding to the evaporator, through conduit means which will now be described.

As shown in Figures 1 and 2, a capillary tube 15 has its inlet 16 connected with the outlet of

the condenser so that liquid refrigerant, at condensing pressure, enters the capillary tube for passage therethrough. This tube imposes its restricting effect to the flow of refrigerant and progressively reduces the refrigerant pressure until the mixture of liquid refrigerant and accumulated flash-gas, at the outlet 17 of said tube, is at evaporating pressure.

A portion of capillary tube 15, according to the usual practice and as indicated at 18, is arranged in heat exchange relationship with suction line 13. Another portion of said tube, in accordance with the present invention, is adapted for heat exchange relationship with a device, generally indicated at 19. This device receives the mixture of liquid and gaseous refrigerant discharged by the capillary tube and is particularly adapted to separate the liquid from the gas, so that the quantity of liquid actually passed by the capillary tube may be put into heat exchange relationship with the refrigerant passing through said tube.

For that purpose, the device 19, as illustrated, takes the form of an upright coil, and as can be more clearly seen in Figures 3 and 4, comprises coiled inner tubing 20 and coiled outer tubing 21. As shown in Figure 3, the lower end 22 of the coiled inner tubing is connected and communicates with outlet 17 of the capillary tube, so that refrigerant is discharged from said tube directly into said inner tubing. In the inner tubing, the refrigerant, because of its velocity and due to the coiled formation of said tubing, is caused to swirl, and the swirling motion, in turn, tends to force the liquid into outer tubing 21 through apertures 23 (more clearly seen in Figure 5) distributed along the length of inner tubing 20. In the construction shown, each convolution of the coiled inner tubing 20 is adapted to hug the innermost surface inside the associated convolution of the coiled outer tubing 21, and the apertures 23 are provided on the outermost wall of the inner tubing. In this manner, the passage of liquid refrigerant from inner tubing 20 through apertures 23 and into outer tubing 21 is insured, because the possibility of the outermost wall of said tubing 20 coming in contact with the inner surface of said tubing 21, thereby obstructing said apertures, is eliminated. From said outer tubing, the refrigerant is delivered to evaporator 10, through a duct 24 connected with the lower end 25 of the outer tubing.

As illustrated, that part of the capillary tube which is adapted for heat exchange relationship with the above described device 19, is coiled about and in contact with the outside surface of all but a few of the lowermost convolutions of the coiled outer tubing 21. Any excess length of capillary tube may be looped, for instance, as shown at 26. It is to be noted that the tubings 20 and 21, as well as the duct 24, are such as to have no appreciable restricting effect on the flow of the refrigerant so that the refrigerant in the device 19 is maintained substantially at the evaporator pressure and temperature. In practice, the mentioned heat exchange device and associated ducts are installed within the insulation of the refrigerator cabinet so as not to be affected by ambient air.

With an arrangement as above described, if a condition arises where the difference in pressure at the ends of capillary tube 15 is such that the rate of flow through the tube is low, so that the quantity of liquid actually passed by the tube is small, then all the liquid available is discharged

through the first few apertures 23, into the lowermost convolutions of outer tubing 21 and, therefore, the liquid does not rise above a predetermined low level, substantially as is indicated in Figure 3. Because the lowermost convolutions of outer tubing 21 are not in heat exchange with the capillary tube, the liquid passed by said tube fails to come into heat exchange relationship with the refrigerant passing through the capillary tube and, consequently, the full length of the tube is available to impose its restriction on the flow of refrigerant, thereby maintaining that balance, between capillary-tube impedance and rate of flow, which is proper for the existing condition.

If, however, a condition arises where the difference in pressure at the ends of capillary tube 15 is such that the rate of flow through the tube is high so that the quantity of liquid actually passed by the tube is greatly increased, then this increased quantity of liquid is discharged, through a greater number of apertures, into the upper convolutions of the outer tubing and reaches a predetermined high level, substantially as is indicated in Figure 3. Because the upper convolutions of the outer tubing are in heat exchange with portions of the capillary tube, the liquid is circulated in heat exchange relationship with the refrigerant passing through said portions of the capillary tube (see Figure 5). Accordingly, the flow restricting effect of those portions of the capillary tube is nullified, so that a greatly shortened length of the tube is made available to impose effective restriction to the flow of refrigerant, and the reduced restriction establishes and maintains that new balance, between capillary-tube impedance and rate of flow, which is proper for the then existing condition.

