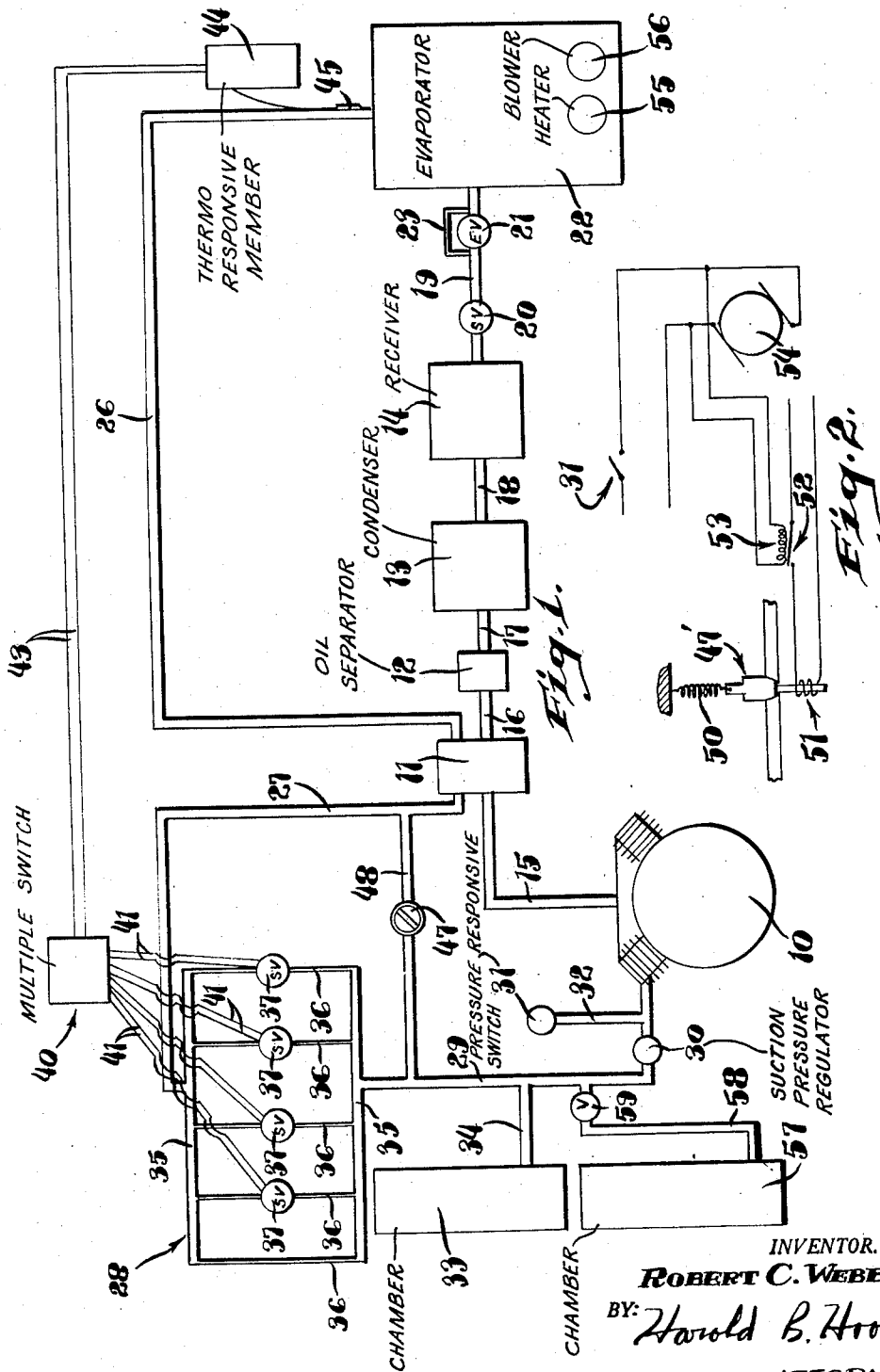


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HIGH SENSITIVITY, LOW-TEMPERATURE CONTROL SYSTEM

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This invention relates to a refrigerating system, and more particularly, to a refrigerating system which is automatically operable to maintain the temperature of the region being refrigerated at a very low value and within very close limits.

