

[54] **METHOD AND SYSTEM FOR COOLING MATERIAL USING CARBON DIOXIDE SNOW**

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[58] Field of Search **62/10, 50, 1, 54, 62/55, 62, 514**

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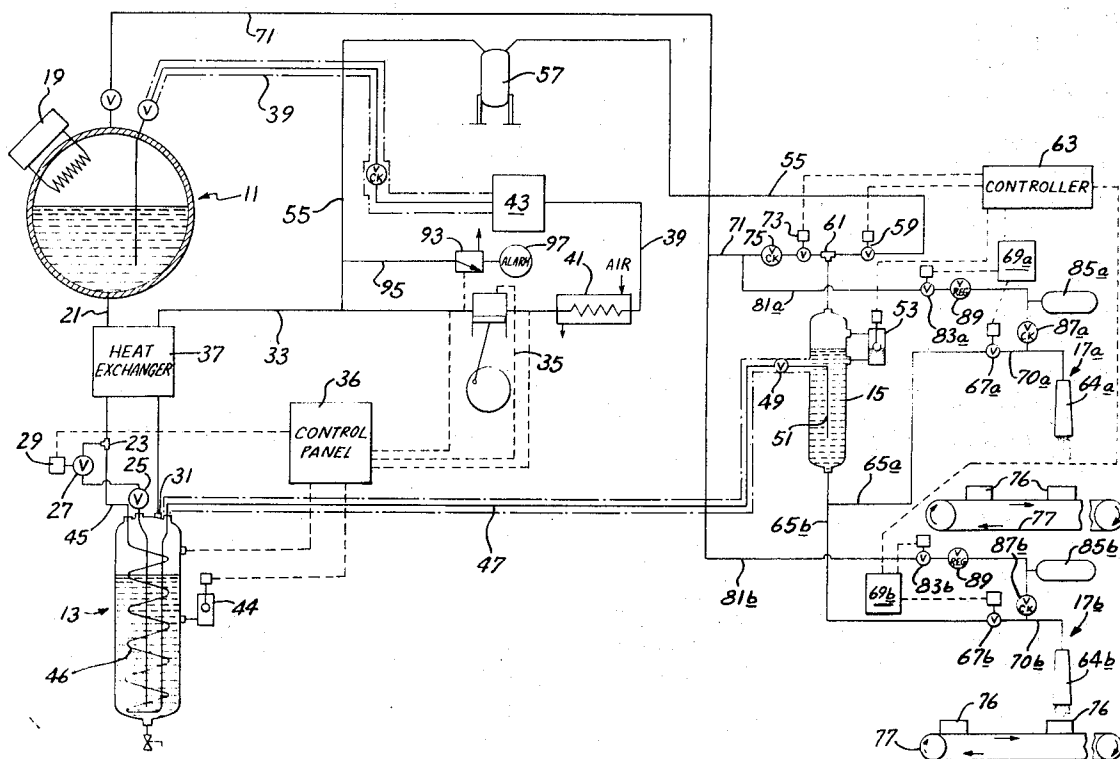
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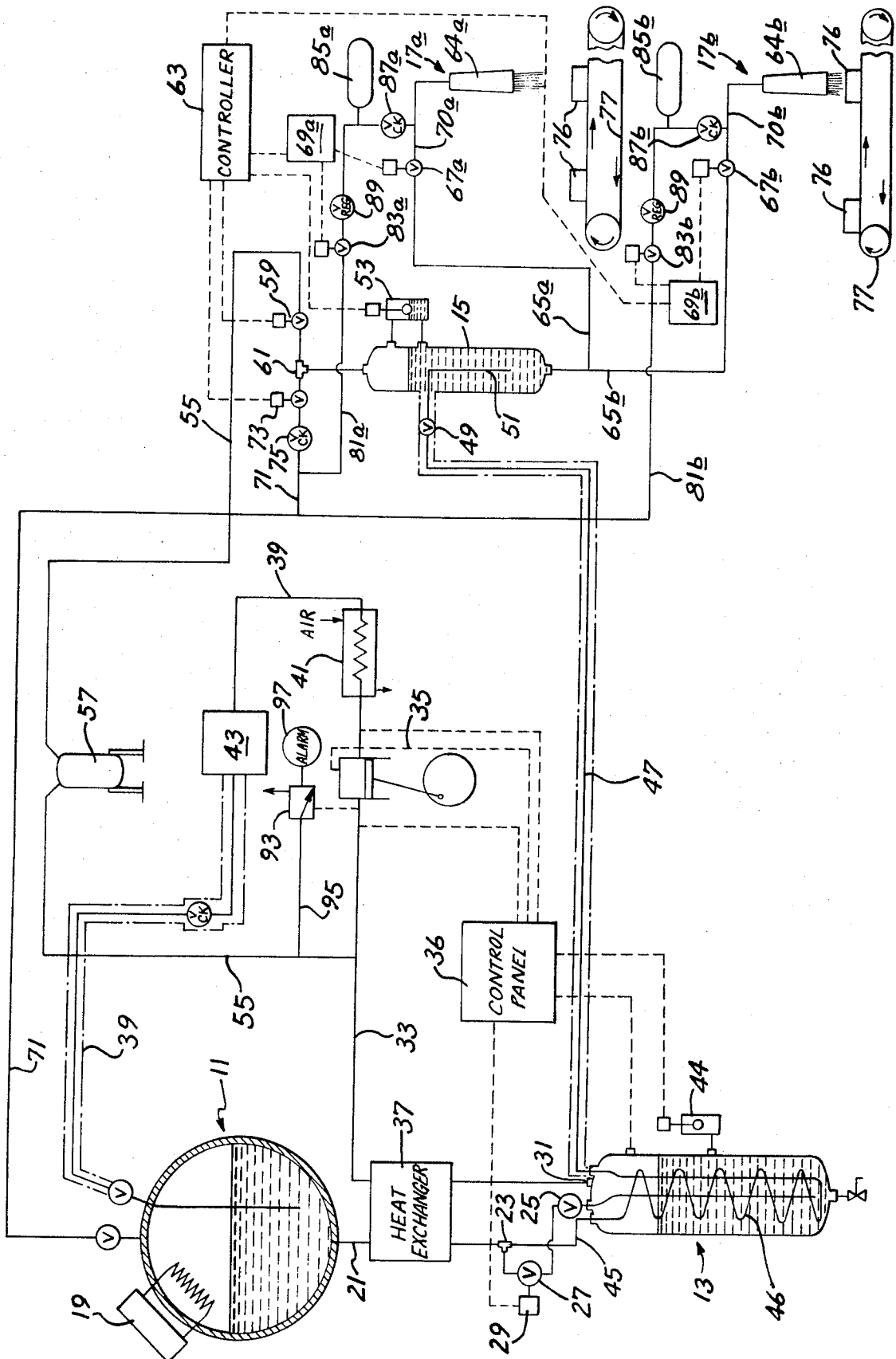
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[57] ABSTRACT

