This specification discloses the method and apparatus for operating a refrigeration system in both powered and nonpowered (free cooling) modes of operation including the method and apparatus for rapidly converting from one mode to the other.
REFRIGERATION APPARATUS AND METHOD OF OPERATING FOR POWERED AND NON-POWERED COOLING MODES

BACKGROUND OF THE INVENTION

During certain seasons when the cooling load is relatively small such as less than 40 percent peak load and if the heat sink is sufficiently cool, it is possible to operate compressor type refrigeration systems, such as for cooling a building, without energizing the compressor. Refrigerant vapor is simply conveyed without compression to a condenser which is maintained at a lower temperature than the evaporator. The condensed refrigerant flows back to the evaporator to again be re-evaporated by the heat from the building conveyed thereto such as by the building chilled water system. The mode of operation is conducted without operation of the compressor, hence its name "free cooling."

In order that the free cooling mode can be operated with a high degree of capacity, it has been found necessary to provide a bypass around the compressor to permit vapor from the evaporator to pass without much restriction to the condenser and to provide a bypass around control devices to permit free flow of liquid from the condenser to the evaporator. Further it has been found necessary to provide special means of more fully wetting the tubes in the evaporator with refrigerant to increase the evaporator capacity. This is so because refrigeration systems are ordinarily charged with a minimum of refrigerant sufficient only to wet all of the evaporator tubes during full load conditions. Because of the violent boiling of the refrigerant under these conditions and the presence of flash gas entering the evaporator, the equivalent quiescent refrigerant level is ordinarily maintained substantially below the top of the tube bundle in the evaporator. For purposes of this disclosure "equivalent quiescent level" is intended to mean the level of refrigerant in the evaporator if suddenly all boiling were to cease without any further ingress or egress of refrigerant to or from the evaporator.

Thus when first attempts were made to operate ordinary refrigeration systems in a free cooling mode, it was found that the evaporator capacity was excessively low due to the lack of refrigerant liquid on the middle and upper rows of tubes.

Several schemes to remedy this problem have been suggested. One scheme that utilizes a refrigerant liquid pump to spray refrigerant liquid over the evaporator tubes is described in U.S. Pat. No. 2,718,766.

Another scheme adds refrigerant from the free cooling mode to immerse all of the tubes of the evaporator and is illustrated in U.S. Pat. No. 3,191,396. In this latter patent a special chamber is provided for storing the additional refrigerant. This chamber is located below the upper most tubes of the evaporator and is filled with refrigerant liquid from the evaporator by venting the special chamber with the evaporator until substantially a common level is reached in the evaporator and special chamber. Only after this level is reached are the chamber liquid line and vent valves closed and the compressor allowed to start for a powered mode of operation. Thus considerable time may be consumed to pass from a free cooling mode to a powered mode of operation.

Likewise considerable time may be consumed to prepare the system for free cooling. A small heater is provided in the special chamber to heat the refrigerant. Only after the refrigerant has reached a certain pressure would refrigerant be forced to higher levels in the evaporator.

SUMMARY OF THE INVENTION

This invention is distinct from the aforementioned prior art as it does not utilize the time consuming means of pressurizing the refrigerant to obtain transfer of the added refrigerant to the evaporator. Furthermore means are provided for resuming normal operation of the compressor immediately upon switching from a free cooling mode of operation to the powered mode of operation.

The first of these distinctive features is accomplished by allowing a predetermined additional liquid refrigerant to flow by gravity to the evaporator without the necessity of pressurizing any liquid refrigerant.

The second mentioned of these distinctive features is accomplished by utilizing the compressor under power to transfer refrigerant from the evaporator to an area where it may be retained out of the evaporator zone.

This invention thus provides a method of operating a refrigeration system which may be converted from a free cooling mode to a powered mode of operation and vice versa without undue delay between the modes of operation.

