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(54) **ATOMIZED LIQUID JET REFRIGERATION SYSTEM**

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(57) **ABSTRACT**

A system for controlling temperature includes an atomizer that forms micron-sized hydrogen-bonded refrigerant droplets within a chamber. A vacuum pump is coupled to the chamber to lower its interior pressure. Under these conditions, the refrigerant droplets evaporate while lowering the temperature of its immediate surrounding. The reduced pressure in the chamber delays the freezing of the refrigerant droplets to below 0° C. at about at least one of a heterogeneous nucleation temperature and a homogenous nucleation temperature of the refrigerant droplets at their size. The atomizer includes a pump that forces a hydrogen-bonded liquid refrigerant through a nozzle.
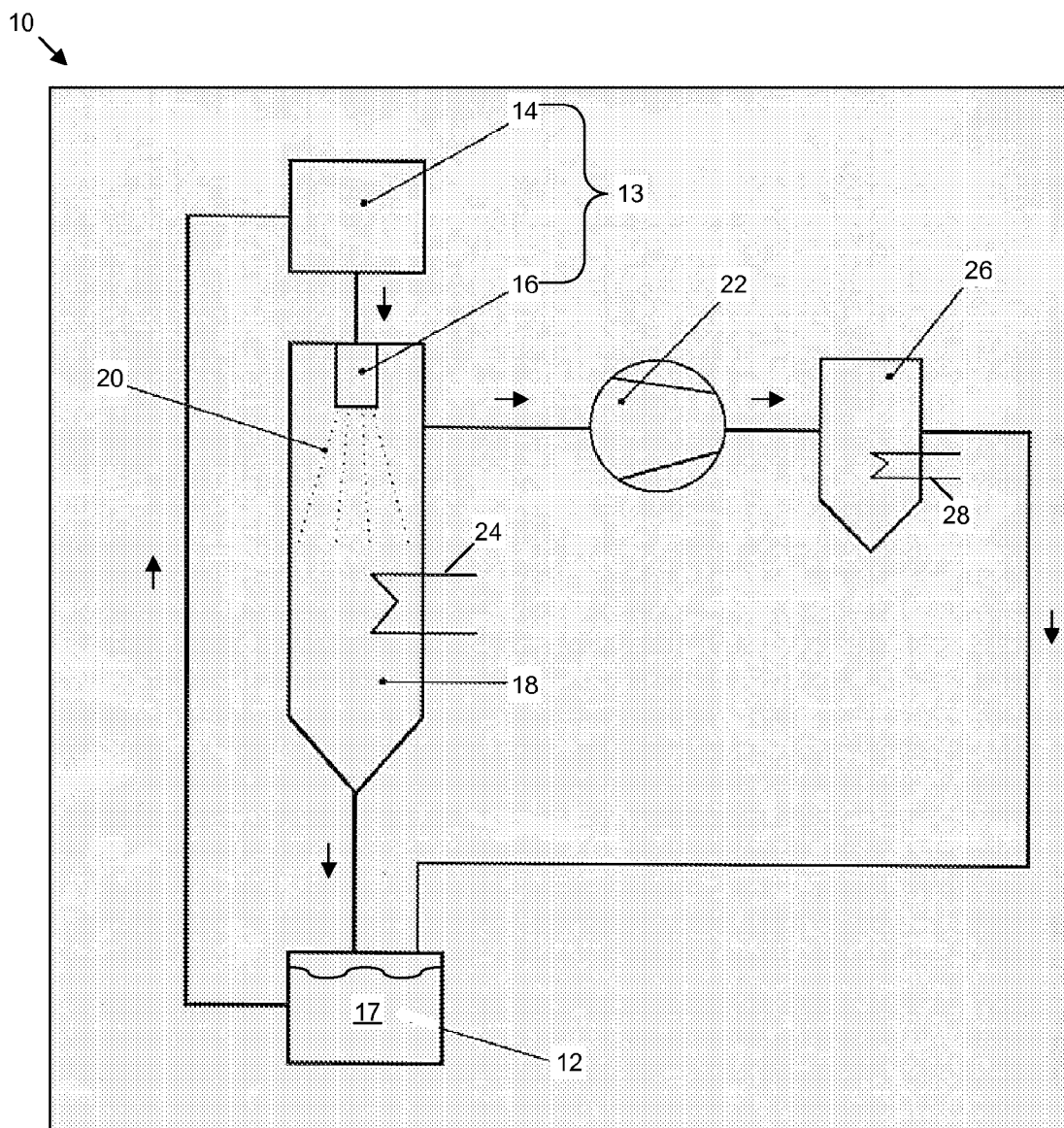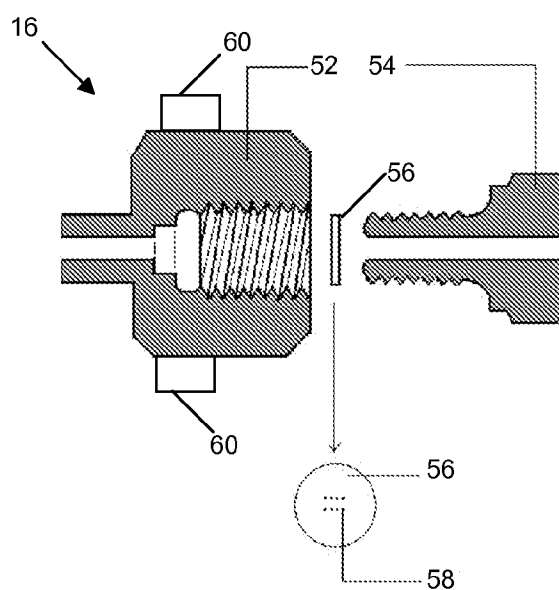
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24