In testing material and equipment for rockets and guided missiles, it is necessary to simulate quite accurately the conditions of temperature (and pressure) to which they will be subjected in flight. In moving vertically from the earth toward outer space, the temperature to which a portion of a body not exposed directly to the sun is subjected drops approximately 3° F. for each thousand feet until a temperature of -85° F. is reached. Rising above the height at which -85° F. is reached, the temperature remains substantially constant to a height of twenty-five miles. The temperature then gradually rises to 150° F. at the height of thirty-five miles. The temperature then drops to -28° F. at a height of approximately fifty miles where it remains constant to a height of approximately one hundred fifty miles. The temperature then drops gradually to -200° F. at a height of approximately two hundred fifty miles.

Conventional mechanical refrigerating systems, particularly such systems which have a sufficiently high capacity to bring the temperature of the region being refrigerated quickly to the desired value, are not capable of maintaining the temperature of the refrigerated region within the comparatively close limits required for tests during which the above temperature conditions must be simulated and for other refrigeration installations. Among the reasons for this is the fact that it is not practical to cycle conventional mechanical refrigerant compressors more often than about once every forty seconds. To avoid cycling the compressor or compressors too frequently, it is necessary to effect a comparatively wide variation between the highest and lowest temperatures provided at the region being refrigerated. Accordingly, an important object of my invention is to provide a novel refrigerating system capable of maintaining the temperature of the refrigerated region within extremely close limits.

A further object of my invention is to provide a novel refrigerating system capable of effecting a very limited temperature variation at the region being refrigerated without cycling the compressor an excessive number of times per unit of time interval.

A further object of my invention is to provide a unique refrigerating system having means for reducing the frequency with which the compressor must be cycled to maintain the temperature of the region being refrigerated within the desired limits.

A further object of my invention is to provide a novel refrigerating system having means for reducing the tendency of the compressor to pass oil from its crankcase or internals into the circuit through which the refrigerant flows.

A further object of my invention is to provide a refrigerating system with means for increasing the capacity

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of the system at times when a considerable temperature drop is desired or required.

A further object of my invention is to provide a novel refrigerating system having safety means for accommodating the excessive pressure exerted by the refrigerant when at comparatively high temperatures.

Further objects of the invention will become apparent as the description proceeds.

To the accomplishment of the above and related objects, my invention may be embodied in the forms illustrated in the accompanying drawings, attention being called to the fact, however, that the drawings are illustrative only, and that change may be made in the specific constructions illustrated and described, so long as the scope of the appended claims is not violated.

Fig. 1 is a more or less diagrammatic view of a refrigerating system embodying my invention; and

Fig. 2 is another more or less diagrammatic view showing a modified form of means for actuating the valve disposed in a conduit located in by-passing relation to my improved control section.

Referring to Fig. 1 of the drawing, a conventional portion of a refrigerating system is shown, which portion consists of a compressor 10, a heat-exchanger 11, an oil separator 12, a condenser 13, and a receiver 14, these components being successively interconnected for the flow therethrough of a suitable refrigerant by means of conduits 15, 16, 17 and 18, respectively. A conduit 19 provides communication for the flow of refrigerant from receiver 14 through a conventional, solenoid-operated shut-off valve 20 and an expansion valve 21 to a conventional evaporator 22 which is preferably of the gravity-flow type. Valve 21 is preferably of the form illustrated and described in my prior United States Patent No. 2,709,340, issued May 31, 1955. It will be apparent upon reference to this patent that this valve takes the form of a thermostatic expansion valve having a thermo-responsive element (not shown herein) disposed at the evaporator outlet. The conduit leading to the interior of the thermostatic valve is coiled about the portion of the valve occupied by a quantity of the relatively warm thermal control fluid which is in heat-exchanging relation with the refrigerant flowing from the evaporator. A by-pass tube 23, as fully disclosed in my above-mentioned patent, is provided which permits a constant, though somewhat reduced, flow of refrigerant through the coiled portion of the conduit leading to the interior of valve 21. This construction is effective to prevent liquefaction of the control fluid in the valve 21 even when the compressor remains quiescent for long periods of time.