More specifically this invention provides a method of operating a refrigeration system including a compressor, a condenser, and a shell-and-tube type evaporator arranged respectively in a closed refrigerant circuit and a storage chamber outside said closed refrigerant circuit for storing above the tubes of said evaporator during operation of said compressor an additional quantity of liquid refrigerant sufficient to immerse substantially all of the tubes in said evaporator when said system is operated on a free cooling mode without operation of said compressor comprising the steps of: preparing said system for operation on a free cooling mode by: venting vapor from said evaporator to said storage chamber, passing by force of gravity the additional liquid refrigerant from said storage chamber into said evaporator to immerse substantially all of the tubes therein, and providing said refrigeration system with a vapor bypass from said evaporator to said condenser; subsequently operating said refrigeration system on a free cooling mode by, bypassing refrigerant vapor from said evaporator around said compressor to said condenser without operating said compressor, returning refrigerant thereby condensed from said condenser to said evaporator for re-evaporation in said evaporator, and retaining the additional quantity of refrigerant in said evaporator sufficient to immerse substantially all of the tubes in said evaporator; passing from the free cooling mode of operation to the powered mode of operation by, energizing said compressor, passing compressed refrigerant vapor through said compressor to said condenser, and removing from said closed refrigerant circuit a quantity of condensed refrigerant equal to said additional quantity by passing substantially said quantity of condensed refrigerant into said storage chamber to thereby reduce the equivalent quiescent level of refrigerant in said evaporator substantially below the upper tubes of said evaporator to a substantially reduced level during operation of said compressor; continuing to operate said system by, continuing energization of said compressor,
continuing to withhold from said closed refrigerant circuit in said storage chamber during continued energization of said compressor substantially said additional quantity of refrigerant. Further, this invention provides refrigerant apparatus comprising a shell-and-tube type refrigerant evaporator; a refrigerant compressor and a refrigerant condenser serially connected in a closed refrigerant circuit; said refrigerant compressor having a suction inlet connected to the shell side of said evaporator and a discharge outlet connected to said condenser; said circuit including first conduit means for conveying liquid refrigerant from said condenser to said evaporator during operation of said compressor; and means for controlling the flow of liquid refrigerant in said conduit means; second conduit means extending from the shell of said evaporator to said condenser bypassing said compressor for conveying refrigerant vapor from said evaporator to said condenser; a shut off valve disposed in said conduit means; a storage chamber disposed to store liquid refrigerant above the uppermost tubes of said evaporator; a second conduit means connecting said storage chamber and said evaporator; and a storage chamber to said evaporator in preparation for operation of said refrigeration apparatus without operation of said condenser; and a shut off valve disposed in said second conduit means for holding liquid refrigerant in said storage chamber during operation of said compressor.

Other aspects and advantages will be apparent as the specification proceeds to describe the invention in detail with reference to the drawings in which like reference characters are used to designate like elements through wherein:

FIG. 1 is a semi-schematic of a refrigeration machine constructed and adapted to perform the method of operating a refrigeration system in accordance with the methods of this invention.

FIG. 2 is a simplified schematic electric diagram for the machine shown in FIG. 1 and FIG. 3 is a modification of the schematic of FIG. 2 whereby the operating modes may be made completely automatic.

FIG. 4 is a modification of the refrigeration machine shown in FIG. 1.

FIG. 5 is another modification of the refrigeration machine shown in FIG. 1.

Now with reference to the refrigeration machine shown in FIG. 1 it will be seen that the refrigeration system includes a refrigerant evaporator 12, a refrigerant compressor 14, and a refrigerant condenser 16. The evaporator 12 is of the flooded shell-and-tube type having a bundle of horizontal tubes 18 through the interior of which water warmed by a load, such as a building, is conducted via inlet and outlet header connections 20 and 22 respectively to boil refrigerant within the evaporator shell. The refrigerant vapor is conducted to the compressor 14 via an inlet conduit 24. The compressor 14 is shown to designate a two stage compressor although aspects of the instant invention are equally applicable to single stage compressor refrigeration systems. The inlets of one or both stages are provided with inlet vanes for controllably throttling the flow of refrigerant to the compressor. It is common practice to control such inlet vanes in response to the temperature of water leaving the evaporator for the building such as near outlet 22. As the water temperature rises, the vanes are opened to thereby load the compressor. Such inlet vanes 26 have been placed in the inlet conduit 24 for purposes of illustration, it being understood that such vanes are generally located with the confines of the compressor shell per se. The compressor input shaft is connected to a drive motor which may be an electric motor, steam turbine or other form of prime mover 28. If electric, motor 28 could also be confined within the compressor shell to thereby make the compressor hermetic.

