

Nov. 5, 1963

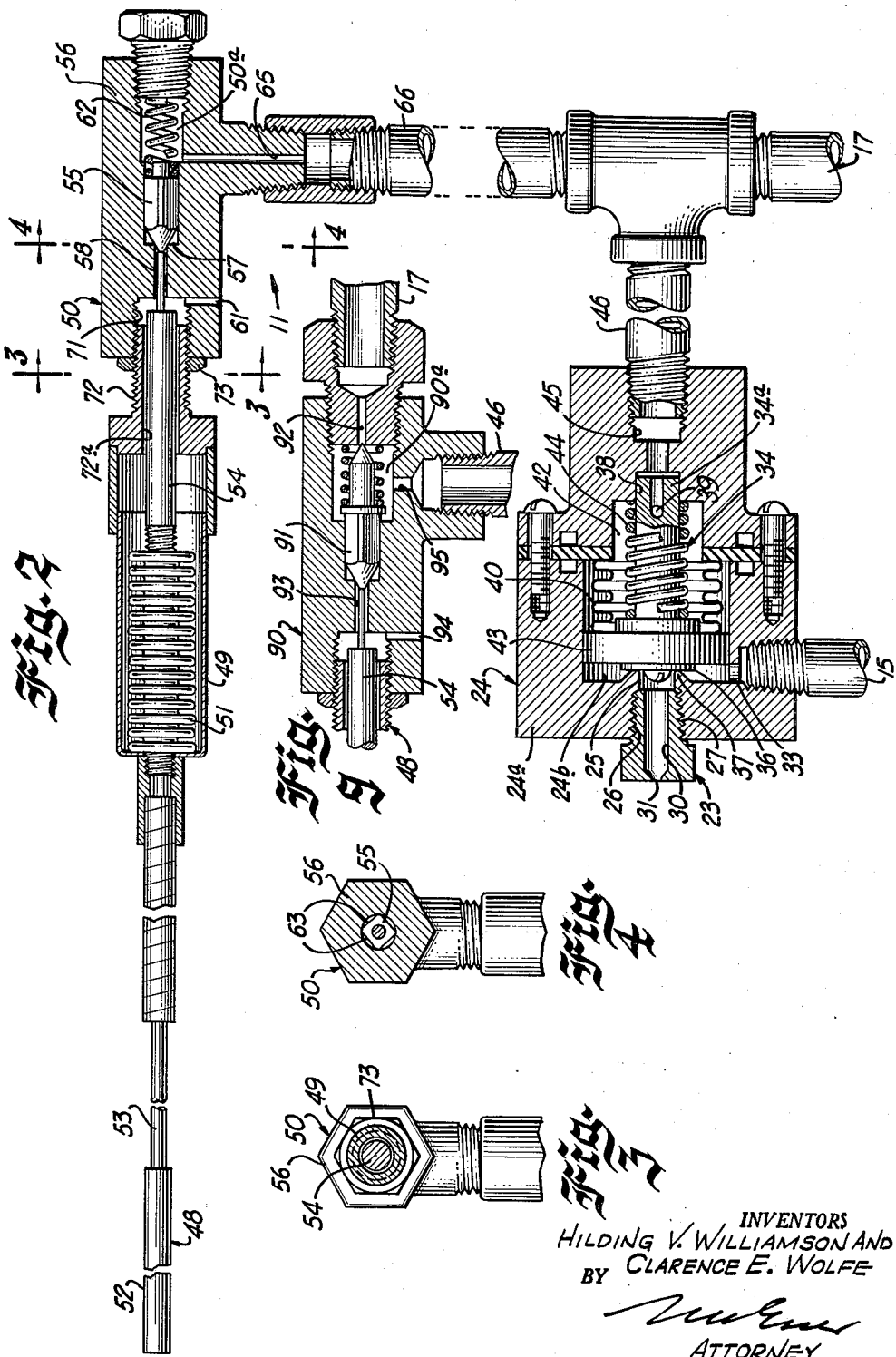
H. V. WILLIAMSON ETAL

3,109,296

APPARATUS AND METHOD FOR REFRIGERATION BY CARBON DIOXIDE

Filed Sept. 29, 1961

3 Sheets-Sheet 2



INVENTORS
HILDING V. WILLIAMSON AND
BY CLARENCE E. WOLFE

Clarence E. Wolfe
ATTORNEY

Nov. 5, 1963

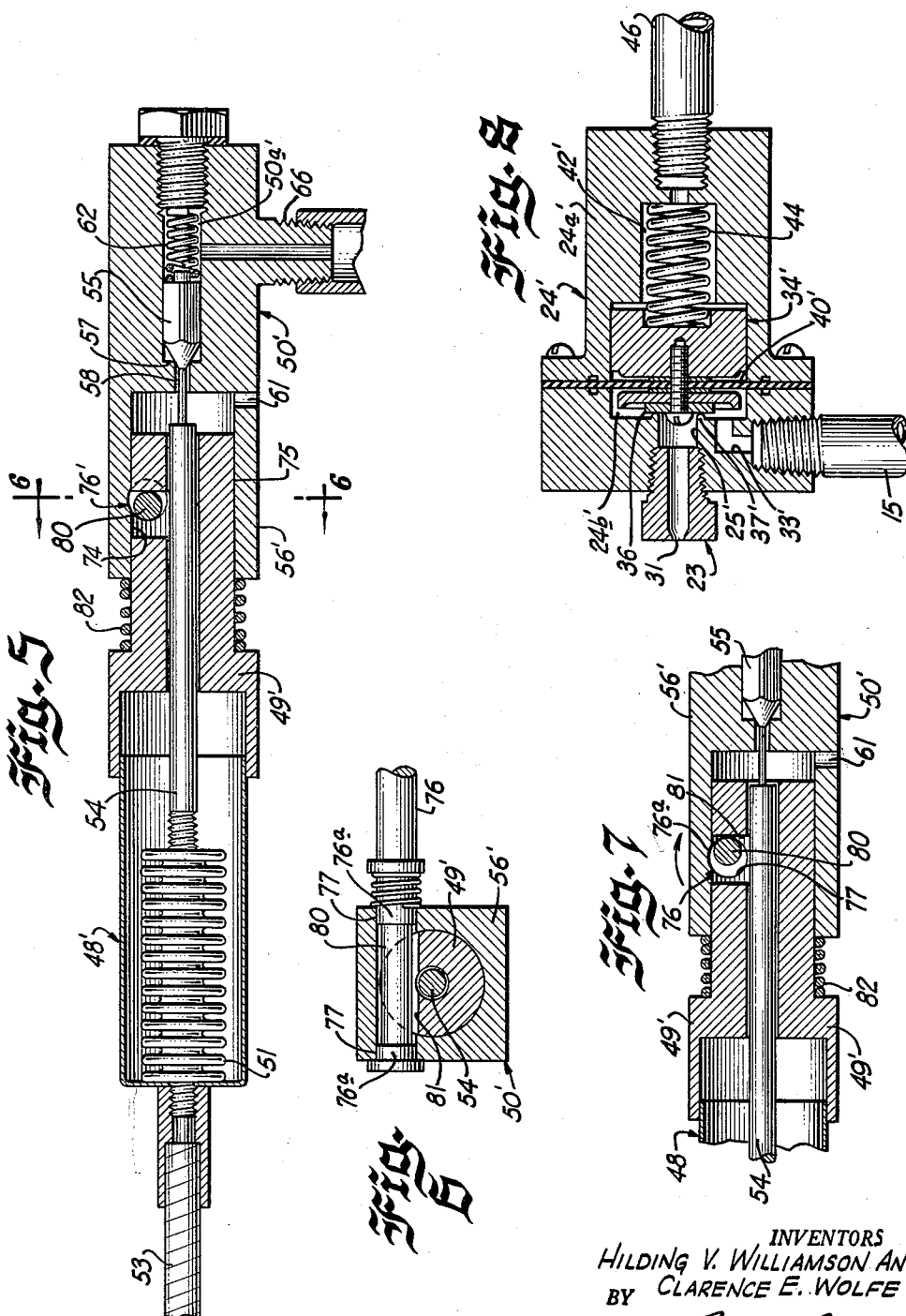
H. V. WILLIAMSON ETAL

3,109,296

APPARATUS AND METHOD FOR REFRIGERATION BY CARBON DIOXIDE

Filed Sept. 29, 1961

3 Sheets-Sheet 3



INVENTORS
HILDING V. WILLIAMSON AND
BY CLARENCE E. WOLFE

Clarence E. Wolfe
ATTORNEY

1

3,109,296

APPARATUS AND METHOD FOR REFRIGERATION BY CARBON DIOXIDE

Hilding V. Williamson, Chicago, and Clarence E. Wolfe, Hinsdale, Ill., assignors to Chemetron Corporation, Chicago, Ill., a corporation of Delaware

Filed Sept. 29, 1961, Ser. No. 141,745

11 Claims. (Cl. 62-76)

This invention relates to an apparatus and to a method for refrigeration, and more specifically to an apparatus and method for refrigerating a compartment by spraying liquid carbon dioxide thereto.

The invention has particular utility in the refrigeration of transport compartments such as insulated railroad cars and motor trucks for highways, and including compartments of trailers adapted to be transported cross-country on railroad cars and then to be transported locally by motor truck or tractor. Moreover, the present invention is suitable for refrigeration of compartments of motor trucks used to make local deliveries of refrigerated goods such as frozen foods, meat and ice cream. Continued opening of the refrigerated compartments for local delivery of frozen foods and the like on a wholesale or retail level presents particular difficulties in maintaining the goods in the proper state of refrigeration.

Mechanical refrigeration systems have been used for the refrigeration of transport compartments, but difficulties arise in maintaining continued operation thereof because of the complexity of the system. Additionally, the high initial cost of such equipment has made it questionable for many applications. Although ice formed of water has been used as a refrigerant or coolant of transport compartments, water-ice as a refrigerant has the disadvantages of requiring re-icing during a long journey and of requiring a large ice load, thereby decreasing the usable payload that can be carried. Moreover, the temperature which can be maintained in the refrigerated compartment is limited with the use of water-ice.

The use of liquid nitrogen has heretofore been proposed as a refrigerant but because of the low temperature necessary to maintain the nitrogen in liquid state, the storage facilities for liquid nitrogen are complex and expensive and generally require a jacketed powder-vacuum insulated storage vessel. Moreover, nitrogen is not always available commercially in all locations. Carbon dioxide has heretofore been used as a refrigerant, forming the well-known Dry Ice in its solid state. While Dry Ice makes a desirable refrigerant for many applications, it requires manual handling which becomes difficult because of the tendency for the Dry Ice to cause burning when it comes in contact with the human hands. Carbon dioxide in the liquid state as a refrigerant has generally required the use of heat exchangers with accompanying complexity of the systems and initial high cost thereof.

