METHOD AND APPARATUS FOR CARBON DIOXIDE COOLING

Apparatus for cooling articles using carbon dioxide as a refrigerant including an enclosure adapted for cooling articles to be conveyed therethrough and a cooling system having snow nozzles in the upper portion thereof. A heat-exchanger is disposed in a lower portion of the enclosure and a conduit connects a source of high pressure CO₂ to the inlet of the heat-exchanger. The outlet from the heat-exchanger is connected to the snow nozzles whereby snow falling into the lower portion of the enclosure and coming to rest on the heat-exchanger absorbs heat during its change of state thereby precooling the high pressure CO₂. The orifice openings in the nozzles are varied with pressure, and blowers assure a blizzard of snow is created within the enclosure.

17 Claims, 3 Drawing Figures
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This invention relates to carbon dioxide refrigeration systems and more particularly to methods for cooling articles using carbon dioxide as a refrigerant and to apparatus for performing such methods.

Mechanical refrigeration units, including those of the air blast type, have long been employed for cooling and freezing articles. More recently, systems employing cryogenics, particularly liquid nitrogen, have begun to enter the commercial market. Carbon dioxide is considered to be excellently suited for use in refrigeration systems of this type, particularly those wherein an expendable refrigerant is employed. Solid carbon dioxide exhibits the advantage of exceptionally good weight efficiency, plus a temperature which is much closer to the freezing point of water than liquid nitrogen.

Various systems have been developed to utilize the refrigeration advantages of carbon dioxide; however, none of the systems has been without drawbacks. Many of these systems have employed a grinding operation wherein large blocks of solid carbon dioxide are reduced to a granular size for the ultimate refrigeration operation, and such systems are considered to be inherently inefficient, giving rise to additional loss of refrigeration capacity to sublimation which occurs in the grinding operation. Thus, improved refrigeration systems for the utilization of carbon dioxide as a refrigerant are desired.

It is an object of the present invention to provide improved refrigeration systems employing liquid carbon dioxide as a refrigerant. Another object is to provide improved methods of cooling articles using the flashing of high pressure liquid carbon dioxide to carbon dioxide snow. A further object is to provide efficient apparatus for utilizing liquid carbon dioxide for the cooling and/or freezing of articles.

These and other objects of the invention should be apparent from a reading of the following detailed description of systems embodying various features of the invention, in conjunction with the accompanying drawings wherein:

FIG. 1 is a diagrammatic view of a refrigeration system embodying various of the features of the invention designed to cool articles which are moved along a conveyor;

FIG. 2 is an enlarged view of one of the snow nozzles shown in the system illustrated in FIG. 1; and

FIG. 3 is a view similar to FIG. 2 of an alternative embodiment of a snow nozzle.

A refrigeration system is diagrammatically illustrated by an enclosure 11 through which articles 13 to be cooled are passed on a moving conveyor 15. Liquid carbon dioxide under high pressure is expanded through a plurality of snow nozzles 17 to create a number of showers of snow within the enclosure. Efficient maintenance of the snow as a blizzard which substantially fills the portion of the enclosure to the left of a vertical baffle 19 is accomplished by the strategic location of several blowers 21 within the enclosure. The snow which falls to the bottom of the enclosure 11 comes to rest upon a lower, hollow heat-exchange plate 23, and the cooling capacity of this snow is utilized to precool the liquid carbon dioxide flowing toward the nozzles 17, thereby increasing the percentage of snow created at the expansion nozzles. Excellent temperature control within the enclosure 11 is maintained by appropriately sensing the temperature and changing the size of the orifices of the nozzles 17 to either increase or decrease the amount of snow created. As a result, the illustrated system provides for fast, efficient cooling of articles 13 and is well adapted to handle a fairly high capacity flow of articles therethrough.