A passageway is provided for the flow of refrigerant from the evaporator 22 back to the compressor 10. As illustrated in Fig. 1, this passageway may include a conduit 26 extending between the evaporator 22 and heat-exchanger 11. The refrigerant flowing from the evaporator 22 back to the compressor 10 flows through conduit 26 to heat-exchanger 11 and passes through member 11 in heat-exchanging relation with the refrigerant flowing from compressor 10 to condenser 13. The refrigerant flowing from the evaporator becomes heated during passage through heat-exchanger 11 whereby maintenance of this relatively cold refrigerant in the gaseous state is ensured; and the compressed, relatively hot refrigerant flowing from the compressor 10 to condenser 13 is pre-cooled during its passage through heat-exchanger 11. This arrangement is particularly advantageous since maintenance in the gaseous state of the refrigerant flowing through my improved control section 28 (later to be described) is necessary to the satisfactory operation of the control section.

The refrigerant flowing from evaporator 22, after passing through heat-exchanger 11, flows through conduit

27, through my improved control section 28, and thence through conduit 29 which leads back to compressor 10. A conventional suction pressure regulator 30 is disposed in conduit 29. Between regulator 30 and compressor 10 a conduit 32 providing communication with and between conduit 29 and a pressure-responsive switch 31 is provided. Switch 31 is responsive to the pressure of the refrigerant in conduit 29 and may be adjustably set to energize and deenergize the motor of compressor 10 automatically.

I provide a chamber 33 in communication through conduit 34, with conduit 29. Chamber 33 provides a reservoir for the flow of refrigerant from control section 28. My improved control section 28 is provided between spaced portions of conduits 27 and 29, respectively, in intermediate relation with respect to evaporator 22 and the portion of conduit 29 which provides communication with the interior of chamber 33. Manifold conduits 35, 35 of control section 28 are disposed in communication with and at opposite ends of a plurality of conduits 36 which are disposed in parallel relation with respect to each other. Each of conduits 36 may be provided with an open-close valve 37, but, as shown in Fig. 1, I prefer to omit such a valve from one of the conduits 36 to provide a constantly free but constricted line of flow from conduit 27 to conduit 29.

The sum of the cross-sectional areas of all of conduits 36 is substantially equal to the cross-sectional area of that portion of the passageway provided by conduits 26 and 27. By selectively opening and closing any one or more of valves 37, the effective cross-sectional area of the passageway between conduits 27 and 29 may be varied to correspondingly meter the flow of refrigerant from conduit 27 to chamber 33. By metering the flow of refrigerant to chamber 33, the rate of flow of refrigerant from evaporator 22 is correspondingly varied and, in turn, the temperature at the evaporator is correspondingly controlled. Such metering is much more accurately and effectively accomplished by means of the plural open-close valves 37 than would be possible through the use of an yform of modulating, automatically-controllable valve known to me.

To control the actuation of valves 37 a conventional, thermo-responsive mechanism 40 may be provided. Mechanism 40 dominates a series of solenoids, said solenoids, in turn, respectively controlling the several valves 37 so that, as the temperature to which the thermo-responsive element 45 is subjected rises, the valves 37 will be successively opened, and as that temperature drops, said valves will be successively closed. A pair of electrical leads 43 connects control mechanism 40 with a thermo-responsive member 44 having a temperature sensitive element 45 disposed to sense the temperature at the evaporator. Control mechanism 40 along with control member 44 and temperature sensitive element 45 represents conventional, commercially obtainable equipment. Mechanism 40 is adjustable to actuate each of valves 37 independently at a respective evaporator temperature. Each valve 37 remains closed when the temperature of the evaporator falls below a respective value and opens when the temperature of the evaporator rises above that respective value. The respective evaporator temperature values above and below which said conduits independently open and close, respectively, are adjusted to be at a slight gradient with respect to one another.

A fairly rough control of the evaporator temperature is maintained by thermostatic expansion valve 21 in metering the flow of refrigerant to the evaporator in response to temperature change at the evaporator. However, as pointed out heretofore, this evaporator temperature control is not sufficiently sensitive to maintain the evaporator temperature within the close limits required and desired for many present day installations. By accurately varying the effective cross-sectional area of

the passageway for the flow of refrigerant from the evaporator to chamber 33, the temperature variation at the evaporator is maintainable within extremely close limits. Using a cascade system in which the control unit 28 is embodied at least in the final stage of the system, I have been successful in maintaining the evaporator temperature within a tolerance of plus or minus 0.1° F., in a range from 300° F. down to -200° F. Of course, this range could be increased; for example, by adding additional compression stages.

