July 4, 1939. C. M. ASHLEY 2,164,761

REFRIGERATING APPARATUS AND METHOD

Filed July 30, 1935 2 Sheets-Sheet 1

Fig. 1.

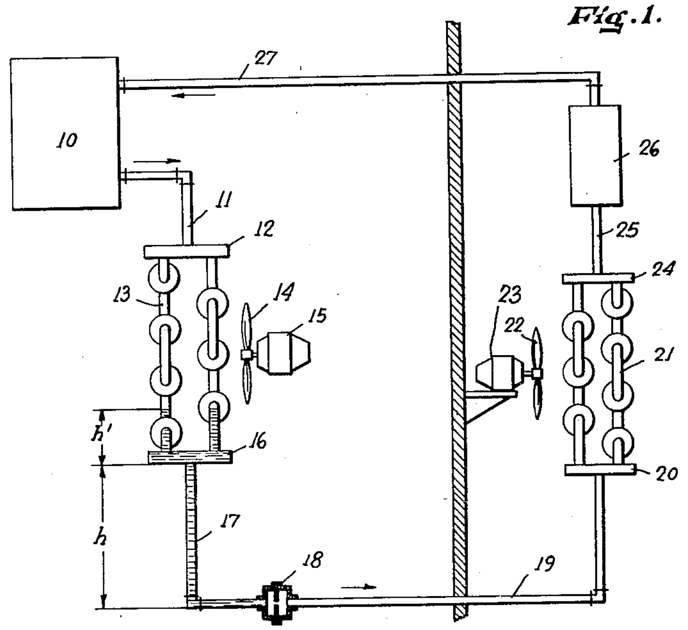

Fig. 2.

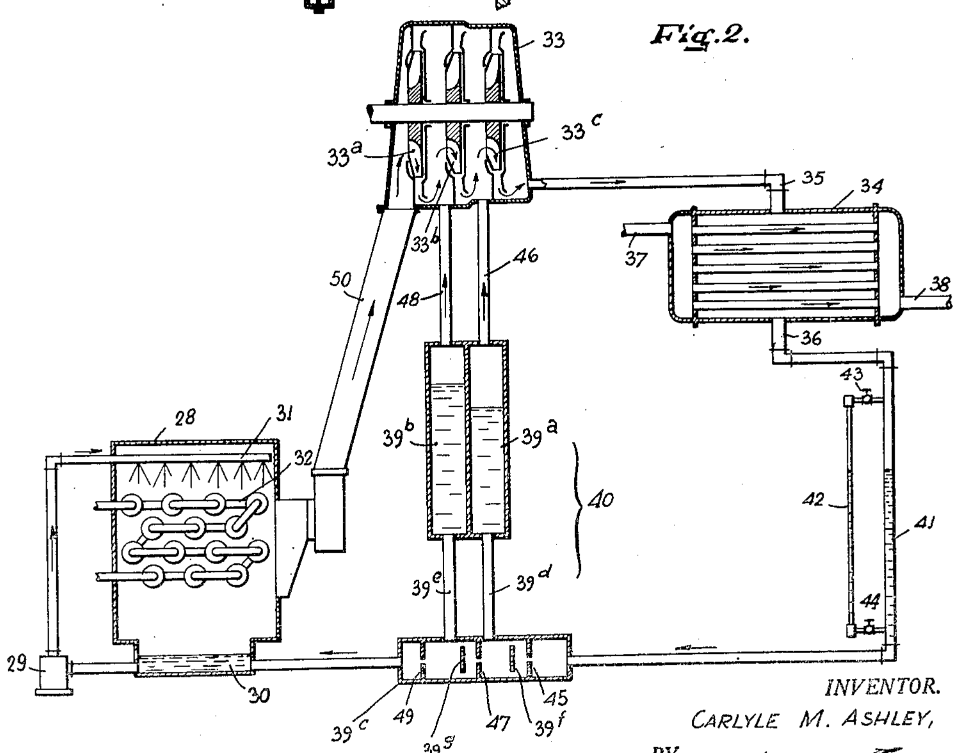

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Fig. 3.