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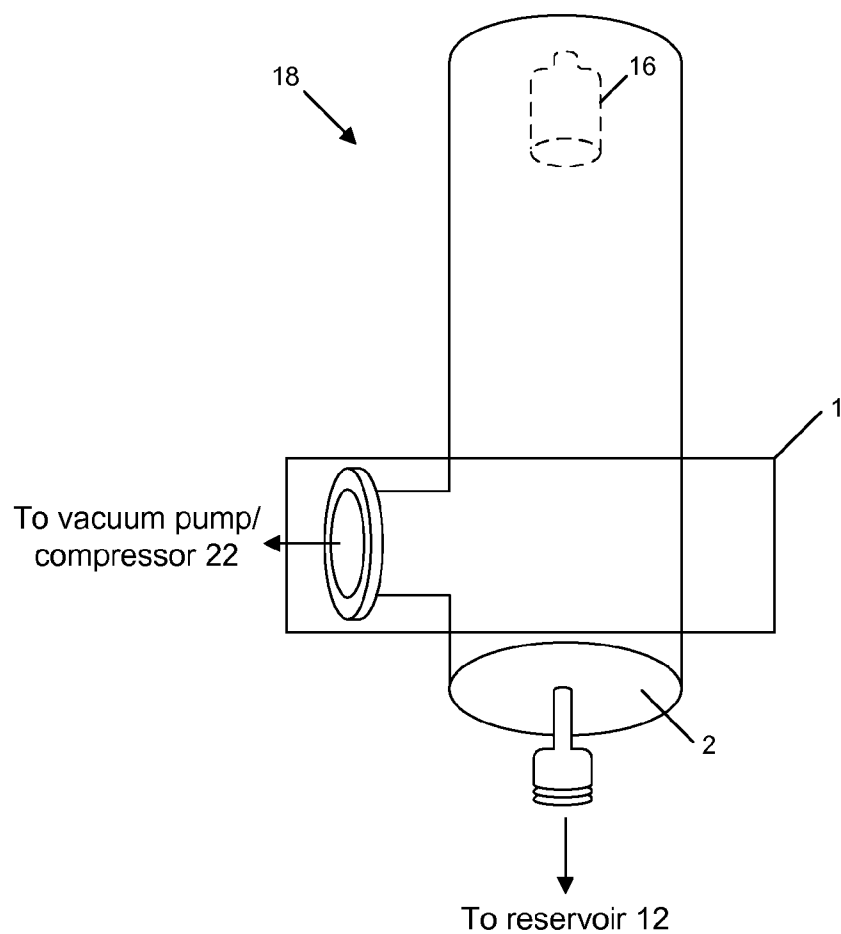
28