It will be noted that my improved control section 28 in cooperation with the chamber 33 is effective to reduce the cost of operating a refrigeration system with which it is associated since a great deal less electrical power is required to cycle the solenoid valves of the control section 28 than to cycle the compressor motor. Chamber 33 is effective to lessen the tendency for oil in the reservoir and internals of the compressor 10 to pass into the circuit through which the refrigerant flows since, upon actuation of the compressor, the chamber provides a cushioning effect on the initial surge in flow of the refrigerant entering the compressor. Also, the provision of chamber 33 increases the capacity of the refrigerating system for quick temperature pull-downs.

As shown in Fig. 1, a conduit 48 may be provided in communication with and between portions of conduits 27 and 29, respectively, in by-passing relationship with respect to control section 28. Valve 47 may be a manually operated, open-close valve, and can be opened whereby the flow of refrigerant from evaporator 22 to chamber 33 moves through conduit 48 and by-passes control section 28. Accordingly, valve 47 provides a safety means whereby it can be opened when excessively high pressures exerted by the refrigerant develop which could not be accommodated by control section 28.

In Fig. 2, I have diagrammatically illustrated a valve 47' and control means therefor, which may be substituted for manually operated valve 47 in conduit 48 as shown in Fig. 1. In the embodiment shown in Fig. 2, valve 47' is biased toward open position by any suitable means such as a spring 50. A solenoid 51 is operatively associated with valve 47' to close the valve when the solenoid is electrically energized. A thermo-responsive switch 52 is disposed in the electrical circuit by which the solenoid is energized. Switch 52 is preferably of the bi-metallic type and when heated remains closed and when cooled is automatically opened. To maintain switch 52 in closed position, a heating element 53 is disposed in heat transfer relation with switch 52 and electrically connected in parallel relationship with motor 54 which drives compressor 10. As shown in Fig. 2, heating element 53 and motor 54, which are in parallel relation with each other, are connected in series relation with pressure-responsive switch 31. Accordingly, the heating element 53 is energized simultaneously with energization of compressor motor 54. During normal operation of the refrigerating system, the compressor motor 54, and consequently heating coil 53, is energized sufficiently frequently that the temperature at thermo-responsive switch 52 is maintained above its opening value by the heating element 53. If the compressor should not be operated during an excessively long interval, such as when the system is shut down for repairs or other purposes, or in case of mechanical or electrical failure in the system, the heat from element 53 will be gradually dissipated and switch 52 will open to deenergize solenoid 51 and permit biasing means 50 to hold valve 47' in its open position. Consequently, the pressure exerted by the gaseous refrigerant in the evaporator 22 and conduit 26, if its temperature should rise during a shut-down period, will be efficiently relieved by chamber 33 which is in communication with conduit 29 and by-passing conduit 48. Sufficient volume is provided by chamber 33 to accommodate the refrigerant expansion resulting from the highest temperature to which the refrigerant in the

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evaporator may be expected to be subjected, and danger of excessive refrigerant pressure in the system is thereby eliminated. Accordingly, manually operated valve 47, and valve 47' provide effective safety means to relieve the pressure exerted by the refrigerant in the evaporator when it is at a comparatively high temperature.

Since the refrigerating system embodying my invention is provided with the above-described safety means, a heating means 55 and a blower 56 may be provided to heat the region in which the evaporator is disposed without the possibility of developing dangerously high refrigerant pressures. By providing suitable means to control the temperature of the region in which the evaporator is disposed when heated, the controlled temperature of the region can be varied well above and below normal circumambient temperatures.

To provide greater capacity for the refrigerating system during periods of quick temperature pull-down, an auxiliary tank or reservoir 57 may be provided. A conduit 58 is provided in communication with and between the interior of tank 57 and conduit 29. A shut-off valve 59 is disposed in conduit 58 and may be operated to close tank 57 from the system at a time when a relatively high degree of vacuum has been pulled in conduit 29 and reservoir 57. If and when it becomes desirable quickly to reduce the temperature in the region affected by the evaporator 22, the valve 59 may be opened, whereby the region of high vacuum in said reservoir is thrown into open communication with the return side of the refrigeration system, to cause a rapid surge of refrigerant flow through the evaporator without subjecting the compressor to such a heavy load as would result in the absence of the reservoir 57. After the desired temperature has been attained in the refrigerated region, continued operation of the system will again produce a high degree of vacuum in the reservoir 57, whereafter the valve 59 may be closed until a quick pull-down is again desired.

