



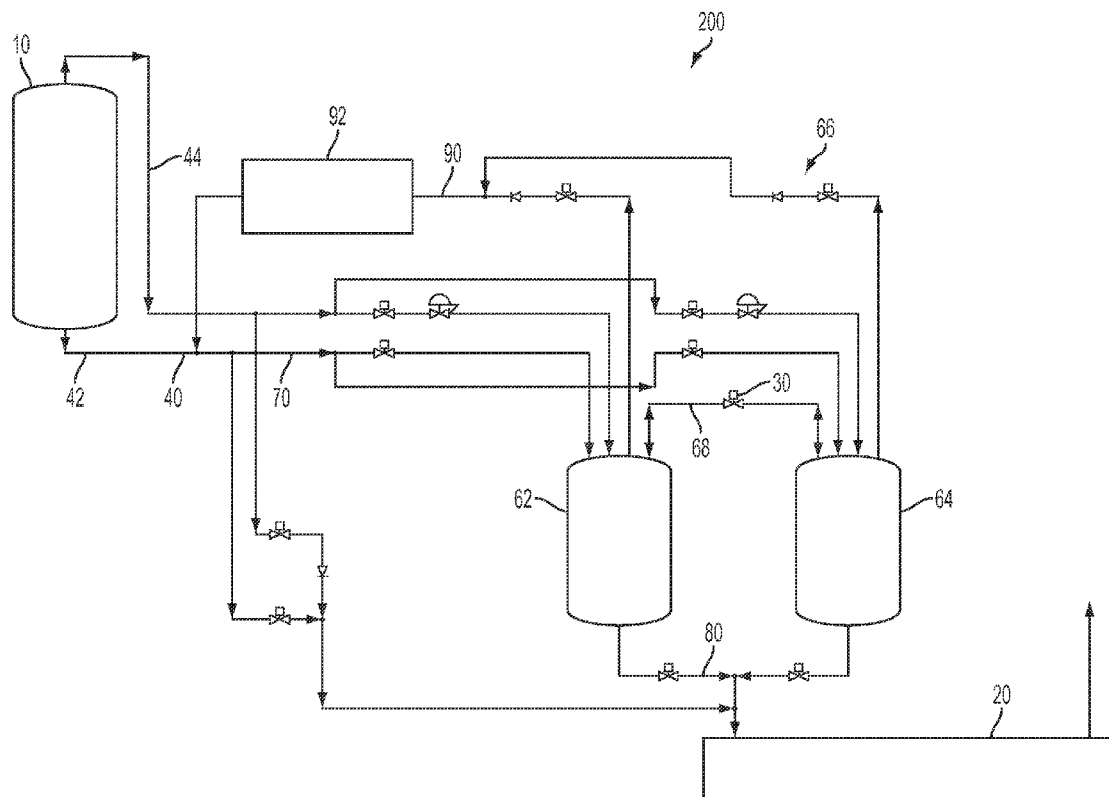
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(57) **ABSTRACT**

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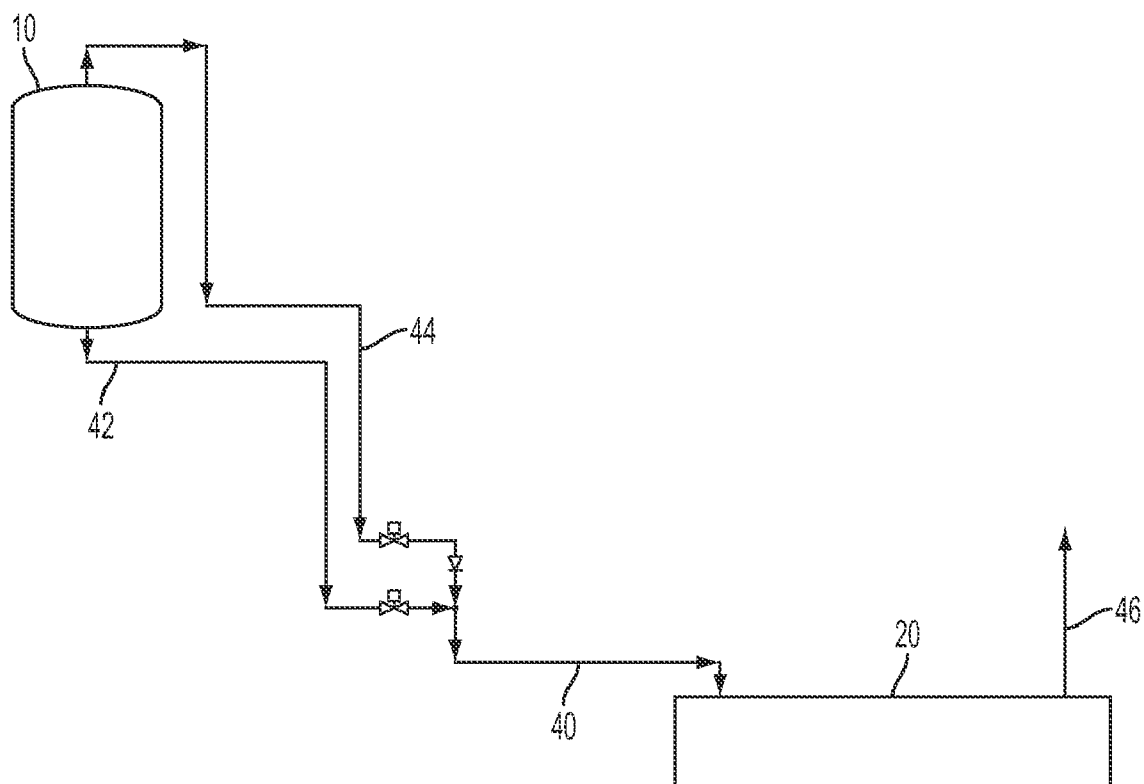