17

12

Fig. 1

Fig. 2

To vacuum pump/
compressor 22
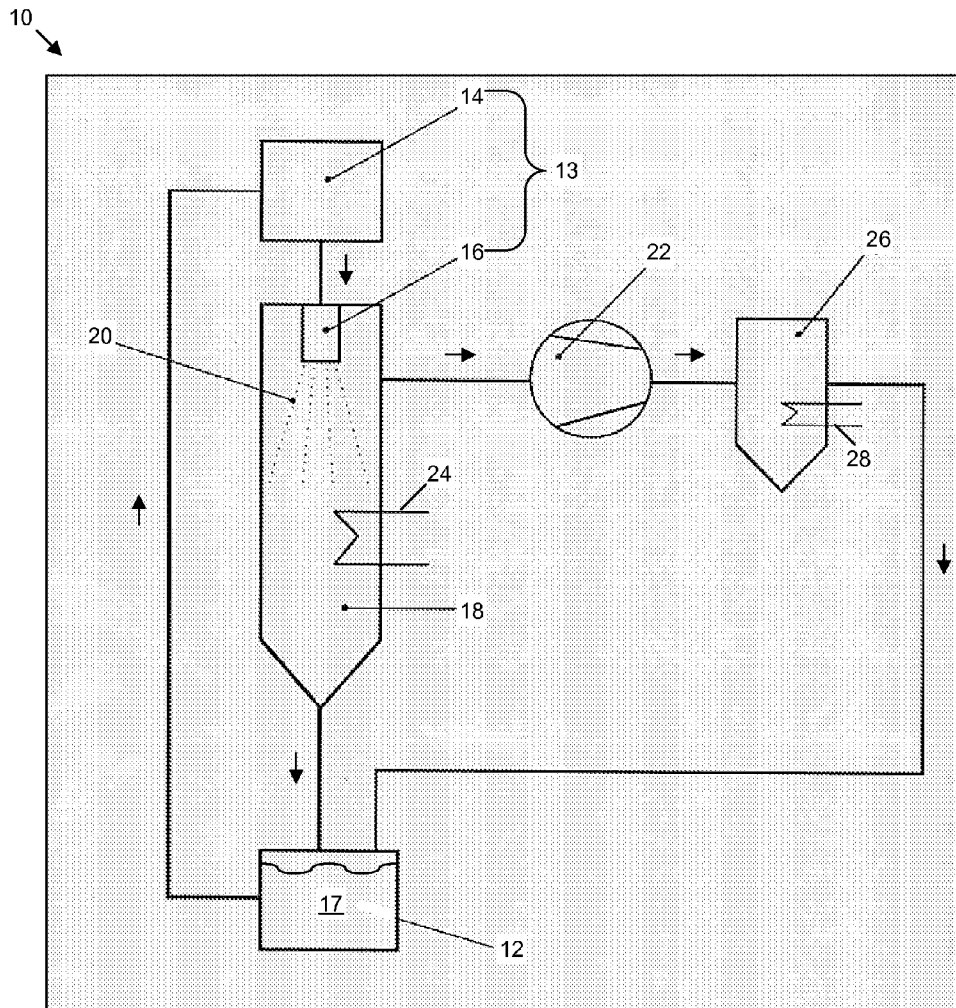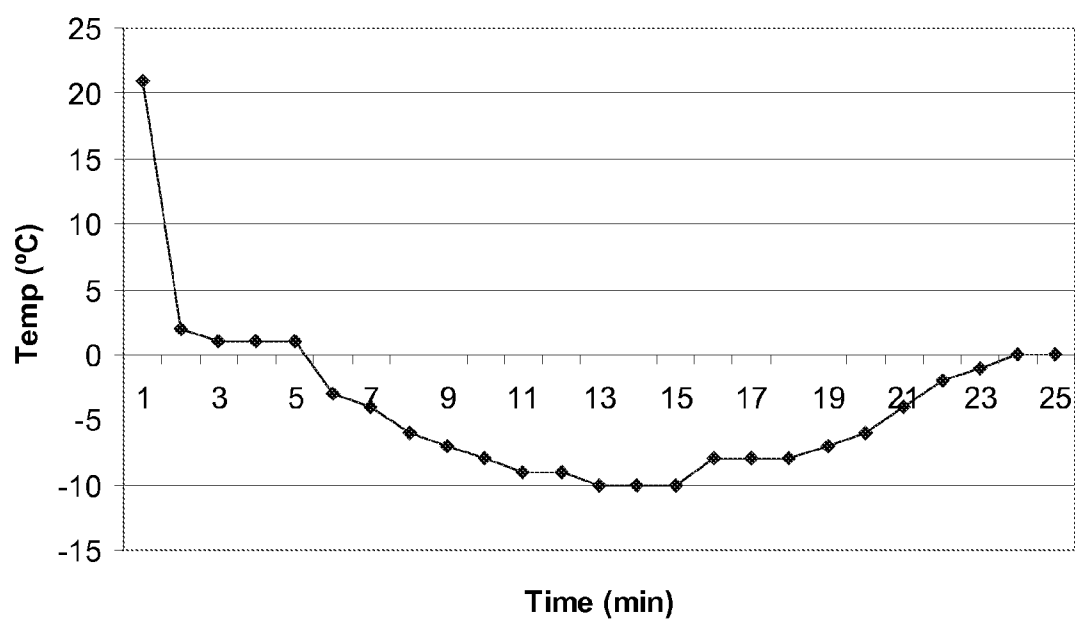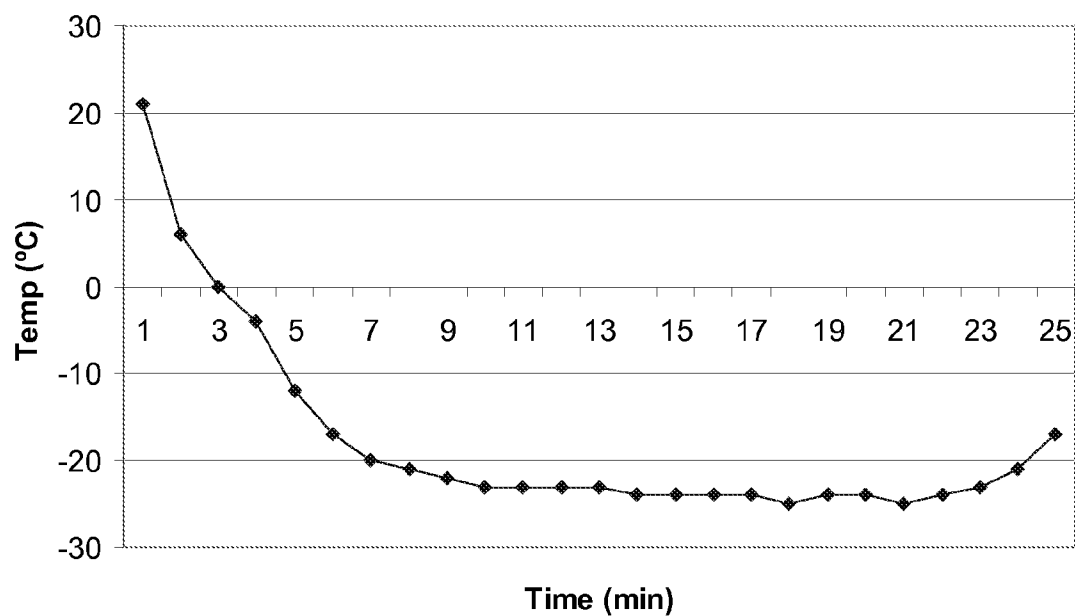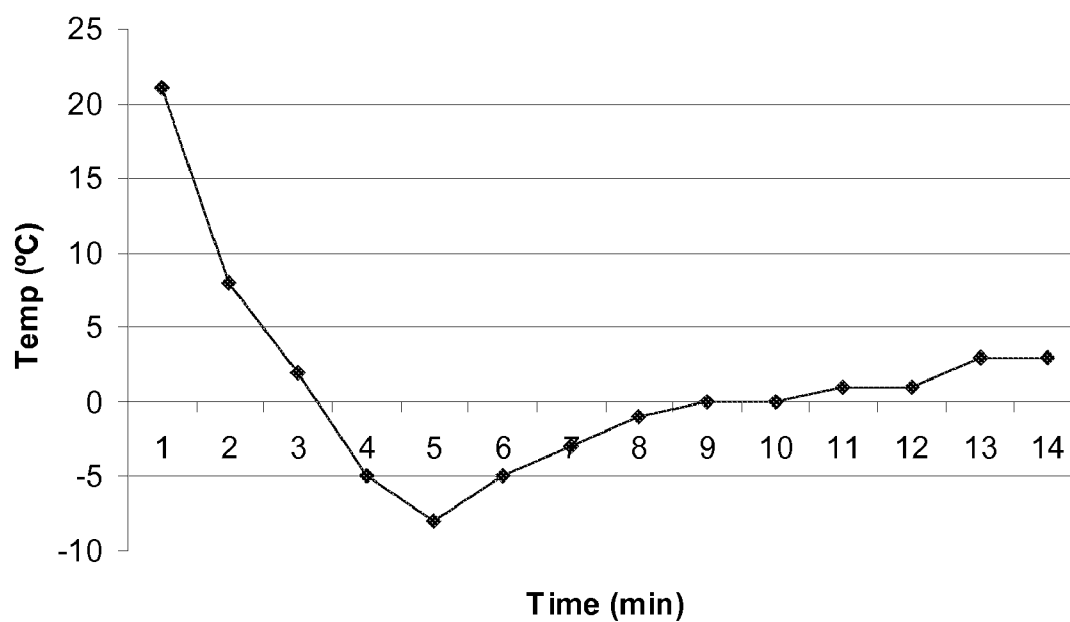
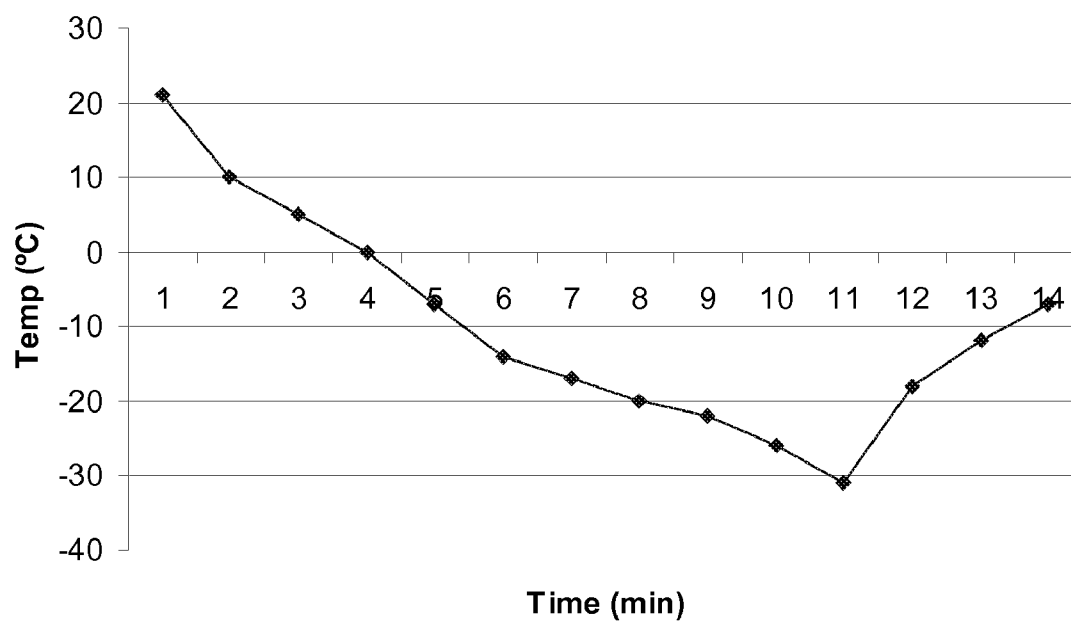To reservoir 12

