Jan. 2, 1968 C. E. WITTER 3,360,955

HELIUM FLUID REFRIGERATOR

Filed Dec. 21, 1966 2 Sheets-Sheet 1

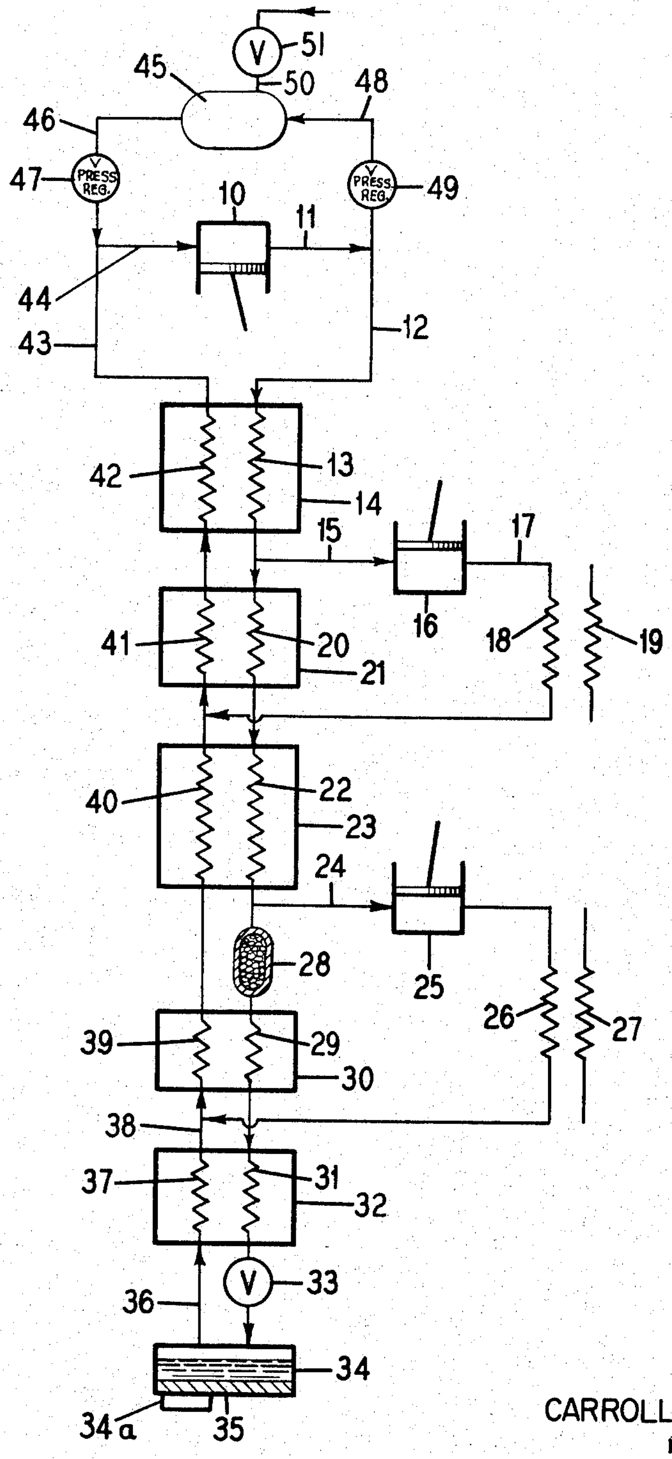


Fig. 1.

