

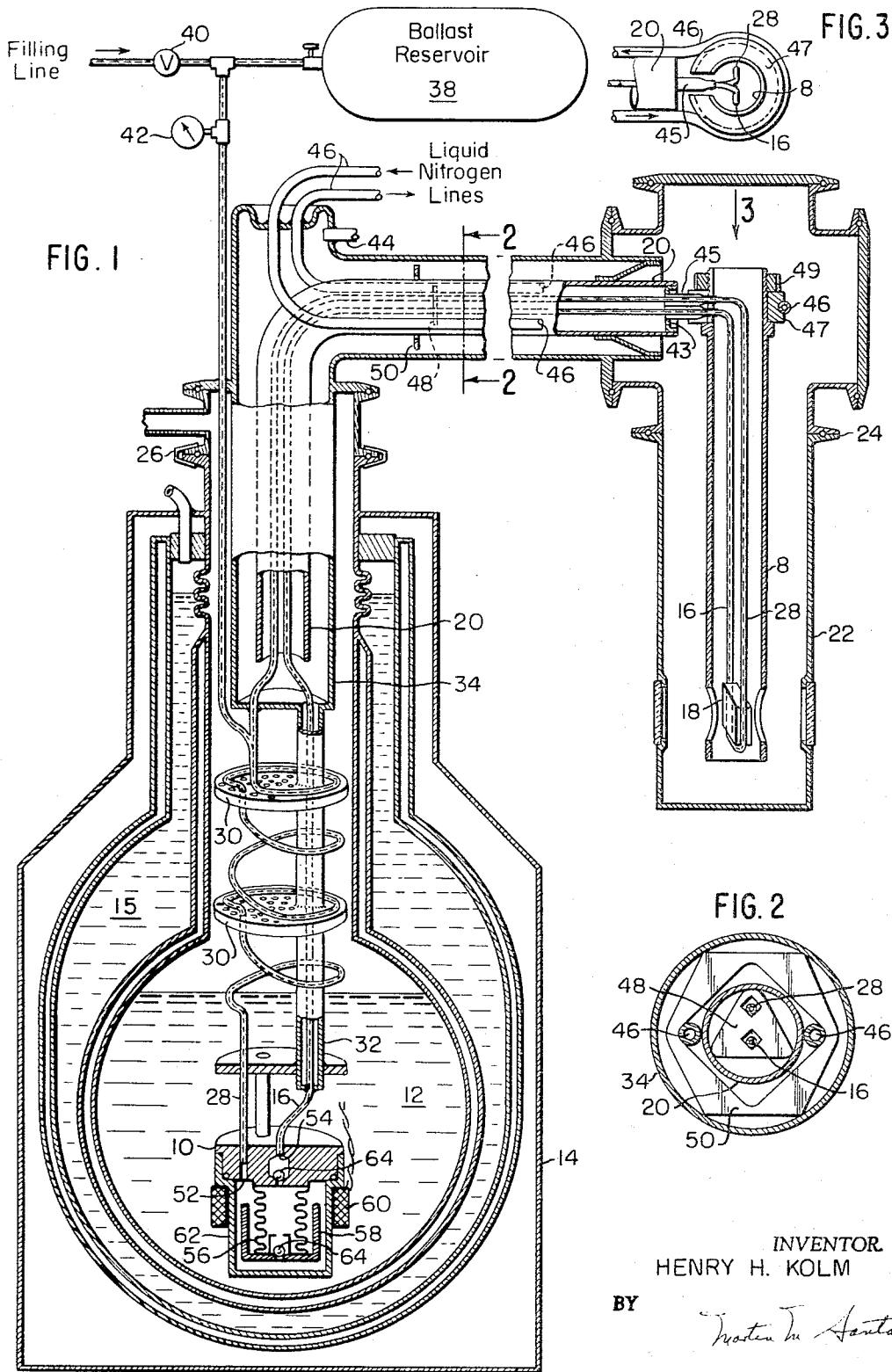
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HELIUM HEAT TRANSFER SYSTEM

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HELIUM HEAT TRANSFER SYSTEM

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ABSTRACT OF THE DISCLOSURE

A closed loop containing circulating helium at a pressure in excess of its critical pressure throughout the loop is used as a heat transfer apparatus. A portion of the loop is in thermal contact with an object to be cooled. Another portion of the loop is in thermal contact with a bath of liquid helium and the vapor from the liquid helium. Heat transfer baffles on the loop in the vapor region increase the efficiency of heat transfer and utilize the cooling capacity of the high enthalpy of the vapor before the circulating helium enters the liquid helium region of the bath.