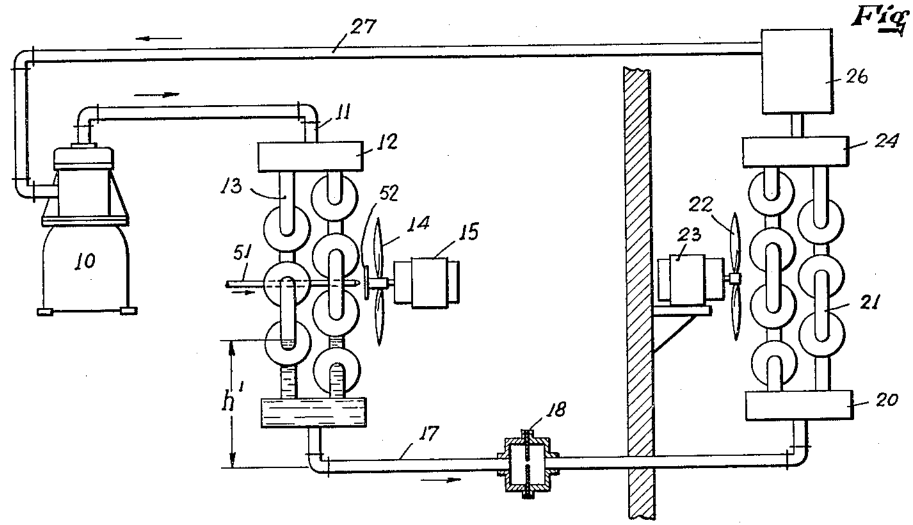
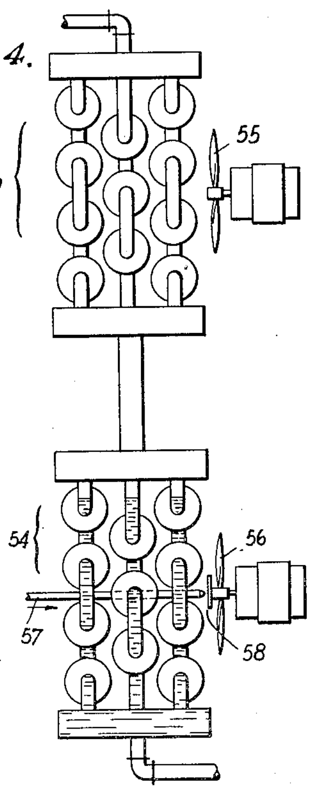


Fig. 4.



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UNITED STATES PATENT OFFICE

2,164,761

REFRIGERATING APPARATUS AND METHOD

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Application July 30, 1935, Serial No. 33,808

5 Claims. (Cl. 62—115)

This invention relates to mechanical refrigeration systems of the vapor process type.

The general object of the invention is to provide a new and improved system of the vapor process type which is simple, efficient and inexpensive.

A refrigerating system, in general, includes three essential elements, namely, an evaporator, a compressor and a condenser. In operation, heat is abstracted from a medium in contact with the evaporator by vaporization of a volatile refrigerant contained therein. The resultant vapor it withdrawn from the evaporator, compressed, and discharged within the condenser. The hot compressed vapor is liquefied by the dissipation of its heat to a medium in heat exchange relation with the condenser. Briefly, heat is absorbed from one medium at a low temperature and dissipated to another medium at a higher temperature. Either water, air or a combination of the two may be utilized as the medium to which the heat given up in condensation is transferred. The refrigerant, of course, is used over and over again.

Since the temperature of the condenser is substantially higher than that of the evaporator, it is apparent that a reduction in the temperature of the refrigerant must take place. This cooling may be effected by evaporation or flashing of the refrigerant. Flashing occurs when a volatile substance passes through an orifice into a region of pressure below the boiling pressure corresponding to the temperature of a volatile substance, and is the vaporizing of part of the substance to cool the remainder.

Generally, flashing is objectionable, for while it effects a desirable end in cooling the remainder of the refrigerant, yet that part of the refrigerant which has flashed has absorbed its latent heat from the remainder of the refrigerant and cannot absorb its latent heat from the medium to be cooled. Thus, there is a loss of useful refrigeration.

Applicant, in copending application, Serial No. 33,807, filed July 30, 1935, has disclosed a method of and means for greatly reducing the amount of flashing needed in a refrigerating system by subcooling the liquid refrigerant, prior to its entry into the evaporator, thus increasing the efficiency and capacity of the system. Ordinarily, however, subcooling may not economically be carried down to the evaporator temperature. Therefore, even though applicant's subcooling process be employed, some flashing will generally be required to reduce the temperature of the refrigerant to that prevailing in the evaporator.