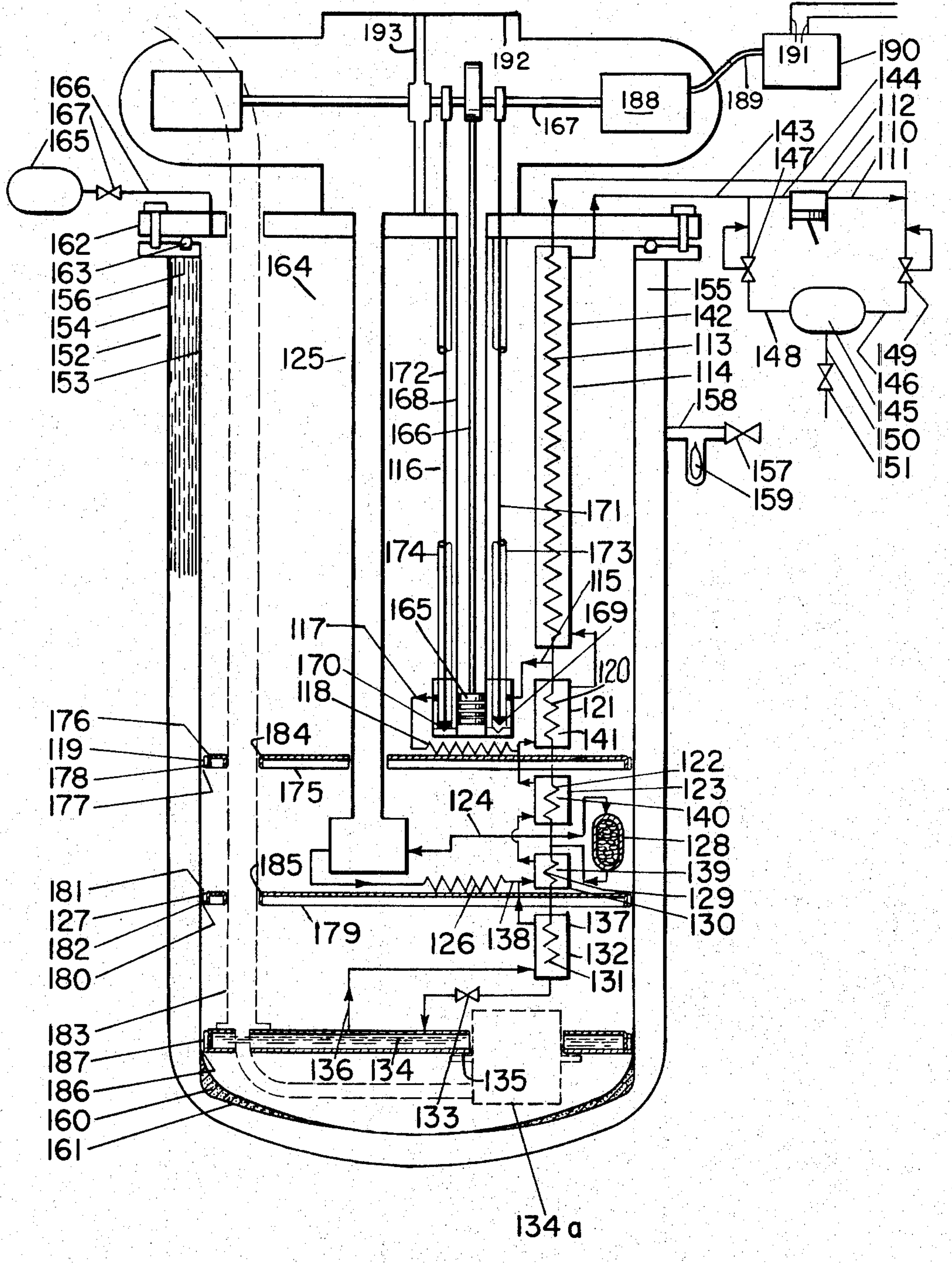
CARROLL E. WITTER
INVENTOR

BY John C. Ledrner
ATTORNEY

Jan. 2, 1968 C. E. WITTER **3,360,955**

HELIUM FLUID REFRIGERATOR

Filed Dec. 21, 1966 2 Sheets-Sheet 2



CARROLL E. WITTER
INVENTOR

Fig. 2.

BY John C. le Traver
ATTORNEY

United States Patent Office

3,360,955

Patented Jan. 2, 1968

3,360,955
HELIUM FLUID REFRIGERATOR

Carroll E. Witter, 1218 La Salle Ave.,
Grand Island, N.Y. 14072

Filed Dec. 21, 1966, Ser. No. 605,127
9 Claims. (Cl. 62—335)

This application is a continuation-in-part of application Ser. No. 481,514, filed Aug. 23, 1965, now abandoned.

This invention relates to a helium fluid refrigerator, and more specifically to a refrigerator employing a closed circuit compression-heat extraction-expansion flow path for producing cryogenic refrigeration in the temperature range of below 20° K.

The advantages of providing operating environments in the temperature region below 20° K. for low electrical noise levels in heat loads such as masers and other amplifiers for radio telescopes, communications satellites, military radar, superconducting computers, and other electronic equipment are now generally recognized.

The prior art has proposed and employed various types of helium fluid refrigerators, one variety being a single-walled casing construction with a high vacuum on the inner working volume of this casing for minimizing ambient heat inleak. The cold components of the refrigerator are contained within the high vacuum atmosphere, and there are several resultant limitations. Any leakage or outgasing of the refrigerator cold components or the heat load tends to destroy the thermal insulating effectiveness, resulting in inefficient, erratic performance and thermal instability. Another disadvantage is that the single walled casing is at the warm ambient temperature throughout its entire length, thus causing high radiative heat transfer losses to the cold end of the refrigerator. That is, the temperature difference between the adjacent single walled casing and the enclosed refrigerator increases progressively from the warm end to the cold end of the refrigerator.

Still another disadvantage of the single casing type refrigerator is that the top flange at the warm end must be extremely tight to maintain the required extreme vacuum. Because of practical limitations on the leak tightness of this flange, it is necessary to vacuum pump the inner working space continually.

Another type of prior art liquid helium temperature refrigerator employs a double-walled vacuum insulated container, with a helium atmosphere inside the inner vessel, and a liquid nitrogen-cooled radiation shield surrounding the cold components. However, apparently on the assumption that heat transfer losses by gaseous convection would be prohibitively high, the inner vessel is filled with powder insulation in which the cold refrigerator components are packed. This prevents maintaining an open, free access region for use of the inner vessel as a working volume into which various experimental heat sources can be readily introduced. That is, the heat source is located at the bottom cold end of the refrigerator, and the powder insulation must be carefully packed around the heat source as well as the superimposed cold assembly before the top flange is closed. Moreover the liquid nitrogen-cooled radiation shield is expensive, and difficult to support and operate.