More specifically, a standard carbon dioxide liquid storage vessel 18 is employed which is designed for the storage of liquid carbon dioxide at about 300 psig, and 0° F. An accompanying refrigeration unit 27, such as a freon condenser, is associated with the storage vessel 25 and is designed to operate continuously, if necessary, to condense carbon dioxide vapor in the vessel. The capacity of the freon condensing unit 27, which is a well known device often used for this purpose, is determined by the operating conditions of the overall installation. It may, for example, be designed to condense about 50 pounds of liquid carbon dioxide an hour at about 300 psig, to support an inventory of some 1,200 pounds of carbon dioxide in the vessel. A line 29 connects the liquid phase of the storage vessel to a suitable pump 31 which provides the necessary head for pumping high pressure liquid CO₂ through the cooling system to accomplish the snow production desired. The high pressure liquid leaving the pump 31 flows to a tee member 33. One leg of the tee member 33 directs the high pressure liquid to an expansion valve 35 or any such similar expansion means leading to a separation tank 37. The flow of liquid through the expansion valve 35 is controlled via a solenoid (not shown) or the like. The expansion valve 35 is designed to efficiently expand the liquid CO₂, which may enter under a pressure of between about 300 psig and about 450 psig, to a vapor-liquid mixture at about 70 psig. Such a mixture has an equilibrium temperature of about -65° F.

Carbon dioxide vapor from the separation tank 37 exits via an upper outlet where it flows through a line 39 to the intake of a compressor 41 which is driven by a suitable motor (not shown). The compressor 41 is operated intermittently to maintain the desired conditions within the separation tank 37 by withdrawing vapor whenever the temperature within the tank rises above a certain predetermined temperature level. The compressor 41 raises the pressure of the carbon dioxide vapor to a sufficient valve to discharge it to a line 43 back into the storage vessel 25, i.e., a bore about 300 psig. The high pressure gas is relatively warm as a result of the heat absorbed in the compressor 41, and a water-cooled heat exchanger 45 or the like may be installed in the return line 43 in order to extract some of the heat from the vapor before it is returned to the storage vessel 25. A check valve 47 is installed in the line 43 to prevent flow in the opposite direction in the return line. Furthermore, a condenser, may, if desired, be installed in the return line 43 to reliquify the vapor before it is returned to the storage vessel 25. However, the warm, high pressure vapor can be bubbled into the liquid carbon dioxide phase in the storage vessel 25. In this manner, the body of liquid carbon dioxide acts as a thermal flywheel, and the freon refrigeration unit 27 associated with the storage vessel is utilized to carry out the reliquification of the high pressure gas therewith.

The cold, lower pressure liquid carbon dioxide is maintained at a desired minimum depth within the separation tank 37 by suitable liquid level control means (not shown). The compressor operation may be controlled by a pressure sensitive switch 49 although other suitable means may be used. The pressure in the separation tank 37 is generally controlled to provide a reservoir of liquid carbon dioxide between about -65° and -75° C.

A heat-exchange coil 51 is located in heat-exchange relationship with the cold, lower pressure liquid carbon dioxide in the separation tank 37. The other leg of the tee member 33 leads into a two-position control valve 53. In the position illustrated in FIG. 1, the high pressure liquid from the pump 31 is directed through the heat-exchange coil 51 and then to a line 55 which includes a check valve 57 and leads into a second tee member 59. When the control valve 53 is in other position, the liquid CO₂ from the tee member 33 is directed to a line 61 leading to another leg of the tee member 59. Thus, the control valve 53 is employed to either include the heat-exchange coil 51 in the liquid cooling circuit or remove it from the cooling circuit, as desired.