FIG. 1
PRIOR ART

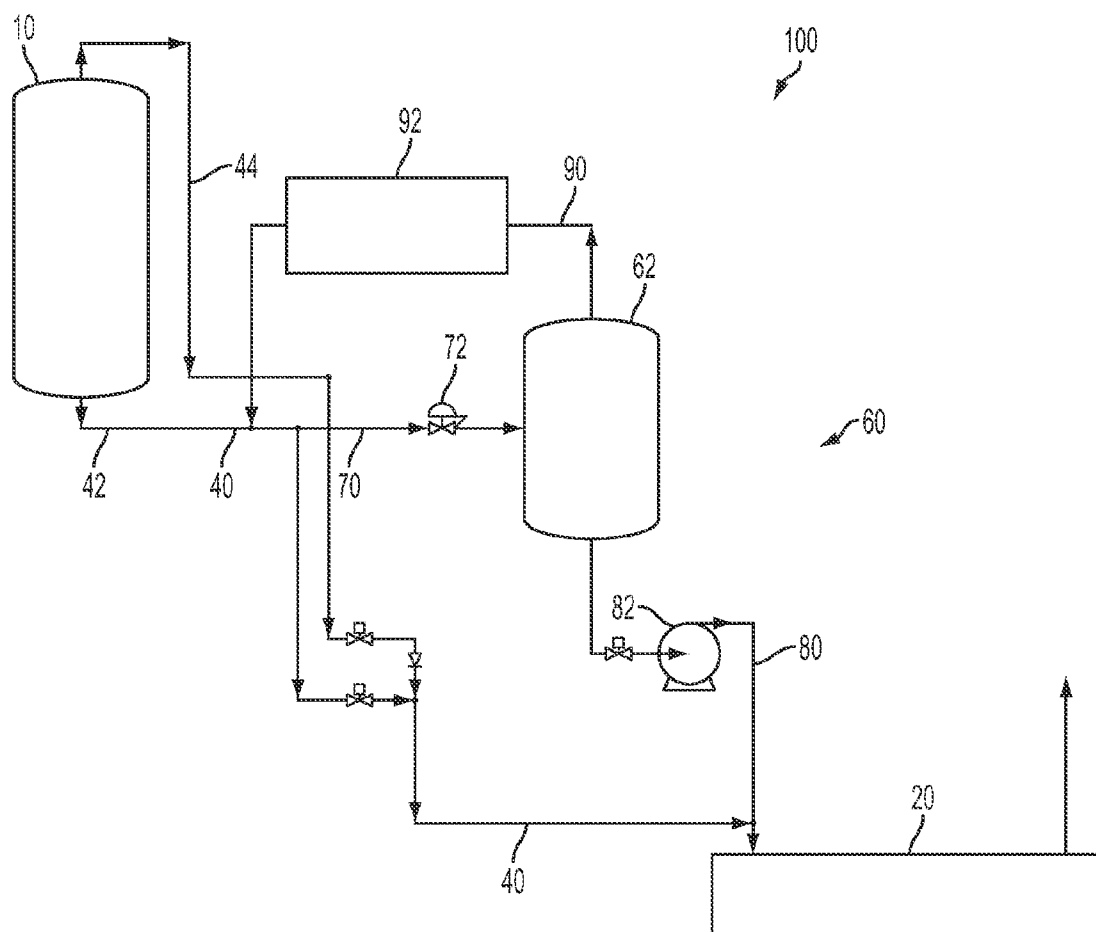


FIG. 2

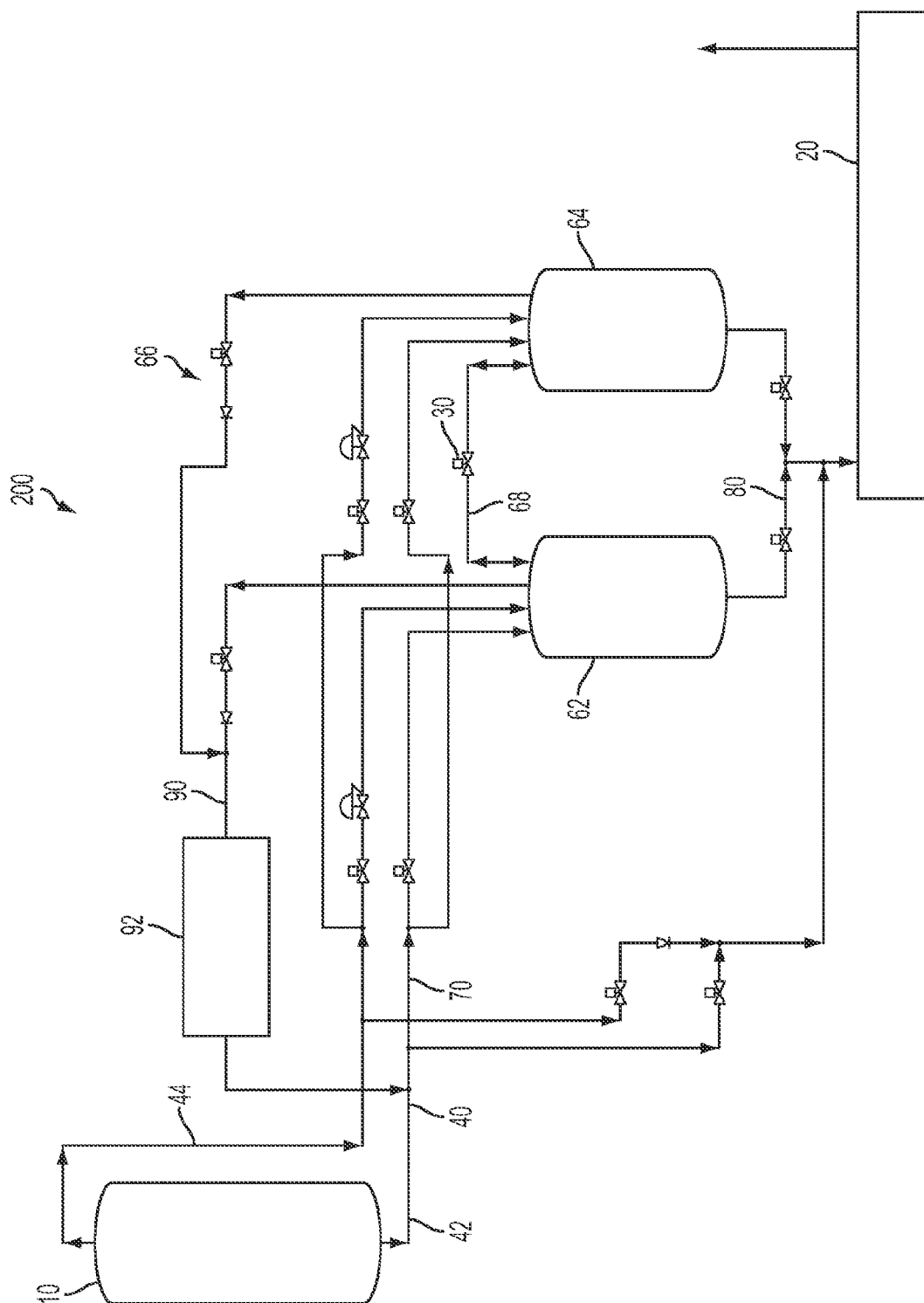


FIG. 3

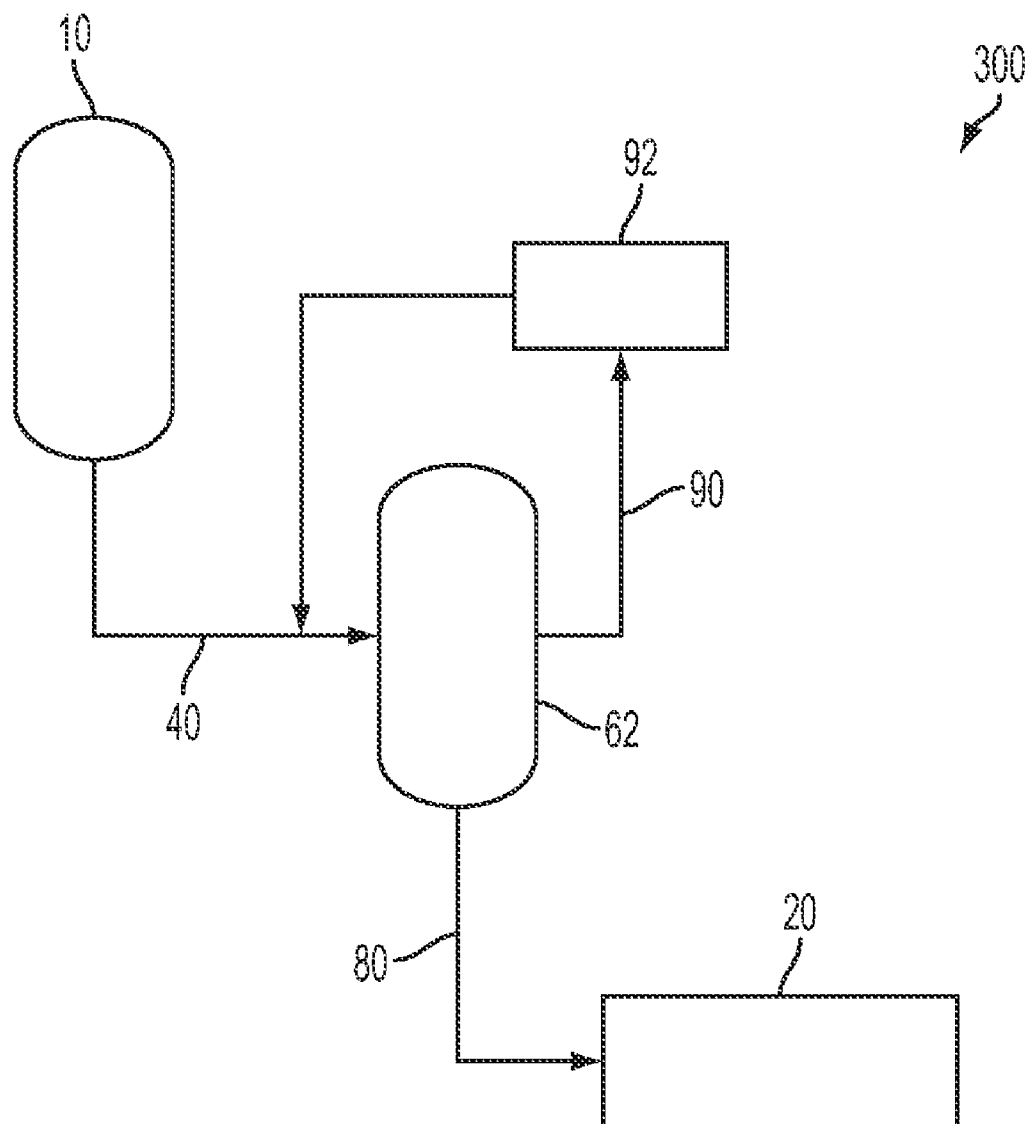


FIG. 4

LIQUID CARBON DIOXIDE REFRIGERATION SYSTEM

FIELD OF INVENTION

[0001] The present invention is directed to a liquid carbon dioxide refrigeration system, and in particular to systems and methods for delivering liquid carbon dioxide to a refrigeration device which recycles carbon dioxide vapor back into the system reducing carbon dioxide released to the atmosphere.

BACKGROUND OF INVENTION

[0002] Carbon dioxide (CO₂) is conventionally used as a refrigerant. For example, solid carbon dioxide (also known as "dry ice") is routinely used for its cooling properties. Liquid carbon dioxide is also a common refrigerant and has many applications, for example, in the food chilling and freezing industry.

[0003] Carbon dioxide is commonly captured from suitable industrial processes such as refinery and fermentation that would otherwise release it directly to the atmosphere. The CO₂ stream is purified, liquefied and stored for use in other industrial processes.