A further limitation of each of these prior art helium fluid refrigerators is that the cold components must be supported solely by vertical suspension from the warm end flange of the container. In the single casing type, lateral stabilization means between the cold components and the casing inner wall cannot be tolerated because of the resultant large heat inleak from the ambient temperature wall. In the double-walled, liquid nitrogen-cooled radiation shield type, lateral stabilization means between the cold components and the inner vessel inner wall are blocked by the intervening radiation shield.

An object of this invention is to provide an improved helium fluid refrigerator.

Another object is to provide such a refrigerator which does not require a high vacuum atmosphere within the inner working volume of the container.

Still another object is to provide a refrigerator characterized by low heat transfer losses due to radiation.

A further object is to provide a refrigerator which does not require packing of the cold components in powderous insulation within the container inner working volume.

A still further object is to provide a helium fluid refrigerator which does not need liquid nitrogen-cooled radiation shields.

An additional object is to provide such a refrigerator permitting the use of lateral stabilization means for the cold components.

Other objects and advantages of the invention will be apparent from the ensuing description, the claims and the drawings in which:

FIGURE 1 is a schematic flowsheet of a suitable closed circuit liquid helium refrigeration-producing circuit with metal thermally conductive members for use in the invention.

FIGURE 2 is an elevation view taken in cross-section of a cold component assembly inside the inner working volume of a double-walled vacuum insulated casing with the warm components of the liquid helium temperature refrigerator shown schematically.

We have found that the aforedescribed objects may be achieved by a particular combination of elements arranged to interact in a heretofore unemployed manner.

One essential element is a double-walled container comprising an inner vessel as the working volume for receiving the cold components and the heat source, and a surrounding outer casing spaced so as to provide an evacuable space therebetween. This space is preferably filled wiith a highly efficient solid thermal insulating material, as for example alternating layers of low conductive fibrous sheeting separating intervening layers of radiation resistant material such as highly reflective sheets. The low conductive layers may for example be permanently precompacted layers of glass fiber paper as described in Matsch U.S.P. 3,009,600 or elastically compressible webs as described in Matsch U.S.P. 3,009,601. The radiation heat reflecting sheets are preferably aluminum or copper foil.

This double-walled vacuum thermal insulating system permits a temperature gradient down the inner vessel wall, roughly comparable to the temperature level of the adjacent cold component in the working volume. That is, the inner wall section adjacent to the first sub-ambient temperature heat exchanger will assume this thermal level whereas the inner wall section adjacent to the coldest heat exchanger will approach the boiling temperature of liquid helium. This temperature gradient drastically reduces the radiative heat losses and improves the overall efficiency of the refrigerator. For example, it has been determined that the side wall heat inleak to a liquid helium temperature refrigerator with alternate layers of glass fiber paper and aluminum foil in the evacuated space of the double-walled container is about two magnitudes less than a single casing straight vacuum insulated refrigerator.

The helium fluid refrigeration-producing closed circuit means includes a gas compressor at the warm end and cold helium fluid expansion means at the cold end. Heat extraction means are provided intermediate the warm and cold ends. The double-walled vacuum insulated container is arranged and positioned so as to gas-tightly enclose the sub-ambient temperature cold components of this circuit.

The existence of the temperature gradient along the inner vessel wall permits the advantageous use of another important element in this refrigerator. At least one metal thermally conducting member is provided within the double-walled vacuum insulated container, and transversely spaced between the warm and cold ends of the helium fluid refrigeration- producing closed circuit means. This thermally conductive member is thermally associated with both the heat extraction means and a relatively warmer region of the storage vessel inner wall. In this manner the thermally conductive member serves as a heat station to receive heat transferred by solid conduction from warmer regions of the storage vessel inner wall, and from warmer portions of the heat source as well as to intercept radiative heat from the warmer sections of the container. This heat is in turn transferred to the heat extractor, and prevented from flowing to the coldest portion of the refrigerator.

Multiple metal thermally conducting members may be employed and transversely spaced between the warm and colds ends of the closed circuit means. In this event multiple heat extraction means are employed, the relatively warm thermally conductive member being thermally associated with both the first heat extractor and a relatively warmer region of the storage vessel inner wall which is above the temperature level of the first heat extractor thermal association.

Similarly the relatively colder heat conducting member is thermally associated with the second heat extractor and a relatively colder region of the storage vessel inner wall. This region is selected to be above the temperature level of the second heat extractor thermal association, but of course below the temperature level of the first heat extractor thermal association. This second thermally conductive member also serves as a heat station to receive heat transferred by solid conduction from warmer portions of the heat source as well as to intercept heat from the intermediate section of the container and prevent same from reaching the cold end.