The vapor discharged from the compressor is conducted via compressor outlet conduit 30 to the condenser 16 which may be also of the shell-and-tube type wherein cooling water such as from a cooling tower is passed through the tubes via cooling water inlet and outlet header connections 32 and 34 respectively.

Refrigerant condensed at the outer surface of the tubes flows during the powered mode of operation from the condenser shell downwardly through a stand pipe 36 through a first flow control device 38 which may take the form of a fixed orifice flow control valve, such as 38 described in U.S. Pat. No. 3,260,676 assigned to the assignee of this invention, or the form of a more conventional variable orifice float valve. The refrigerant then passes from the valve 38 through a conduit 40 to an economizer flash chamber 42. The flash gas from the economizer 42 is conducted via conduit 44 to inlet of the second stage of compressor 14 for recompression. The liquid refrigerant from the economizer is conducted to a second stand pipe 46 which leads to a second flow control device 48, which may be similar to flow control device 38, from whence the refrigerant is conducted via conduit 50 to be distributed into the evaporator shell. The operation and advantages of an economizer are well known and for the sake of brevity will not be further discussed here.

For purposes of carrying out the preferred embodiment of the instant invention, a chamber 52 is located above evaporator 12. Chamber 52 is used as a means for storing a predetermined additional amount of liquid refrigerant and thus preventing this additional quantity of refrigerant from returning to the evaporator when the system is operated in the powered mode. A conduit 56 connects the bottom of stand pipe 36 to the bottom of chamber 52. Thus during the powered mode of operation, some liquid passing in stand pipe 36 will also pass through conduit 56 into chamber 52. So that the chamber 52 may be substantially filled with refrigerant liquid, it is provided with a vapor vent 58 which extends between the upper portion of chamber 52 via restriction or orifice 60 to conduit 40. When chamber 52 is filled with refrigerant liquid, orifice 60 operates to limit the flow of liquid through chamber 52. Flow control device 38 is sized to compensate for the flow through orifice 60.

The elevation of chamber 52 above the evaporator is limited only by the pressure differential between its liquid supply and return vent. It will also be evident that the chamber 52 may be vented to evaporator pressure through a vent 58a and orifice 60a shown in FIGS. 4 and 5 in which case the liquid supply may be either from the condenser as shown in FIG. 4 or from the economizer zone as shown in FIG. 5 by line 56a. It is thus the pressure differential within the system when operated on the power mode that causes chamber 52 to be filled with liquid refrigerant.
For purposes of carrying out the free cooling mode of operation in accordance with the methods of this invention, the bottom of stand pipe 36 is connected via an automatically powered normally closed shutoff valve 62 and conduit 57 to conduit 50. Furthermore, there is provided a compressor valve bypass conduit 66 extending between upper portions of the shells of condenser 16 and evaporator 12 adjacent ends thereof remote from the heretofore mentioned conduits 24 and 30. Conduit 66 is also provided with an automatically powered normally closed shutoff valve 67.

The method of operating the above described refrigeration system may best be understood by referring further to the schematic diagram of FIG. 2. For purposes of this description let it be assumed that the system had previously been operating with power and that chamber 52 accordingly is substantially full of liquid refrigerant and that the quiescent level of liquid refrigerant in the evaporator is correspondingly reduced by the predetermined quantity of refrigerant retained in chamber 52. Further let it be assumed that conditions are such that the free cooling mode of operation is preferred, i.e., the load is less than about 40% of full load and that the temperature of cooling water entering condenser 16 at 32 is sufficiently below the desired temperature for the water leaving evaporator 12 at outlet 22.

The system is set into the free cooling mode of operation simply by moving switch 68 into the solid line position to complete a circuit from line 1 to line 2 including switch 68, the actuator of valve 62 and the actuator of valve 64 whereby valves 62 and 64 are powered to the fully open positions. A second circuit is also completed which includes switch 68, normally closed contact 69, and actuator control 72 for inlet vanes 26.