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

ATOMIZED LIQUID JET REFRIGERATION SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part of U.S. patent application Ser. No. 10/865,659, filed on Jun. 9, 2004, and incorporated herein by reference.

FIELD OF INVENTION

[0002] This invention relates to refrigeration systems.

DESCRIPTION OF RELATED ART

[0003] Conventional refrigeration systems employ the compression technology of chlorofluorocarbon (CFC), hydrofluorocarbon (HFC), hydrochlorofluorocarbon (HCFC), and ammonium (NH_3) refrigerants. Gaseous refrigerants are compressed to the liquid state through heat exchanges with the environment. Evaporations of liquefied CFC or NH_3 refrigerants provide the cooling mechanism. Because the heat of vaporization of NH_3 is larger than those of CFCs, and that NH_3 is easily compressible to a condensed phase, NH_3 compression refrigeration systems are widely utilized in various manufacturing industries and in large storage facilities. On the other hand, the corrosive characteristics of NH_3 require that special operational precautions to be imposed. Thus, domestic refrigerators and air-conditioners (including motor vehicle ACs) invariably utilize the compression technology of CFC refrigerants.

[0004] Under the Montreal Protocol, CFCs were phased out on January 1996 and HCFCs will be phased out on January 2020 in developed countries. Under the Kyoto Protocol, greenhouse gases emitted by the developed countries must be reduced by 5.2% of the 1990 level from 2008 to 2012. As one of the six greenhouse gases identified in the Kyoto Protocol, HFC refrigerants can no longer be considered as a substitute for CFC refrigerants. The formidable issues of ozone depletion and the greenhouse effect caused by CFC, HCFC, and HFC refrigerants demand a new refrigeration technology.

[0005] Propane, carbon dioxide, and ammonium refrigerants have been proposed as replacements for the CFC, HCFC, and HFC refrigerants. However, these refrigerants are inherent hazardous to human health. For example, propane can leak and cause an explosion or a fire. The high pressure of a carbon dioxide refrigeration system, often greater than 73 atmospheres, is inherently dangerous. The use of carbon dioxide in confined space also runs the risk of suffocating the inhabitants. Likewise, ammonium is well-known for its toxicity.