[0004] It is industry standard for liquid carbon dioxide to be supplied in a tank or vessel. At room temperature and pressure, carbon dioxide is in a gaseous state. To keep the carbon dioxide in a substantially liquid state, the storage tanks are typically maintained at a temperature between approximately -15° F. and approximately 0° F. and at a pressure between approximately 250 psia and approximately 300 psia. The carbon dioxide may be stored in these tanks until needed.

[0005] As shown in FIG. 1, a conventional liquid carbon dioxide refrigeration system includes a carbon dioxide storage tank 10 coupled to a refrigeration device 20 (such as a freezer) via a fluid conduit 40. A first fluid conduit 42 delivers liquid carbon dioxide into the refrigeration device where it is sprayed onto items to be cooled. A second fluid conduit 44 may also be provided to introduce vapor carbon dioxide from the storage tank and into the refrigeration device. The carbon dioxide vapor may be used to pressurize the line, to move the liquid carbon dioxide through the fluid conduit, and/or to prevent the liquid carbon dioxide from turning into a solid and freezing and/or clogging the fluid conduit 40. As the carbon dioxide passes through the refrigeration system and provides refrigeration, the carbon dioxide converts into vapor which is removed from the system via an exhaust 46.

[0006] One alternative to supplying CO₂ to remote locations is described by Tyree in U.S. Pat. No. 4,693,737. Tyree found that providing sub-cooled liquid CO₂ to the work stations resulted in less CO₂ being expended for a given cooling requirement. Tyree also attempts to conserve CO₂ vapor generated during the production of the near triple point CO₂ used to cool the storage cabinets. Tyree describes returning the vapor to a solid CO₂ bunker where it would condense into a solid and could later be returned to the main storage vessel by a compressor for reuse. While the present invention takes advantage of the additional refrigeration available from near triple point CO₂, it provides a direct method of re-liquefying the CO₂ vapor generated during the sub-cooling process through the use of an in-line compressor and heat exchanger. While the invention described by Tyree could be used for low refrigeration demand applications, the equipment needed for large demand requirements would be prohibitively large and expensive.

[0007] An alternative to recycle CO₂ for large refrigeration applications is described in U.S. Pat. No. 5,966,946 by Girard et al. Girard describes a method of recapturing CO₂ vapor generated in a refrigeration enclosure. Girard ensures a suitably high CO₂ vapor concentration, compresses it and re-liquefies it for reuse in the refrigeration enclosure. The present invention utilizes the additional refrigeration capacity of sub-cooled CO₂ and recycles and re-liquefies generated vapor with a less complex process. The less complicated process stems from the fact that the present invention provides a closed loop vapor recycle process.

SUMMARY OF INVENTION

[0008] In one illustrative embodiment, a method of delivering liquid carbon dioxide to a refrigeration device is provided. The method includes releasing carbon dioxide from a storage tank into a fluid conduit and toward a refrigeration device, separating the carbon dioxide into a carbon dioxide vapor portion and a liquid carbon dioxide portion, reliquefying and recycling the vapor carbon dioxide portion into the supply fluid conduit or storage tank, and introducing the separated liquid carbon dioxide portion into the refrigeration device.

[0009] In another illustrative embodiment, a liquid carbon dioxide refrigeration system provides a secondary flow circuit which is configured to be coupled to a primary fluid conduit extending between a carbon dioxide storage tank and a refrigeration device configured to receive carbon dioxide from the storage tank. The secondary flow circuit includes a first vessel constructed and arranged to separate carbon dioxide into a vapor carbon dioxide portion and a liquid carbon dioxide portion, and a downstream conduit coupled to the first vessel and constructed and arranged such that the liquid carbon dioxide portion can pass either into the refrigeration system or into the primary fluid conduit. The secondary flow route further includes a recycle conduit coupled to the first vessel, the recycle conduit constructed and arranged to recycle the vapor carbon dioxide portion back to the primary fluid conduit; and the recycle conduit includes a refrigeration package configured to compress and cool the vapor carbon dioxide portion.

[0010] In yet another illustrative embodiment, a liquid carbon dioxide refrigeration system is provided. The refrigeration system includes a storage tank constructed and arranged for storing liquid carbon dioxide, a first vessel constructed and arranged to separate carbon dioxide into a vapor carbon dioxide portion and a liquid carbon dioxide portion, and a first conduit coupled to the storage tank and the first vessel and constructed and arranged such that carbon dioxide can pass from the storage tank to the first vessel. The system further includes a second conduit coupled to the first vessel and constructed and arranged such that the liquid carbon dioxide portion can pass into a refrigeration system, and a third conduit coupled to the first vessel and the first conduit, the third conduit constructed and arranged to recycle the carbon dioxide vapor portion back to the first conduit, and wherein the third conduit comprises a refrigeration package configured to compress and liquefy the vapor carbon dioxide portion.

[0011] In a further illustrative embodiment, a liquid carbon dioxide refrigeration system is provided. The refrigeration system includes a storage tank constructed and arranged for storing liquid carbon dioxide, and a primary fluid conduit having a first end coupled to the storage tank and a second end configured to be coupled to a refrigeration device, where the

primary fluid conduit is configured to allow carbon dioxide to pass from the storage tank and into the refrigeration device. The refrigeration system further includes a secondary flow circuit coupled to the primary fluid conduit, the secondary flow circuit including a first vessel constructed and arranged to separate carbon dioxide into a carbon dioxide vapor portion and a liquid carbon dioxide portion, and a secondary fluid conduit coupled to the primary fluid conduit and the first vessel, the secondary fluid conduit constructed and arranged such that the carbon dioxide can pass from the primary fluid conduit and into the first vessel. The secondary fluid circuit also includes a downstream conduit coupled to the first vessel and constructed and arranged such that the liquid carbon dioxide portion can pass either into the refrigeration system or into the primary fluid conduit, and a recycle conduit coupled to the first vessel and the primary fluid conduit, the recycle conduit constructed and arranged to comprise a refrigeration package configured to compress and liquefy the vapor carbon dioxide portion to recycle the liquefied carbon dioxide portion back to the primary fluid conduit.

