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Ware

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[54] **REFRIGERATION APPARATUS AND METHOD OF OPERATING FOR POWERED AND NONPOWERED COOLING MODES**

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[73] Assignee: The Trane Company, La Crosse, Wis.

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[52] **U.S. Cl.** **62/498,** 62/149, 62/174, 62/510, 62/512, 62/196, 62/115, 62/117

[51] **Int. Cl.** **F25b 1/00**

[58] **Field of Search** 62/149, 174, 512, 62/115, 117, 498, 196

[56] **References Cited**

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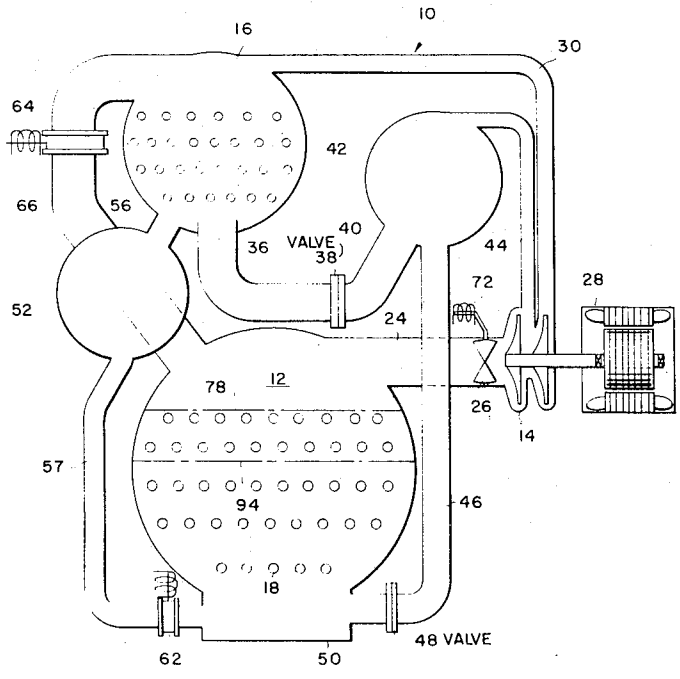
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Attorney—Arthur O. Andersen et al.

[57] **ABSTRACT**

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.