[0006] In the prior art, water is not used as the refrigerant for a compression cycle refrigerating system. A. D. Althouse, C. H. Turnquist, A. F. Bracciano, "Modern Refrigeration and Air Conditioning," The Goodheart-Willcox Co., South Holland, Ill., 1988, p. 295. However, water is the refrigerant for steam jet refrigeration used to air-condition large facilities. Id. A steam jet refrigeration chiller employs the momentum of steam to pump away gaseous water molecules. Thus, evaporation of water in the chill tank under reduced pressure cools down the water reservoir in the chill tank. This is an inefficient method that relies on an inex-pensive supply of high pressure steam and can only cool the water reservoir to about 4° C. In general, practitioners in the field are convinced that a refrigeration scheme based on a pure water refrigerant cannot go beyond the standard freezing point of H_2O at 0° C.

[0007] In the prior art, such as U.S. Pat. Nos. 2,159,251, 2,386,554, 4,866,947, 5,046,321, and 6,672,091, atomizers have been used instead of the expansion valve in conventional compression cycle refrigerating systems to improve the evaporation rate of the refrigerant.

[0008] Thus, what is needed is a refrigeration system that (1) employs a refrigerant that is environmental-friendly, chemically non-corrosive, non-flammable, and physiologically harmless, and (2) provides the same or better performance while consuming the same or less energy as conventional technologies.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a block diagram of a refrigeration system in one embodiment of the invention.

[0010] FIG. 2 is a schematic of a nozzle used to generate jets of micron-sized refrigerant droplets in one embodiment of the invention.

[0011] FIG. 3 is a schematic of a low-pressure heat exchanger for transferring heat away from ambient air to refrigerant droplets in one embodiment of the invention.

[0012] FIGS. 4 and 5 are charts illustrating the result of an open loop water refrigeration system in one embodiment of the invention.

[0013] FIGS. 6 and 7 are charts illustrating the result of an open loop alcohol refrigeration system in one embodiment of the invention.

[0014] Use of the same reference numbers in different figures indicates similar or identical elements.

SUMMARY

[0015] In one embodiment of the invention, a system for controlling temperature includes an atomizer that forms micron-sized hydrogen-bonded refrigerant droplets within a chamber. A vacuum pump is coupled to the chamber to lower its interior pressure. Under these conditions, the refrigerant droplets evaporate while lowering the temperature of its immediate surrounding. The reduced pressure in the chamber delays the freezing of the refrigerant droplets to below 0° C. at about at least one of a heterogeneous nucleation temperature and a homogenous nucleation temperature of the refrigerant droplets at their size. In one embodiment, the atomizer includes a pump that forces a hydrogen-bonded liquid refrigerant through a nozzle.

[0016] In one embodiment, a method for controlling temperature includes lowering the pressure within a chamber and generating micron-sized hydrogen-bonded refrigerant droplets within the chamber. Under these conditions, the refrigerant droplets evaporate while lowering the temperature of its immediate surrounding. The reduced pressure in the chamber delays the freezing of the refrigerant droplets to below 0° C. at about at least one of a heterogeneous nucleation temperature and a homogenous nucleation temperature of the refrigerant droplets at their size. In one

embodiment, the refrigerant droplets are generated by pumping a hydrogen-bonded liquid refrigerant through a nozzle.

DETAILED DESCRIPTION

[0017] A liquid jet refrigeration system utilizes the atomization of hydrogen-bonded liquid refrigerants to meet environmental needs, occupational safety standards, and fast cooling rates. The evaporation efficiencies of environmental-friendly hydrogen-bonded liquid refrigerants are greatly enhanced by atomizing them into streams of micron-sized refrigerant droplets. In addition to the advantage of the large heats of vaporization of hydrogen-bonded liquid refrigerants, these gaseous refrigerants are easily condensed under compression. Energy consumptions of the liquid jet refrigeration system are more efficient in comparison with those of conventional technologies.

[0018] After 1950, refrigerants that are liquids at room temperatures (25° C.) and 1 atmosphere have never been considered for refrigeration systems using compression technologies. However, there are many hydrogen-bonded liquids that are environmental-friendly, chemically non-corrosive, non-flammable, and physiologically harmless (e.g., alcohol/water mixtures, such as ethyl alcohol (C_2H_5OH)). Above all, they exhibit heats of vaporization larger than those of NH_3 (ΔH_{vap}^0=40.6 kJ/mole, 43.5 kJ/mole, and 23.35 kJ/mole for water, ethyl alcohol, and ammonia, respectively).

[0019] According to their phase diagrams and thermodynamic properties, these liquid refrigerants evaporate spontaneously under reduced pressure. Meanwhile, the evaporated molecules that escape from the surface carry away the internal energy of the liquid (heats of vaporization). Thus, the evaporation of the liquefied refrigerant (e.g., water initially at 25° C.) cools the remaining liquid into a state of lower temperature under reduced pressure. This refrigeration mechanism can be maintained in principle as long as a good vacuum environment (e.g., better than 0.1 mbar) is created above the liquid surface.

[0020] In practice, the rate of evaporation is not controlled thermodynamically but kinetically. According to the kinetic theory of gases, the rate of evaporation

$$\frac{dN}{dt}$$

is given by:

$$\frac{dN}{dt} = -\frac{\Delta P N_A A}{(2\pi MRT)^{1/2}}, \qquad (1)$$

where ΔP is the pressure difference between the equilibrium vapor pressure of the liquid at temperature T and the gaseous pressure of the environment, N_A is the Avogadro number, M is the molecular weight, R is the gas constant, and A is the surface area of the liquid phase. When a 1 cm³ liquid droplet is dispersed into 1 μm micro-spheres, the surface area is increased by four orders of magnitude (10^4). Consequently,

the rate of cooling is substantially enhanced by atomizing the liquid into micron-sized droplets (i.e., dispersing a liquid into mist).