The opening of valve 62 in FIGS. 1 and 4 permits substantially all the liquid refrigerant retained in chamber 52 to be immediately dumped into the evaporator 12 thereby raising the liquid refrigerant therein to a high level 78 to immerse substantially all the tubes of the evaporator. If sufficient time has lapsed from the end of the power mode, the liquid refrigerant will have already drained to the evaporator via conduit 56a in FIG. 5 and conduit 40, economizer 42 in FIGS. 1 and 4, stand pipe 46, orifice 48 and conduit 50. The opening of valve 64 permits refrigerant vapor to be drawn freely from evaporator 12 to condenser 16 whereupon it is condensed and returned via stand pipe 26, valve 62, conduit 57, and conduit 50 to evaporator 12. A secondary path for passage of refrigerant vapor from condenser 12 to evaporator 16 also is provided by conduit 24, compressor 14 and conduit 30. It should be reiterated that during this mode of operation compressor 14 is not operated, however the compressor does not block the free flow of refrigerant therethrough. Upon the aforementioned energization of actuator 72, vanes 26 are actuated from a preset minimum opening to the fully open position.

Should the load exceed the capacity of the system as operated on the free cooling mode, switch 68 may be instantaneously placed in the dot-dash line position of FIG. 2 whereby valves 62, 64 are immediately closed and vanes 26 returned to a minimum opening position. Furthermore a first circuit is immediately energized including switch 68, and contactor coil 80 whereupon contacts 82 are immediately closed to energize a second circuit including switch 68, contacts 82 and compressor motor 28. A third circuit is established including switch 68, rheostat 84, contacts 85, and vane actuator 72 whereby vanes 26 are immediately moved to a second preselected minimum position at which excessive quantities of liquid refrigerant will not be drawn into the compressor inlet despite the high level of refrigerant in the evaporator. This minimum may be manually adjusted at rheostat 84. A fourth circuit is also established including switch 68 and coil 86 of snap-acting time delay relay 88.

Time delay relay 88 includes contacts 69 and 85 (previously mentioned) and contacts 90. The relay has two positions; a first position in which contacts 69 and 85 are closed and contacts 90 open; and a second position in which contacts 69 and 85 are open and contacts 90 closed. The relay is intended to be snap-acting, i.e., movement from one position to the other position is substantially instantaneous. However, the movement from the first position to the second position is not effected immediately upon energization of coil 86 as this movement is delayed for a predetermined time by action of single way dash pot 92. The time delay selected is the time that it takes to insure that the level of refrigerant in the evaporator has fallen to that at which no danger of excessive liquid refrigerant carryover into the compressor will take place. After this period of time contacts 85 are opened and contacts 90 closed thereby placing the control of the vanes upon bellows 74 whose sensor bulb 76 is located in outlet 22 to be responsive to the load. It should be appreciated that coils 80, 86, 62 and 64 are selected to have sufficiently high impedence whereby they have no substantial effect upon other parallel circuits.

Now considering the system operation upon moving switch 68 from the free cooling mode to the powered mode, the following events happen. Valves 62 and 64 are immediately closed. The compressor is immediately started. The vanes 26 immediately and temporarily assume a minimum open position whereby refrigerant gas is withdrawn from the evaporator, compressed and delivered to the condenser. The rate is limited to prevent liquid carryover. The condensed refrigerant passes down stand pipe 36 to chamber 52 (FIGS. 1 and 4). Some of the refrigerant passes through flow control 38 into flash chamber 42, the gaseous portion being returned to the second stage of the compressor and the liquid portion being delivered to the evaporator via flow control 48 for re-evaporation and to chamber 52 in FIG. 5 via conduit 56a. The pressure at the liquid supply line for chamber 52 permits chamber 52 to be substantially filled as the top of the chamber is vented through orifice 60 (60a in FIG. 4 and 60b in FIG. 5). Because this quantity of refrigerant retained in chamber 52 is not permitted to return to the evaporator during the powered mode, the equivalent quiescent refrigerant level in the evaporator is reduced to a lower level designated at 94.