According to the present invention, liquid carbon dioxide sprayed into the refrigerated compartment makes a desirable refrigerant. However, carbon dioxide cannot exist in the liquid state at atmospheric pressure, but only in the solid or gaseous state. Carbon dioxide exists in the liquid state only at pressures above the triple point, or about 75 lbs. per square inch absolute. Accordingly, there is a tendency for liquid carbon dioxide to solidify while being sprayed into a refrigerating compartment, thereby preventing proper functioning of the refrigerating system, and specifically of the spray nozzles thereof, unless the carbon dioxide is quickly passed through the triple point. Moreover, additional difficulty arises because the carbon dioxide system may be used in trailers carried by railroad cars and other transport applications where electrical power for control may not be available.

2

It is therefore an object of the present invention to provide an improved refrigeration system.

A further object of the present invention is to provide an improved refrigeration system which overcomes the above-mentioned difficulties.

A further object of the present invention is to provide an improved refrigeration system which is particularly advantageous for use in transport compartments of motor vehicles, railroad cars, and the like.

Yet a further object of the present invention is to provide an improved refrigeration system which is low in initial cost and economical to maintain and operate.

Still a further object of the present invention is to provide an improved refrigeration system that does not require electrical power to operate or control the same.

A further object of the present invention is to provide an improved refrigeration system operating on liquid carbon dioxide.

Still another object of the present invention is to provide an improved refrigeration system for spraying liquid carbon dioxide in a refrigerating compartment.

A further object of the present invention is to provide an improved method of refrigeration.

And still another object of the present invention is to provide an improved method of spraying carbon dioxide into a refrigerating compartment.

Briefly stated, the invention is directed to an apparatus and method for refrigeration of compartments by spraying liquid carbon dioxide within the compartment. The improved refrigeration system is particularly adapted for cooling the refrigerating compartment of transport vehicles. In accordance with the invention, the discharge of liquid carbon dioxide from a supply tank containing liquid carbon dioxide under pressure is automatically controlled. The pressure of the vapor in the carbon dioxide tank is used to keep a liquid discharge valve closed thereby to prevent the discharge of the liquid carbon dioxide refrigerant into the compartment when the temperature in the compartment is below a preselected level. A temperature sensing device actuates a vapor control valve which releases the vapor pressure and allows the liquid discharge valve to open and the liquid refrigerant to be sprayed into the compartment.