[0021] Furthermore, atomizing the liquid into micron-sized droplets delays the onset of freezing from heterogeneous nucleation because the probability of enclosing impurities (nucleation centers) inside the individual micron-sized droplets is greatly reduced. For example, the chances for a water droplet having a 1 mm diameter to enclose impurities are nine orders of magnitude higher (10^9) higher than droplets having a 1 μm diameter. If impurities are eliminated, a pure micron-sized droplet can be supercooled below its heterogeneous nucleation temperature down to its homogenous nucleation temperature before freezing. All of this allows micro-sized droplets to be cooled to very low temperatures before freezing.

[0022] As long as the micron-sized droplets remain in the liquid state, the vapor pressure of the liquid state can sustain the vaporization cooling process until nucleation sets in to freeze the micron-sized droplets. Once the micron-sized droplets freeze, the vaporization cooling process would slow and the cooling temperature would reach a limit because the evaporation rates of the solid micron-sized spheres are lower than those of the liquid micron-sized droplets. This is because thermodynamically, the equilibrium vapor pressure of liquid is greater than solid. For example, the equilibrium vapor pressure of supercooled water is about 20% higher than ice in the temperature range 0 to –25° C.

[0023] Nonetheless, the evaporative cooling is operative for both the liquid and solid micron-sized droplets so long as the external pressure is kept low (e.g., below 0.1 mbar for water). In other words, the cooling effect is a kinetic process that relies on the surface area and the vapor pressure at a designated temperature of the refrigerant. The refrigeration performance of the micron-sized droplets in a vacuum environment depends predominantly on the total surface areas of micron-sized droplets and partially on the relative abundances of these droplets in the supercooled and solid states.

[0024] There are many techniques to atomize liquids into micron-sized droplets, including (1) liquid jet atomization by pumping a liquid through micron-sized pinholes, (2) ultrasonic atomization, (3) piezoelectric atomization, and (4) DC-discharge atomization. Presently, experiments demonstrate that liquid jet atomization serves the refrigeration purpose quite well. For example, a refrigeration chamber can be cooled from 21° C. to –20° C. around 6 minutes. The cooling mechanism is provided by the evaporation of micron-sized refrigerant droplets under reduced pressure. The micron-sized refrigerant droplets are created by pumping the liquid refrigerant through a nozzle having an array of micron-sized pinholes.

[0025] FIG. 1 illustrates a refrigeration system 10 in one embodiment of the invention. System 10 includes a liquid refrigerant reservoir 12 that stores a liquid refrigerant 17. Liquid refrigerant 17 is preferably in a liquid state at 25° C. and 1 atmosphere. Liquid refrigerant 17 is preferably a hydrogen-bonded liquid such as water, alcohol (e.g., ethanol or methanol), an alcohol/water mixture (e.g., a 70:30 mixture of ethanol and water), or diethyl ether. In one embodiment, pure water refrigerant is used.

[0026] From liquid refrigerant 17 in reservoir 12, an atomizer 13 generates micron-sized refrigerant droplets 20.

In one embodiment, atomizer **13** includes a liquid pump **14** and a nozzle **16**. Liquid pump **14** forces liquid refrigerant **17** through nozzle **16** to inject micron-sized refrigerant droplets **20** into a low-pressure chamber **18** (e.g., a heat exchanger). In one embodiment, liquid pump **14** (e.g., a NP-CX-100 from Nihon Seimitsu Kagaku of Tokyo, Japan) delivers a flow rate of 80 ml/min at a pressure of 30 bar.

[0027] FIG. 2 illustrates the details of nozzle **16**. Nozzle **16** includes a vacuum female fitting **52** and a vacuum male fitting **54** (e.g., VCR® fittings made by Cajon Company of Macedonia, Ohio). A nozzle plate **56** is inserted into vacuum female fitting **52** and secured by vacuum male fitting **54**. Nozzle plate **56** has micron-sized pinholes **58** (only one is labeled) that disperse liquid refrigerant **17** as jets of micron-sized refrigerant droplets **20** having a diameter of less than 50 μm.

[0028] In one embodiment, pinholes **58** have a diameter of 80 μm and generate refrigerant droplets **20** having a diameter of approximately 10 μm. In this embodiment, nozzle plate **56** is a stainless steel plate having a diameter of 13 mm and a thickness of 1 mm. In this embodiment, six or more pinholes **58** are laser-drilled into nozzle plate **56** (e.g., by a COMPEX 200 and SCANMATE 2E laser system made by Lambda Physik of Göttingen, Germany).

[0029] Nozzle **16** may include a heater **60** (e.g., an electric heater or a water heater that circulates room temperature water around the nozzle) to prevent liquid refrigerant **17** from clogging nozzle **16** when it freezes. Parameters such as the flow rate, the applied pressure, the number of pinholes in the nozzle array, and the pinhole size may be modified to generate the micron-sized refrigerant droplets of the appropriate size.

[0030] Referring back to FIG. 1, a vacuum pump/compressor **22** reduces the pressure within heat exchanger **18** so that refrigerant droplets **20** evaporate when introduced into heat exchanger **18** and absorb heat from the remaining refrigerant droplets and its immediate surroundings. Vacuum pump/compressor **22** can be a mechanical pump or a Roots pump with a backup mechanical vacuum pump (e.g., a RSV 1508 Roots pump made by Alcatel of Annecy Cedex, France, and an SD-450 vacuum pump made by Varian of Lexington, Mass.). The large surface area of the atomized droplets greatly enhances their evaporate rate. In one embodiment, the pressure within heat exchanger **18** is reduced to 0.01 mbar. Heat exchanger **18** may include a conduit **24** that carries a medium (e.g., ambient air) that is cooled as the medium travels into and out of heat exchanger **18**. Alternatively, the medium can simply be blown over the outer surface of heat exchanger **18**.