The enclosure 11 is constructed so that the conveyor 15 for carrying the articles 13 to be cooled or frozen passes generally centrally therethrough. The plurality of snow nozzles 17 are located near the top of the enclosure 11. The spray nozzles are positioned to direct showers of snow downward and at an angle toward the articles 13 approaching on the conveyor 15. Each of the nozzles 17 is designed to open only when a certain minimum pressure differential is achieved between the liquid being fed to the nozzles and the enclosure, which is usually at
about atmospheric pressure. The specific construction of the nozzles 17 is explained in detail hereinafter. The pressure difference in promoting extremely efficient transfer of heat from the surfaces of the laminar vapor layers adjacent to the surfaces of the articles and accordingly permits a high throughput of product for a refrigerating system of limited size. The snow blizzard within the enclosure 11 is maintained via the strategic placement of the plurality of blowers 21 which are arranged to create a circulation path throughout the enclosure, causing snow to continuously swirl about the articles moving along the conveyor. The blowers 21 are assisted in their creation of the desired circulation path by the vertical baffle 19 and by an optional horizontal baffle 63, which may be positioned between the upper and lower reaches of the conveyor belt 15, resulting in the formation of an atmosphere of snow particles and cold vapor resembling a blizzard. The vertical baffle 19 separates the enclosure 11 into a blizzard region to the left and a preliminary cooling region to the right. A perforated conveyor belt is preferably employed to facilitate creation of desired blizzard of CO\textsubscript{2} snow and the extraction of heat from all of the surfaces of the articles 13. The baffle 19 is pivoted at its upper end, and its disposition is controlled by a motor-operated controller 62 which is connected to a temperature sensor 64 located adjacent the entrance to the enclosure. If the temperature of the vapor near the entrance rises above the desired level, the controller 62 swings the baffle 19 to the left to admit more of the colder vapor from the blizzard region.

Although the blowers 21 are quite effective in creating the swirling blizzard desired to achieve the desired regulation of some snow will continue to reach the bottom surface of the enclosure 11. In order to prevent a buildup of snow on the bottom of the enclosure and to make a practical use of the cooling value of the snow, the hollow heat-exchange plate 23 is provided in the enclosure. The hollow plate 23 occupies the bottom of the portion of the enclosure referred to before as the final cooling region wherein all the nozzles 17 are located. All of the liquid carbon dioxide which is fed to the nozzles first passes through the hollow heat-exchange plate 23 where the heat of sublimation of the solid CO\textsubscript{2} is utilized to precool the high pressure liquid CO\textsubscript{2}. By precooling the high pressure liquid, a more efficient expansion to form carbon dioxide snow is created, i.e., the lower the temperature of the liquid at the nozzle 17, the greater the percentage of the snow which is created in the expansion relative to the amount of vapor which is created.

In the illustrated system, the enclosure 11 is constructed and the blowers 21 are located so that the major portion of the cold vapor flows upstream of the conveyor 15 through the preliminary cooling region to the right of baffle 19. Thus, the vapor effects some precooling of the articles 13 proceeding along the conveyor before it exits from the generally open upstream end of the enclosure. The enclosure 11 is at substantially atmospheric pressure inasmuch as there is no attempt to construct a pressure barrier at either end thereof. Moreover, in order to take fuller advantage of the cooling capacity of the cold CO\textsubscript{2} vapor, entrance and/or exit tunnels (such as are known in the art) can be constructed to promote further heat-exchange contact between the articles 13 and the cold vapor before the vapor is allowed to escape. Although it might be possible to reclaim the carbon dioxide exiting from the enclosure, in most commercial operations it is not considered to be economically feasible to attempt maintenance of at least as low a concentration of liquid as exists in the articles 13, and as a result the vapor is not used to recharge the enclosure.

Control of the snow making operation is facilitated greatly by employing snow nozzles which have variable orifices. Accordingly, by increasing the effective size of the orifice, a significantly larger quantity of liquid will be flashed to snow and vapor than if only the pressure of the feed were changed. Conversely, by decreasing the size of the orifice, the amount of snow which is created at least as low a concentration of liquid as exists in the文章中。
come the biasing of the spring 91. At this point, the plate 87 is caused to move away from the housing 79 extending the bellows 89 and raising the plug so as to provide an annular opening between the orifice 81 and the conical surface of the plug 85. The distance which the plug 85 is moved away from the orifice 81 is dependent upon the pressure in the feed line 69, which pressure, as was previously indicated, is regulated by the control valve 67.