A quick-acting liquid discharge valve is provided so that the liquid carbon dioxide in the space between the valve and the spray nozzle is quickly moved through the triple point thereby minimizing the solidification of the carbon dioxide in the system. In accordance with one embodiment of the invention, the valve is a pneumatically actuated quick-acting valve which includes a pressure differential responsive means and a portion of one side of the pressure differential responsive means forms a valve portion which is seatable against a valve seat opening in the body of the valve. The liquid carbon dioxide is placed in communication with one side of the pressure responsive means and the other side of the pressure responsive means is in communication with the vapor in the carbon dioxide tank. A flow restricting plug is positioned in the carbon dioxide vapor line leading to the valve. The pressure differential responsive device is therefore controlled by the pressure of the liquid carbon dioxide on one side thereof and by the pressure of the carbon dioxide vapor on the other side thereof. The carbon dioxide vapor is bled off the valve in response to the temperature within the refrigerating compartment to cause the pressure differential responsive means in the valve to actuate the valve and to move the valve portion relative to the valve seat opening to open and close the valve. It will be appreciated that when the valve portion is seated against the valve seat, the pressure of the carbon dioxide liquid on the one side of the pressure re-

sponsive means acts only on the difference between the cross-sectional area of the pressure responsive means and the area of the seat opening while the pressure of the carbon dioxide vapor on the opposite side of the pressure differential responsive means acts on the entire cross-sectional area thereof to force and maintain the valve in a closed position. However, once the valve begins to open, that is, as the valve portion rises off the valve seat opening, the force of the liquid carbon dioxide on the one side of the pressure differential responsive means is applied to the entire cross-sectional area of the pressure responsive means and, accordingly, results in a quick snap-acting valve opening.

The instant invention is also directed to the method of spraying liquid carbon dioxide into a compartment. The method of the present invention is carried out by storing a quantity of liquid carbon dioxide under pressure, and periodically discharging a portion of the liquid carbon dioxide into the refrigerating compartment in response to the temperature in the compartment. The discharge of the liquid carbon dioxide into the compartment is rapidly initiated to begin the discharge and is rapidly terminated to end the discharge, thereby quickly bringing the carbon dioxide liquid through the triple point and preventing the formation of solid carbon dioxide. The pressure of the carbon dioxide liquid and the carbon dioxide vapor is utilized to initiate and terminate the discharge.

The invention together with additional objects and advantages will best be understood from the following description of specific embodiments thereof, when read in connection with the accompanying drawings, in which:

FIG. 1 is a somewhat schematic, partly sectional view, of a refrigerated transport compartment equipped with the new refrigerating system according to the present invention;

FIG. 2 is a fragmentary, partly sectional view, of certain components of the refrigerating system according to the present invention;

FIG. 3 is a cross-sectional view of one of the system components, taken along line 3—3 of FIG. 2, and assuming that FIG. 2 shows the entire component;

FIG. 4 is a cross-sectional view of one component of the system, taken along line 4—4 of FIG. 2, and assuming that FIG. 2 shows the complete component;

FIG. 5 is a cross-sectional view of a modified temperature responsive control valve for use in an improved refrigerating system according to the present invention;

FIG. 6 is a cross-sectional view of the valve of FIG. 5, taken along line 6—6 thereof, and assuming that FIG. 5 illustrates the entire control valve;

FIG. 7 is a fragmentary, cross-sectional view of the valve of FIG. 5, illustrated in another of its operating portions;

FIG. 8 is a cross-sectional view of a liquid carbon dioxide discharge valve and nozzle according to another embodiment of the present invention; and

FIG. 9 is a cross-sectional view of a temperature responsive control according to another embodiment of the present invention.

Referring now to the drawings, and particularly to the embodiment of FIGS. 1 to 4 thereof, there is illustrated a refrigerated transport compartment 10 equipped with an improved refrigerating system 11 according to the present invention. The transport compartment 10 may comprise the body of a highway truck or trailer, or of a railroad car, or other transportation medium. The transport compartment 10 is adapted for carrying and transporting crates or other packages of frozen food, meat, ice cream and similar refrigerated items 12.

In order to provide liquid carbon dioxide for the refrigerant, the system 11 includes a tank or pressure vessel 13 containing liquid carbon dioxide 14 under pressure. In order to maintain the carbon dioxide 14 in the vessel 13 liquefied, the pressure within the tank 13 must be

greater than the triple point, i.e., greater than about 75 lbs. per square inch absolute. A pressure range extending from about 150 to about 300 lbs. per square inch absolute is considered to be a satisfactory pressure range for the present invention. The lower portion of this range is desirable because of the increase in the refrigerating effect of liquid carbon dioxide with decrease in pressure. In one embodiment of the present invention, the vessel 13 was filled with liquid carbon dioxide 14 at a pressure of about 250 lbs. per square inch absolute. A liquid carbon dioxide supply conduit 15 extends into the vessel 13 below the level of the liquid carbon dioxide 14 within the vessel 13. It will be appreciated that the space above the liquid carbon dioxide 14 in the vessel 13 is filled with carbon dioxide vapor 16 or carbon dioxide in the gaseous state due to the vapor pressure of the liquid carbon dioxide. A vapor conduit 17 communicates with the carbon dioxide vapor 16. The vessel 13 is additionally provided with a safety pressure relief valve 20 extending externally of the compartment 10 and a filler line 21 and filler valve 22, also extending externally of the transport compartment 10. The vessel 13 is also provided with the usual pressure equalizing line (not shown) for connecting the vapor space of vessel 13 with the vapor space of a supply vessel (not shown) during a filling operation.

The walls of the transport compartment 10 may be provided with suitable insulation material as required by the temperature desired within the compartment. Similarly, the walls of the vessel 13 may be provided with suitable insulating material. Where the pressure vessel 13 is placed within the transport compartment 10 and the compartment 10 is operated at approximately 0° F., or less, the vessel may be installed as shown without insulation. Insulation is preferably applied to the pressure vessel 13 if the operating temperature in the compartment 10 containing the vessel is to be higher, such as 40° F., as may be required for certain types of lading. Of course, the pressure vessel can also be installed outside of the refrigerated transport compartment 10; in such a case it should be well insulated in order to avoid loss of efficiency by heat from outside air.