This invention relates to a novel heat transfer system and in particular to a heat transfer system which utilizes as the heat transfer medium helium under high pressure within a closed system.

The apparatus of this invention utilizes the unique physical properties of helium to effect very efficient heat transfer and to attain any desired continuously variable cryogenic temperature from 1° K. to room temperature. Helium has physical properties which allow it to remain a liquid at temperatures as close to absolute zero as have ever been attained (0.01° K.) under pressures of up to the order of 22 atm. Helium also has an extremely low heat of vaporization (0.616 kg./cal./l. at 4.21° K.) and when compared with water it will be seen that helium will boil away over 800 times as rapidly when each is at its respective boiling point. Thus, if helium is to be used as a cooling medium by its vaporization only, the process will be quite expensive and wasteful.

Helium has a physical property which is of special significance to this invention. Its total enthalpy is quite high. Thus, although very little energy is required to vaporize or boil helium, a tremendous amount of energy is required to raise the temperature of the helium vapor. This is in contrast with water which requires very little energy to raise the temperature of its vapor or steam. Therefore, the total enthalpy of helium can be utilized to effect very efficient heat transfer. For example, it requires 28 liters of liquid helium to cool one pound of aluminum from 273° K. to 77° K. if only the heat of vaporization is utilized, whereas it requires only 0.4 liter of liquid helium to accomplish the same result if the total enthalpy of the liquid helium is used. This invention, therefore, utilizes the peculiar physical properties of helium to effect a very efficient and economical heat transfer system.

In the past it has been customary procedure to maintain cryogenic environments by the immersion of objects or apparatus to be cooled in a bath of cryogenic fluid. The cryogenic fluid used depended upon the temperature to which the object was to be cooled. Thus, cryogenic baths ranging from Dry Ice and acetone mixtures to liquid helium can be used depending upon the temperature desired. The immersion method involved several serious shortcomings in its application. Temperatures can be varied only over a narrow range depending upon the vapor pressure of the cryogenic fluid used. In applications involving the cooling by immersion of large superconducting magnets an explosion hazard exists in the event of the accidental quenching of the superconductivity due to excess current, magnetic field, or heat, thereby releasing tremend-

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ous amounts of energy which will explosively evaporate the helium. In other applications such as the operation of masers at the focus of large radar and radio telescopes the necessity for a liquid helium bath causes cumbersome design and replenishment problems. Even in small scale laboratory applications the bath immersion technique frequently creates radiation access problems and requires expensive and delicate windows through multiple vacuum walls and radiation shields.

The shortcomings of the immersion technique have been widely recognized for some time and various attempts have been made to maintain cryogenic environments by circulating cryogenic fluid or gas through a system of tubing. None of these has been successful, however, because of the inherent thermal instability of a boiling circulation in systems of this sort which have always been operated at or near atmospheric pressure. In the event of a local hot spot a large fraction of the fluid evaporates, expands by a factor of about 600, and causes enough back pressure to prevent further flow. For the same reason systems designed to maintain a cryogenic temperature are entirely inadequate to achieve initial cool-down. To circumvent this problem would require cooling channels of impractically large cross-section.

It is, therefore, an object of this invention to provide a system for transferring heat which is free from the problems inherent in cryogenic immersion techniques and low pressure circulation techniques.

It is a further object of this invention to effect stable and controllable heat transfer at any desired temperature from about 1° K. to about 300° K.

It is another object of this invention to provide a heat transfer apparatus which is broader in scope of application and capable of more efficient and economical heat transfer than cryogenic systems heretofore known.

It is a feature of this invention that helium is circulated through a closed system at a pressure above its critical point.

It is a further feature of this invention that the total enthalpy of the liquid helium reservoir is utilized during cool-down rather than only its heat of vaporization.

It is another feature of this invention that the vacuum jacket and radiation shield surrounding the heat sink is independent from that surrounding the remainder of the system to permit ready access to the object being cooled.

It is another feature of this invention that the closed system remains permanently filled with helium and need never be opened.

These and other objects and features of the present invention will be apparent from the specific description and discussion which follows.

The present invention is based upon recognition of the fact that liquid helium among its various unusual physical properties exhibits an entirely unique reluctance to solidify under pressure. This property is a manifestation of the very loose binding between helium atoms and their large quantum mechanical zero point energy. As a result liquid helium can be compressed to pressures considerably above its critical point beyond which there no longer exists any distinction between liquid and gas. In this region above the critical point the fluid behaves like a very compressible liquid, has about one and one-half times its density at atmospheric pressure, exhibits a viscosity almost as low as the viscosity at atmospheric pressure, and is incapable of cavitation or local boiling regardless of the heat input or temperature. Thus, the helium in this state constitutes as perfect a heat transfer medium as has ever been conceived.