High pressure liquid CO₂ from a storage vessel is sub-cooled by flashing a portion of a liquid stream therefrom to liquid plus vapor and passing the remaining portion of the liquid stream in heat-exchange therewith. The lower pressure vapor, which is compressed and returned to the storage vessel, is used to transfer the subcooled liquid CO₂ to a holding tank which may be located at a substantial distance from and above the storage vessel. High pressure vapor from the storage vessel is employed to intermittently supply subcooled high pressure CO₂ to one or more snow-making devices, located closer to the holding tank, which apply CO₂ snow to the material being cooled. High pressure vapor is also employed to prevent snow formation in the system upstream of the snow-making devices.

13 Claims, 1 Drawing Figure





METHOD AND SYSTEM FOR COOLING MATERIAL USING CARBON DIOXIDE SNOW

This application is a continuation-in-part of my application Ser. No. 14,525, filed Feb. 26, 1970 now U.S. Pat. No. 3,660,985.

This invention relates to the production of solid carbon dioxide snow for cooling material, and more particularly to systems for cooling material by the application of carbon dioxide snow at locations separated substantial distances from carbon dioxide storage vessels.

Liquid carbon dioxide is delivered to and maintained within standard carbon dioxide storage vessels at a pressure of about 300 psig. and a temperature of about 0° F. Liquid carbon dioxide, generally after transformation to carbon dioxide snow, has come into wider and wider use throughout the United States for the cooling and/or freezing of material, particularly food products. Generally, liquid carbon dioxide is delivered to the installation of the user by tank truck or the like and is pumped from the tank to an easily accessible storage vessel located at ground level. Oftentimes, the points of ultimate use in a plant of the user are located a considerable distance from the storage vessel, and in many instances, a point of end use may be located one or two or more stories vertically above the ground level storage vessel. Heretofore, auxiliary pumps have been employed to provide sufficient hydraulic head to maintain high pressure in the liquid carbon dioxide lines at distantly located snow-making devices. Such pumps require maintenance and inherently at least slightly raise the temperature of the liquid carbon dioxide being circulated. Moreover, when two snow-making devices are located adjacent one another on the upper floor of a plant, separate conduit systems and pumps have been installed to provide available liquid capacity should both systems be operated at the same time. All of these factors have increased the complexity and decreased the efficiency of liquid carbon dioxide cooling systems. More efficient systems have accordingly been desired.

It is an object of the present invention to provide efficient systems for producing carbon dioxide snow. Another object is to provide efficient apparatus for cooling material by the application of carbon dioxide snow. Still another object is to provide an improved system for producing carbon dioxide snow from intermittently operated snow-making devices. A further object is to provide an efficient system for operation with normal liquid carbon dioxide storage vessels to provide for the efficient production of carbon dioxide snow for cooling material at distant locations using a plurality of snow-making devices. These and other objects of the invention should be apparent from the following detailed description of a system embodying various of the features of the invention when read in conjunction with the illustrated diagrammatic drawing of such a system.

Briefly, an efficient system has been found for producing carbon dioxide snow for cooling material using a plurality of snow-making devices located a substantial distance from the carbon dioxide storage vessel. The high pressure liquid carbon dioxide available at a standard storage vessel 11 is first subcooled by expanding liquid carbon dioxide from the storage vessel to create a reservoir of very cold liquid CO₂ plus vapor in a heat-exchanger 13 and passing the main stream of high pressure liquid carbon dioxide in heat-exchange with this reservoir to subcool the liquid, for example, to a tem-

perature between about -40° f. to -70° F. The subcooled liquid is then caused to flow to a chamber or holding tank 15 located generally adjacent snow-making devices 17a and 17b which will apply the snow to the material being cooled or frozen.

Interconnection between the low pressure vapor created in the heat-exchanger 13 and the holding tank 15 is utilized to create a pressure differential which induces the flow of the high pressure liquid from the storage vessel 11 through the heat-exchanger 13 and into the holding tank 15 where the subcooled liquid is then ready for immediate use. When one of the snow-making devices 17 calls for the supply of liquid CO₂ for expansion to CO₂ snow for cooling, the connection with the low pressure vapor is broken, and the holding tank 15 is interconnected with the high pressure vapor available in the storage vessel 11. Most of this available pressure is used to supply high pressure, subcooled liquid CO₂ to the expansion nozzles of the snow-making devices 17. As a result, extremely efficient operation of snow-making devices 17 located substantial vertical and horizontal distances from the liquid CO₂ storage vessel 11 is achieved without the employment of circulating pumps.

Referring now to the drawing, a standard carbon dioxide liquid storage vessel 11 is illustrated which is designed for the storage of liquid carbon dioxide at about 300 p.s.i.g. and 0° F. A refrigeration unit 19 is associated with the storage vessel 11 and is designed to operate continuously, if necessary, to condense carbon dioxide vapor in the vessel to liquid. The capacity of the refrigeration unit 19, which may be a freon condenser or some similar unit commonly used for this purpose, is determined by the intended operating conditions of the overall installation. For example, if a number of snow-making devices 17 are employed within the plant, it may be desirable to utilize a refrigeration unit 19 that can condense 850 pounds of carbon dioxide an hour at approximately 300 p.s.i.g., an overall capacity of some 8,400 pounds of carbon dioxide a day.