It is an object of the invention to control the required flashing in a refrigeration system employing a fixed orifice to effect regulation of the system, i. e., to supply to the evaporator liquid refrigerant at rates varying with changes in heat load on the system.

When a volatile refrigerant is passed through a fixed orifice, an increase in the refrigerant velocity tends to cause an increase in the rate at which liquid refrigerant is delivered from the orifice. However, the increase in the velocity through the orifice tends also to increase the volume of flash vapors which are formed in the vicinity of the orifice, and which restrict the passage of liquid refrigerant therethrough. As the velocity of the refrigerant through the orifice is increased, the rate at which liquid refrigerant is delivered from the orifice increases until the velocity reaches a point known as the critical velocity. As the velocity increases beyond this point, the rate at which liquid refrigerant is delivered from the orifice falls off, due to the increase in the formation of flash vapors restricting the orifice. Since the rate of delivery of liquid refrigerant from an orifice is controlled by the restricting effect of flash vapors, and since flashing is dependent upon the temperature and pressure of the refrigerant, it follows that by controlling the temperature of refrigerant supplied to an orifice and/or by controlling the pressure of refrigerant at the orifice, the rate at which liquid refrigerant will be discharged therefrom may be controlled.

It is an object of the invention to control the rate of discharge of liquid refrigerant from a fixed orifice serving an evaporator by regulating the temperature and/or pressure of the liquid refrigerant supplied to the orifice responsive to variations in heat load on the evaporator.

When volatile refrigerant is passed through an orifice and the pressure drops to such a point that flashing just begins, a further decrease in pressure will not substantially increase the rate at which the orifice will discharge liquid refrigerant, since the flash vapors will restrict the passage thereof. It will be seen, therefore, that by controlling the factors which determine when flashing begins to occur, it is possible to control the rate at which liquid refrigerant will be delivered from the orifice.

In the present invention, applicant provides a refrigeration system utilizing an orifice of fixed opening. The fixed orifice supplies liquid refrigerant to an evaporator at a rate which varies in accordance with the load on the system. This regulation is effected in either or both of two ways: first, by controlling the temperature of refrigerant supplied to the orifice, and second, by controlling the pressure of the refrigerant at the orifice.

By carrying the liquid receiver on the low pressure side of the system, between the evaporator and the compressor, applicant accumulates on the high pressure side of the fixed orifice a quantity of refrigerant liquid which varies with the load on the system. If the evaporator is of the flash type, an increase in load causes an increase in the superheat of refrigerant vapors passing from the evaporator. This increase in the superheat causes increased vaporization of refrigerant in the liquid receiver, so that an augmented volume of refrigerant vapor passes to the condenser and is there liquefied. The vaporization of liquid in the receiver is further increased, with a rise in heat load, by a change in the heat transmission between the receiver and the evaporator. Moreover, a rise in heat load tends to increase the entrainment of liquid refrigerant from the receiver. With a decrease in heat load, a reverse operation occurs.

If the evaporator is of the flooded type, no liquid receiver at the outlet of the evaporator is required. When an increase of load on a flooded evaporator occurs, the increase is taken up by the vaporization of a greater quantity of refrigerant, the vapors, when condensed, forming a greater accumulation of refrigerant liquid on the high pressure side of the orifice. A decrease in heat load will similarly cause a reduction in the quantity of refrigerant liquid accumulated on the high pressure side of the orifice.

The accumulated liquid is subcooled prior to its admission to the evaporator through the orifice, or is used to build up a hydrostatic pressure on the orifice, or is used in both of these ways in combination. With an increase in heat load on the system, there will be an increase in the subcooling and/or hydrostatic pressure effects, providing for delivery to the evaporator of liquid refrigerant at an increased rate to meet the increase in heat load. As the load on the system decreases, and the quantity of refrigerant liquid accumulated on the condenser side of the fixed orifice decreases, the subcooling and/or hydrostatic pressure effects will decrease, and flashing will have a greater effect in restricting the flow of refrigerant liquid through the orifice, so that the rate at which refrigerant liquid will be delivered to the evaporator will be decreased.