It will be understood that if any condition, between the two above mentioned limits, arises to effect the rate of flow and the quantity of liquid actually passed by the tube, then the restriction of the capillary tube will be accordingly affected to provide for appropriate impedance values throughout the entire operation range of the system. This is because, in operating, the heat exchange device acts to regulate the rate of flow of refrigerant through the capillary tube, in accordance with the difference in pressure which exists between the inlet and the outlet ends of said tube. However, in accomplishing this result, the device 19, due to its particular construction and association with the capillary tube, does not prevent the refrigerating system from operating in accordance with thermodynamic laws which insure the most efficient refrigerating effects. The main reason for this accomplishment is that the device provides for an arrangement which still allows the design of a system wherein optimum rate of flow for a given difference between condensing pressure and evaporating pressure is assured, and which functions to maintain such optimum rate of flow over a wide range in pressure differences arising from changes between said two pressures. Moreover, by reason of the fact that the device effects separation of the liquid from the flash gas, and thereby makes it possible for liquid refrigerant to be immediately available for heat exchange with the refrigerant flowing through one or more of the coiled portions of the capillary tube, the establishment of optimum rate of flow, for the existing difference between the two above mentioned and controlling pressures, is instantaneous. This in itself constitutes one of the most

important features of the invention because, at all times, the efficient operation of the refrigerating system is kept at its peak.

With reference to the system as illustrated in Figure 1, and as more clearly appears from the structure shown in Figure 3, the gas which separates from the liquid in inner tubing 20, continues to rise in said tubing and is discharged at the free or opened upper end 27 of the latter. This upper end of the inner tubing 20 terminates at and discharges into the upper end portion 26 of outer tubing 21, which portion is suitably sealed so that the gas may eventually pass with the liquid, through duct 24 and evaporator 10, and return to the compressor.

With reference to the system as illustrated in Figure 2, most of the flash gas which separates from the liquid in inner tubing 20, is caused to by-pass the evaporator during normal cycling of the system. For that purpose, as is shown in Figure 4, the upper end portion of coiled outer tubing 21 provides a seal about inner tubing 20 at a point ahead of its opened end 27, and is provided with an extension 29 which discharges into an accumulator 30 (Figure 2) interposed in suction line 13. During a normal cycling operation, the flash gas discharged into the accumulator 30, through tubing extension 29, mingles with the gas discharged through the section of suction line which leads from the evaporator to said accumulator. From the accumulator, the gas flows to the compressor through the section of suction line which leads from the accumulator to the motor-compressor 11.

The system, is illustrated in Figure 2, has the further advantage that, during pull-down operation, the quantity of liquid which normally must pass through the evaporator, is limited so as to reduce the suction pressure to a point where the work done by the motor is materially lessened. The power expended to operate the compressor is largely a function of the suction pressure, and during pull-down operations when the suction pressure is abnormally high, the power required to operate the compressor greatly exceeds the power required for normal operations. In an effort to take care of this condition, it is usually necessary to employ a motor which is larger and more powerful than would normally be needed. If, however, the rate of flow of refrigerant is controlled during pull-down periods so as to regulate the suction pressure, then a motor of adequate size and power for normal cycling operations can be used effectively to perform any work which may be demanded of it.

This advantage is readily obtained with a system as shown in Figure 2, because the arrangement definitely limits the amount of liquid which may be fed to the evaporator during pull-down periods. In that manner, the suction pressure is so adjusted that it imposes no abnormal burden on the motor-compressor. This results from the fact that, during a pull-down cycle, the apertures 23 in inner tubing 20 allow only so much liquid to pass for feeding to the evaporator. The remaining or excess refrigerant discharged by the restrictor or capillary tube passes out of the opened end 27 of inner tubing 20 and is discharged through tubing extension 29 into accumulator 30. Such excess refrigerant, therefore, is temporarily inactive and, consequently, the evaporator is partly starved so that its thermal capacity is reduced which results in reducing the work required to be done by the motor-compressor. At the end of a pull-down cycle, when the suction pressure is lowered to the extent that the flow rate through the device 19 starves the accumulator, then the evaporator is completely flooded for normal operation.

It is to be noted that the accumulator 30 is such that the level of the liquid refrigerant in said accumulator never rises to a point where it can be fed to the motor-compressor through the section of suction line which leads from the accumulator to the motor-compressor. For that reason, the mentioned section of suction line opens into the upper portion of the accumulator and well above the discharge end of the tubing extension 29.

In Figure 6, a modified device for heat exchange with capillary tube 15, is shown at 19*a*. In accordance with the modified embodiment, the capillary tube 15 discharges directly into the lower end 22*a* of coiled tubing 20*a* with which portions of said capillary tube are in heat exchange relationship. The upper end 27*a* of coil tubing 20*a* communicates with a manifold-like member 21*a* which in turn communicates with the previously mentioned duct 24 leading to the evaporator. The member 21*a* is provided with a plurality of take-offs 23*a* which communicate with spaced convolutions of the coiled tubing 20*a*, and which control the level of liquid refrigerant in said tubing in accordance with the rate of flow and quantity of refrigerant passed by the capillary tube. In effect, coiled tubing 20*a* is equivalent to the inner coil tubing of the device shown in Figure 3, and member 21*a* is equivalent to the outer coil tubing of that device. Therefore, the operations of a device constructed as shown in Figure 6, is the same as the operation which was described above in connection with a device constructed as shown in Figure 3.

