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REFRIGERATION METHOD AND APPARATUS EMPLOYING THE JOULE-THOMSON EFFECT

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FIG. 1

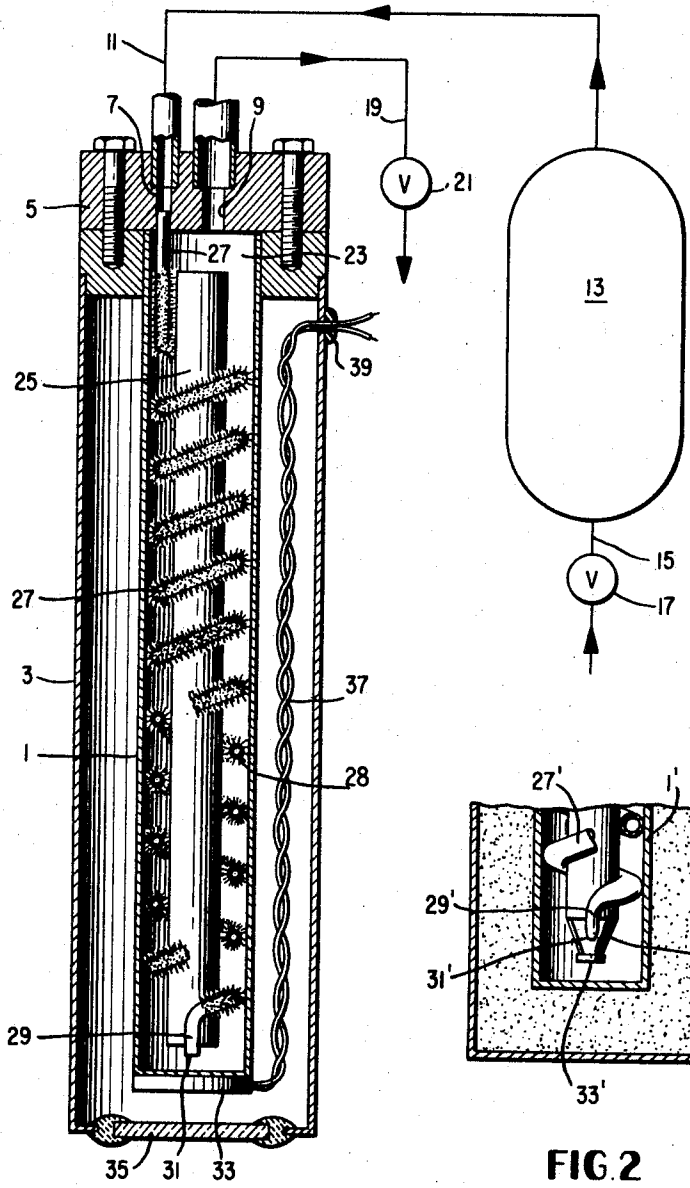


FIG. 2

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REFRIGERATION METHOD AND APPARATUS EMPLOYING THE JOULE-THOMSON EFFECT

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The present invention relates to refrigeration methods and apparatus, more particularly of the type designed to provide refrigeration at cryogenic levels for predeterminable periods of time.

It is an object of the present invention to provide refrigeration methods and apparatus that achieve low temperature levels very quickly.

Another object of the present invention is the provision of refrigeration methods and apparatus that maintain desired low temperature levels for extended periods of time.

Still another object of the present invention is the provision of refrigeration methods and apparatus adapted to be embodied in portable devices that are light weight and that in operation require no compressors or other power-driven equipment.

Finally, it is an object of the present invention to provide refrigeration apparatus that will be simple and inexpensive to manufacture, easy to charge, operate and recharge, and rugged and durable in use.

Other objects and advantages of the present invention will become more apparent from a consideration of the following description, taken in connection with the accompanying drawing, in which:

FIGURE 1 is a view partly in cross section and partly diagrammatic of a refrigeration apparatus and cycle according to the present invention; and

FIGURE 2 is a fragmentary view similar to a portion of FIGURE 1 but showing a modified form of the invention.