The illustrated nozzle 17 design not only provides excellent regulation of the flow rate of CO₂ through the nozzles, but it also prevents clogging of the nozzles because it assures that there is no substantial buildup of snow on the feed side of the orifice 81. For example, if some ancillary valve were used to remove pressure from the header 73 when it was desired to halt the snow-making, the liquid in the header and the nozzles would change to solid CO₂ in situ if simple orifices were employed. For example, if the nozzles 17 are set close to the orifices 81 at about 295 psig., when the system is shut down if the high pressure liquid remaining in the line 69 and the header 73 slowly warms, maintenance of the high pressure avoids the occurrence of solid CO₂ on the feed side of the orifices 81. If vaporization occurs, the vapor escapes either through the check valve 77 or the nozzles 17, but the high pressure condition is generally maintained.

During preparation for startup of the refrigeration apparatus, the control valve 67 in the return line 69 is usually maintained in wide open position, and the pump 31 is operated to circulate high pressure liquid CO₂ throughout the cooling system. The two-position valve 53 is placed in the position illustrated to send the stream of liquid CO₂ through the heat-exchange coil 51 surrounding the separation tank 37 and into the heat-exchange plate 23 in the bottom of the enclosure 11. The passage of the cold liquid through the heat-exchange plate 23 serves to initially cool down the refrigeration control valve 77 wide open, all of the liquid flowing through the heat-exchange plate 23 also passes through the return line 75 into the storage vessel 25 because the pressure in the header does not reach the minimum value required to open the nozzles 17. However, it is desirable to maintain the pressure just high enough to bleed some CO₂ through the nozzles 17. This creates a slow positive flow of CO₂ out of the enclosure and prevents the entry of humidity-bearing air. If the separation tank 37 has not been previously filled to the desired level with liquid, the completion of filling the tank reservoir takes place at this time. The approximate -65°F temperature in the separation tank 37 further cools the high pressure, approximately 0°F liquid CO₂ being pumped into the heat-exchange coil 51, and this subcooled fluid in turn cools the enclosed snow ambient by its passage through the heat-exchange plate 23.

When operation of the refrigeration system is ready to begin, automatic control of the control valve 67 and the two-position valve 53 is initiated. The temperature sensor 65 in the enclosure 11 responds to the relatively high temperature therein and causes the control valve 67 to reduce its opening. This produces an increase in the pressure in the header 73 and opens the nozzles 17 to spray snow into the enclosure 11 as feeding the articles 13 to be cooled therethrough on the conveyor is about to begin.

The two-position valve 53 is operated by a controller associated therewith which is connected to a temperature sensor 95 in the line 69 between the heat-exchange plate 23 and the header 73. The temperature sensor 95 reads the temperature of the high pressure liquid CO₂ being fed to the nozzles which is desirably held at about -60°F. Whenever the temperature at this point falls below a predetermined lower limit (e.g., -62°F), the two-position valve 53 is shifted to connect the stream from the tee member 33 to the line 61 so the high pressure liquid is precooled only by the passage upon the heat-exchange plate 23 at the bottom of the enclosure. Operation in this manner removes the heat-exchange coil 51 adjacent the separation tank from the cooling system circuit. When the temperature sensed by the sensor 95 rises above a desired upper limit (e.g., -58°F) the two-position valve 53 is caused to return to the illustrated position wherein additional precooling is provided to the high pressure liquid by passing it through the heat-exchange coil 51 adjacent the separation tank 37.

As previously indicated, the maintenance of at least about 350 psig. at the nozzles 17 assures that finely particulate carbon dioxide snow is created. The fineness of the snow, in combination with the air circulation pattern created by the strategically placed blowers 21, facilitates the production of the desired blizzard within the enclosure 11. In the illustrated apparatus, the range of pressure employed at the nozzles 17 for snow-making is usually between about 350 psig. and 450 psig. Although higher pressures might be employed, they are not considered to be of any specific advantage. By the creation of such a snow blizzard within the enclosure 11, it is found that excellent cooling of the articles 13 is achieved and that a high throughput of articles can be maintained through the refrigeration system.