Additional heat conducting members may be provided and positioned in a similar manner between the warm and cold ends of the fluid circuit and the inner storage vessel inner wall. The number of heat conductive members which may be advantageously employed depends to a large extent on the number of heat extractors employed in the helium fluid refrigeration-producing closed circuit.

Since the heat conducting members may contact the inner storage vessel inner wall without introducing additional heat flux into the refrigerator, they may also be employed as lateral support means for the refrigerator and the heat load, as for example electronic components. This additional support function is not possible with a single-walled container because the wall is at ambient temperature throughout its length.

Another preferred feature of this novel refrigerator is the provision of a gaseous helium atmosphere within the inner vessel in the space surrounding the cold components. The pressure of this helium may be sub-atmospheric or even atmospheric (14.7 p.s.i.a.). This gaseous helium environment affords several significant advantages. From the heat transfer standpoint, it improves the drawing off of heat from the inner vessel wall and from the heat load to the metal thermal heat conducting members by the medium of gaseous conduction. Absent this gaseous environment, heat transfer would be solely by solid conduction. Another important and very practical advantage of the gaseous helium environment is that the gas-tightness requirements of all joints are relaxed, as compared to the tightness needed when the joints separate a high vacuum from the ambient pressure. Moreover it is not necessary to vacuum pump the inner vessel working space, eliminating the need for the pump and its attendent power supply.

In a preferred embodiment, the metal thermal heat conducting members are sized to provide a narrow annular space of less than about ⅛ inch between their outer edges and the inner storage vessel inner wall. One of the significant discoveries embodied in this invention is that such an annular space coupled with the specified helium atmosphere provides as effective heat transfer between the cooler metal heat conducting members and the inner storage vessel inner wall as does light metal-to-metal contact under extreme vacuum. This discovery avoids the need for providing such metal-to-metal contact, an important simplification in manufacturing the present helium refrigerator. It is extremely difficult and expensive to provide the relatively thin inner storage vessel inner wall with a machining tolerance sufficient to insure continuous but light metal-to-metal contact with the metal heat conducting members. In marked contrast, the inner storage vessel inner wall of this refrigerator need not be machined after shaping. The metal heat conducting members may be simply formed by conventional means to be slightly undersized with respect to this wall, thereby providing the needed small annular space. The helium gas in the space thus provides the needed thermal association between the two members.

The ability to design the metal heat conducting members as lateral support means without reliance upon metal-to-metal contact with the inner vessel wall permits the entire cold component assembly to be readily removable intact from the double-walled container. This greatly facilitates the assembly of the cold components and the container, and also facilitates the installation and/or inspection of the various experimental devices (heat sources) capable of being operated within the refrigerator.

Referring now more specifically to FIGURE 1, helium is compressed to about 190 p.s.i.a. in compressor **10**, cooled to about 300° K. in an after cooler (not shown) in discharge conduit **11**, and directed through connecting conduit **12** to passageway **13** of first heat exchanger **14**. In the latter the compressed helium gas is partially cooled to about 78° K. and part of this gas, e.g. 30%, is diverted through conduit **15** to a first external heat extractor as for example first work expander **16**. In the latter the gas is expanded to about 14.7 p.s.i.a. and thereby further cooled to about 55° K.

The resulting expanded and further cooled helium gas from expander **16** in discharge conduit **17** is heat exchanged in passageway **18** with a relatively warmer section **19** of the inner storage vessel inner wall and warmed to about 60° K. The partially warmed expanded helium gas is then joined with the recycling vaporized helium at about the same temperature level, as subsequently described in detail.

At the same time, the undiverted part of the compressed partially cooled helium gas emerging from the cold end of first heat exchanger **14** in conduit **12** is directed to passageway **20** in the warm end of second heat exchanger **21** for further cooling to about 62° K. The emerging further cooled helium gas at the cold end of second heat exchanger **21** is then directed to passageway **22** at the warm end of third heat exchanger **23** and still further cooled therein to about 19° K. A portion, e.g. 60%, of this cold helium gas is diverted through branch conduit **24** to the higher pressure side of second work expander heat extractor **25**. The diverted gas is thus expanded to about 14.7 p.s.i.a. and simultaneously additionally cooled to about 11.5° K. This additionally cooled expanded helium gas is heat exchanged in passageway **26** with a section **27** of the storage vessel inner wall and warmed to about 12° K. Section **27** is relatively colder than section **19** of the storage vessel inner wall, but relatively warmer than the additionally cooled expanded helium gas. The resulting partially warmed expanded helium gas is then joined with the recycling vaporized helium at about the same temperature level, as subsequently described in detail.

The undiverted cold helium gas at the cold end of third heat exchanger 23 at about 19° K. is directed through conduit 12 to selective adsorbent bed 28, e.g. activated charcoal, where the uncondensed impurities such as neon or hydrogen are removed. The purified cold helium gas is next flowed to the warm end of passageway 29 in fourth heat exchanger 30 where this gas is additionally cooled to about 12° K. The emerging colder helium gas is then directed to the warm end of passageway 31 in fifth heat exchanger 32 for cooling to about 5.5° K.