For purposes of illustration, let it be assumed that the refrigerant employed is methyl chloride, and that the temperature of the boiling liquid refrigerant is 108.5 degrees. The pressure at the surface of the accumulated condensate will be 120 pounds. If the condensate be accumulated to such a vertical height that it develops a hydrostatic pressure of 20 pounds, the pressure on the orifice will be 140 pounds, or 20 pounds above the pressure at which methyl chloride at 108.5 degrees will begin to flash. Methyl chloride supplied to the orifice at 108.5 degrees and at 140 pounds pressure will pass through the orifice a distance corresponding to a pressure drop of 20 pounds before it will begin to flash, whereas if it were supplied to the orifice at the same temperature and at a pressure of 120 pounds, flashing would begin immediately. Thus, delaying the flashing has the effect of causing it to occur at a point beyond the restricted portion of the orifice. The flash vapors are then less effective in impeding the flow of liquid refrigerant through the orifice, and the liquid refrigerant is passed through the orifice at a greater rate. If the load on the system increases, the greater accumulation of condensate will develop a greater hydrostatic head on the orifice. Let it be assumed, as above, that the temperature of the boiling refrigerant is 108.5 degrees, that the pressure at the surface of the accumulated condensate is 120 pounds, and that the hydrostatic head developed is 30 pounds. Then the pressure on the orifice will be 150 pounds. Liquid refrigerant supplied to the orifice under these conditions will pass through a distance corresponding to a pressure drop of 30 pounds before flashing begins to occur, so that flashing begins at a point still further removed from the restricted portion of the orifice than in the former case. The flash vapors are then less effective than in the former case in impeding the flow of liquid refrigerant through the orifice, and the liquid refrigerant will be passed through the orifice at a greater rate to take care of the increase in load.

When regulation is effected by subcooling, the operation is similar. Instead of building up in a vertical column or the like, however, the condensate is accumulated in a heat exchange device. As the accumulation of liquid refrigerant increases, it is subjected to increased cooling action of the cooling medium in the heat exchange device. With an increase of load, therefore, there is an increase in the accumulation of liquid refrigerant within the heat exchange device, and a decrease in the temperature of the liquid refrigerant. A decrease in load will similarly effect a rise in the temperature of refrigerant supplied to the orifice.

That the temperature of the refrigerant controls the flow of liquid refrigerant through the orifice will appear from the following example. Let us assume, as above, that the temperature of boiling methyl chloride is 108.5 degrees, at a pressure of 120 pounds. Assume, further, that this refrigerant is accumulated within a heat exchange device to such a height that its temperature is lowered to 97.5 degrees, and that it is then delivered to an orifice at that reduced temperature and at a pressure of 120 pounds. The boiling pressure corresponding to a temperature of 97.5 degrees is 100 pounds. The liquid refrigerant passing through the orifice will not begin to flash, therefore, until it has passed through a distance corresponding to a pressure drop of 20 pounds. Thus the rate at which the liquid refrigerant is passed through a fixed orifice may be increased to the same degree by cooling the refrigerant 11 degrees or by building up a hydrostatic pressure of 20 pounds on the orifice, as described above.

With an increase in load, the liquid refrigerant may be accumulated in the heat exchange device to such a height that the refrigerant passing therefrom is at a temperature of 91.5 degrees. The boiling pressure corresponding to a temperature of 91.5 degrees is 90 pounds. Therefore, when liquid refrigerant is supplied to the orifice at 120 pounds pressure and at 91.5 degrees, flashing will not begin until the liquid refrigerant has passed through a distance corresponding to a pressure drop of 30 pounds. In such case, the orifice will deliver liquid refrigerant at a greater rate than when the refrigerant is cooled to 97.5 degrees, thus to meet the increased load requirements. Cooling the liquid refrigerant 17 degrees has the same effect on the regulation of the system as building up a hydrostatic pressure of 30 pounds on the orifice.

In addition to the action just described, it is to be noted that when gravity head regulation is used, an increase in load which causes an increased pressure on the orifice, tends to cause the discharge of refrigerant liquid from the orifice at an increased rate, in accordance with the formula $v^2=2gh$. When subcooling is used, an increase in load, which increases the subcooling, is accompanied by a decrease in the flashing required for each unit volume of refrigerant supplied to the orifice.