[0031] As refrigerant droplets **20** evaporate and absorb heat from the remaining refrigerant droplets, the remaining refrigerant droplets can cool down to about either the heterogeneous or the homogenous nucleation temperature depending on the purity and the size of the droplets. For example, water droplets of 100 μm have a heterogeneous nucleation temperature of about −30° C. and water droplets of 1 μm have a homogeneous nucleation temperature of about −40° C. Thus, the small size of refrigerant droplets **20** allows them to cool down to very low temperatures and in the extreme case allows them to supercool down to its homogenous nucleation temperature.

[0032] FIG. 3 illustrates heat exchanger **18** in one embodiment of the invention. Heat exchanger **18** has an outlet to

vacuum pump/compressor **22** located on an opposite end away from nozzle **16**. Heat exchanger **18** can be made of any conventional form, e.g., coil or fin types. The medium that is cooled can be any gaseous or liquefied heat transfer materials. In one embodiment, the medium is used to cool a space such as a room or a refrigeration compartment. Any refrigerant droplets **20** that do not evaporate are collected at the bottom of heat exchanger **18** and returned to reservoir **12**.

[0033] In one embodiment, system **10** is an open loop refrigeration system because liquid refrigerant **17**, like water, can be safely expelled into the environment. In this embodiment, vacuum pump/compressor **22** simply expels the gaseous refrigerant into the atmosphere. In this embodiment, reservoir **12** can be replaced by a water supply line (e.g., a city supplied water line to a home or a business).

[0034] In one embodiment, system **10** is a closed cycle refrigeration system because liquid refrigerant **17** cannot be safely expelled into the environment. In this embodiment, vacuum pump/compressor **22** compresses the gaseous refrigerant into an atmospheric pressure chamber **26** (e.g., another heat exchanger).

[0035] Referring back to FIG. **1**, heat changer **26** may include a conduit **28** that carries another medium (e.g., ambient air) that condenses the gaseous refrigerants as the medium travels into and out of heat exchanger **26**. Alternatively, the medium can simply be blown over the outer surface of heat exchanger **26**. As the gaseous refrigerant condenses, it heats the medium. The heated medium can be any gaseous or liquefied heat transfer materials. In one embodiment, the heated medium is expelled to the environment. In one embodiment, the heated medium is used to heat a space such as a room or a heating compartment. The cooled liquid refrigerant **17** then exits heat exchanger **26** and returns to reservoir **12**.

[0036] FIGS. 4 and 5 show the experimental results of one embodiment of an open loop refrigeration system **10** using a pure water refrigerant, a 6-pinhole nozzle **16**, and a flow rate of **80** ml/minute. Specifically, FIG. **4** shows the temperature recorded at location **1** (FIG. **3**) around heat exchanger **18**, and FIG. **5** shows the temperatures recorded at location **2** (FIG. **3**) at the bottom of heat exchanger **18**. As can be seen in FIGS. **4** and **5**, the temperature began to rise at the end of the experiment. This is because the water refrigerant started to clog nozzle **16** when it froze because nozzle **16** was not heated in the experiment. The results show that temperatures as low as −25° C. can be achieved, which is unexpected for a water refrigeration system and not disclosed by any known prior art.

[0037] Applicant believes that the water refrigerant did not cool beyond the heterogeneous nucleation temperature due to the impurities introduced into the water refrigerant by the experimental refrigeration system. These impurities form nucleators around which ice is formed, thereby preventing the water refrigerant from being cooled beyond the heterogeneous nucleation temperature. Even without supercooling, the water refrigeration system was able to provide sufficient cooling for most application. Conventional refinements of the refrigeration system would reduce or remove the impurities and allow supercooling of the water refrigerant to temperatures down to the homogenous nucleation temperature.

[0038] FIGS. 6 and 7 show the experimental results of one embodiment of an open loop refrigeration system 10 using an ethanol refrigerant (99.5%), a 6-pinhole nozzle 16, and a flow rate of 80 ml/minute. Specifically, FIG. 6 shows the temperature recorded at location 1 (FIG. 3) around heat exchanger 18, and FIG. 7 shows the temperatures recorded at location 2 (FIG. 3) at the bottom of heat exchanger 18. Again as can be seen in FIGS. 6 and 7, the temperature began to rise at the end of the experiment. This is because the ethanol refrigerant started to clog nozzle 16 when it froze because nozzle 16 was not heated in the experiment.

[0039] For a fast cooling rate and an ultimate low temperature, methanol/water or ethanol/water refrigerant may be used in system 10. For an environmentally friendly, chemically non-corrosive, non-flammable, and physiologically harmless refrigerant, pure water or ethanol/water refrigerant may be used in system 10. Thus, water systems can find their roles in the market of domestic appliances, while pure ethanol, ethanol/water, and methanol/water refrigeration systems can be employed in manufacturing industries and in large storage facilities.

[0040] Various other adaptations and combinations of features of the embodiments disclosed are within the scope of the invention. For example, hydrogen-bonded liquid refrigerants are not limited to the specific chemical compounds mentioned above. The material, the fabrication method, and the characteristics of the nozzle are not limited to those mentioned above. Liquid atomization by other well-known techniques, such as ultrasonic, piezoelectric, and electric discharge methods, can be used in place of the pump and the nozzle. Numerous embodiments are encompassed by the following claims.