5 Claims, 3 Drawing Figures



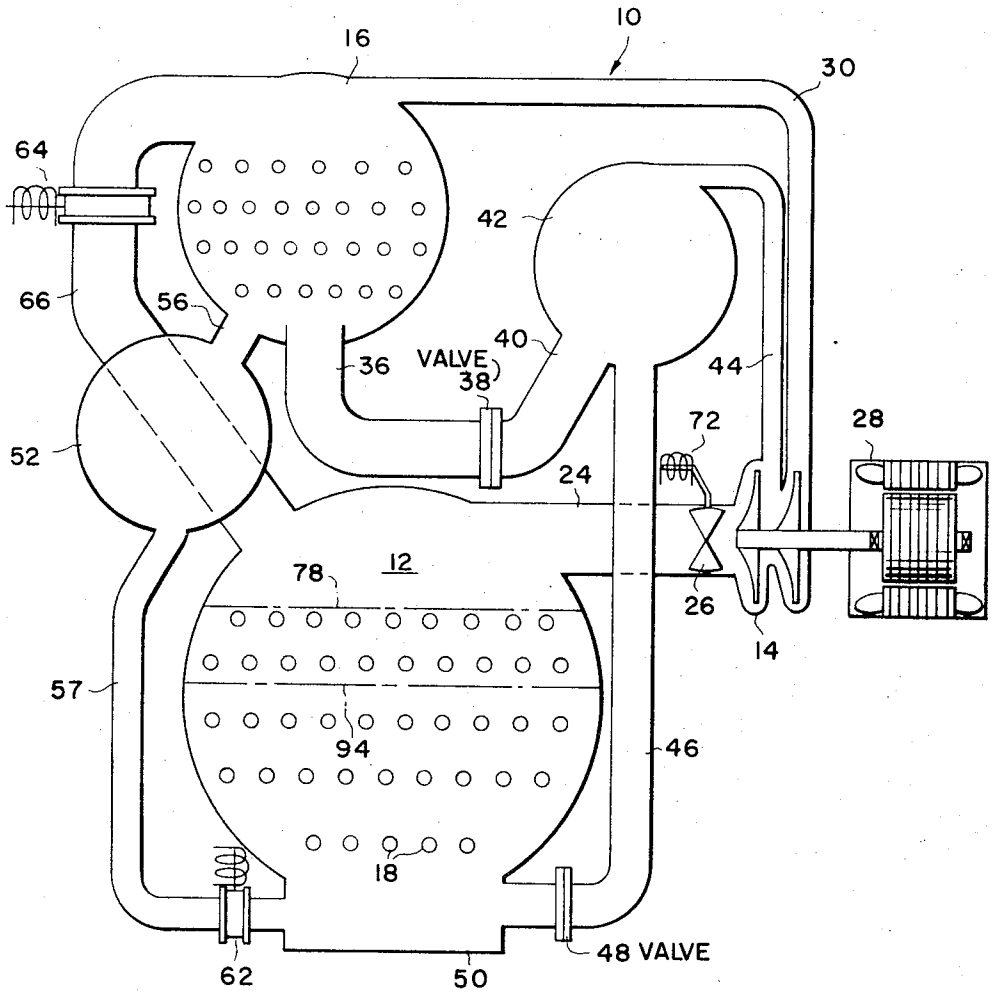

10
16
30
64
42
66
56
40
36
VALVE
38
44
72
28
52
24
78
12
26
14
57
94
46
18
62
50
48 VALVE

FIG. 1

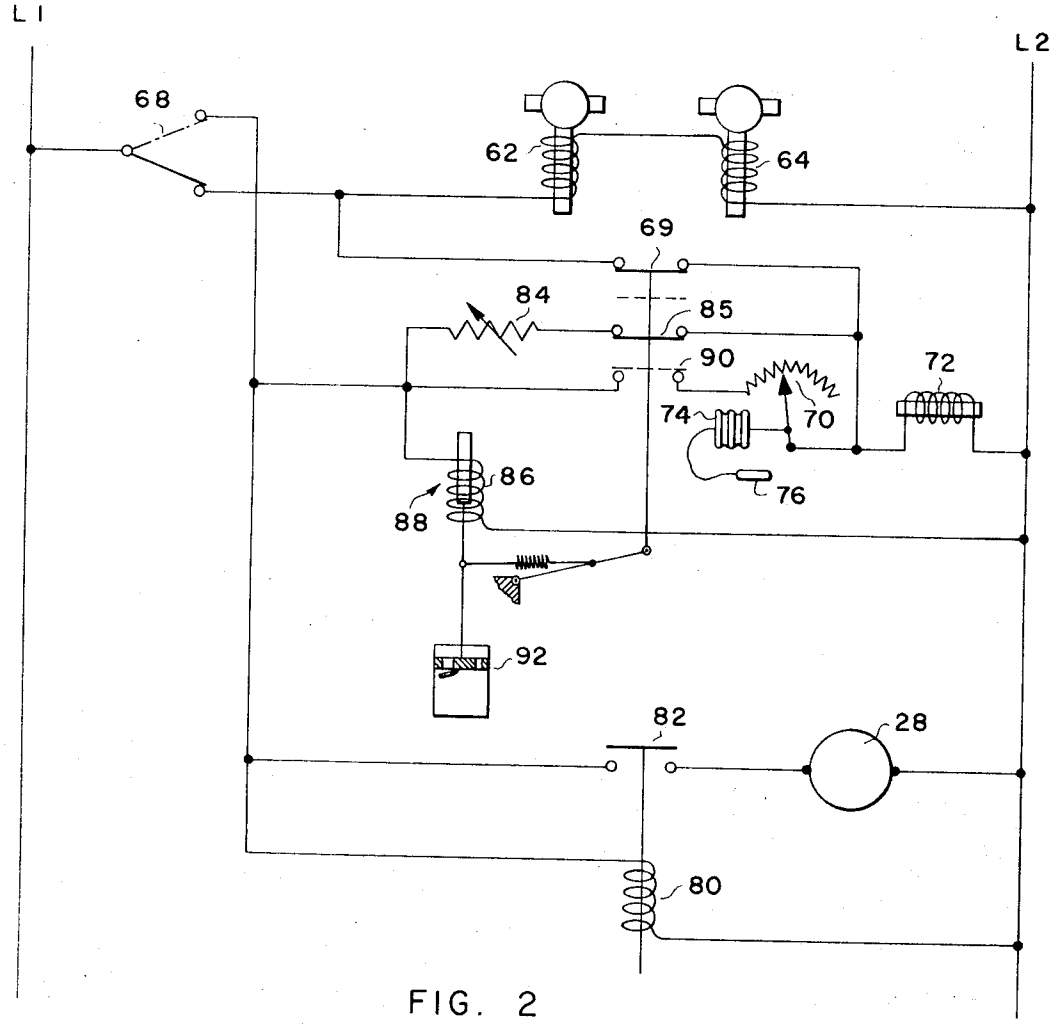

L1
L2
68
62
64
69
84
85
90
72
74
70
86
88
76
92
82
28
80

FIG. 2

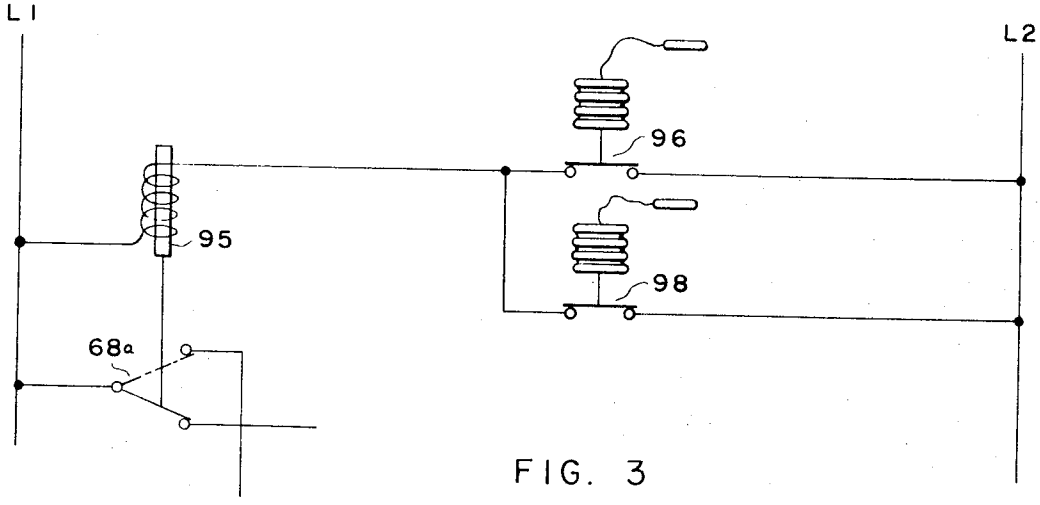

L1
L2
96
95
98
68a

FIG. 3

REFRIGERATION APPARATUS AND METHOD OF OPERATING FOR POWERED AND NONPOWERED 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 liquid flow control device 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 for 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 refrigeration apparatus adapted to be operated in the cooling mode alternatively with the compressor operating and without the compressor operating comprising: a refrigerant evaporator, a refrigerant compressor, and a refrigerant condenser disposed above said evaporator serially connected in a closed refrigerant circuit; a liquid refrigerant storage chamber outside said refrigerant circuit disposed above said evaporator and below said condenser for storing liquid refrigerant during operation of said compressor; first conduit means connecting the lower portion of said condenser with said storage chamber for conducting via force of gravity liquid refrigerant from said condenser to said storage chamber; second conduit means for connecting said storage chamber to said evaporator for conducting via force of gravity refrigerant liquid from said storage chamber to said evaporator; first valve means in said second conduit means for terminating flow from said storage chamber during operation of said compressor; third conduit means connecting said evaporator to said condenser; and second valve means in said third conduit means for terminating flow of refrigerant vapor through said third conduit means 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 throughout wherein:

FIG. 1 is a semi-schematic of a refrigeration machine constructed in accordance with 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.