[0012] Various embodiments of the present invention provide certain advantages. Not all embodiments of the invention share the same advantages and those that do may not share them under all circumstances.

[0013] Further features and advantages of the present invention, as well as the structure of various embodiments that incorporate aspects of the invention are described in detail below with reference to the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0014] The foregoing and other objects and advantages of the invention will be appreciated more fully from the following drawings, wherein like reference characters designate like features, in which:

[0015] FIG. 1 is a schematic diagram of a prior art liquid carbon dioxide refrigeration system;

[0016] FIG. 2 is a schematic diagram of a liquid carbon dioxide refrigeration system according to one embodiment of the present invention;

[0017] FIG. 3 is a schematic diagram of a liquid carbon dioxide refrigeration system according to another embodiment of the present invention; and

[0018] FIG. 4 is a schematic diagram of a liquid carbon dioxide refrigeration system according to yet another embodiment of the present invention.

DETAILED DESCRIPTION

[0019] The cooling capacity of liquid carbon dioxide increases as liquid carbon dioxide approaches its triple point (i.e. the temperature and pressure at which a substance simultaneously exists in a solid phase, a liquid phase and a gas phase). It is thus desirable for liquid carbon dioxide to be near its triple point in a refrigeration system, because when the temperature is near the triple point, liquid carbon dioxide provides the greatest increase in cooling capacity per unit mass.

[0020] In particular, in a refrigeration system, such as the one illustrated in FIG. 1, once in the refrigeration device 20, the liquid carbon dioxide expands to form a solid phase and a vapor phase. On a mass basis, about half of the liquid carbon dioxide converts to solid, the other half to vapor. Applicant recognized that a majority of the refrigeration results from the solid phase and minimal refrigeration occurs from the vapor

phase. Applicant further recognized that when the carbon dioxide is close to its triple point, the percentage of the solid phase increases, thus increasing the available refrigeration. Applicant also recognized the difficulty in moving the near triple point liquid carbon dioxide due to its tendency to flash from the liquid state directly into the vapor and solid states due to pressure drops from valves and piping and liquid head.

[0021] One aspect of the present invention is directed to a refrigeration system that is able to recover a portion of the carbon dioxide vapor and recycle it back into the system. It is contemplated that this may improve the efficiency of a refrigeration system and may, for example, increase the cooling capacity for a carbon dioxide storage tank 10 on a mass basis. In particular, the recycled vapor carbon dioxide recovered from the system may be converted into liquid carbon dioxide which can be used to cool the refrigeration device. As shown in FIG. 1, this vapor carbon dioxide would otherwise not be used and would be vented off to atmosphere via the exhaust 46. It is contemplated that this increase in efficiency may decrease the total amount of carbon dioxide consumption for a particular refrigeration device 20.

[0022] Another aspect of the present invention is directed to a refrigeration system that is able to produce liquid carbon dioxide near its triple point in an on-going process for immediate use in the refrigeration device. As mentioned above, as carbon dioxide approaches its triple point, the cooling capacity increases which may improve the efficiency of the refrigeration system.

[0023] One or more of the above aspects of the present invention may be achieved by separating the carbon dioxide into a vapor carbon dioxide portion and a liquid carbon dioxide portion. The liquid carbon dioxide portion may be near its triple point and can pass on to the refrigeration system, and the vapor carbon dioxide portion can be recycled back into the refrigeration system. As set forth in greater detail below, the refrigeration system may include a vessel 62 that is configured to separate carbon dioxide into a vapor carbon dioxide portion and a liquid carbon dioxide portion. As discussed below, the vessel 62 may be part of a secondary flow circuit 60 which is configured to be coupled to the primary fluid conduit 40 which extends between the carbon dioxide storage tank 10 and the refrigeration device 20. It should be appreciated that for purposes herein, the phrase "liquid carbon dioxide" is used to refer to carbon dioxide in which a majority of the mass and/or volume of the carbon dioxide is in a liquid state. One of skill in the art would recognize that some amount of vapor carbon dioxide may exist in liquid carbon dioxide. A change in temperature and/or pressure may cause the state or phase of the carbon dioxide to change. For example, carbon dioxide which is approximately 100% in a liquid state may exit the storage tank 10, and at a downstream location in the conduit 40, vapor carbon dioxide may form in the conduit. This may be caused by the pressure drop in the pipe and/or may be caused by a heat gain. Likewise, the phrase "carbon dioxide vapor" is used to refer to carbon dioxide in which a majority of the mass and/or volume of the carbon dioxide is in a gaseous state. One of skill in the art would recognize that some amount of liquid carbon dioxide and/or solid carbon dioxide may exist in carbon dioxide vapor under the proper circumstances. Furthermore, the phrase "solid carbon dioxide" is used to refer to carbon dioxide in which a majority of the mass and/or volume of the carbon dioxide is in a solid

state. One of skill in the art would recognize that some amount of carbon dioxide vapor and/or liquid carbon dioxide may exist in solid carbon dioxide.

[0024] When separating the carbon dioxide vapor portion from the liquid carbon dioxide portion, the liquid carbon dioxide portion may reach a temperature and a pressure approaching its triple point. And, by removing some of the vapor from the carbon dioxide, the cooling capacity of the carbon dioxide may increase. As mentioned above, in a refrigeration system, such as the one illustrated in FIG. 1, once in the refrigeration device 20, the liquid carbon dioxide expands to form a solid phase and a vapor phase. When using liquid carbon dioxide from a conventional carbon dioxide storage tank at conventional storage conditions (approximately 0° F. and at a pressure of approximately 300 psia), once the liquid carbon dioxide enters the refrigeration device 20, the carbon dioxide may expand into approximately 54% vapor and approximately 46% solid carbon dioxide by mass. In contrast, in one embodiment, after the carbon dioxide is separated in first vessel 62, the liquid carbon dioxide portion may be at a temperature and pressure such that it is closer to its triple point such that once the liquid carbon dioxide enters the refrigeration device 20, the carbon dioxide may expand into approximately 42% vapor and approximately 58% solid carbon dioxide by mass. Turning to FIG. 2, one embodiment of a refrigeration system 100 with a first vessel 62 for separating carbon dioxide is illustrated. Similar to the conventional refrigeration system shown in FIG. 1, this system 100 includes a carbon dioxide storage tank 10 coupled to a refrigeration device 20 (such as a freezer) via a primary fluid conduit 40. The primary fluid conduit 40 includes a first fluid conduit 42 for delivering liquid carbon dioxide into the refrigeration device and a second fluid conduit 44 for introducing vapor carbon dioxide into the refrigeration device. As mentioned above, the vapor carbon dioxide may be used to pressurize the line, to move the liquid carbon dioxide through the fluid conduit, and/or to prevent the liquid carbon dioxide from turning into a solid and freezing and/or clogging the fluid conduit 40 and/or the refrigeration device.