As a means of spraying the liquid carbon dioxide into the compartment 10, there is provided a spray nozzle or plug 23 which communicates with the liquid carbon dioxide 14 in the vessel 13 through a liquid carbon dioxide discharge control valve 24 and the supply conduit 15. As is best illustrated in FIG. 2, the discharge control valve 24 includes a valve body or housing 24a having an expandable valve or liquid chamber 24b for liquid carbon dioxide. A liquid discharge port or valve seat opening 25 and a liquid inlet port 33 extend through the housing 24a and communicate with the liquid chamber 24b. The spray nozzle 23 is provided with external threads 27 received in internal threads 26 in the liquid discharge port 25. An axial passageway 30 extends through the spray nozzle 23 and the passageway 30 forms a metering orifice 31 at its outer end to provide a spray 32 of liquid carbon dioxide as illustrated in FIG. 1.

The discharge control valve 24 controls the periodic discharge of liquid carbon dioxide through the spray nozzle 23 as required to maintain the desired temperature in the compartment 10. The discharge control valve 24 is pneumatically operable, and, as shown, is actuated by the pressure of the liquid carbon dioxide 14 to bias the valve into an open position, and by the carbon dioxide vapor 16 in the pressure vessel 13 to bias the valve closed. Moreover, the valve 24 is of the quick-acting type so that the volume of liquid carbon dioxide between the valve and the metering orifice 31 is rapidly transferred from the high supply pressure to the pressure of the compartment 10, passing quickly through the triple point pressure so that solidification of the liquid carbon dioxide does not occur within the spray nozzle 23.

The discharge control valve 24 in the illustrated em-

5

bodiment includes a valve stem assembly 34 formed with a valve stem 34a provided with a resilient disk or valve portion 36 at one end which is seatable against a valve seat 37 forming the liquid discharge port 25. In order to move the resilient disk 36 relative to the valve seat 37 to close and open the liquid discharge port 25, the valve stem 34a carries a pressure differential responsive means, here shown as a bellows 40 having its edges sealed to the housing 24a and forming a movable wall of the chamber 24b. The bellows 40 also form a wall of an expandable carbon dioxide vapor chamber 42 for receiving carbon dioxide vapor. A disk or piston 43 is positioned on the end of the valve stem 34a to center the bellows 40 within the valve housing 24a. The stem 34a extends into a guide bore 38 in the housing 24a to further center and align the valve stem assembly 34 with the vapor chamber 42. A plurality of vapor passageways 39 extend through the valve stem 34a interconnecting the vapor chamber 42 and a vapor port 45. A vapor conduit 46 is connected to the vapor port 45 and the conduit 17 to interconnect the vapor chamber 42 and the vessel 13 to provide carbon dioxide vapor to the vapor chamber 42. The resilient disk 36 forms an end portion of the pressure differential responsive means 40, thereby reducing the effective cross-sectional area of the bellows 40 when the disk 36 is seated against the valve seat 37. A compression spring 44 positioned in the vapor chamber 42 is effective to bias the bellows 40 to a valve closed position as illustrated in FIG. 2.

In operation, briefly, carbon dioxide vapor is supplied to the vapor chamber 42 of the valve 24 through the vapor conduit 17, vapor port 45, and passageways 39. With the valve 24 in the closed position illustrated in FIG. 2, the pressure of the liquid carbon dioxide in the liquid chamber 24b will act on the pressure differential bellows 40 on an effective area equal to the cross-sectional area of the bellows 40, less the cross-sectional area of the valve seat opening 25; the pressure of the carbon dioxide vapor in the chamber 42 will always act on an effective area of the bellows 40 equal to the cross-sectional area of the bellows 40. If the carbon dioxide vapor is bled from the vapor chamber 42, the pressure of the liquid carbon dioxide in the liquid carbon dioxide chamber 24b will be effective to raise the resilient disk 36 from the valve seat 37 against the return bias of the carbon dioxide vapor in the vapor chamber 42 and the return bias of the spring 44. Once the resilient disk 36 has lifted from the valve seat 37, the pressure of the liquid carbon dioxide now acts over the entire cross-sectional area of the bellows 40, including the cross-sectional area of the valve seat opening 25, and the valve 24 is quickly opened with a snap action due to the increased effective cross-sectional area of the bellows 40 to the liquid carbon dioxide. In order to close the valve 24, the pressure in the vapor chamber 42 is permitted to build up to approximately equal that of the pressure of the liquid carbon dioxide in the valve chamber 24b. Once the pressure of the liquid carbon dioxide and vaporous carbon dioxide balance each other on respective sides of the bellows 40, the spring 44 is effective to bias the resilient disk 36 toward a valve closing position against the valve seat 37. However, as the resilient disk 36 approaches the valve seat 37, the effective cross-sectional area of the bellows 40 exposed to the liquid carbon dioxide is reduced by the cross-sectional area of the valve seat opening 25 and the restraining force on the bellows 40 is accordingly reduced by a proportionate amount. Consequently, the vapor pressure in the vapor chamber 42 is effective to rapidly close the valve 24 with a snap action.

In order to permit the vapor in the vapor chamber 42 to be bled from the valve 24, the vapor conduit 17 is provided with a flow-restricting means 47, here indicated as a coupling enclosing a porous plug (not shown) having a restrictive passageway therethrough. It will be under-

6

stood that other types of flow restriction devices such as an orifice, a needle valve, a capillary tube in place of conduit 17, etc., may be used to perform the function of flow-restricting means 47. The flow-restricting means 47 permits the carbon dioxide vapor 16 in the vapor chamber 42 to be selectively withdrawn more rapidly than additional vapor can be supplied thereto through the flow-restricting means 47, thereby to reduce the vapor pressure in the vapor chamber 42.

Withdrawal of carbon dioxide vapor from the vapor chamber 42 is controlled by a temperature responsive control means including a temperature sensing device 48 and temperature responsive vapor control valve 50. The temperature sensing device 48 includes a body or housing 49 containing a fluid filled bellows 51 connected to a fluid filled bulb 52 through suitable tubing 53. The fluid filled bulb 52 is exposed to the ambient temperature in the transport compartment 10 and the fluid in the bulb 52 expands and contracts in response to temperature changes within the compartment 10. Specifically, as the temperature in the compartment 10 increases, the fluid in the bulb 52 expands and is pushed into the bellows 51 which then is forced to expand or elongate. As the bellows 51 expands, it pushes against a thrust pin 54 in the housing 49 of the temperature sensing device 48.