After sufficient time has lapsed by action of dash-pot 92 to insure that the lower level has been reached so that no excessive liquid carryover to the compressor will take place, relay 88 is switched thereby placing vanes 26 at the control of load sensor 76. If at any time during the powered mode it is desired to switch to the free cooling mode, it is only necessary to place switch 68 in the solid line position and the free cooling mode aforesaid will be resumed.

Thus it will be seen that the method of operation permits the refrigeration system to be switched from the
free cooling mode to the powered mode or vice versa with only a single movement of switch 68. The reduction of evaporator refrigerant level is extremely fast as this is done with the assistance of the energized compressor. The returning of the additional refrigerant to the evaporator upon switching to the free cooling mode is also extremely fast as the additional refrigerant is literally dumped into the evaporator upon opening of valve 62. Because of this extremely rapid response, it is possible to completely automate the operative modes simply by automating switch 68. Thus in the modification shown in FIG. 3 switch 68A is an automatic version of switch 68 and is moved to the power modes position (dash-dot line) by energization of solenoid actuator 95 and to the free cooling position (solid line) by de-energization of actuator 95. Solenoid 95 is disposed in series with parallel switches 96 and 98. Switch 96 is actuated by a bellows and bulb sensor to close at a predetermined high temperature and is arranged to sense condenser inlet water temperature at 32. Switch 98 is actuated by a bellows and bulb sensor to close at a predetermined high temperature and is arranged to sense evaporator outlet water temperature at 22. Thus if either the condenser temperature is too high for free cooling as indicated by closure of switch 96 or the refrigeration load too great for free cooling as indicated by closure of switch 98, switch 68A will be positioned for the power mode. Only when the condenser water is sufficiently cool and the refrigeration load sufficiently light to permit free cooling will switch 68A be placed in the free cooling position.

It should be appreciated that the controls shown have been greatly simplified to clearly illustrate the invention. Obviously many variations can be made both to these controls and the apparatus without departing from the true spirit of the invention. I accordingly desire my invention to be limited only by the claims.

I claim:

1. A method of operating a refrigeration system including a compressor, a condenser, and a shell-and-tube type evaporator arranged respectively in a closed refrigerant circuit and having a liquid refrigerant storage chamber comprising the steps of:

A. operating said refrigeration system on a free cooling mode by:
   1. bypassing refrigerant vapor from said evaporator around said compressor to said condenser without operating said compressor,
   2. returning refrigerant thereby condensed from said condenser to said evaporator for re-evaporation in said evaporator, and
   3. retaining an additional quantity of liquid refrigerant in said evaporator sufficient to immerse substantially all the tubes in said evaporator;
B. passing from the free cooling mode of operation to the powered mode of operation by:
   1. energizing said compressor,
   2. passing compressed refrigerant vapor through said compressor to said condenser, and
   3. removing from said closed refrigerant circuit a quantity of condensed refrigerant equal to said additional quantity by passing substantially said quantity of condensed refrigerant into said storage chamber to thereby reduce the equivalent quiescent level of refrigerant in said evaporator substantially below the upper tubes of said evaporator to a substantially reduced level during operation of said compressor;

C. continuing to operate said system by:
   1. continuing energization of said compressor, and
   2. continuing to withhold from said closed refrigerant circuit in said storage chamber during continued energization of said compressor substantially said additional quantity of refrigerant.

2. The method as defined by claim 1 wherein the step B3 includes the step of passing said quantity of condensed refrigerant out of said closed refrigerant circuit by applying thereto a differential in pressure within said refrigerant circuit generated by said compressor.

3. The method as defined by claim 2 or operating a refrigeration system having an economizer wherein said quantity of condensed refrigerant is forced from said refrigerant circuit at substantially condenser pressure and simultaneously vented to a portion of said refrigerant circuit at substantially economizer pressure.

4. The method as defined by claim 2 wherein said quantity of condensed refrigerant is forced from said refrigerant circuit at substantially condenser pressure and simultaneously vented to a portion of said refrigerant circuit at substantially evaporator pressure.