A conduit 21 leads from the liquid phase of the storage vessel to a tee member 23 generally adjacent the heat-exchanger 13. A portion of the liquid flow through the conduit 21 is directed through one leg of the tee 23 to an expansion valve 25, or any such similar expansion means, leading to the shell side of the heat-exchanger 13. The flow of liquid to the expansion valve 25 is controlled by a valve 27 which is opened or closed by a solenoid 29. The expansion valve 25 is designed to efficiently expand the liquid carbon dioxide, which enters at a pressure of about 300 p.s.i.g., to a lower pressure, e.g., about 70 p.s.i.g. At about 70 p.s.i.g., a liquid-vapor carbon dioxide mixture is formed which has an equilibrium temperature about -65° F., and such a reservoir of lower temperature fluid is maintained on the shell side of the heat-exchanger 13.

Maintenance of the desired fluid pressure on the shell side of the heat-exchanger 13 is accomplished by withdrawing carbon dioxide vapor from an upper outlet 31 through a conduit 33 leading to the intake of a compressor 35 that is controlled through a control panel 36. The conduit 33 directs the exiting vapor through the shell side of a vapor-liquid heat-exchanger 37 which is also connected in the conduit 21. Accordingly, the high pressure liquid carbon dioxide leaving the storage vessel 11 passes through the tube side of this heat-exchanger 37, thereby flowing in heat-exchange rela-

tionship with the cold vapor leaving the main heat-exchanger 13. Thus, the cooling capacity of the cold low pressure vapor is utilized to precool the high pressure liquid carbon dioxide being supplied from the storage vessel 11, and depending upon a particular installation, heat-exchange with the cold vapor may cool the liquid carbon dioxide about 10° F. However, it should be understood that the use of the heat-exchanger 37 is optional, and if for example it may be desired to have the compressor 35 operate at a lower temperature, this may provide a reason for omitting the heat-exchanger 37.

The compressor 35 raises the pressure of the liquid carbon dioxide sufficiently, i.e., to about 300 p.s.i.g., to discharge it into the storage vessel 11 through a return conduit 29. The high pressure gas is relatively warm as a result of the heat absorbed in the compressor 35, and an air-cooled heat-exchanger 41 or the like is preferably installed in the return conduit 39 in order to initially extract some of this heat from the vapor. If desired, another heat-exchanger (not shown) can be disposed following the heat-exchanger 41, and the other side of this heat-exchanger connected to the cold vapor line 33 between the heat-exchanger 37 and the compressor 35 to thus further utilize the cold temperature of the vapor flowing toward the compressor 35 to remove heat.

The return conduit 39 is located to bubble the warm high pressure vapor into the liquid phase of the carbon dioxide in the storage vessel, and thus the body of liquid carbon dioxide acts as a thermal flywheel. The refrigeration unit 19 associated with this storage vessel 11 is accordingly usually utilized to carry out the reliquification of the high pressure vapor. Depending upon the relative capacity of the storage vessel 11 and the capability of the associated refrigeration unit 19, and depending upon the intended rate at which carbon dioxide will be expanded to create snow at the snow-making devices 17, it may be desirable to include an auxiliary condenser 43 in the return conduit 39. This would hold particularly true for a system being installed as a part of pre-existing equipment wherein the original rated capacity may be lower than intended. The return conduit 39 is preferably insulated downstream of such an auxiliary condenser.