The vapor control valve 50 includes a valve body or housing 56 forming a valve chamber 50a. A needle valve 55 within the valve chamber 50a is biased against a valve seat 57 forming a vapor discharge port 58 and communicating with the atmosphere or compartment 10 through an exhaust opening 61. A compression spring 62 in the chamber 50a is positioned to bias the needle valve 55 into a valve closed position. As best illustrated in FIG. 4, the needle valve is of generally square cross section, rounded at its corners, so as to provide a plurality of passageways 63 around the needle valve 55 through the valve chamber 50a. The valve chamber 50a is provided with a vapor inlet passageway 65 which communicates with the vapor chamber 42 in the discharge control valve 24 through a vapor conduit 66 and the conduit 46. The thrust pin 54 extends through the vapor discharge port 58 to engage the needle valve 55. Expansion of the bellows 51 due to a temperature rise in the compartment 10 is effective to move the thrust pin 54 to unseat the needle valve 55, and thereby bleed the vapor from the vapor compartment 42.

In order to provide for manually turning the refrigeration system 11 on and off when the transport vehicle carrying the compartment 10 is in use or is sitting idle, the vapor conduit 66 leading from the vapor control valve 50 to the discharge control valve 24 is provided with a manually controllable shutoff valve 70, FIG. 1. When the valve 70 is closed, carbon dioxide vapor cannot be bled from the gaseous carbon dioxide chamber 42 and the build-up of vapor pressure through the conduit 17 and the flow-restricting means 47 into the vapor chamber 42 will close the discharge control valve 24.

For adjusting the temperature in the compartment 10, the thrust pin 54 and the bellows 51 of the temperature sensing device 48 are selectively positionable relative to the vapor control valve 50 to vary the amount of bellows expansion required to unseat the needle valve 55 through the pin 54. This is readily accomplished in the embodiment of FIGS. 1 to 4 by providing the housing 56 of the vapor control valve 50 with an internally threaded bore 71 axially aligned with the needle valve 55, and providing the housing 49 with an externally threaded projection 72 threaded into the bore 71. The thrust pin 54 extends through an opening 72a in the projection 72 into the vapor discharge port 58 to engage the needle valve 55. The relative positions of the temperature sensing device 48 and vapor control valve 50 are locked by a lock nut 73. Threading the housing 49 of the temperature sensing device 48 relatively outward of the housing 56 of the vapor control valve 50 results in moving the

bellows 51 and associated thrust pin 54 further away from the needle valve 55 so that a greater expansion of the bellows 51 is required to unseat the needle valve 55 and, accordingly, a higher temperature will be required in the compartment 10 in order to actuate the vapor control valve 50 to bleed the carbon dioxide vapor from the discharge control valve 24.

From the above-detailed description, the operation of the improved refrigeration system is believed clear. However, briefly, it will be appreciated that if the carbon dioxide vapor is bled from the vapor chamber 42, the pressure of the liquid carbon dioxide in the expandable valve chamber 24b will be effective to over-ride the restraining force of the carbon dioxide vapor in the vapor chamber 42 and the return bias of the spring 44 to open the valve 24 by lifting the resilient disk 36 from the valve seat 37 thereof. Moreover, due to the sudden change in the effective area of the bellows 40 when the resilient disk 36 is seated on the valve seat 37 and when the resilient disk 36 is lifted from the valve seat 37, once opening or closing of the valve 24 has begun, the opening and closing will thereafter be accomplished quickly and positively.

When it is desired to start up the refrigeration system 11, the manually controlled shutoff valve 70 is opened so that the vapor chamber 42 is placed in communication with the vapor control valve chamber 50a. If the temperature in the refrigerator compartment 10 is above the preselected temperature adjustment of the temperature sensing device 48 and vapor control valve 50, as determined by the relative positioning of these components through the threaded connection of projection 72 and bore 71, the fluid in the fluid filled bulb 52 will be expanded sufficiently to expand the fluid filled bellows 51 causing the thrust pin 54 to hold the needle valve 55 unseated from the valve seat 57. In this position, the vapor chamber 42 is placed in communication with the interior of the compartment 10 through the conduits 46 and 66, the vapor inlet passageway 65, the valve chamber 50a including the passageways 63, the vapor discharge port 58, and the exhaust opening 61. Although carbon dioxide vapor 16 will continuously pass through the flow-restricting means 47, such vapor will be exhausted through the aforementioned exhaust opening 61 and vapor pressure will not build up in the vapor chamber 42. Liquid carbon dioxide 14, on the other hand, will be transported to the valve chamber 24b through the conduit 15 and will act on the bellows 40 to be effective to lift the resilient disk 36 from the valve seat 37 in the above-described manner. The liquid carbon dioxide will then be discharged as a spray through the metering orifice 31 of the spray nozzle 23 and will cool the refrigerated compartment 10.

As soon as the temperature of the compartment 10 has been brought down to the preselected level, the fluid in the fluid filled bulb 52 will contract, permitting the bellows 51 to contract. The compression spring 62 will be effective to bias the needle valve 55 against the valve seat 57 and to terminate the exhaust of carbon dioxide vapor through the exhaust opening 61. With the exhaust of the carbon dioxide vapor terminated, the pressure in the vapor chamber 42 will begin to build up as a result of the vapor which is filtering through the flow-restricting means 47 and when the pressure in the vapor chamber 42 approaches the pressure of the liquid carbon dioxide in the valve chamber 24b the valve stem assembly 34 will be driven into a valve closed position by the compression spring 44 and will operate rapidly and positively as a result of the reduction in the effective area of the bellows 40 as the disk 36 approaches the valve seat 37.