Briefly, the invention comprises the discovery that a desirably low level of temperature may be quickly achieved and long maintained if a body of compressed fluid is maintained in heat exchange relationship with a member to be cooled, whereupon cooling is initiated by rapidly dropping the pressure of the fluid to cool the member quickly and intensively, after which a cold fluid is passed in heat exchange with the member to maintain the member cold during a relatively long period of less intensive cooling. In the preferred form of the invention, two bodies of compressed fluid are maintained in fluid communication with each other through a relatively small opening and subsequently fluid communication is established between one of the bodies of fluid and a region of lower pressure through a second opening substantially larger than the first opening, thereby to initiate a relatively short period of intensive cooling as fluid of that one body quickly drops in pressure, and a relatively long period of less intensive cooling as fluid of the other body of fluid passes through that first relatively small opening. The fluid expanding through the small opening or orifice may be played on a cold spot. The short period of intensive cooling simply drops the temperature suddenly, while the relatively long period of less intensive cooling further drops the temperature and maintains it at the desired low level. Stated another way, the quick initial evacuation cools down the system, while the slow evacuation through the orifice maintains the cold spot cold. In the preferred form, two bodies of fluid are used, one of which is evacuated quickly and the other of which is thereupon evacuated slowly. In the preferred form, the bodies of fluid are continuously in fluid communication with each other through that relatively small opening, both before and during use of the device; but it is only when the one body of fluid is quickly evacuated that the other flows into the space previously occupied by the one.

Referring now to the drawing in greater detail, there is shown in FIGURE 1 apparatus according to the present invention, including an inner cylindrical shell 1 and an outer cylindrical shell 3 within which shell 1 is disposed. The ends of shells 1 and 3 are closed and the side and end walls of shells 1 and 3 are spaced from each other. Shells 1 and 3 are each connected at their open ends, which are their upper ends in FIGURE 1, with a head 5. Head 5 has an inlet opening 7 therethrough and an outlet opening 9 therethrough. The space between shells 1 and 3 is hermetically sealed by head 5; and the space within shell 1 is hermetically sealed by head 5 except through openings 7 and 9.

An inlet conduit 11 is secured to head 5 and communicates with inlet opening 7 at one end and with a reservoir or chamber 13 at its other end. Chamber 13 is a pressure vessel and is adapted to contain a body of compressed fluid under high pressure. Chamber 13 is provided with a filling conduit 15 controlled by a valve 17, so that when valve 17 is opened, chamber 13 may be filled with compressed fluid; but when valve 17 is closed, fluid cannot escape from reservoir 13 through conduit 15.

The device of the present invention is also provided with an outlet conduit 19 that communicates at one end with outlet opening 9 and is open to the ambient environment at its other end. Conduit 19 is provided with a valve 21 which when open permits fluid to flow freely through conduit 19 at a high flow rate, but which when closed prevents the outward flow of fluid from within shell 1 through conduit 19.

Inner cylindrical shell 1 thus defines a chamber 23 adapted to contain a body of compressed fluid. Chamber 23 also contains an elongated mandrel 25 which may be of cylindrical shape and which is disposed axially of chamber 23. Mandrel 25 is of a diameter substantially smaller than the internal diameter of inner shell 1; and an elongated conduit 27 is wrapped helically about mandrel 25 and may have an external diameter substantially smaller than the difference in radii of mandrel 25 and the inner wall of shell 1. A multiplicity of spines 28 are bonded to and extend radially outward from conduit 27 a distance such that the diameter of the conduit including its spines is about equal to the difference in radii of mandrel 25 and the inner wall of shell 1, so that the assembly of shell 1, mandrel 25, conduit 27 and spines 28 supports itself through the contact of the various elements with each other. Spines 28 improve the heat exchange between the tube and shell sides of conduit 27 and could instead be helical fins or other shapes of fins.

At its upper end as seen in FIGURE 1, conduit 27 communicates with inlet opening 7; while at its lower end as seen in FIGURE 1, conduit 27 has an end portion 29 that terminates at the lower end thereof as seen in FIGURE 1 in an opening 31 of a diameter substantially the same as the internal diameter of conduit 27 and end portion 29. Opening 31 is non-valved and is continuously open. Conduit 27 is continuously open between opening 31 and chamber 13, so that chambers 13 and 23 are continuously in fluid communication with each other through conduit 11, conduit 27 and opening 31.