A feature of the invention resides in the provision of an orifice of predetermined fixed opening for supplying refrigerant to an evaporator.

Another feature of the invention resides in the provision of a refrigeration system including a compressor, a condenser, a pressure chamber, a fixed orifice, an evaporator and a liquid receiver, through which refrigerant successively passes.

Another feature of the invention resides in the provision of a refrigeration system including a compressor, a condenser, a subcooler, a fixed orifice, an evaporator and a liquid receiver, through which refrigerant successively passes.

Another feature of the invention resides in developing pressure on an orifice by means of a head of volatile refrigerant liquid to control the rate at which refrigerant liquid is discharged from the orifice.

Another feature of the invention resides in cooling the refrigerant supplied to a fixed orifice serving an evaporator to control the rate at which liquid refrigerant is passed to the evaporator from the orifice.

Another feature of the invention resides in the provision of a series of gravity chambers, interconnected by orifices, from each of which chambers refrigerant vapors may be returned to a compressor in a course bypassing an evaporator.

Another feature of the invention resides in the provision of means for passing refrigerant through a plurality of orifices, and passing refrigerant vapors formed at each orifice to different stages of a multi-staged compressing apparatus.

Other objects, features and advantages of the invention will appear from the following description to be read in connection with the accompanying drawings, in which:

Fig. 1 is a diagrammatic view, in elevation, of a refrigerating system embodying applicant's invention;

Fig. 2 is an elevational view illustrating the application of the invention to a refrigerating system including a multi-stage centrifugal compressor and an economizer;

Fig. 3 is a diagrammatic view of another form of the invention; and

Fig. 4 represents a sectionalized condenser and subcooling apparatus, to be used in the circuit of Fig. 3.

Referring now to the drawings, hot compressed vapor leaves compressor **10** through pipe **11** and is admitted through inlet header **12** to the condenser coils **13**, where it is condensed. As illustrated, the condenser is cooled by air currents set up by fan **14**, driven by motor **15**, which is supplied with electric current from any suitable source. Refrigerant liquid leaves the condenser through outlet header **16** and enters pipe **17**. The function of this pipe is to provide a reservoir for the accumulation of a vertical column of refrigerant liquid. This column is of such height that the hydrostatic pressure at the bottom of the pipe **17** will be considerable. Thus, the cross-sectional area of pipe **17** need not be greater than would ordinarily be required to accommodate refrigerant flow, but the vertical height of the pipe is greater than it would be in conventional installations. The refrigerant is then fed through orifice **18**, adjusted to a fixed predetermined opening, through pipe **19**, and through inlet header **20** to the evaporator coils **21**, where it absorbs heat from the medium to be cooled. As illustrated, the refrigerant absorbs heat from air currents set up by fan **22**, driven by motor **23**. The refrigerant is then passed through outlet header **24** and pipe **25** to the liquid receiver **26**, where the refrigerant vapors are separated from any liquid which may have remained unevaporated in passing through the expansion coils **21**. The vapor is then returned, through pipe **27**, to the compressor, completing the refrigerating cycle.

In this system, the condenser pressure is augmented by the hydrostatic pressure developed by the column of liquid refrigerant, so that the total head on the orifice is the sum of the two component pressures. The increase in pressure due to hydrostatic head is accomplished with practically no increase in the power consumption of the system. As above explained, this increase in pressure is effective to reduce the restricting effect of flashing which takes place at and in the immediate vicinity of the orifice, and to increase the rate at which liquid refrigerant is delivered from the orifice. When the load on the evaporator decreases, the height of the column of liquid refrigerant is reduced, the pressure on the orifice is reduced, and the rate at which the liquid refrigerant is delivered from the orifice is decreased.

In refrigeration systems employing ammonia, carbon dioxide or similar refrigerants, working pressures on the high side of the compressor may range from 180 to 1400 pounds per square inch. To add appreciably to these pressures by means of a gravity head would necessitate the use of unreasonably high columns of refrigerant. However, in systems using Carrene, Dielene or similar refrigerants, applicant's invention may be employed to advantage, since the working pressures in such systems approximate or are below atmospheric pressure. A column of liquid, therefore, of not unreasonable height, adds appreciably to the condenser pressure.