In accordance with the improved method of spraying liquid carbon dioxide into a refrigerated compartment 10, the invention is carried out by storing a quantity of liquid carbon dioxide 14 under pressure above the triple point of approximately 75 lbs. per square inch absolute, for example, at a pressure in the range of 150 to about 300

lbs. per square inch absolute. The liquid carbon dioxide is supplied to a discharge nozzle 23 for discharge into the refrigerated compartment 10 in response to the temperature changes in the temperature sensing device 48. A portion of the liquid carbon dioxide is periodically discharged into the compartment 10 under the control of the discharge control valve 24. Because of the rapid change in the effective area of the pressure differential responsive bellows 40, the discharge of the carbon dioxide is rapidly initiated when the vapor pressure in the vapor chamber 42 is reduced to a level wherein the pressure of the liquid carbon dioxide is sufficient to unseat the resilient disk 36 from the valve seat 37. Similarly, the discharge of liquid carbon dioxide 14 through the spray nozzle 23 is rapidly terminated due to the change in the effective area of the bellows 40 as soon as the resilient disk 36 is biased toward the valve seat 37 by the building up of the vapor pressure in the vapor chamber 42 to approximately the same pressure as the liquid carbon dioxide, thereby permitting the compression spring 44 to bias the valve stem assembly 34 toward a closed position. The rapid initiation and termination of the discharge of the carbon dioxide is effected by the utilization of the pressure of the carbon dioxide liquid and the vapor pressure of the carbon dioxide vapor. The difference obtained in the vapor pressure and the liquid pressure of the carbon dioxide is applied to opposite sides of the pressure differential responsive device 40 under the control of the temperature sensing device 48 and the vapor control valve 50.

In the above-described embodiment, the operating temperature or the temperature at which the vapor control valve 50 begins to open is adjusted by means of the threaded connection between the temperature sensing device 48 and the vapor control valve 60 and then locked in position with the lock nut 73. FIGS. 5 to 7 illustrate an embodiment of the present invention wherein the operating temperature for the transport compartment may be more readily field adjusted. Similar parts of the system of FIGS. 5 to 7 and of the system of FIGS. 1 to 4 are represented by the same reference characters. FIGS. 5 to 7 illustrate a temperature sensing device 48' provided with a housing 49' and including the fluid filled bellows 51 connected to a fluid filled bulb (not shown) through suitable tubing 53. As heretofore described, the fluid filled bulb is exposed to the ambient temperature in the refrigerated compartment and the fluid in the bulb expands and contracts in response to temperature changes within the compartment. As the bellows 51 expands, it pushes against a thrust pin 54 in the body 49' of the temperature sensing device 48'.

There is provided an associated vapor control valve 50' including the needle valve 55 within a valve chamber 50a' of a valve body 56' and biased against the valve seat 57 forming a vapor discharge port 58. The compression spring 62 is effective to bias the needle valve 55 into a closed position.

For adjusting the temperature in the refrigerating compartment, the thrust pin 54 of the temperature sensing device 48' is selectively positionable relative to the vapor control valve 50' to vary the expansion of the bellows required to unseat the needle valve 55 through the pin 54. In the embodiment of FIGS. 5 to 7, this is readily accomplished by providing for axial adjustment of the thrust pin 54 and needle valve 55 by providing an axial aperture 74 in the vapor control valve 50 and an associated projection 75 on the body 49' of the temperature sensing device 48' and slidably positioned within the aperture 74. Relative movement of the projection 75 into the aperture 74 is effective to regulate the amount of bellows expansion necessary to unseat the needle valve 55. The temperature sensing device 48' and the vapor control valve 50' are held in accurate position by a cam arrangement including a temperature setting cam shaft 76 having aligned bearing portions 76a journaled in aligned aper-

9

tures 77 in the body 56'. The bearing portions 76a are interconnected by an eccentrically positioned cam portion 80 passing through a cam follower slot 81 in the valve body 49' of the temperature sensing device 48'. The shaft is provided with a suitable temperature selecting knob (not shown) to provide for manual rotation of the shaft 76. A compression spring 82 biases the temperature sensing device 48' and the vapor control valve 50' away from each other.

In operation, the cam portion 80 of the cam shaft 76 rides against the forward surface of the cam follower groove 81, as illustrated in FIGS. 5 and 7. Rotation of the shaft 76 about the bearing portions 76a thereof is effective to progressively move the cam portion 80 of the shaft 76 from a rearward position as illustrated in FIG. 5 to a forward position as illustrated in FIG. 7, thereby adjusting the relative positioning of the temperature sensing element 48' and the vapor control valve 50'. Accordingly, the temperature in the refrigerated compartment at which the bellows 51 unseats the needle valve 55 may be readily and accurately adjusted.

FIG. 8 illustrates a modified form of liquid carbon dioxide discharge control valve wherein a diaphragm is utilized in place of an expansion bellows. The same reference characters identify similar parts in FIG. 8 and in the preceding figures. The discharge control valve 24' illustrated in FIG. 8 includes a valve body 24a' having an expandable valve chamber 24b' connected to receive liquid carbon dioxide 14 through the supply conduit 15. A discharge port or valve seat opening 25' communicates with the valve chamber 24b'. The spray nozzle 23 is positioned in the discharge port 25' and provided with a metering orifice 31 at its outer end to provide for a spray of liquid carbon dioxide. The body 24a' of the discharge control valve 24 is provided with a liquid carbon dioxide inlet port 33' opening into the valve chamber 24b' and communicating with the valve seat opening 25'. Moreover, the valve 24' includes a valve stem assembly 34' provided with a resilient disk or valve portion 36 seatable against a valve seat 37' forming the discharge port 25'.

In order to move the resilient disk 36 relative to the valve seat 37' to close and open the valve stem opening the chamber 24b', the valve stem assembly 34' is provided with a pressure differential responsive means, here shown as a flexible diaphragm 40'. One side of the diaphragm 40' forms a movable wall of the chamber 24b' through which the liquid carbon dioxide flows, and the other side of the diaphragm 40' forms a wall of vapor chamber 42' for receiving carbon dioxide vapor 16. The resilient disk 36 forms an end portion of the pressure responsive means 40', thereby reducing the effective cross-sectional area of the diaphragm 40' when the disk 36 is seated against the valve seat 37'. A compression spring 44 positioned in the gaseous carbon dioxide chamber 42' is effective to bias the diaphragm 40' toward a valve closed position as illustrated in FIG. 8.