[0025] In the embodiment of FIG. 2, the vessel 62 is part of a secondary flow circuit 60 which branches off from the primary fluid conduit 40. As illustrated, the secondary flow circuit 60 includes a secondary fluid conduit 70 which is coupled to the primary fluid conduit 40 and the first vessel 62 and is arranged such that the carbon dioxide can pass from the primary fluid conduit 40 and into the first vessel 62 to separate the carbon dioxide into a vapor carbon dioxide portion and a liquid carbon dioxide portion. As discussed below, in the vessel 62, the pressure of the carbon dioxide may be decreased and the temperature of the carbon dioxide may be decreased such that the carbon dioxide approaches its triple point. It is also contemplated that such a change in temperature and pressure may help to separate the vapor portion from the liquid portion.

[0026] The secondary flow circuit 60 may also include a downstream conduit 80 coupled to the first vessel 62 and arranged such that the liquid carbon dioxide portion can pass into the refrigeration system 20. It should be appreciated that the downstream conduit 80 may be configured such that the liquid carbon dioxide portion passes to another conduit, such as the primary conduit 40 before passing into the refrigeration system, as the invention is not so limited. As illustrated, the secondary flow circuit 60 further includes a recycle conduit 90 coupled to the first vessel 62 and the primary fluid conduit

40 and arranged to recycle the vapor carbon dioxide portion back to the primary fluid conduit 40 or the storage vessel 10.

[0027] As illustrated, the secondary fluid conduit 70 may include a pressure reducing element 72 which is configured to lower the pressure of the carbon dioxide. It is contemplated that the pressure of the carbon dioxide may be lowered to a point close to its triple point. As mentioned above, the carbon dioxide may exit the storage tank 10 having a pressure of approximately 300 psia. In one embodiment, the pressure reducing element 72 lowers the pressure of the carbon dioxide down to at least approximately 78-80 psia. It should be recognized that lowering the pressure of the carbon dioxide removes energy from the carbon dioxide which may help to facilitate the separation of the liquid carbon dioxide portion from the vapor carbon dioxide portion. The pressure reducing element 72 may be a valve or other pressure regulator which would be readily apparent to one having ordinary skill in the art.

[0028] As shown in FIG. 2, the recycle conduit 90 includes a refrigeration package 92 downstream of the first vessel 62 which is configured to compress and cool the vapor carbon dioxide portion. As mentioned above, the pressure of the carbon dioxide may be lowered, for example, down to approximately 80 psia before the carbon dioxide is separated into a vapor portion and a liquid portion. Thereafter, the refrigeration package 92 may compress the vapor portion to increase its pressure before being introduced back to the primary fluid conduit 40. Furthermore, the temperature of the carbon dioxide may be decreased in the first vessel 62 during separation. For example, in one embodiment, the carbon dioxide may exit the storage tank 10 having a temperature of approximately 0° F. The vessel 62 may be configured to lower the temperature of the carbon dioxide down to approximately -67° F. to -68° F. (the triple point temperature of carbon dioxide is approximately -69.9° F.). The refrigeration package 92 may be configured to compress and liquefy the vapor carbon dioxide portion before being introduced back to the primary fluid conduit 40.

[0029] The secondary flow circuit 60 may be positioned such that the recycled vapor portion of the carbon dioxide exits the vessel 62 and the refrigeration package 92 and flows back into the primary fluid conduit 40. As shown, carbon dioxide may enter the secondary flow circuit 60 through the secondary fluid conduit 70 which is coupled to the primary fluid conduit 40 at a first location on the primary fluid conduit. The recycled vapor portion of the carbon dioxide may flow back into the primary fluid conduit 40 at a second location on the primary fluid conduit 40 which is upstream from the first location where primary fluid conduit 40 meets secondary fluid conduit 70. Alternatively, the recycled vapor portion of the carbon dioxide may flow directly to the storage vessel 10.

[0030] It is contemplated that the vessel 62 may be positioned proximate the refrigeration device 20 such that once separated in the vessel 62, the liquid portion of the carbon dioxide may pass through the downstream conduit 80 and into the refrigeration device 20 due to gravity. For example, the vessel 62 may be positioned on top of or in an elevated position with respect to the refrigeration device 20.

[0031] As illustrated, in another embodiment, the downstream conduit 80 includes a pump 82. It should be appreciated that the pump 82 may be used to drive the liquid portion of the carbon dioxide into the refrigeration device 20. It should also be appreciated that the pump 82 may assist in increasing the pressure of the liquid carbon dioxide portion.

For example, in one embodiment, the pump **82** is configured to raise the pressure of the liquid carbon dioxide, preferably to a range between 150 psia to 300 psia and most preferably between 200 psia to 250 psia. The pump **82** may be configured to turn the liquid carbon dioxide portion into a subcooled liquid.

[0032] It should be appreciated that the secondary flow circuit **60** may be configured such that the loop components may be retrofitted to an existing refrigeration system, such as the one shown in FIG. 1. It is also contemplated that the secondary flow circuit **60** may be configured as part of a new refrigeration system, as the invention is not so limited.