Carrene and similar refrigerants which operate at pressures of approximately one atmosphere or less, are most commonly used in systems including centrifugal compressors. Fig. 2 illustrates the manner in which the invention may be utilized in a centrifugal compression system embracing a multi-stage compressor. **28** designates an evaporator, in which refrigerant liquid is supplied by pump **29** from sump **30** to sprays **31** for distribution over coils **32**, through which is circulated the medium to be cooled. **33** designates a multi-stage centrifugal compressor. **34** designates a condenser of the shell and tube type, having a refrigerant inlet **35**, a refrigerant outlet **36**, an inlet header **37**, and an outlet header **38** for a suitable cooling medium. **39a** and **39b** are chambers connected to an orifice chamber **39c** by conduits **39d** and **39e** to form an economizer generally designated at **40**. The function of the economizer is to reduce the power requirements of the system by permitting the necessary flashing of refrigerant to take place in stages. Flash vapors from all stages but the last, are taken off and by-passed around the evaporator to suitable stages of the compressor.

In operation, liquid refrigerant from the condenser **34** is accumulated in pipe **41** to a height indicated by gauge glass **42**, which is preferably provided with stop cocks **43** and **44**. The height of the column indicates the load on the machine. As the refrigerant passes through orifice **45**, a certain amount of flashing occurs, cooling the liquid refrigerant. The resultant vapors rise to the top of chamber **39***a*, whence they are drawn off through pipe **46**. Unevaporated refrigerant accumulates in chamber **39***a* and conduit **39***d*, building up a hydrostatic head on orifice **47**. As refrigerant flows through orifice **47**, a certain amount of flashing again occurs, cooling the liquid refrigerant still more. As in the case of chamber **39***a*, flash vapors rise to the top of chamber **39***b*, whence they are drawn off through pipe **48**. Cooled liquid refrigerant in chamber **39***b* and conduit **39***e* builds up a hydrostatic head on orifice **49** through which it then passes to evaporator **28**. Baffles **39***f* and **39***g* prevent refrigerant from "blowing through" chamber **39***c*. Refrigerant vapors pass through passage **50** to the compressor **33**, where in successive stages **33***a*, **33***b*, and **33***c* they are compressed, in a manner well known in the art. Pipe **46** is connected to the inlet of stage **33***c*, and pipe **48** is connected to the inlet of stage **33***b*. In practice, the apparatus is so designed that pipe **46** passes refrigerant vapor at a pressure corresponding to the inlet pressure of stage **33***c*, and pipe **48** passes refrigerant at a pressure corresponding to the inlet pressure of stage **33***b*. Thus, refrigerant which has been vaporized is returned to appropriate stages of the compressor without passing through the evaporator where it can do no useful refrigerating work. Since the vapor returned through pipe **46** is at a pressure substantially equal to that prevailing at the outlet of stage **33***b*, it is apparent that there is no necessity for passing it through compressor stages **33***a* and **33***b*. Moreover, routing the flash vapors from chamber **39***a* directly to stage **33***c* through pipe **46** saves the amount of power that would be consumed in passing those vapors needlessly through compressor stages **33***a* and **33***b*. Similarly, the routing of flash vapors from chamber **39***b* directly to stage **33***b* through pipe **48** saves the amount of power that would be consumed in passing those vapors needlessly through compressor stage **33***a*. In applying the invention, pipe **41**, chambers **39***a* and **39***b*, and conduits **39***d* and **39***e* are preferably of such proportions that the liquid accumulated within them will develop a substantial hydrostatic head. While a three-stage compressor is illustrated, it is contemplated that the invention may be applied to a compressor of any number of stages; and while a centrifugal compressor is shown, it is apparent that compression may take place in a compressor of any desired type or construction, without departing from the spirit and scope of this invention.

In the arrangement of Fig. 3, the liquid refrigerant is accumulated within the condenser of the system, which is provided with an extra length of cooling coils. Liquid accumulated within the condenser is subcooled by the action of the condensing medium, the subcooling effect increasing as the accumulation of liquid within the condenser increases. In Fig. 3, condensed refrigerant is evaporatively subcooled by air currents set up by fan **14** and water from pipe **51**, which is discharged against target **52** to form a fine spray. If desired, of course, the condenser and subcooling unit may be sectionalized. Thus, for the condenser of Fig. 3, there may be substituted the separate units of Fig. 4, in which **53** is the condenser proper, in which liquefaction takes place, and **54** is the subcooler, in which refrigerant liquid is accumulated and cooled. Air cooling or evaporative cooling may be utilized as desired. As illustrated, the condenser proper is air cooled by fan **55**, while the subcooling section of the condenser is evaporatively cooled by fan **56** and water discharged from pipe **57** against target **58**.