The operation of the above-described valve 24' is similar to the valve 24 heretofore described in detail. Briefly, carbon dioxide vapor is supplied to the vapor chamber 42' of the valve 24' through the vapor conduit 46 and is effective to bias the resilient disk 36 against the valve seat 37'. With the valve 24' in this closed position, the pressure of the liquid carbon dioxide in the valve chamber 24b' will act on the pressure differential diaphragm 40' on an area equal to the cross-sectional area of the diaphragm 40' less the cross-sectional area of the discharge port 25'; the pressure of the carbon dioxide vapor in the vapor chamber 42' will always act on an effective area of diaphragm 40' equal to the cross-sectional area of the diaphragm 40' and will be sufficient, in combination with the bias of the spring 44, to maintain the valve 24' closed. However, if the carbon dioxide vapor is bled from the gaseous carbon dioxide chamber 42' the pressure of the liquid carbon dioxide in the valve chamber 24b' will be effective to raise the resilient disk 36 from

10

the valve seat 37' against the return bias of the vapor in the vapor chamber 42' and the return bias of the spring 44. Once the resilient disk 36 has lifted from the valve seat 37', the pressure of the liquid carbon dioxide now acts over the entire cross-sectional area of the diaphragm 40', including the cross-sectional area of the discharge port 25', and the valve 24' is quickly opened with a snap action due to the increased effective cross-sectional area over pressure differential diaphragm 40' to the liquid carbon dioxide. Similarly, once the pressure in the gaseous carbon dioxide chamber 42' is permitted to build up to approximately equal that of the pressure of the liquid carbon dioxide in the valve chamber 24b', the spring 44 will bias the valve stem assembly 34' into a valve closed position.

In all of the described embodiments, it will be seen that the liquid discharge valve opens and closes rapidly and positively so that there is no appreciable time during which the pressure in the volume between the discharge seat and the metering orifice would remain below the triple point pressure of approximately 75 lbs. per square inch absolute. In accordance with the present invention, the release and admission of the carbon dioxide vapor may be accomplished in any suitable manner, for example, a two-way vapor valve may be placed between the conduits 17 and 46, as illustrated in the embodiment of FIG. 9. The vapor valve would then connect the conduit 46 alternately with the conduit 17 and with an exhaust to atmosphere or to the compartment 10. Referring to FIG. 9, identical components of FIG. 9 and the preceding embodiments are identified by the same characters. Specifically, there is illustrated a two-way vapor control valve 90 having a needle valve 91 which closes a vapor inlet passageway 92 when unseated from a vapor discharge port 93. The vapor discharge port 93 communicates with an exhaust opening 94. The vapor control valve 90 is installed in the system with the vapor inlet passageway 92 connected to the vapor supply conduit 17 and with the vapor conduit 46 from the vapor chamber 42 communicating with a valve chamber 90a thereof through an additional port 95. The vapor control valve 90 is actuated through the temperature sensing device 48 by the thrust pin 54 thereof which extends through the vapor discharge port 93.

In operation, with the compartment 10 at the preselected low temperature, carbon dioxide vapor will be admitted into the vapor chamber 42 through the passageway 92, the valve chamber 90a, and port 95 to close the discharge valve 24. When the temperature in the compartment 10 rises above the preselected setting of the temperature responsive control means, the temperature sensing device 48 will be effective to unseat the needle valve 91 from the vapor discharge port 93, opening the vapor discharge port 93 and closing the vapor inlet passageway 92 so that the vapor chamber 42 is exhausted through the conduit 46, port 95, valve chamber 90a, vapor discharge port 93, and exhaust opening 94.

In all of the described embodiments, it will be seen that the liquid discharge valve opens and closes rapidly and positively so that there is no appreciable time during which the pressure in the volume between the discharge seat and the metering orifice would remain below the triple point pressure of approximately 75 lbs. per square inch absolute. Consequently, the liquid carbon dioxide passes through the valve and is not converted into the solid Dry Ice which would otherwise quickly plug up the metering orifice. Moreover, the discharge control valves of the described embodiment are operated by the liquid and vapor pressure of the carbon dioxide from the pressure vessel 13 and no external electrical or pneumatic power is required to actuate or control the system. The system provides an economical arrangement, low in initial cost, and easy to maintain and operate.

Although certain preferred embodiments have been de-

scribed by way of illustration, many modifications will occur to those skilled in the art. It is therefore intended in the appended claims to cover all such modifications as fall within the true spirit and scope of this invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. Apparatus for refrigerating a compartment comprising a vessel containing liquid carbon dioxide under pressure, nozzle means opening into said compartment for spraying liquid carbon dioxide into said compartment, quick acting valve means having a discharge communicating with said nozzle, conduit means connecting said valve means and said vessel connected to supply liquid carbon dioxide to said valve means, temperature sensing means responsive to the temperature in said compartment, and control means operatively associated with said temperature sensing means connected to actuate said valve means in response to the temperature in said compartment, the pressure of carbon dioxide vapor in said vessel being effective to actuate said valve means under the control of said control means.

2. Apparatus for refrigerating a compartment comprising a tank containing liquid carbon dioxide under pressure, fluid pressure actuated quick acting valve means including a pressure differential responsive means, nozzle means communicating with one side of said pressure differential responsive means and opening into said compartment for spraying liquid carbon dioxide into said compartment, conduit means interconnecting said one side and said tank for supplying liquid carbon dioxide to said valve means, conduit means interconnecting said tank and the other side of said pressure differential responsive means for supplying carbon dioxide vapor to said valve means, flow restricting means in the last mentioned conduit means, temperature sensing means responsive to the temperature in said compartment, and control means operatively associated with said temperature sensing means connected to bleed carbon dioxide vapor from said other side of said pressure differential responsive means under the control of said temperature sensing means.

3. Apparatus as set forth in claim 2 above wherein a portion of said one side of said pressure differential responsive means forms a valve portion seatable against a valve seat to close an opening in the body of said valve means, and wherein said nozzle means communicates with said opening so that when said valve portion is seated on said valve seat the pressure of the liquid carbon dioxide on said one side of said pressure differential responsive means acts on the cross sectional area of said pressure differential responsive means less the cross sectional area of said opening and when said valve portion is unseated from said valve seat opening said pressure acts on the full cross sectional area of said pressure differential responsive means.

4. Apparatus for refrigerating a compartment comprising a tank for storing liquid carbon dioxide under pressure, nozzle means opening into said compartment for spraying liquid carbon dioxide into said compartment, conduit means communicating between said tank and said nozzle means for transporting liquid carbon dioxide from said tank to said nozzle means, quick acting valve means in said conduit means operable in response to the temperature in said compartment, said quick acting valve means being operable by fluid pressure, means operatively interconnecting said valve means and said tank to provide carbon dioxide vapor under pressure from said tank to operate said valve means, and temperature responsive control means controlling said last mentioned means.