What is claimed is:

1. A compression cycle refrigeration system, comprising:

a chamber;

a vacuum pump coupled to the chamber, the vacuum pump lowering pressure within the chamber to 0.1 mbar or less;

a supply of a liquid hydrogen-bonded refrigerant;

an atomizer coupled between the supply and the chamber, the atomizer outputting micron-sized refrigerant droplets into the chamber;

wherein the refrigerant droplets have diameters that are 50 microns or less, the refrigerant droplets evaporate to form a gaseous refrigerant by absorbing heat from its surrounding, and a low pressure in the chamber delays freezing of the refrigerant droplets to below 0° C. at about at least one of a heterogeneous nucleation temperature and a homogenous nucleation temperature of the refrigerant droplets at their size.

2. The system of claim 1, wherein the pressure within the chamber is 0.01 mbar or less, and the refrigerant droplets have diameters of about 10 microns.

3. The system of claim 1, wherein the atomizer is selected from the group consisting of an ultrasonic atomizer, a piezoelectric atomizer, and an electric discharge atomizer.

4. The system of claim 1, wherein the atomizer includes:

a nozzle; and

a pump coupled between the supply and the nozzle, wherein the pump forces the liquid hydrogen-bonded refrigerant through the nozzle to form the micron-sized refrigerant droplets.

5. The system of claim 4, wherein the nozzle comprises pinholes.

6. The system of claim 5, wherein the pinholes have a diameter of 20 microns or less.

7. The system of claim 4, wherein the nozzle further a heater to heat the nozzle.

8. The system of claim 1, wherein the hydrogen-bonded refrigerant is in its liquid state at 25° C. and 1 atmosphere.

9. The system of claim 1, wherein the hydrogen-bonded refrigerant is water.

10. The system of claim 9, wherein the vacuum pump expels the gaseous refrigerant to the atmosphere.

11. The system of claim 1, wherein the hydrogen-bonded refrigerant is selected from the group consisting of alcohol and alcohol/water mixture.

12. The system of claim 11, wherein the alcohol/water mixture comprises a 70:30 mixture of ethyl alcohol and water.

13. The system of claim 1, wherein the chamber is a heat exchanger including a conduit carrying a medium into and out from the heat exchanger to cool the medium.

14. The system of claim 13, wherein the medium is air used to cool a space.

15. The system of claim 1, wherein a medium is moved over the outer surface of the chamber to cool the medium.

16. The system of claim 15, wherein the medium is air used to cool a space.

17. The system of claim 1, further comprising:

another chamber coupled to between the vacuum pump and the supply, wherein the vacuum pump compresses the gaseous refrigerant into said another chamber, the gaseous refrigerant condenses inside said another chamber to form the liquid refrigerant by loosing heat to its surrounding and is returned to the supply.

18. The system of claim 17, wherein the chamber is a heat exchanger including a conduit carrying a medium into and out from the heat exchanger to absorb heat from the gaseous refrigerant.

19. The system of claim 17, wherein a medium is moved over the outer surface of the chamber to absorb heat from the gaseous refrigerant.

20. The system of claim 17, wherein the supply is further coupled to the chamber to collect any refrigerant droplets that do not evaporate.

21. A method for controlling temperature, comprising:

reducing pressure within a chamber with a vacuum pump to 0.1 mbar or less;

atomizing a liquid hydrogen-bonded refrigerant to form micron-sized hydrogen-bonded refrigerant droplets within the chamber;

wherein the refrigerant droplets have diameters that are 50 microns or less, the refrigerant droplets evaporate to form a gaseous refrigerant by absorbing heat from its surrounding, and a low pressure in the chamber delays freezing of the refrigerant droplets to below 0° C. at

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about at least one of a heterogeneous nucleation temperature and a homogenous nucleation temperature of the refrigerant droplets at their size.

22. The method of claim 21, wherein the pressure within the chamber is 0.01 mbar or less, and the refrigerant droplets have diameters of about 10 microns.

23. The method of claim 21, wherein said atomizing comprises a method selected from the group consisting of an ultrasonic atomizing method, a piezoelectric atomizing method, and an electric discharge atomizing method.

24. The method of claim 21, wherein said atomizing comprises pumping the liquid refrigerant through a nozzle with a pump.

25. The method of claim 24, wherein the nozzle comprises pinholes, the pinholes comprising a diameter of 20 microns or less.

26. The method of claim 25, further comprising heating the nozzle.

27. The method of claim 21, wherein the hydrogen-bonded refrigerant is in its liquid state at 25° C. and 1 atmosphere.

28. The method of claim 21, wherein the hydrogen-bonded refrigerant is water.

29. The method of claim 28, further comprising expelling the gaseous refrigerant to the atmosphere.

30. The method of claim 21, wherein the hydrogen-bonded refrigerant is selected from the group consisting of alcohol and alcohol/water mixture.

31. The method of claim 30, wherein the alcohol/water mixture comprises a 70:30 mixture of ethyl alcohol and water.

32. The method of claim 21, wherein a medium passed into and out of the chamber to cool the medium.

33. The method of claim 32, wherein the medium is air used to cool a space.

34. The method of claim 21, wherein a medium passed over the chamber to cool the medium.

35. The method of claim 34, wherein the medium is air used to cool a space.

36. The method of claim 21, further comprising:

compressing the gaseous refrigerant with the vacuum pump into another chamber;

condensing the gaseous refrigerant in said another chamber to form the liquid refrigerant; and

returning the liquid refrigerant for use in said atomizing.

37. The method of claim 36, wherein said condensing the gaseous refrigerant comprises passing a medium into and out of said another chamber to heat the medium.

38. The method of claim 36, wherein said condensing the gaseous refrigerant comprises passing a medium over said another chamber to cool the medium.

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