Trouble-free operation is obtained through the nozzle design which, as previously indicated, facilitates excellent regulation of the temperature within the enclosure to permit a very narrow temperature range. The overall system concept not only positively prevents a buildup of snow in the refrigeration enclosure, but efficiently utilizes the snow falling to the bottom of the enclosure 11 to precool the high pressure liquid being pumped to the nozzles 17, thereby substantially increasing the overall efficiency of the system. Handling a high throughput of product is furthermore assured, together with continued good efficiency of operation, by the provision of the separation tank 37 which stands ready to provide further precooling of the high pressure liquid CO₂ should the temperature in the conduit 69 rise above the desired upper limit.

Modifications to the illustrated embodiments as would be obvious to one having the ordinary skill in the art are considered as falling within the scope of the invention which is defined by the claims appended hereto. For example, an alternative design of a nozzle is shown in FIG. 3, wherein a nozzle 17' is shown designed for attachment of its housing 79' to the upper wall of the enclosure. The nozzle 17' contains a plug 85' which is stationary and an orifice 81' which is made movable by attachment of the lower wall of the housing 79' to a bellows. Adjustment may be provided by attaching the upper end of a spring 91' to a movable sleeve. It is also noted that instead of employing a two-position valve 53, a more sophisticated flow controller might be used which would divert a portion of the high pressure stream through the heat-exchange coil 51 to obtain a more exact control of temperature in the conduit 69.

Various of the features of the invention are set forth in the following claims.

What is claimed is:

1. Apparatus for cooliing material using carbon dioxide as a refrigerant, which apparatus comprises means defining an enclosure adapted for cooling material to be conveyed therethrough, means for conveying material through said enclosure, and a cooling system which includes snow nozzle means for expanding high pressure liquid CO₂ to snow and vapor and directing said snow onto the material being conveyed through said enclosure, first heat-exchange means disposed in a lower portion of said enclosure at a location below the material on said conveying means where said heat-exchange means will collect snow falling therebelow, first conduit means for connecting a source of high pressure CO₂ to the inlet to said heat-exchange means, and build-up conduit means for connecting the outlet from said first heat-exchange means to said snow nozzle means, whereby snow falling into the lower portion of said enclosure and coming to rest on said heat exchange means absorbs heat during its change of state thereby precooling the high pressure CO₂ flowing toward said nozzle means and preventing excessive snow buildup in said enclosure.

2. Apparatus in accordance with claim 1 wherein a tank is provided, wherein expansion means is provided in association
with said tank for expanding high pressure CO₂ to lower pressure lower temperature CO₂, wherein second heat-exchange means is disposed in heat-exchange relationship with said lower temperature liquid in said tank and wherein third conduit means is provided for connecting said second heat-exchange means between said high pressure CO₂ source and said first heat-exchange means.

3. Apparatus in accordance with claim 2 wherein said source of CO₂ is a storage vessel and wherein a compressor is provided for withdrawing CO₂ vapor from said tank and returning the compressed vapor to said CO₂ storage vessel.

4. Apparatus in accordance with claim 2 wherein first temperature control means is provided which senses the temperature of the high pressure liquid CO₂ in said second conduit means, and wherein first valve means is provided in said first conduit means which is operated by said temperature control means, said first valve means being effective to direct the liquid CO₂ through said second heat-exchange means whenever the temperature in said second conduit means rises above a preselected value.

5. Apparatus in accordance with claim 4 wherein a pump is provided for pumping the high pressure liquid CO₂ through said cooling system, wherein second valve means is provided in connection with said second conduit means and wherein second temperature control means is provided for sensing the temperature within said enclosure and controlling said second valve means appropriately to decrease or increase the pressure in said second conduit means and thereby regulate flow of high pressure CO₂ through said nozzle means.

6. Apparatus in accordance with claim 5 wherein said nozzle means includes an orifice the effective area of which is dependent upon the liquid pressure at the nozzle, being designed to enlarge the effective area of said orifice as the liquid pressure increases.