The resulting still colder helium gas is isenthalpically expanded through valve 33 to atmospheric pressure (14.7 p.s.i.a.), corresponding to the helium boiling point of 4.2° K. The liquid-vapor mixture passes to container 34, and heat source item 34*a* to be refrigerated is preferably tightly secured against the outer wall 35 of this container for efficient heat transfer by solid conduction. Alternatively the heat source item 34*a* may be immersed directly in the liquid helium within container 34. The liquid helium fraction produced by isenthalpic expansion (the Joule-Thompson effect) is vaporized by this heat load.

The cold helium vapor emerging from container 34 is recycled through the previously described five heat exchangers 14, 21, 23, 30 and 32, where its sensible refrigeration is recovered in cooling the higher pressure helium gas. More specifically, this cold helium vapor is initially directed through conduit 36 to the cold end of low pressure passageway 37 of fifth heat exchanger 32. This vapor enters the exchanger 32 at about 4.2° K. and flows in countercurrent relation with the cold helium gas in passageway 31 and is itself partially warmed to about 12° K. This partially warmed helium vapor emerges from the warm end of fifth exchanger 32 into conduit 36 and is joined by the partially warmed further expanded helium gas in conduit 24 from second work expander 25. This gas is at about the same temperature as the partially warmed helium vapor so that mixing losses are avoided and process control is simplified.

The combined partially warmed helium stream at about 12° K. in conduit 38 is then fed to the cold end of passageway 39 in fourth heat exchanger 30. The stream flows in countercurrent heat exchange relation with the purified helium gas in thermally associated passageway 29, and emerges from the warm end at about 16° K. This further warmed helium stream is next directed to the cold end of passageway 40 in third heat exchanger 23 for still further cooling of the helium gas in thermally associated passageway 22. The still further warmed low pressure helium gas emerges from the warm end of passageway 40 at about 60° K., and is joined with the work expanded and partially warmed helium gas from conduit 15 at about 60° K. As in the case of the second colder work expanded gas, the juncture occurs in the heat exchanger train at a point where the partially warmed work expanded gas temperature approximates that of the recycling low pressure helium gas.

The combined low pressure helium gas enters the cold end of passageway 41 in second heat exchanger 21 and serves to further cool the undiverted partially cooled higher pressure helium gas in thermally associated conduit 20, emerging from the warm end at about 72° K. As a final heat exchange step, this gas is flowed to the cold end of passageway 42 in first heat exchanger 14 for partial cooling of the higher pressure aftercooled helium gas in thermally associated passageway 13. The warmed low pressure helium gas emerges from the warm end of passageway 42 at about 294° K. and is recycled at about 11.4 p.s.i.a. from conduit 43 through joining conduit 44 to the suction side of compressor 10. Surge tank 45 is connected across compressor 10 by low pressure conduit 46 having pressure regulator 47, and by higher pressure conduit 48 having pressure regulator 49 therein. These regulators supply helium gas to surge tank 45 and bleed off helium gas therefrom as necessary to maintain predetermined pressure levels at the warm end of the circuit. Makeup helium gas is supplied to surge tank 45 from an external source through conduit 50 having control valve 51 therein.

The refrigerator is controlled by adjusting the speed of the expansion engines 16 and 25, the discharge pressure of compressor 10, and the setting of isenthalpic expansion valve 33. For a given heat load, the compressor discharge pressure is normally first set by the expansion valve 33 setting and the expansion engine speeds are used for refined adjustments. If the heat load increases, more liquid helium is vaporized in container 34 and discharged thereby depleting the supply. This liquid deficiency may be replenished by increasing the fluid flow through valve 33 by further opening same. In this event, it is necessary to increase the speed of expansion engines 16 and 25 to increase the helium flow through the high pressure side of the heat exchanger train and produce more refrigeration to balance the increased heat load. To accomplish this increased flow, the pressure regulator 49 is partially closed. If the heat load decreases, adjustments are made opposite to those described. The temperature level of the boiling liquid helium in container 34 is set by controlling the suction pressure of the compressor 10, using the pressure regulator 47.

Referring now to FIGURE 2, elements corresponding to those illustrated in FIGURE 1 are identified by the same reference numeral plus 100. The heat exchanger train comprising units 114, 121, 123, 130 and 132 as well as the first and second work expanders 116 and 125 and the interconnecting fluid conduits are identical to those described in conjunction with FIGURE 1.