If desired, regulation may be accomplished by both subcooling and developing a hydrostatic head on the orifice, in combination, by providing both a column and a subcooler. It is to be understood, however, that even when such operation is not contemplated, the subcooling and pressure head are not independent of each other, but mutually contribute at all times to the regulation of the system. Thus, when a column of liquid refrigerant is accumulated to develop a gravity head, the liquid refrigerant will generally be cooled somewhat before it passes through the orifice, so that there is effected a certain amount of subcooling. The subcooling effect will increase with increases in the height of the column, and will decrease when the height of the column is reduced. So, also, when the liquid is accumulated in a heat exchange device for subcooling purposes, it develops a head on the orifice which varies directly with the height of the liquid in the heat exchange device.

In the following claims, the term "subcooling" shall be understood to mean cooling the refrigerant liquid below the critical condensing temperature in any manner other than by flashing prior to its admission to the evaporator. The term "subcooler" shall be understood to relate to a heat exchange device in which refrigerant liquid is subcooled prior to its admission to the evaporator.

The term "pressure chamber" shall be understood to mean any device in which refrigerant liquid is confined for the purpose of developing hydrostatic pressure.

I claim:

1. A method of regulating a refrigeration system including a condenser, an evaporator and a plurality of fixed orifices which consists in condensing refrigerant, evaporating the liquid refrigerant in a plurality of successive steps at different pressures, accumulating liquid refrigerant to develop a hydrostatic pressure on each of the orifices, increasing the accumulation of refrigerant in response to increases in heat load on the evaporator, and decreasing the accumulation of refrigerant in response to decreases in heat load on the evaporator.

2. In a refrigerating apparatus of the character described, a condenser, a pressure chamber, means forming a fixed orifice, an evaporator, a liquid receiver in which the pressure is substantially equal to that prevailing in the evaporator, and means for circulating refrigerant successively through said elements in a closed and continuous cycle, whereby condensed refrigerant will accumulate within said pressure chamber and exert a hydrostatic pressure on said orifice, the hydrostatic pressure increasing in response to increases in heat load on the evaporator and de-

creasing in response to decreases in heat load on the evaporator.

3. In a refrigerating system, means for condensing refrigerant, means for accumulating the condensed liquid refrigerant, means forming an orifice of predetermined opening adapted to receive refrigerant liquid from said accumulating means, an evaporator adapted to receive refrigerant passing through said orifice from said accumulating means, a liquid receiver connected to the outlet side of said evaporator and in which the pressure is substantially equal to the evaporator pressure, all of said elements comprising parts of a closed and continuous circuit, and fluid-displacement means for circulating refrigerant through said elements in succession.

4. In a refrigerating system, means for increasing the pressure of refrigerant vapors in a plurality of stages, means for condensing compressed refrigerant, means including a plurality of expansion devices each having a fixed orifice for evaporating liquid refrigerant in a plurality of stages at successively lower pressures, means for accumulating a quantity of liquid refrigerant for developing substantial hydrostatic pressures on said orifices in response to relatively high heat load on the system and for accumulating a relatively smaller quantity of liquid for developing relatively small hydrostatic pressures on said orifices in response to relatively low heat load on the system, and means for passing refrigerant vapors from different evaporator stages to different compressor stages in unmixed condition in such manner that the pressure of refrigerant vapor passed to each compressor stage approximates the inlet pressure of said compressor stage.

5. In a refrigerating system, means for condensing refrigerant, means for accumulating the condensed liquid refrigerant, means forming an orifice of predetermined opening adapted to receive refrigerant liquid from said accumulating means, an evaporator adapted to receive refrigerant passing through said orifice from said accumulating means, a liquid receiver connected to the outlet side of said evaporator and in which the pressure is substantially equal to the evaporator pressure, all of said elements comprising parts of a closed and continuous circuit, fluid-displacement means for circulating refrigerant through the above mentioned elements in succession, and means for subcooling the accumulated refrigerant.

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