The desired liquid level is maintained within the main heat-exchanger 13 by a level-reading device 44 operating through the control panel 36. The valve 27 is opened to supply more liquid CO₂ to the expansion valve 25 whenever the liquid reaches a preset minimum depth, and the valve 27 is closed when a preset maximum depth is reached. The operation of the compressor 35 is controlled by reading the vapor pressure in the upper portion of the heat-exchanger 13. The control panel 36 is set to drive the compressor 35 whenever the pressure exceeds a desired value by about 5 p.s.i. and to halt operation of the compressor 35 when the vapor pressure reaches a preselected lower limit, e.g., about 5 p.s.i. below the desired value. For example, the control panel may be employed to maintain the liquid-vapor mixture on the shell side of the heat-exchanger 13 at a pressure between about 65 p.s.i.g. and about 75 p.s.i.g., the equilibrium temperature of carbon dioxide in this pressure range being about -65° F.

The liquid carbon dioxide flowing through the other leg of the tee member 23 travels through a line 45 to a helical coil which constitutes the tube side of the heat-exchanger 13. The high pressure liquid carbon di-

oxide flowing through the coil is efficiently cooled by the cold liquid-vapor mixture on the shell side of the heat-exchanger 13. Depending upon the rate at which liquid carbon dioxide travels through the coil, the high pressure liquid carbon dioxide can be cooled to a temperature within about 10 or 15° of the temperature of the low temperature liquid-vapor mixture therein. Generally, the high pressure carbon dioxide is subcooled to at least about -40° F. or -50° F.

The subcooled liquid CO₂ exiting from the heat-exchange coil 46 flows through an insulated conduit 47 leading to a fill tube 51 located in the holding tank 15. Although a valve 49 may be provided in the line 47, it is not utilized during normal operation and is maintained in the open position. A liquid level control mechanism 53 is connected to the holding tank 15 and maintains the desired minimum liquid level within the holding tank 15 as explained hereinafter.

The holding tank 15 is desirably located in the vicinity of the snow-making devices 17 where the expansion to CO₂ snow will occur, and accordingly it may be located on the fourth or fifth floor of a building where the carbon dioxide storage vessel 11 is located on the ground floor. To cause the filling of the holding tank 15 to the desired level to occur, an interconnection is provided between the cold vapor line 33 and the upper portion of the holding tank 15. A conduit 55 connects to the cold vapor line 33 at a location between the heat-exchanger 37 and the compressor 35, and the conduit 55 desirably contains an accumulator 57. The other end of the conduit 55 is connected through a solenoid-operated valve 59 to a tee 61 leading to the upper end of the holding tank 15.

The solenoid-operated valve 59 is actuated by a main control mechanism 63 which is interconnected electrically with the liquid level control mechanism 53. Accordingly, when the liquid level controller 53 indicates that the level within the holding tank 15 is below its minimum setting, the valve 59 is opened (unless snow-making is proceeding as explained hereinafter) thus causing the pressure above the liquid in the holding tank to drop to approximately that on the shell side of the heat-exchanger 13, e.g., about 70 p.s.i.g., and causing liquid CO₂ to be drawn into the tank through the fill tube 51 which discharges into the bottom region thereof.

In the illustrated installation, the holding tank 15 serves a pair of snow-making devices 17a and 17b, each of which is illustrated as including a standard snow horn 64 which includes a centrally located, fixed orifice nozzle. A pair of branch lines 65 lead from the exit opening from the bottom of the holding tank 15, and each contains a solenoid-operated valve 67 which is connected to a controller 69. The controllers 69a and 69b are each connected back to the main control mechanism 63. The supply valves 67 are each connected by a conduit 70 to the snow horns 64.

The pressure of the subcooled liquid carbon dioxide in the holding tank is dropped in order to induce the filling of the tank; however, as soon as filling to the desired level is completed, the valve 59 is closed. In order to repressurize the holding tank 15 whenever one of the snow-making devices 17 calls for the supply of the subcooled liquid carbon dioxide to create snow, the other leg of the tee member 61 leading to the upper end of the holding tank 15 is connected via the conduit 71 to the vapor phase of the liquid storage vessel 11. Accord-

ingly, whenever a solenoid-operated valve 73 in the line is opened, the high pressure vapor in the liquid storage vessel 11 is made available to pressurize the holding tank 15. A check valve 75 in the line 71 permits vapor flow in only one direction, and the check valve 75 is appropriately loaded to require a sufficient amount of force to hold it open to decrease the vapor pressure at the tee 61 to a valve just below the liquid pressure in the fill tube 51. This arrangement assures against having liquid flowing backward in the line 47 during snow-making; actually the withdrawal of liquid CO₂ for snow-making induces some simultaneous refilling from the line 47 through the submerged fill tube 51.