Opening 31 opens onto the closed end of inner shell 1; and a low temperature component such as an infrared cell 33 is secured to the underside of the closed end of shell 1 to be cooled by fluid from opening 31 playing on

the inner side of the closed end of the shell. The space between shells 1 and 3 is evacuated, and the bottom of shell 3 is closed by a transparent window 35 of a material such as sapphire so that infrared cell 33 may "see" its environment. Infrared cell 33 is connected with the exterior of the device through electrical wires 37 that extend through outer shell 3 through a hermetic seal 39 which may be of plastic, ceramic or metallic composition.

In use, the apparatus is charged by introducing fluid under pressure through conduit 15 with valve 17 open. The fluid is a fluid which will be in vapor phase at atmospheric pressure and room temperature and is preferably at such temperature and pressure as to be in liquid phase in the charged system or to be a critical fluid of analogous density. Examples of suitable fluids are nitrogen and Freon–13, which is trifluorochloromethane. The fluid is introduced into the system under such pressure that upon expansion through conduit 27 and out through opening 31 it will be so cold by virtue of the Joule-Thomson effect as to be at least partially in liquid phase. Slender non-orificed tubes such as conduit 27 for the production of refrigeration are described in greater detail in copending application Serial No. 120,008, filed June 27, 1961. Chamber 13 becomes filled with the fluid upon charging, the fluid then passing through conduit 11 and conduit 27 and through opening 31 into chamber 23. If desired, valve 21, which controls conduit 19, may be left open at the beginning of charging to purge the system of undesired vapors.

To build up pressure, valve 21 is closed and with valve 17 open, the refrigerant fluid is introduced in the system until the pressure throughout the system, that is, in both of chambers 13 and 23, is uniform at the desired pressure level. For nitrogen at room temperature, a suitable charging pressure is 3500 p.s.i., while for Freon–13 at room temperature, a suitable pressure is 500 p.s.i. If the system is subjected to higher temperature, the Freon–13 may have to be charged at substantially higher pressures, for the critical temperature of Freon–13 is 84° F.; and above that temperature, the Freon–13 will not be stored as liquid but rather as a critical fluid. Accordingly, for such higher temperatures, the Freon–13 will be charged at 1000–2000 p.s.i., so that upon expansion through opening 31 the expanded fluid will be at least partly in liquid phase. The charging pressure can easily be determined by reference to the pressure-enthalpy diagram of the fluid in question, by following the isotherm of the initial temperature to a pressure level such that upon expansion at constant enthalpy, the end point will lie in the wholly or largely liquid region of the diagram.

Of course, the selection of the fluid to be charged will be governed by the temperature level it is desired to reach. Nitrogen will give a temperature level of about —320° F., while Freon–13 will give a temperature level of about —118° F. For a temperature level of about —200° F., Freon–14, which is tetrafluoromethane, could be used, and so on.

To initiate the cooling cycle after the system is placed in a state of readiness, it is necessary only to open the valve 21. As previously mentioned, valve 21 permits a high flow rate of fluid therethrough, with the result that chamber 23 falls very rapidly from the charged pressure of the closed system to ambient pressure, which will ordinarily be atmospheric or below. This very rapid evacuation of chamber 23 provides a very fast initial cooling of the entire inner sleeve 1 and cell 33 or 33′, along with conduit 27. Thereafter, the fluid in conduit 27 passes through opening 31 to this newly created region of low pressure, namely, chamber 23. No valve action is needed to interconnect chambers 13 and 23 upon the opening of valve 21, for chambers 13 and 23 have been continuously in fluid communication with each other through opening 31. But as the pressure in chambers 13 and 23 was equal, there was no fluid flow through opening 31. Upon the establishment of a low pressure zone in chamber 23, however, by evacuating chamber 23 rapidly past valve 21, fluid now flows from chamber 13 through conduit 27 through opening 31, and in so flowing becomes cooled by the Joule-Thomson effect. This continuous stream of expanded and cooled fluid, at least partly in liquid phase, plays against the closed end of inner shell 1 and cools cell 33 by conduction through shell 1.

As the liquid thus formed vaporizes, the vapor passes in countercurrent heat exchange with spines 28 and about the turns of conduit 27 on its way toward outlet 9. This cold fluid thus precools the fluid flowing on the tube side of conduit 27 toward opening 31. Shell 1, mandrel 25, conduit 27 with opening 31 at the end thereof, and spines 28, in the environment of a supply of high pressure fluid to the tube side of conduit 27 and the venting of the shell side of conduit 27 to the surroundings, thus provide in effect a heat exchanger of which the warm end is shown at the top of FIGURE 1 and the cold end is shown at the bottom of FIGURE 1, so that not only is a desirably low level of temperature very quickly reached, but also that low level is maintained with a relatively quite small flow of fluid from chamber 13.