5. Apparatus for refrigerating a compartment comprising a tank containing liquid carbon dioxide under pressure, fluid pressure operated quick acting control valve means for said liquid carbon dioxide including a valve housing, a valve stem assembly within said housing, a pressure differential responsive member carried by said stem assembly and sealed with said housing dividing said

housing into a first chamber for liquid and into a second chamber for vapor, said first chamber being provided with a liquid inlet port and a liquid outlet port, a valve seat formed in said housing around said liquid outlet port, a valve portion carried by said stem assembly and movable with said stem assembly to seat against said valve seat, means biasing said stem assembly in a direction to seat said valve portion against said valve seat, a vapor port communicating with said second chamber, nozzle means communicating with said liquid outlet port and opening into said compartment for spraying liquid carbon dioxide into said compartment, conduit means interconnecting said liquid inlet port and said liquid carbon dioxide in said tank for supplying liquid carbon dioxide to said valve means, conduit means interconnecting said tank and said vapor port for supplying carbon dioxide vapor to said valve means, flow restricting means in the last mentioned conduit means, temperature sensing means responsive to the temperature in said compartment, and control means operatively associated with said temperature sensing means connected to bleed carbon dioxide vapor from said second chamber under the control of said temperature sensing means.

6. A quick acting control valve for liquid carbon dioxide and the like comprising a valve housing, a valve stem assembly within said housing, a pressure differential responsive member carried by said stem assembly and sealed with said housing dividing said housing into a first chamber for liquid and into a second chamber for vapor, said first chamber being provided with a liquid inlet port and a liquid outlet port, a valve seat formed in said housing around said liquid outlet port, a valve portion carried by said stem assembly and movable with said stem assembly to seat against said valve seat, means biasing said stem assembly in a direction to seat said valve portion against said valve seat, and a vapor port communicating with said second chamber for supplying vapor to said second chamber and for bleeding vapor from said second chamber.

7. Apparatus for refrigerating a compartment comprising a tank containing liquid carbon dioxide under pressure; fluid pressure operated quick acting valve means including a pressure differential responsive means, nozzle means communicating with one side of pressure differential responsive means and opening into said compartment for spraying liquid carbon dioxide into said compartment; conduit means interconnecting said one side and said tank for supplying liquid carbon dioxide to said valve means; conduit means interconnecting said tank and the other side of said pressure differential responsive means for supplying carbon dioxide vapor to said valve means; flow restricting means in the last mentioned conduit means; a temperature sensing device including a housing, an expandable member in said housing, a temperature sensing bulb positioned within said compartment, conduit means interconnecting said expandable member and said bulb, a temperature sensitive fluid filling said bulb, expandable member, and conduit means, and a thrust member extending from said housing operatively associated with said expandable member; a vapor control valve including a valve body having a valve chamber, a vapor inlet port communicating with said chamber, a vapor outlet port for exhausting vapor from said chamber and forming a valve seat in said housing, a needle valve in said housing, means biasing said needle valve against said seat; means provided on said temperature sensitive device and said vapor control valve for interconnecting said device and said valve with said thrust member engageable to unseat said needle valve in response to expansion of said expandable member; and conduit means interconnecting said vapor inlet port and said other side of said pressure differential responsive means.

8. A method of spraying liquid carbon dioxide into a compartment comprising the steps of storing a quantity of liquid carbon dioxide under pressure, supplying said liquid

carbon dioxide under pressure for discharge into said compartment, and periodically discharging a portion of said liquid carbon dioxide from said pressure to the pressure in said compartment and including the steps of rapidly initiating the discharge of said carbon dioxide to begin said discharge and rapidly terminating said discharge of said carbon dioxide, utilizing the pressure of said liquid carbon dioxide to effect the rapid initiation of the discharge of the said carbon dioxide and utilizing the pressure of carbon dioxide vapor to effect the rapid termination of said discharge of liquid carbon dioxide.

9. A method of spraying liquid carbon dioxide into a compartment comprising the steps of storing a quantity of liquid carbon dioxide under pressure, supplying said liquid carbon dioxide under pressure for discharge into said compartment, and periodically discharging a portion of said liquid carbon dioxide from said pressure to the pressure in said compartment and including the steps of rapidly initiating the discharge of said carbon dioxide to begin said discharge and rapidly terminating said discharge of said carbon dioxide, providing a pressure differential of the pressure of said carbon dioxide to effect the rapid initiation and the rapid termination of said discharge, and controlling said pressure differential in response to the temperature in said compartment.

10. A method of spraying liquid carbon dioxide into a compartment comprising the steps of storing a quantity of liquid carbon dioxide under pressure, transporting said liquid carbon dioxide under pressure for discharge into said compartment and including the steps of passing said liquid carbon dioxide through a valve seat opening in a valve into a discharge means and discharging the carbon dioxide through said discharge means into said compartment, biasing said valve toward an open position by the pressure of the liquid carbon dioxide in said valve, supplying carbon dioxide vapor under pressure from the stored liquid carbon dioxide to said valve, biasing said valve toward a closed position by the pressure of the carbon dioxide vapor, restricting the rate of flow of carbon dioxide vapor to said valve, and periodically bleeding the carbon dioxide vapor from said valve in response to tem-

perature change in said compartment to actuate said valve.

11. Apparatus for refrigerating a compartment comprising a vessel containing liquid carbon dioxide under pressure; fluid pressure operating valve means for spraying liquid carbon dioxide into said compartment including a housing, means forming a first chamber for liquid and a second chamber for vapor within said housing including a pressure differential responsive member disposed between them, said first chamber being provided with a liquid inlet port and a liquid outlet port, first conduit means connecting said vessel to said first chamber for supplying liquid carbon dioxide to said first chamber, second conduit means connecting said vessel to said second chamber for supplying carbon dioxide vapor to said second chamber, a valve seat formed in said housing around said liquid outlet port, a valve member movable by said pressure differential responsive member to seat against said valve seat, said valve member being biased toward an open position by the pressure of liquid carbon dioxide on said valve member, said valve member being biased toward a closed position by the pressure of carbon dioxide vapor in said second chamber, means forming a vapor port communicating with said second chamber, and means for periodically bleeding the carbon dioxide vapor from said second chamber in response to temperature change in said compartment to actuate said valve member toward an open position.

References Cited in the file of this patent

UNITED STATES PATENTS

1,347,689	Fitts	July 27, 1920
2,172,916	Vidal	Sept. 12, 1939
2,337,600	Harris	Dec. 26, 1943
2,475,755	Pearson	July 12, 1949
2,496,816	Schlumbohm	Feb. 7, 1950
2,587,363	Miller	Feb. 26, 1952
2,665,072	Ray	Jan. 5, 1954
2,968,161	Bliss	Jan. 17, 1961
2,988,898	Hesson et al.	June 20, 1961
3,014,664	Meyer et al.	Dec. 26, 1961