[0033] Turning now to FIG. 3, another embodiment of a refrigeration system **200** is illustrated. This refrigeration system includes many of the same components discussed above and shown in FIG. 2, and thus like components are given like reference numbers. The system **200** disclosed in FIG. 3 includes a secondary flow circuit **66** configured to separate carbon dioxide into a vapor carbon dioxide portion and a liquid carbon dioxide portion. This particular embodiment includes a first vessel **62** and a second vessel **64**, where each vessel is configured to separate the carbon dioxide into a vapor portion and a liquid portion. The refrigeration system **200** may be configured to cycle between separating carbon dioxide in the first vessel **62** and separating carbon dioxide in the second vessel **64**. It should be appreciated that the present invention further contemplates three, four or more vessels **62**, **64**, as the invention is not so limited. The refrigeration system **200** shown in FIG. 3 may be configured to produce liquid carbon dioxide near its triple point in an on-going process for immediate use in the refrigeration device.

[0034] Liquid carbon dioxide may be introduced into the secondary flow circuit **66** through the secondary fluid conduit **70** and as shown, may pass into either the first vessel **62** or the second vessel **64**. The secondary fluid conduit **70** may include one or more pressure reducing elements **72** which are configured to lower the pressure of the carbon dioxide delivered to the vessels **62**, **64**. It is also contemplated that one vessel may be filled with carbon dioxide and thereafter, the pressure within that vessel **62**, **64** may be reduced to facilitate the separation of the vapor portion from the liquid portion. It may take a period of time to fill, depressurize, pressurize and/or evacuate a vessel **62**. Thus, a plurality of vessels **62**, **64** may be provided so that a second vessel **64** may be separating carbon dioxide, and thus producing a liquid portion of the carbon dioxide near the triple point condition to introduce into the refrigeration device **20** while the first vessel **62** is being filled with carbon dioxide, depressurized, pressurized, and/or evacuated. In one embodiment, the plurality of vessels **62**, **64** are configured such that a substantially continuous stream of liquid carbon dioxide near the triple point can flow into the conduit **80** as the system cycles between the first vessel **62** and the second vessel **64**.

[0035] As shown, the first and second vessels **62**, **64** may be coupled to the second primary fluid conduit **44** such that vapor carbon dioxide from the storage tank **10** may be introduced into the first and second vessels **62**, **64**. It is contemplated that fluid conduit **44** may be used to adjust the pressure within the vessels **62**, **64**. For example, fluid conduit **44** may be used to increase the pressure within the vessels **62**, **64** from approximately 80 psia to approximately 300 psia resulting in a false head pressure to assist fluid movement in conduit **80** into the refrigeration device **20**. In one embodiment, a conduit

68 couples the first vessel **62** to the second vessel **64** via valve **30** and is configured to adjust the pressure between the first and second vessels.

[0036] Once the carbon dioxide is separated in one of the vessels **62**, **64**, the liquid portion is introduced into the downstream conduit **80** to pass into the refrigeration device **20**. The vapor portion that is removed from the vessel **62**, **64** during the separation process is introduced into the recycle conduit **90** to recycle the vapor portion back into the primary conduit **40**. As discussed above, the recycle conduit **90** may include a refrigeration package **92** downstream of the vessels **62**, **64** and is configured to compress and warm the vapor carbon dioxide portion before being introduced back into the primary conduit **40**.

[0037] Turning now to FIG. 4, another embodiment of a refrigeration system **300** is disclosed. The refrigeration system **300** is similar to the systems **100**, **200** discussed above, except this system **300** does not have a separate secondary flow circuit that branches out from the primary conduit. This refrigeration system **300** has a liquid carbon dioxide storage tank **10** and a refrigeration package **20** positioned downstream of the storage tank **10** and configured to receive carbon dioxide from the tank. The system **300** further includes a first vessel **62** arranged to separate carbon dioxide into a vapor carbon dioxide portion and a liquid carbon dioxide portion. A first conduit **40** (similar to primary conduit **40** discussed above) is coupled to the storage tank **10** and the first vessel **62** such that liquid carbon dioxide can pass from the storage tank and into the first vessel **62**. The first conduit **40** may include a pressure reducing element **72** which is configured to lower the pressure of the carbon dioxide. A downstream conduit **80** (similar to downstream conduit **80** discussed above) is coupled to the first vessel **62** and arranged such that the liquid carbon dioxide portion can pass into a refrigeration system **20**. A recycle conduit **90** (similar to recycle conduit **90** discussed above) is coupled to the first vessel **62** and the first conduit **40** and is arranged to recycle the vapor carbon dioxide portion back to the first conduit **40**. As shown, the recycle conduit **90** may include a refrigeration package **92** configured to compress and cool the vapor carbon dioxide portion before being introduced back into the first conduit **40**. The refrigeration system **300** shown in FIG. 4 may be configured to produce liquid carbon dioxide near its triple point in real-time.

[0038] A method of delivering liquid carbon dioxide to a refrigeration device in accordance with the present invention may include one or more of the following acts of: releasing carbon dioxide from a storage tank into a fluid conduit and toward a refrigeration device, separating the carbon dioxide into a vapor carbon dioxide portion and a liquid carbon dioxide portion, recycling the vapor carbon dioxide portion into the fluid conduit, and introducing the liquid carbon dioxide portion into the refrigeration device.

[0039] For the purposes of simplifying the figures, some lines/connections to the vessels and tanks that are routinely provided in the carbon dioxide industry and more specifically in a refrigeration system have been omitted, such as, but not limited to fill or transfer lines, auxiliary liquid or vapor lines, surge tanks, safety relief valves, filters, vents, purge valves, and pressure gauges. System monitoring devices, controls and programmers may be included if desired. Valves may, for example, be electric or pneumatic, and may be either remotely controlled or manually controlled, as the invention is not so limited.