Chambers 13 and 23 are shown spaced from each other, but of course it will be understood that they can be in unitary assembly with each other as for example if they were disposed at opposite ends of a cartridge and separated by a medial partition. It will also be understood that what is important is that an opening be provided at 31, regardless of whether this opening is in the form shown or is in the form of an orifice. An orificed heat exchanger is shown in FIGURE 2, in which the component 33′ is a small transmitter which does not need to "see" anything, so that the closed end of shell 3′ is opaque and the space between shells 1′ and 3′ is filled with a powdered insulating material, for example, pyrogenic silica having a particle size range of about 0.005–0.020 microns, which is available commercially from the Geoffrey L. Cabot Company under the trademark "Cabosil." In this case, component 33′ can be placed inside shell 1′ and can be removable as a unit with the mandrel and the tubing. In the embodiment of FIGURE 2, the conduit 27′ is substantially larger in diameter throughout most of its length but is provided with a necked-down end portion 29′ that terminates at its end in an orifice 31′ which is the opening through which the compressed fluid is expanded. Fluid emerging from orifice 31′ plays directly on component 33′.

Moreover, chamber 23 can be quickly vented to the surroundings or to a region of lower pressure by any of a variety of methods other than the opening of a valve such as valve 21. For example, a rupture disc can be used in place of valve 21 and can be opened by a variety of means, such as a shearing device or a small explosive squib.

It will of course be appreciated that when the term "fluid" is used in this specification and the appended claims, the term is intended to include not only liquid and vapor but also critical fluids that are neither liquid nor vapor. It will also be understood that conventional means may be employed for the prevention of plugging of the orifice or other opening by means of relatively high boiling contaminants, such conventional means taking for example the form of filters or adsorbers or both, preferably disposed in conduit 11, as set forth in greater detail in the above-identified copending application.

From a consideration of the foregoing disclosure, it will be obvious that all of the initially recited objects of the present invention have been achieved.

Although the invention has been described and illustrated in connection with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit of the invention, as those skilled in this art will readily understand. Such modifications and variations are considered

to be within the purview and scope of the present invention as defined by the appended claims.

What is claimed is:

1. A method of rapidly decreasing the temperature of a member at a desired time, comprising:

(a) maintaining a state of readiness by maintaining a body of compressed fluid in heat exchange relationship with the member to be cooled;

(b) at a desired time, abruptly establishing free fluid communication between said body of fluid and a region of lower pressure;

(c) passing cold fluid obtained by the abruptly established free communication, in heat exchange relationship with said member to be cooled for a relatively short period and at a high rate of cooling to lower the temperature of said member rapidly;

(d) performing a Joule-Thomson expansion of additional compressed fluid into a low pressure zone created by said abruptly established free communication;

(e) passing the resultant Joule-Thomson cooled fluid in heat exchange relationship with said member to be cooled for a relatively long period, but at a lower rate of cooling said member than the rate for said short period of cooling, to at least maintain said member at the low temperature levels achieved by said relatively short period of cooling.

2. The method of claim 1 wherein said region of lower pressure is ambient pressure.

3. The method of claim 1, wherein (a) said body of compressed fluid is maintained in direct heat exchange relationship with the member to be cooled.

4. A method of rapidly decreasing the temperature of a member at a desired time, comprising:

(a) maintaining two bodies of compressed fluid in communication with each other through a first opening, said body upstream of said first opening having an upstream side and a downstream side, said body downstream of said opening having an upstream side and a downstream side, said upstream side of said upstream body being in communication with said downstream side of said downstream body only through the downstream side of the upstream body and the upstream side of the downstream body;

(b) abruptly establishing fluid communication between the downstream side of said downstream body and a region of lower pressure through a second opening substantially larger than said first opening;

(c) passing cooled fluid obtained by the abruptly established free communication, in heat exchange relationship with the said member to be cooled for a relatively short period and at a high rate of cooling to lower the temperature of said member rapidly;

(d) performing a Joule-Thomson expansion of said upstream body through said first opening, and

(e) passing the resultant Joule-Thomson cooled fluid in heat exchange relationship with said member to be cooled for a relatively long period, but at a lower rate of cooling said member than the rate of said short period of cooling to at least maintain said member at the low temperature levels achieved by said relatively short period of cooling.