The cold component assembly is positioned within double-walled vacuum insulated container 152 comprising inner storage vessel 153 and surrounding outer casing 154 with a vacuum space 155 therebetween. This space 155 is for example filled with composite thermal insulation 156 comprising alternate layers of low conductive permanently precompacted glass fiber paper sheets and highly reflective aluminum foil. The individual glass fibers have predominating diameter of 0.5–0.75 micron and the paper weighs about 1.6 grams/sq. ft. surface area. The aluminum foil layers may have a thickness of about 0.25 mil and this composite insulation is preferably installed at or near its optimum density of about 60 layers/inch of vacuum space cross-section. Space 155 may be permanently evacuated by attaching a vacuum pump to valve 157 communicating with such space through conduit 158, and reducing the pressure to less than one micron Hg. After closing valve 157 the pump is disconnected. Hydrogen from possible degassing of the metallic walls enclosing vacuum space 155 is removed by getter material 159, for example palladium oxide as described in U.S.P. 3,108,706 to L. C. Matsch et al. Gases tending to accumulate in vacuum space 155 having higher boiling points than hydrogen, e.g. moisture, are removed by adsorbent material 160, e.g. crystalline zeolitic molecular sieve, as described in U.S.P. 2,900,800 to P. E. Loveday. This adsorbent material 160 is retained in compartment 161 attached to the colder portion of inner vessel 153 and in gas communication with vacuum space 155.

The warm open end of container 152 is covered by flange 162 and gas-tightly sealed with O-ring 163. The preferred gaseous helium atmosphere within the inner vessel working volume 164 is maintained by an external helium source 165 communicating with such volume by means of gas conduit 166 having control valve 167 therein. Alternatively this atmosphere could be provided by bleeding off a small quantity of low pressure helium gas from conduit 143 downstream of first heat exchanger 114.

The cold component assembly positioned within inner vessel working volume 164 includes not only the heat exchanger train but also first work expander 116 and second work expander 125. First expander 116 includes piston 165 mechanically coupled by reciprocating rod 166 to crankshaft 167. The piston-rod assembly extends longitudinally inwardly from the container warm end, and is enclosed in housing 168. First expander inlet and discharge valves 169 and 170 are mechanically coupled by lift rods 171 and 172 respectively to crankshaft 167 and are enclosed in respective housings 173 and 174. Second expander 125 is mechanically identical to first expander 116.

The expanded and further cooled helium gas in conduit 117 is heat exchanged with sheet metal heat conducting plate member 175 by passage through serpentine conduit 118 metallically bonded to the upper surface of the plate. The latter is also physically supported by the bond to conduit 118 and extends transversely across the inner vessel working volume 164 so as to substantially fill this portion of the volume inwardly of the plate outer edge 176. Plate 175 is preferably sized so that its outer edge 176 does not physically touch the relatively warmer section 119 of storage vessel inner wall, but a narrow annular space 177 of less than about ⅛ inch is provided therebetween. As previously described, the helium gas in working volume 164 provides the necessary thermal association between the plate outer edge 176 and storage vessel inner wall warmer section 119 through the heat transfer mechanism of gaseous conduction. The plate outer edge 176 is bent substantially parallel to the inner vessel wall 153 so as to provide an extended surface area for efficient heat transfer by gaseous conduction.

As previously discussed, one of the advantages of the present refrigerator is that the entire cold component assembly may be laterally stabilized against the storage vessel inner wall without increasing ambient heat inleak. Since the preferred embodiment is provided with an annular space between plate outer edge 176 and vessel inner wall warmer section 119, stabilizing means should not entirely enclose this space but instead may be spaced around the perimeter of the plate. Suitable stabilizing means may for example comprise multiple pads 178 bonded to plate outer edge 176, formed of a plastic such as polytetrafluoroethylene and sized to provide light physical contact with the storage vessel inner wall.

The expanded and still further cooled helium gas in conduit 124 is heat exchanged with colder sheet metal heat conducting plate member 179 by passage through serpentine conduit 126 metallically bonded to the upper surface of the plate, and in the same manner as warmer sheet metal heat conducting plate member 175. Colder plate 179 is supported in the same manner as warm plate 175 and also preferably sized to provide a narrow annular space 180 of less than ⅛ inch between its outer edge 181 and the storage vessel inner wall colder section 127. Multiple stabilizing pads 182 are spaced around the perimeter of colder plate 179 in annular space 180 in a manner analogous to pads 178.

If a metal-to-metal contact between the storage vessel inner wall 153 and the plate outer edges 176 and 181 is desired for improved thermal association, such contact may be provided by resilient metallic members such as springs or brushes distributed around the plate perimeters.

Heat load 134*a* is preferably attached to the lower surface 135 of liquid helium container 134 by for example mechanical means, and is cooled by heat extraction through the metal-to-metal interface and into the boiling liquid. In all uses of the helium refrigerator for cooling heat loads, there must be means for communication between the load and the ambient surroundings. For example, if the heat load is a superconducting magnet, the communication means may be electric power conductors. If the heat load is a maser crystal, the communication means may be a wave guide and wires for transmitting and receiving signals. Communication means 183 is illustrated as a metal duct which may comprise a wave guide or may contain electric wires preferably secured to the duct by thermally conductive retainers. Heat source communicating means 183 extends from the cold end to the warm end of the refrigerator and through sealing flange 162. Accordingly it constitutes a source of ambient heat inleak and is thermally associated with metal heat conducting members 175 and 179. As illustrated openings are provided in members 175 and 179 for extending heat source communicating means 183 therethrough, and the thermal association is enhanced by bending the opening edges 184 and 185 parallel to and in metal-to-metal contact with such means 183. Thus, the heat inleak from the heat source communicating means 183 is transferred by metal conducting members 175 and 179 to the outflowing expanded low pressure helium gas.