5. The method as defined by claim 2 for operating a refrigeration system having an economizer wherein said quantity of condensed refrigerant is forced from said refrigerant circuit at substantially economizer pressure and simultaneously vented to a portion of said refrigerant circuit at substantially evaporator pressure.

6. A method of operating a refrigeration system including a compressor, a condenser, and a shell-and-tube type evaporator arranged respectively in a closed refrigerant circuit and a storage chamber outside said closed refrigerant circuit for storing above the tubes of said evaporator during operation of said compressor an additional quantity of liquid refrigerant sufficient to immerse substantially all of the tubes in said evaporator when said system is operated on a free cooling mode without operation of said compressor comprising the steps of:

A. preparing said system for operation on a free cooling mode by:
   1. venting vapor from said refrigerant circuit to said storage chamber,
   2. passing by force of gravity the additional liquid refrigerant from said storage chamber into said evaporator to immerse substantially all of the tubes therein, and
   3. providing said refrigeration system with a vapor bypass from said evaporator around said compressor to said condenser;

B. Subsequently operating said refrigeration system on a free cooling mode by:
   1. bypassing refrigerant vapor from said evaporator around said compressor to said condenser without operating said compressor,
   2. returning refrigerant thereby condensed from said condenser to said evaporator for re-evaporation in said evaporator, and
   3. retaining the additional quantity of refrigerant in said evaporator sufficient to immerse substantially all of the tubes in said evaporator.

7. The method of operating a refrigeration system as defined in claim 6 further including the steps of:

A. passing from the free cooling mode of operation to the powered mode of operation by,
1. energizing said compressor, 
2. passing compressed refrigerant vapor through said compressor to said condenser, and 
3. removing from said closed refrigerant circuit a quantity of condensed refrigerant equal to said additional quantity by passing substantially said quantity of condensed refrigerant into said storage chamber to thereby reduce the equivalent quiescent level of refrigerant in said evaporator substantially below the upper tubes of said evaporator to a substantially reduced level during operation of said compressor; 

B. continuing to operate said system by, 
1. continuing energization of said compressor, and 
2. continuing to withhold from said closed refrigerant circuit in said storage chamber during continued energization of said compressor substantially said additional quantity of refrigerant. 

8. Refrigerant apparatus comprising a shell-and-tube type refrigerant evaporator, a refrigerant compressor and a refrigerant condenser serially connected in a closed refrigerant circuit; said refrigerant compressor having a suction inlet connected to the shell side of said evaporator and a discharge outlet connected to said condenser; said circuit including first conduit means for conveying liquid refrigerant from said condenser to said evaporator during operation of said compressor; and means for controlling the flow of liquid refrigerant in said first conduit means; second conduit means extending from the shell of said evaporator to said condenser bypassing said compressor for conveying refrigerant vapor from said evaporator to said condenser; a shutoff valve disposed in said second conduit means; a storage chamber outside said closed refrigerant circuit disposed to store liquid refrigerant above the uppermost tubes of said evaporator; a third conduit means connecting said storage chamber and said evaporator for conveying liquid refrigerant from said storage chamber to said evaporator in preparation for operation of said refrigeration apparatus without operation of said compressor; and means for holding liquid refrigerant in said storage chamber during operation of said compressor. 

9. The apparatus as defined by claim 8 including fourth conduit means for conveying liquid refrigerant from said condenser to said storage chamber. 

10. The apparatus as defined by claim 9 including a refrigerant vapor vent passageway extending from the upper portion of said storage chamber to that portion of said circuit at substantially evaporator pressure. 

11. The apparatus as defined by claim 9 wherein said first conduit means includes an economizer chamber and further including a vapor vent passageway extending from the upper portion of said storage chamber to that portion of said circuit at substantially economizer chamber pressure. 

12. The apparatus as defined by claim 8 wherein said first conduit means includes an economizer chamber and further including a fourth conduit means for conveying liquid refrigerant from a portion of said circuit at substantially economizer chamber pressure to said storage chamber. 

13. The apparatus as defined by claim 12 including a refrigerant vapor vent passageway extending from the upper portion of said storage chamber to that portion of said circuit at substantially evaporator pressure.