I claim as my invention:

1. A refrigerating system comprising a compressor, a condenser and an evaporator, means interconnecting said compressor, condenser and evaporator to permit the flow of refrigerant from the compressor, through the condenser and then through the evaporator, means providing a passageway connecting said evaporator for the flow of refrigerant therefrom to said compressor, a chamber having its interior in communication with said passageway, and means for varying the effective cross-sectional area of a portion of said passageway in response to corresponding changes in temperature at said evaporator to meter the flow of said refrigerant through said passageway and thereby maintain the temperature at said evaporator within close limits, said last-named means comprising means providing a plurality of flow paths connected in parallel, the sum of the flow capacity of said flow paths substantially equalling the flow capacity of said passageway, means for independently closing each of said flow paths, and means for actuating said respective closing means successively at successive temperature values arising at said evaporator.

2. A refrigerating system comprising a compressor, a condenser and an evaporator, means interconnecting said compressor, condenser and evaporator to permit the flow of refrigerant from the compressor, through the condenser and then through the evaporator, means providing a passageway connecting said evaporator for the flow of refrigerant therefrom to said compressor, a chamber having its interior in communication with said passageway, a portion of said passageway being formed by a plurality of conduits connected in parallel relation with each other, the sum of the cross-sectional areas of the hollow portions of all of said conduits being substantially equal to the cross-sectional area of the portion of said passageway extending between said first-mentioned portion and said evaporator, means for closing each of

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said conduits when the temperature of the evaporator falls below a respective value and for opening each of said conduits when the temperature of the evaporator rises above that respective value, the respective evaporator temperature values, above and below which said conduits open and close, respectively, being at a slight gradient with respect to one another.

3. The apparatus as set forth in claim 2 wherein said last-named means comprises a solenoid valve disposed in operative relationship with each of a plurality of said conduits, said valves being operatively connected to a temperature responsive element disposed at the outlet of said evaporator.

4. A refrigerating system comprising a compressor, a condenser and an evaporator, means interconnecting said compressor, condenser and evaporator to permit the flow of refrigerant from the compressor, through the condenser and then through the evaporator, means providing a passageway connecting said evaporator for the flow of refrigerant therefrom to said compressor, a first chamber and an auxiliary chamber, each chamber having its interior in communication with said passageway, means for closing off said auxiliary chamber from communication with said passageway when a relatively high vacuum condition exists in said auxiliary chamber and for opening said auxiliary chamber into communication with said passageway during periods of quick temperature pull-down, and means for varying the effective cross-sectional area of a portion of said passageway in response to corresponding changes in said temperature at said evaporator to meter the flow of said refrigerant from said evaporator and thereby maintain the temperature of said evaporator within close limits.

5. A refrigerating system comprising a compressor, a condenser and an evaporator, means interconnecting said compressor, condenser and evaporator to permit the flow of refrigerant from the compressor, through the condenser and then through the evaporator, means providing a passageway connecting said evaporator for the flow of refrigerant therefrom to said compressor, a chamber having its interior in communication with said passageway, means for varying the effective cross-sectional area of a portion of said passageway in response to corresponding changes in temperature at said evaporator to meter the flow of said refrigerant from the evaporator and thereby maintain the temperature at said evaporator within close limits, conduit means in communication with spaced portions of said passageway and in by-passing relation with the means for varying the effective area of a portion of said passageway, and valve means to open and close said last-named conduit means.

6. The apparatus as set forth in claim 5 including means for actuating said valve means to maintain said last-named conduit means open after an excessive time interval during which said compressor remains quiescent.

7. A refrigerating system comprising a compressor, a condenser and an evaporator, means interconnecting said compressor, condenser and evaporator to permit the flow of refrigerant from the compressor, through the condenser and then through the evaporator, means providing a passageway connecting said evaporator for the flow of refrigerant therefrom to said compressor and means for varying the effective cross-sectional area of a portion of said passageway in response to corresponding changes in temperature at said evaporator to meter the flow of said refrigerant through said passageway and thereby maintain the temperature at said evaporator within close limits, said last-named means comprising means providing a plurality of flow paths connected in parallel, the sum of the flow capacities of said flow paths substantially equalling the flow capacity of said passageway, means for independently closing each of said flow

paths, and means for actuating said respective closing means successively at successive temperature values arising at said evaporator.

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