It will be appreciated that any heat inleak passing the colder plate member 179 must be absorbed by the cold helium fluid in container 134. Accordingly, this container does not serve as a heat station in the same manner as warmer and colder plate members 175 and 176, because the purpose of these stations is to prevent heat from reaching the helium fluid at the coldest level of the refrigerator. However, it preferably extends transversely across the inner vessel working volume in a manner similar to these plates and in the form of a thin flange-shaped vessel.

The entire cold component assembly is preferably secured to the warm end flange 162 so that the assembly may be removed from the inner vessel by disconnecting the flange. Accordingly it is preferred to stabilize the liquid container against the storage vessel inner wall in the same manner as plates 175 and 179. That is, narrow annular space 186 separates the liquid helium container outer edge and storage vessel inner wall 153, and multiple pads 187 are positioned in this space around the container perimeter. These pads 187 provide the desired lateral stabilization of the cold components-heat load assembly at the refrigerator cold end.

A power absorber as for example rotary electric generator 188 is driven by crankshaft 167. The generated current is extracted through wires 189 leading to controller 190 which may contain for example a variable resistance for dissipating the energy. Varying the resistive load attached to generator 188 affords a convenient means for controlling its speed of rotation and hence for controlling the reciprocating speed of first work expander 116. Any external power required for operation of controller 190 is provided through electrical power connections 191.

Crankcase and power absorber enclosure 192 contains partition 193 separating the aforedescribed mechanical-electrical assembly for operating first work expander 116 from a similar mechanical electrical assembly for operating second work expander 125.

The use of double-walled, vacuum insulated container whose vacuum space 155 is hermetically separated from working volume 164, permits an emergency mode of operating heat load 134*a* not otherwise possible. In the event of mechanical breakdown of the refrigeration-producing closed circuit means, the operation or test of heat load 134*a* need not be interrupted, but may be continued by direct admission of a liquid helium into the working volume from an external source. Such admission of liquid helium may be accomplished by means similar to items 165, 166 and 167 for introducing gaseous helium, except that the source will necessarily be a well-insulated vessel for storing and dispensing the cold liquid. Liquid helium introduced into volume 164 will collect in the bottom of inner vessel 153, and heat from heat source 134*a* will be effectively transferred across narrow annular space 186 into the inner vessel wall and thence into the boiling liquid.

Although preferred embodiments of this invention have been described in detail, it should be recognized that certain modifications may be made and certain elements may be deleted, all within its spirit.

For example, the FIGURES 1 and 2 embodiments are specifically directed to a liquid helium refrigerator, but the invention is equally suitable for providing gaseous helium refrigeration at temperatures below about 20° K. In this event, two heat extractors may not be needed to achieve the desired temperature and one heat extractor may be adequate. Accordingly, only one metal thermally conducting member would be employed, and thermally associated with the single heat extractor.

In a gaseous helium refrigerator it is not necessary to use an isenthalpic expansion valve at the cold end of the closed circuit, but instead pass the entire helium gas stream through a work expander heat extractor at such cold end. The resulting cold helium gas may be heat exchanged with a heat source within the inner vessel working volume, or alternatively the cold gas may be directed through a thermally insulated conduit to the outside of the refrigerator for heat exchange with the heat source, and thereafter returned to the refrigerator. In the latter embodiment, the thermally insulated conduit is preferably passed through the metal thermally conducting members in thermal association therewith. Similarly, helium liquid may be transferred through a thermally insulated conduit to the refrigerator exterior for heat exchange with the heat source, and recycled as gas.

Although isentropic expansion engines, i.e., work expanders, are the preferred heat extractors in the present refrigerator, other well-known types of heat extractors may be employed as for example an external source of liquid nitrogen, liquid air, or liquid hydrogen. In such an embodiment the higher pressure helium gas discharged from a warmer heat exchanger may be passed through a coil immersed in the liquid nitrogen container within the inner vessel working volume, and discharged therefrom at a colder temperature for further cooling in the remaining units of the heat exchanger train. The liquid nitrogen will of course boil by virtue of this heat transfer, and the resulting vapor may be discharged in a conduit extending through the working volume and the container wall or top flange for release to the atmosphere. The nitrogen boil-off may be replaced by a second conduit connected to an external liquid nitrogen source and also extending through the container wall or top flange to the liquid nitrogen container in the working volume. The metal thermally conducting member may be bonded to the liquid nitrogen container outer wall to effect the necessary thermal association and heat transfer.

Still another suitable though less effective heat extractor means is the throttle expansion of higher pressure cold gaseous helium at a temperature below about 40° K. to a lower pressure. Each throttle expansion through a suitable valve will additionally cool the lower pressure gas, which in turn may be heat exchanged with the metal thermally conductive member. This heat exchange may for example be obtained by bonding the throttle expansion discharge conduit to the thermally conductive member.