Whenever one of the snow-making devices 17 calls for the supply of liquid CO₂ for expansion to snow, the signal from the controller 69 which opens the valve 67 causes the main control mechanism 63 to close the low pressure vapor valve 59, should it happen to be open, and open the high pressure vapor valve 73. As a result, the high pressure vapor available at the upper surface of the subcooled liquid in the holding tank 15 forces liquid CO₂ to flow through the respective branch conduit 65 to the expansion nozzle in the snow horn 64 where it is transformed into snow and vapor. The snow created is directed against the material being cooled, which in the drawing is illustrated as containers 76 of material which are transported intermittently along conveyers 77. Because the high pressure vapor available in the storage vessel 11 will remain within a fairly narrow pressure range, the pressure of the subcooled liquid CO₂ supplied to the snow horns 64 will be substantially constant. As a result, the metering orifices in the snow horns 64 will create a predictable amount of snow in a unit of time, and thus a time interval can be accurately used to provide a desired amount of snow for one container 76.

A branch line 81 from the high pressure vapor line 71 is connected to each of the snow-making devices 17. Each branch line 81a and 81b contains a solenoid-actuated valve 83 that is connected to the controller 69 which is designed to open the valve 83 at the same time as, or just prior to the time, the supply valve 67 is opened to feed high pressure liquid CO₂ to the snow nozzle. Each branch line 81 also contains an accumulator 85 and a check valve 87. The conduit leading from the check valve 87 is connected into the liquid supply line at a location just downstream of the supply valve 67.

As previously indicated, the snow-making devices 17 are designed to operate intermittently, as for example in a case where a container 76 of meat or poultry that has been readied for shipment is then blanketed with carbon dioxide snow. A pressure regulator 89 is set to supply vapor to the check valve 87 at a pressure at least about 10 to 15 p.s.i. below the pressure at which the liquid CO₂ is being supplied to the expansion nozzle in the snow horn 64. Accordingly, when both of the valves 67 and 83 are open, the high pressure vapor will not flow past the check valve 87; however, the accumulator 85 will fill with CO₂ vapor at the pressure set by the regulator 89.

When the creation of snow for the desired cooling operation is completed and the operator halts snow-making, the controller 69 simultaneously closes both of the valves 67 and 83, and if the other snow-making device 17 is not operating, the main controller 63 closes the valve 73. As soon as the liquid pressure drops in the

supply line 70, the check valve 87 immediately opens, and the vapor from the accumulator 85 begins to flow through the line 70 and out the orifice, flushing therefrom all of the liquid CO₂ downstream of the supply valve 67. This gas flushing which is carried out at the fairly high pressure of the vapor in the accumulator 85 assures that transformation of the liquid CO₂ to solid CO₂ snow does not occur upstream of the orifice in the snow horn 64. Because of its nature, liquid CO₂ is easily transformed to solid CO₂ as a result of any pressure drop below the critical pressure, i.e., about 77 p.s.i.a., and a blockage within the supply line 80 leading to the snow-making orifice will require shutdown for maintenance and corresponding loss of production. Instead of using the accumulator 85 to store a predetermined amount of vapor, the controller 69 may be employed to allow the vapor supply valve 83 to remain open for a predetermined time interval after closing the liquid supply valve 67 and thereby regulate the gas flushing in this manner. Moreover, the opening of the valve 83 slightly before the valve 67 is opened will provide the higher CO₂ vapor pressure downstream of the valve 67 when it opens (rather than atmospheric pressure), thus guarding against any instantaneous the locally just downstream of the valve 67.