Figure 7 shows the construction of a device as illustrated in Figure 6 for use in a system such as is represented in Figure 2. For that purpose, the upper end 28*a* of member 21*a* is sealed, and the upper end 27*a* of coiled tubing 20*a* is extended for communication with accumulator 30 (Figure 2). The tubing extension serves the same purpose as tubing extension 29 of the arrangement shown in Figure 2 and, therefore, the system operates in the same manner as previously described.

From the foregoing description, it will be appreciated that the invention provides a simple yet dependable arrangement whereby the rate of flow of refrigerant through a refrigerating system of the capillary tube type, is adequately controlled and instantaneously regulated so that optimum efficient operation is maintained regardless of variations in pressure conditions which tend to affect, deleteriously, the proper function of such a system. Moreover, by using a system incorporating the invention, the proper quantity of liquid refrigerant is made available for passage through the capillary tube, and the capillary tube itself functions to maintain the flow of refrigerant at the optimum rate for the particular pressure condition under which the system is operating.

Although several arrangements embodying the invention have been described with great particularity, it is to be noted that this has been done by way of example only. Various changes in the details of construction and in the combination and association of parts may be resorted to without departing from the spirit of the invention which is subject only to such limitations as are imposed by the prior art or are specifically called for in the appended claims.

I claim:

1. In a refrigerating system having a condenser and an evaporator, a restrictor tube for receiving refrigerant at condensing pressure from the condenser and for discharging a mixture of liquid and gaseous refrigerant at evaporating pressure, and conduit means disposed to receive refrigerant discharged by the restrictor tube for delivery to the evaporator, said conduit means including a pair of tubing sections with passageways therebetween providing for separation of the liquid from the gaseous refrigerant, one of said tubing sections being associated in heat exchange relationship with said tube.

2. In a refrigerating system having a condenser and an evaporator, a restrictor tube for receiving refrigerant at condensing pressure from the condenser and for discharging a mixture of liquid and gaseous refrigerant at evaporating pressure, and a device including tubing sections, one section communicating with the discharge end of the restrictor tube to receive the mixture discharged thereby and having means along its length to provide for passage of the liquid into the other section, said other section having portions in heat exchange relationship with the restrictor tube to apply such liquid in heat exchange relationship with refrigerant in said tube.

3. In a refrigerating system having a condenser and an evaporator, a restrictor tube for receiving refrigerant at condensing pressure from the condenser and for discharging a mixture of liquid and gaseous refrigerant at evaporating pressure, and a device including inner and outer tubing sections, the inner tubing section communicating with the discharge end of the restrictor tube to receive the mixture discharged thereby, and having apertures along its length to provide for passage of the liquid into the outer tubing section, said outer tubing section having portions in heat exchange relationship with the restrictor tube to apply such liquid in heat exchange relationship with refrigerant in said tube.

4. In a refrigerating system having a condenser and an evaporator, a restrictor tube for receiving refrigerant at condensing pressure from the condenser and for discharging a mixture of liquid and gaseous refrigerant at evaporating pressure, and a device including coiled tubing disposed to receive the mixture discharged by the restrictor tube and having portions in heat exchange with said tube, and a manifold-like member having take-offs communicating with spaced convolutions of the coiled tubing and effective to control the level of liquid refrigerant in said tubing for heat exchange relationship with a variable portion of the length of the restrictor tube depending upon the rate of flow of refrigerant through the latter.

5. In a refrigerating system having a condenser and an evaporator, a restrictor tube for receiving refrigerant at condensing pressure from the condenser and for discharging liquid refrigerant and flash gas at evaporating pressure, means including tubing disposed to receive refrigerant discharged by the restrictor tube and adapted to separate the liquid from the flash gas and to apply the liquid in heat exchange relationship with said tube, means between said tubing and evaporator for conveying such liquid to the evaporator, and means between said tubing and condenser for delivering flash gas to the condenser.

6. In a refrigerating system having a compressor, a condenser and an evaporator, a restrictor tube for receiving liquid refrigerant from the condenser and for discharging a mixture of liquid and gaseous refrigerant, a device disposed to receive refrigerant from the restrictor tube for delivery to the evaporator and adapted to separate liquid from gas and to apply the separated liquid in heat exchange relationship with said tube, and means including a refrigerant accumulator between said device and compressor and adapted to receive gas and excess liquid refrigerant passed by said device and to discharge gas into the compressor for delivery to the condenser.

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