7. Apparatus in accordance with claim 5 wherein said nozzle means includes means in association therewith for preventing flow therethrough whenever the pressure in said second conduit means falls below a preselected value of at least about 100 psig.

8. A method for cooling material using carbon dioxide as a refrigerant, which method comprises conveying material to be cooled through an enclosure, expanding high pressure liquid carbon dioxide into the enclosure through spray nozzle means to produce carbon dioxide snow and directing said snow onto the material being conveyed therethrough, some of said snow falling below the material being conveyed, collecting said carbon dioxide snow falling therebelow on heat-exchange means, and employing the cooling capacity of said carbon dioxide snow collected upon the heat-exchange means to precool liquid CO₂ flowing toward the nozzle means to thereby prevent excessive snow build-up at the bottom of the enclosure and increase the efficiency of said expansion of said high pressure liquid.

9. A method in accordance with claim 8 wherein liquid CO₂ is pumped from a source to the nozzle means so the pressure differential at the nozzle means is at least about 350 psi, wherein a portion of said high pressure CO₂ is diverted to heat-exchange means where it is flashed to a lower pressure low temperature liquid-gas system and wherein said high pressure liquid CO₂ is caused to at least intermittently flow in heat-exchange relationship with the low temperature liquid in heat-exchange means to achieve a desired amount of precooling.

10. A method in accordance with claim 9 wherein the liquid reaching the nozzle means is precooled to a temperature of at least as low as about −60°F.

11. A method for cooling material using carbon dioxide as a refrigerant, which method comprises moving material to be cooled through an enclosure, expanding high pressure liquid CO₂ through snow nozzle means to create CO₂ vapor and snow within said enclosure, sensing the temperature within said enclosure, changing the effective area of an orifice in the snow nozzle means in response to measured temperature sensed to increase or decrease the flow therethrough and achieve a desired temperature within said enclosure and maintaining a predetermined minimum pressure of liquid CO₂ at said snow nozzle orifice when the orifice is closed.

12. A method in accordance with claim 11 wherein the pressure of the high pressure liquid CO₂ being fed to said snow nozzle means is regulated in response to said temperature sensed and wherein said change in orifice effective area directly results from the change in liquid CO₂ pressure at said snow nozzle means.

13. A method in accordance with claim 12 wherein lowering of said liquid CO₂ pressure to said predetermined minimum pressure results in closing the orifice to flow therethrough and wherein said predetermined minimum pressure is not less than about 100 psig.

14. Apparatus for cooling material using CO₂ as a refrigerant, which apparatus comprises means defining an enclosure, means for moving material to be cooled through said enclosure, snow nozzle means having orifice means through which high pressure liquid CO₂ is expanded to create CO₂ snow and vapor, means for connecting said snow nozzle means to a source of high pressure CO₂, means for sensing the temperature within said enclosure, and means for changing the effective area of said orifice means in response to said temperature sensed within said enclosure and for closing said orifice to flow of liquid CO₂ therethrough while maintaining a predetermined minimum pressure of liquid CO₂ at said snow nozzle orifice when said orifice is closed.

15. Apparatus in accordance with claim 14 wherein pressure regulator means connected to said temperature sensing means is provided for changing the pressure of said liquid CO₂ being supplied to said snow nozzle means and wherein said means for changing the effective area of said orifice means is operated directly by the liquid CO₂ pressure at said snow nozzle means.

16. Apparatus in accordance with claim 15 wherein said snow nozzle means includes a tapered plug proportioned to fit into said orifice to close said orifice and means mounting said plug and said orifice for relative movement and biasing same to the closed position.

17. Apparatus in accordance with claim 16 wherein said mounting means includes a preloaded tension spring biasing said plug and said orifice to the closed position and means for adjusting the tension upon said spring to thereby alter said predetermined minimum pressure at which opening and closing of said orifice occurs.
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,672,181

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Inventor(s) Lewis Tyree, Jr.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 30, "a bore" should be "above".
Column 6, line 66, "build-up" should be "second"

Signed and sealed this 26th day of December 1972.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCALK
Commissioner of Patents