As can be seen in the illustrated installation, a pair of snow-making devices 17a and 17b are fed from a single holding tank 15. The control system and the size of the conduits used are such that both of the snow-making devices 17 can be operated at the same time should both operations happen to call for snow-making during the same time period. Because both of the snow-making devices 17 are designed for intermittent operation, there will be dwell periods between snow-making operation when neither will be calling for supply of high pressure liquid CO₂ for snow-making. During these dwell periods, refilling of the holding tank 15 to the desired level is carried out automatically by opening the low pressure vapor valve 59, as previously explained. Of course, as mentioned hereinbefore, filling of the holding tank 15 is induced simultaneous with withdrawal. The capacity of the holding tank 15 is appropriately selected so that an adequate safety margin is provided so that the holding tank 15 will not be exhausted of subcooled liquid before it has the opportunity to be specifically refilled.

An additional feature of the system is the provision in the low pressure vapor line 55 of a pilot-operated valve 93 which is connected in a branch conduit 95 leading from the low pressure line at a location between the compressor 35 and the heat-exchanger 37. The discharge side of the pilot-operated valve 93 leads either to a reserve accumulator (not shown) or to the atmosphere at a location exterior of the building. The pilot-operated valve 93 is set to open if the vapor pressure reaches a value a predetermined amount, e.g., 15 p.s.i., above the upper vapor pressure limit at which the compressor 35 is set to go into operation. The pilot-operated valve 93 opens when this pressure is reached and simultaneously actuates an alarm or signal system 97 which may be both visual and audible. The valve 93 remains open until the vapor pressure in the line 55 drops to a lower value, which would usually be the same as the minimum value at which the compressor 35 is set to halt operation. As a result of this auxiliary arrangement, snow-making operation can be maintained even though some malfunction in the compressor oper-

ation may occur. This arrangement permits production to be carried on while repairs to the compressor 35 are being effected, and this may well prove to be quite important to food industry operations wherein continuous capability of cooling the products being produced is all important.

The establishment of the holding tank 15 provides a reservoir of extremely cold liquid carbon dioxide in the vicinity of the point of ultimate use which can supply a plurality of snow-making devices 17. The system avoids the need for providing an auxiliary circulating pump for each snow-making device and accordingly avoids the line losses, the power requirements and the maintenance of such a system. Moreover, the reservoir of extremely cold liquid carbon dioxide, which is ready for supply immediately and under high pressure to a snow-making device, will be efficiently transformed to greater than 50 percent by weight of carbon dioxide snow because of its low temperature and high pressure. Although the system itself is relatively simple, protection is inherently provided against blockages within the supply conduits leading to the snow-making orifices in the snow horns 64 which could give rise to maintenance problems, and thus trouble-free operation is routinely accomplished.

Modifications to the illustrated embodiment as would be obvious to one having the ordinary skill in the art are considered to fall within the scope of the invention which is defined by the claims appended hereto.

Various of the features of the invention are set forth in the claims which follow.

What is claimed is:

1. A method for cooling material using CO₂ snow, which method comprises supplying high pressure liquid CO₂ to heat-exchange means from a storage vessel containing liquid CO₂ and CO₂ vapor, expanding said high pressure liquid CO₂ to produce a zone of lower pressure lower temperature liquid CO₂ plus vapor at one side of the heat-exchange means, withdrawing vapor from said lower pressure zone and compressing said withdrawn vapor and returning the compressed vapor to the storage vessel, passing additional high pressure liquid CO₂ in heat exchange with said lower pressure liquid to subcool said additional high pressure liquid CO₂, supplying said subcooled liquid CO₂ to a holding tank by periodically connecting the holding tank to said lower pressure zone, intermittently applying high pressure to said subcooled liquid CO₂ in said holding tank and causing said subcooled liquid CO₂ to flow from the holding tank to snow-making means, expanding said subcooled liquid CO₂ in the snow-making means to create CO₂ snow and applying said CO₂ snow to material to be cooled.