Now with reference to the refrigeration machine shown in FIG. 1 it will be seen that the refrigeration system 10 includes a refrigerant evaporator 12, a refriger-

ant 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 headers (not shown) to boil refrigerant within the evaporator shell. The refrigerant vapor is conducted to the compressor **14** via an inlet conduit **24**. The compressor **14** shown is intended to designate a two stage compressor although aspects of the instant invention are equally applicable to single stage compressor refrigeration systems. The inlet of the first stage is 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.

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 may 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 (not shown).

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. 3,260,067 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 below condenser **16** and 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 condenser **16** to the top of chamber **52**. The inlet of conduit **56** is slightly lower than the inlet of stand pipe **36** so refrigerant condensate preferentially enters chamber **52** until chamber **52** has been filled.

For purposes of carrying out the free cooling mode of operation in accordance with the methods of this invention, the bottom of chamber **52** is connected via conduit **57** having an automatically powered normally closed shut off valve **62** to conduit **50**. Furthermore there is provided a compressor vapor bypass conduit **66** extending between upper portions of the shells of condenser **16** and evaporator **12**.

Conduit **66** is also provided with an automatically powered normally closed shutoff valve **64**.

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 equivalent 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 percent of full load and that the temperature of condenser cooling water is sufficiently below the desired temperature for the water leaving evaporator **12**.

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** permits substantially all of 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. The opening of valve **64** permits refrigerant vapor to pass freely from evaporator **12** to condenser **16** whereupon it is condensed and returned via conduit **56**, chamber **52**, conduit **57**, valve **62** 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 actuator **74** whose sensor bulb **76** is located at the evaporator water outlet responsive to the load. It should be appreciated that both coils **86** and **80** are selected to have sufficiently high impedance 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 preferentially passes via gravity through conduit **56** into chamber **52.** When chamber **52** has been filled, liquid refrigerant passes down stand pipe **36** 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 conduit **46** and flow control **48** for re-evaporation.

Because this quantity of refrigerant in chamber **52** and conduits **56** and **57** 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 aforedescribed 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 filling of chamber **52** with liquid refrigerant requires only gravity and is not dependent upon pressure differentials in the system. 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 **68*a*** is an automatic version of switch **68** and is moved to the power mode 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 switch **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. 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. 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 **68*a*** 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 **68*a*** 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. Compression refrigeration apparatus adapted to be operated in the cooling mode alternatively with the compressor operating and without the compressor operating comprising: a refrigerant evaporator, a refrigerant compressor, and a refrigerant condenser disposed above said evaporator serially connected in a closed refrigerant circuit; a liquid refrigerant storage chamber outside said refrigerant circuit disposed above said evaporator and below said condenser for storing liquid refrigerant during operation of said compressor; first conduit means connecting the lower portion of said condenser with said storage chamber for conducting via force of gravity liquid refrigerant from said condenser to said storage chamber; second conduit means for connecting said storage chamber to said evaporator for conducting via force of gravity refrigerant liquid from said storage chamber to said evaporator; first valve means in said second conduit means for terminating flow from said storage chamber during operation of said compressor; third conduit means connecting said evaporator to said condenser; and second valve means in said third conduit means for terminating flow of refrigerant vapor through said third conduit means during operation of said compressor.

2. The apparatus as defined by claim **1** including an economizer in said closed refrigerant circuit between said condenser and evaporator for receiving refrigerant from said condenser and means for preferentially directing refrigerant condensate from said condenser to said first conduit means.

3. The apparatus as defined by claim **1** including means for preferentially directing refrigerant condensate from said condenser to said first conduit means.

4. The apparatus as defined by claim **1** wherein said first conduit means functions to simultaneously supply liquid refrigerant to said storage chamber from said

condenser and to vent refrigerant vapor from said storage chamber to said condenser.

5. The apparatus as defined by claim 4 wherein said first conduit means defines a single passage way inclined upwardly from the upper portion of said storage chamber to said condenser thereby permitting passage of refrigerant gas from said storage chamber to said condenser upon filling said storage chamber with refrigerant liquid.

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