[0040] It should be appreciated that various embodiments of the present invention may be formed with one or more of the above-described features. The above aspects and features of the invention may be employed in any suitable combination as the present invention is not limited in this respect. It should also be appreciated that the drawings illustrate various components and features which may be incorporated into various embodiments of the present invention. For simplification, some of the drawings may illustrate more than one optional feature or component. However, the present invention is not limited to the specific embodiments disclosed in the drawings. It should be recognized that the present invention encompasses embodiments which may include only a portion of the components illustrated in any one drawing figure, and/or may also encompass embodiments combining components illustrated in multiple different drawing figures.

[0041] It should be understood that the foregoing description of various embodiments of the invention are intended merely to be illustrative thereof and that other embodiments, modifications, and equivalents of the invention are within the scope of the invention recited in the claims appended hereto.

1. A method of delivering liquid carbon dioxide to a refrigeration device, the method comprising:

- releasing carbon dioxide from a storage tank into a fluid conduit and toward a refrigeration device;
- separating the carbon dioxide into a vapor carbon dioxide portion and a liquid carbon dioxide portion;
- recycling the vapor carbon dioxide portion into the fluid conduit; and
- introducing the liquid carbon dioxide portion near its triple point into the refrigeration device.

2. The method of claim 1, wherein the act of recycling the vapor carbon dioxide portion into the fluid conduit includes a refrigerating package for the vapor carbon dioxide portion.

3. The method of claim 1, wherein the act of separating the carbon dioxide includes reducing the pressure of the carbon dioxide.

4. The method of claim 3, wherein the act of separating the carbon dioxide includes introducing the carbon dioxide into a first vessel, and wherein the pressure of the first vessel is maintained below the pressure of the introduced carbon dioxide.

5. The method of claim 3, wherein the act of separating the carbon dioxide includes introducing the carbon dioxide into a first vessel, and wherein the pressure of the carbon dioxide is reduced after the carbon dioxide is introduced into the first vessel.

6. The method of claim 1, wherein the carbon dioxide is released into a primary fluid conduit extending between the storage tank and the refrigeration device, and the act of separating the carbon dioxide includes transferring the carbon dioxide into a secondary flow circuit for additional conditioning.

7. The method of claim 1, wherein the act of introducing the liquid carbon dioxide portion into the refrigeration device includes pumping the liquid carbon dioxide portion into the refrigeration device.

8. The method of claim 1, wherein the act of separating the carbon dioxide includes introducing a first portion of the carbon dioxide into a first vessel and introducing a second portion of the carbon dioxide into two or more vessels.

9. A liquid carbon dioxide refrigeration system secondary flow circuit configured to be coupled to a primary fluid conduit extending between a carbon dioxide storage tank and a

refrigeration device configured to receive carbon dioxide from the storage tank, the secondary flow circuit comprising:

- a first vessel constructed and arranged to separate carbon dioxide into a vapor carbon dioxide portion and a liquid carbon dioxide portion;
- a downstream conduit coupled to the first vessel and constructed and arranged such that the liquid carbon dioxide portion can pass either into the refrigeration system or into the primary fluid conduit;
- a recycle conduit coupled to the first vessel, the recycle conduit constructed and arranged to recycle the vapor carbon dioxide portion back to the primary fluid conduit; and

wherein the recycle conduit comprises a refrigeration package configured to compress and liquefy vapor carbon dioxide portion.

10. The liquid carbon dioxide refrigeration system secondary flow circuit of claim 9, further comprising:

- a second vessel constructed and arranged to separate the carbon dioxide into a vapor carbon dioxide portion and a liquid carbon dioxide portion, wherein the secondary flow circuit is configured to cycle between separating carbon dioxide in the first vessel and two or more vessels.

11. The liquid carbon dioxide refrigeration system secondary flow circuit of claim 9, further comprising a pressure reducing element positioned upstream of the first vessel and configured to lower the pressure of the carbon dioxide.

12. The liquid carbon dioxide refrigeration system secondary flow circuit of claim 9, wherein the downstream conduit comprises a pump.

13. A liquid carbon dioxide refrigeration system comprising:

- a storage tank constructed and arranged for storing liquid carbon dioxide;
- a primary fluid conduit having a first end coupled to the storage tank and a second end configured to be coupled to a refrigeration device, wherein the primary fluid conduit is configured to allow carbon dioxide to pass from the storage tank and into the refrigeration device;
- a secondary flow circuit coupled to the primary fluid conduit, the secondary flow circuit comprising:
 - a first vessel constructed and arranged to separate carbon dioxide into a vapor carbon dioxide portion and a liquid carbon dioxide portion;
 - a secondary conduit coupled to the primary fluid conduit and the first vessel, the secondary fluid conduit constructed and arranged such that the carbon dioxide can pass from the primary fluid conduit and into the first vessel;
 - a downstream conduit coupled to the first vessel and constructed and arranged such that the liquid carbon dioxide portion can pass either into the refrigeration system or into the primary fluid conduit; and
 - a recycle conduit coupled to the first vessel and the primary fluid conduit, the recycle conduit constructed and arranged to recycle the vapor carbon dioxide portion back to the primary fluid conduit.

14. The liquid carbon dioxide refrigeration system of claim 13, wherein the recycle conduit comprises a refrigeration package configured to compress and liquefy the carbon dioxide vapor portion.

15. The liquid carbon dioxide refrigeration system of claim 13 wherein the secondary fluid conduit is coupled to the

primary fluid conduit at a first location on the primary fluid conduit and the recycle conduit is coupled to the primary fluid conduit at a second location on the primary fluid conduit, wherein the second location is upstream of the first location.

16. The liquid carbon dioxide refrigeration system of claim **13**, wherein the secondary flow circuit further comprises a second vessel constructed and arranged to separate the carbon dioxide into a vapor carbon dioxide portion and a liquid carbon dioxide portion, and wherein the secondary flow cir-

cuit is configured to cycle between separating carbon dioxide in the first vessel and in the second vessel.

17. The liquid carbon dioxide refrigeration system of claim **16**, wherein the secondary flow circuit further comprises a conduit coupling the first vessel to the second vessel and configured to adjust the pressure between the first vessel and the second vessel.

* * * * *