5. The method of claim 4 wherein the upstream body is passed in heat exchange relationship with said downstream body during said relatively short period.

6. A method of rapidly decreasing the temperature of a member at a desired time, comprising the successive steps of:

(a) at a desired time, abruptly establishing free fluid communication between a body of compressed fluid and a region of lower pressure;

(b) passing cold fluid obtained by the abruptly established free communication in heat exchange relationship with the member to be cooled for a relatively short period and at a high rate of cooling to lower the temperature of said member rapidly;

(c) performing a Joule-Thomson expansion of additional compressed fluid into a low pressure zone created by said abruptly established free communication;

(d) passing the resultant Joule-Thomson cooled fluid in heat exchange relationship with said member to be cooled for a relatively long period, but at a lower rate of cooling said member than the rate for said short period of cooling, where, in said relatively long period, said member to be cooled is cooled with both said cooled fluid obtained by the abruptly established free communication and the Joule-Thomson cooled fluid; and

(e) cooling said member with only said Joule-Thomson cooled fluid.

7. Lightweight portable refrigeration apparatus employing a Joule-Thomson effect comprising a pair of chambers free from moving parts and containing a quantity of compressed fluid, the chambers being sealed but communicating with each other through a first opening, and means for establishing fluid communication between one said chamber and a region of lower pressure through a second opening substantially larger than said first opening, said means including off-on valve means at said second opening thereby to initiate a relatively short period of intensive cooling as fluid of said one chamber drops in pressure and a relatively long period of less intensive cooling as fluid of the other said chamber passes through said first opening.

8. Apparatus as claimed in claim 7, and means for conducting fluid of said other chamber toward said first opening along an extended heat exchange path through said one chamber.

9. Refrigeration apparatus comprising one chamber with a solid surface to be cooled within the chamber and another chamber, the chambers being sealed but communicating with each other through a first opening, said first opening being disposed adjacent to said solid surface with the axis of the opening transverse to said solid surface so that fluid issuing from said first opening into said one chamber is directed against said solid surface, and means for establishing fluid communication between said one chamber and a region of lower pressure through a second opening substantially larger than said first opening thereby to initiate a relatively short period of intensive cooling of said solid surface as fluid of said one chamber drops in pressure and a relatively long period of less intensive cooling of said solid surface as fluid of said another chamber passes through said first opening and contacts said solid surface.

10. Apparatus as claimed in claim 9, and a member to be cooled, said solid surface being an inside surface of said chamber in indirect heat exchange realtionship with said member to be cooled.

11. Apparatus as claimed in claim 9, and a member to be cooled disposed within said chamber, said solid surface being a surface of said member to be cooled.

12. Refrigeration apparatus employing a Joule-Thomson effect comprising a pair of chambers containing a quantity of compressed fluid, the chambers being sealed from one another but communicating with each other through only a first opening, means for establishing fluid communication between one said chamber and a region of lower pressure through a second opening substantially larger than said first opening, said means including off-on valve means at said second opening thereby to initiate a relatively short period of intensive cooling as fluid of said one chamber drops in pressure and a relatively long period of less intensive cooling as fluid of the other said chamber passes through said first opening, and means for conducting fluid of said other chamber toward said first opening along an extended heat exchange path through said one chamber.

13. Refrigeration apparatus comprising one chamber

with a solid surface to be cooled within the chamber and another chamber, the chambers being sealed but communicating with each other through a first opening, said first opening being so disposed relative to said solid surface that fluid issuing from said first opening into said one chamber is directed toward said solid surface, means for establishing fluid communication between said one chamber and a region of lower pressure through a second opening substantially larger than said first opening thereby to initiate a relatively short period of intensive cooling of said solid surface as fluid of said one chamber drops in pressure and a relatively long period of less intensive cooling of said solid surface as fluid of said other chamber passes through said first opening and contacts said solid surface, and a member to be cooled, said solid surface being an inside surface of said chamber

in indirect heat exchange relationship with said member to be cooled.

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