What is claimed is:

1. A helium refrigerator comprising:

(a) helium fluid refrigeration-producing closed circuit means having a warm end and including a gas compressor at the warm end as an above-ambient temperature component, and including as sub-ambient temperature cold components: (1) cold helium fluid expansion means at the cold end, (2) heat extraction means intermediate the warm and cold ends, and (3) means for heat exchanging compressed warmer helium gas and colder lower pressure helium gas intermediate the warm and cold ends;

(b) a heat source and means for heat exchanging the helium fluid discharged from said cold helium fluid expansion means (a) (1) with said heat source;

(c) a double-walled vacuum insulated container comprising an inner storage vessel and a surrounding outer casing with a vacuum space therebetween, and a removable cover flange arranged and positioned so as to gas-tightly enclose and suspend the sub-ambient temperature cold components of said helium fluid refrigeration-producing closed circuit means (a) from said cover flange; and

(d) a metal thermally conducting member within said double-walled vacuum insulated container transversely spaced and suspended between the warm and cold ends of the said helium fluid refrigeration-producing closed circuit means (a), being thermally associated with said heat extraction means and also thermally associated with a relatively warmer region of the storage vessel inner wall so as to receive heat from such region for solid conductive transfer to the heat extractor means.

2. A helium refrigerator according to claim **1** in which said heat extraction means is a work expander.

3. A helium refrigerator according to claim **1** in which said heat extraction means is an external supply of liquid nitrogen.

4. A helium refrigerator according to claim **1** in which said metal thermally conducting member is sized to provide a narrow annular space of less than about ⅛ inch between its outer edge and the storage vessel inner wall.

5. A helium refrigerator according to claim **4** in which said metal thermally conducting member is additionally shaped to substantially fill the transverse space within said inner storage vessel inwardly of said narrow annular space and surrounding the outer surface of said helium fluid refrigeration-producing closed circuit means (a) being positioned substantially normal to and extending through said metal thermally conducting member.

6. A helium refrigerator according to claim **1** in which said metal thermally conducting member is arranged and positioned to laterally support said helium fluid refrigeration-producing closed circuit means within said storage vessel.

7. A helium refrigerator according to claim **1** in which said heat extractor means comprises a work expander and low pressure cold helium discharge conduit means, and said metal thermally conductive member is thermally associated with said conduit means.

8. A helium refrigerator comprising:

(a) helium fluid refrigeration-producing closed circuit means having a warm end and a cold end and including a gas compressor at the warm end as an above-ambient temperature component, and including a sub-ambient temperature cold components: (1) an isenthalpic expansion valve and (2) a liquid helium receiving container at the cold end, (3) a first heat extractor at a relatively warmer intermediate level, (4) a second work expander heat extractor at a relatively colder thermal level, and (5) means for heat exchanging compressed warmer helium gas and colder lower pressure helium vapor;

(b) a heat source thermally associated with said liquid helium receiving container;

(c) a double-walled vacuum insulated container comprising an inner storage vessel and a surrounding outer casing with a vacuum space therebetween and a removable cover flange arranged and positioned so as to gas-tightly enclose and suspend the sub-ambient temperature cold components of said helium fluid refrigeration-producing closed circuit means (a) from said cover flange;

(d) at least two metal thermally conducting members within said double-walled vacuum insulated container each transversely spaced and suspended between the warm and cold ends of said helium fluid refrigeration-producing closed circuit means (a), the relatively warm thermally conducting member being thermally associated with said first heat extractor and also thermally associated with a relatively warmer region of the storage vessel inner wall which is above the temperature level of the first heat extractor thermal association so as to receive heat from said relatively warmer region for solid conductive transfer to said first heat extractor, and the relatively colder heat conducting member being thermally associated with said second work expander heat extractor and also thermally associated with a relatively colder region of the storage vessel inner wall which is above the temperature level of the second heat extractor thermal association so as to receive heat from said relatively colder region for solid conductive transfer to said second work expander heat extractor; and

(e) means for providing a gaseous helium environment within said inner storage vessel and in the space surrounding the closed circuit means (a) and said metal thermal conducting members (d).

9. A helium refrigerator according to claim 1 in which alternate layers of glass fiber paper sheets and reflective metal foil are provided as composite thermal insulation material in the vacuum space of said double-walled vacuum insulated container (c).

References Cited

UNITED STATES PATENTS

2,966,034	12/1960	Gifford	62—6
3,092,976	6/1963	Hashemi-Tafreshi	62—335
3,115,015	12/1963	Hogan	62—6
3,122,044	2/1964	Aberle	62—259
3,125,863	3/1964	Hood	62—332
3,128,605	4/1964	Malaker	62—6
3,195,322	7/1965	London	62—67
3,199,304	8/1965	Zeitz	62—335
3,220,201	11/1965	Heuchling	62—6
3,299,646	1/1967	Stuart	62—6

OTHER REFERENCES

Collins and Cannaday: "Expansion Machines for Low Temperature Processes," pp. 40–64, 108–112, Oxford University Press, 1958.

WILLIAM J. WYE, *Primary Examiner.*