2. A method in accordance with claim 1 wherein high pressure is applied to the holding tank by interconnection with the vapor portion of the storage vessel.

3. A method in accordance with claim 1 wherein liquid CO₂ is supplied from the holding tank to a plurality of snow-making means.

4. A method in accordance with claim 1 wherein subsequent to said intermittent snow-making, the snow-making means is flushed with CO₂ vapor from the storage vessel to prevent the formation of solid CO₂ upstream of orifice means in the snow-making means.

5. A method in accordance with claim 4 wherein CO₂ vapor is also supplied to said snow-making means just

prior to said intermittent flow of liquid CO₂ to said snow-making means.

6. A system for cooling material using CO₂ snow, which system comprises a storage vessel for holding liquid CO₂ and CO₂ vapor at high pressure, a device for making CO₂ snow and applying said CO₂ snow to material to be cooled which device is spaced a substantial distance from said storage vessel, a holding tank located relatively near said snow-making device, heat-exchange means, first means for supplying high pressure liquid CO₂ from said storage vessel to said heat-exchange means, means connected to said supply means for expanding the high pressure liquid CO₂ to produce lower pressure lower temperature liquid CO₂ plus vapor at one side of said heat-exchange means, second means for supplying high pressure liquid CO₂ from said storage vessel to the other side of said heat-exchange means to thereby pass high pressure liquid CO₂ through said heat-exchange means to subcool said high pressure liquid CO₂, a compressor, first conduit means interconnecting the compressor inlet and the vapor section of said one side of said heat-exchange means and the upper portion of said holding tank, first valve means in said first conduit means for isolating said holding tank therefrom, a line connecting the discharge of said compressor to said storage vessel, second conduit means connecting a subcooled liquid CO₂ outlet from said heat-exchange means to said holding tank, third conduit means connecting said holding tank to said snow-making device, third valve means in said third conduit means, fourth conduit means interconnecting said holding tank and the vapor section of said storage vessel, fourth valve means in said fourth conduit means and control means interconnected with said first, third and fourth valve means, said control means being operable to close said third and fourth valve means and to open said first valve means to cause subcooled high pressure liquid CO₂ to flow into said holding tank and said control means also being operable to close said first valve means and to open said third and fourth valve means to cause high pressure subcooled liquid CO₂ to be supplied from said holding tank to said snow-making device to create CO₂ snow for application to material to be cooled.

7. A system in accordance with claim 6 wherein a plurality of snow-making devices are provided and connected to said holding tank by said third conduit means and wherein separate third valve means is provided for each of said snow-making devices.

8. A system in accordance with claim 6 wherein said first conduit means includes a vapor accumulator.

9. A system in accordance with claim 6 wherein means is provided in said first conduit means for maintaining the CO₂ vapor pressure supplied to said holding tank at a value less than the pressure of said subcooled liquid CO₂ in said second conduit means.

10. A system in accordance with claim 6 wherein means is provided for operating said compressor whenever the vapor pressure on said one side of said heat-exchange means reaches a preselected value and wherein said first conduit means includes additional valve means set to open at a pressure a predetermined amount above said preselected value and thereby maintain the vapor pressure in said first conduit means well below the pressure of the subcooled liquid CO₂ in said second conduit means.

11. A system in accordance with claim 6 wherein means is provided for supplying CO₂ vapor at at least about 80 p.s.i.a. to said third conduit means at a location between said third valve means and said snow-making device for flushing liquid CO₂ therefrom at the closing of said third valve means.

12. A system in accordance with claim 11 wherein said flushing CO₂ vapor supply means includes an interconnection with said fourth conduit means, a vapor ac-

cummulator and check valve means located between said accumulator and said third conduit means.

13. A system in accordance with claim 11 wherein said control means is connected to said flushing CO₂ vapor supply means and is operable to supply CO₂ vapor to said third conduit means just prior to the opening of said third valve means and at a pressure less than that of said high pressure subcooled liquid CO₂.

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