A preferred form of the invention comprises an apparatus for maintaining any continuously variable temperature between 1° K. and 300° K. by transferring heat

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from the object to be cooled to a storage container of liquid helium. The heat transfer in said apparatus is accomplished through the use of a closed circulation loop of small diameter stainless steel tubing containing helium at a pressure considerably above its critical pressure (approx. 1,000 p.s.i.). The closed circulation loop includes a circulating pump and a heat exchanger which is partially immersed in the storage container of liquid helium and which is designed to take full advantage of the vapor enthalpy in the boiled-off gas. At the remote end of the loop the object to be cooled is thermally connected to the loop by means of a heat sink. Also connected into the loop is a buffer volume having sufficient capacity at room temperature to prevent excessive pressure rise when the system is warmed to room temperature.

The high pressure tubing is insulated by a vacuum jacketed radiation shield, to minimize heat absorption by the liquid helium as it is circulated through the system. The object to be cooled is made to contact the surface of the heat sink and this portion of the system is surrounded only by a separate single wall vacuum jacket enclosing a radiation shield. This separate section is automatically evacuated by cryo-pumping when the circulating pump is turned on. Thus, to operate the system it is merely necessary to immerse the heat exchanger assembly into a helium storage Dewar and to turn on the circulating pump. The system will very quickly reach any desired temperature which can then be stabilized by automatically controlling the circulation rate. When low temperature is no longer needed the pump is turned off and immediately thereafter the vacuum jacket can be removed for access to the apparatus.

The operation of the invention will be apparent from the detailed description and the accompanying drawings in which:

FIG. 1 is a view in side elevation, partially broken away, of a low temperature refrigeration system.

FIG. 2 is a cross sectional view of the helium transfer line which interconnects the heat exchanger and heat sink section of the system.

FIG. 3 is a view taken in the direction of the line 3, showing details of the disconnectable connection between the heat sink structure and the transfer line.

The heat transfer system as shown in FIG. 1 basically comprises a circulating pump 10, a loop of high pressure stainless steel tubing comprising discharge line 16 and return line 28, and a copper heat sink 18. Helium which is the heat transfer medium is pumped through this closed system at a pressure above its critical point. The system is filled with pure helium through valve 40 and and buffer volume 38 reduces pressure fluctuations when the system temperature is allowed to rise to room temperature. The object to be cooled is thermally connected to the heat sink 18 where heat is transferred from it to the heat transfer medium.

The helium being circulated through the system is maintained at a cryogenic temperature by means of a heat exchanger wherein a section of the heat transfer system including pump 10 and a portion of the discharge line 16 and return line 28 is immersed in liquid helium 12 contained in a standard liquid helium storage Dewar 14 with a jacket of liquid nitrogen 15. The return line 28 is wound around copper baffles 30 to increase the efficiency of the heat transfer through increased contact with the boil-off vapor from the reservoir of liquid helium 12. Thus, the heat exchanger which can be removed at flange 26 is designed to take full advantage of the vapor enthalpy of the boil-off vapor which is especially effective for efficient cooling during the initial cool-down of the system.

Once the helium heat transfer medium is cooled down to the proper cryogenic temperature it is necessary to maintain it at that temperature as it is circulated through the system. For this purpose the system is insulated to minimize heat absorption. Vacuum jacket 32 surrounds

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discharge line 16 as it emerges from pump 10. This vacuum jacket is enlarged as it becomes vacuum jacket 34. The purpose of the enlarged vacuum jacket is to accommodate a perforated copper radiation shield 20 as shown in FIG. 2. Radiation shield 20 is cooled by liquid nitrogen which is circulated through tubing 46. The combination of a vacuum jacket and a liquid nitrogen cooled radiation shield effectively prevents heat absorption from the surrounding atmosphere by the helium heat transfer medium. It will be seen that return line 28 emerges from the vacuum jacket 34 as the vacuum jacket 34 narrows to become vacuum jacket 32. The purpose of this is to allow return line 28 to contact the boil-off vapor from the liquid helium reservoir 12, thus acting as a heat exchanger to cool the returning helium heat transfer medium. Vacuum jackets 32 and 34 are evacuated through valve 44 and the system pressure is monitored by gage 42.

The heat sink 18 is maintained under vacuum and is surrounded by vacuum jacket 22. This portion of the system is not evacuated through valve 44 as is the remainder of the system. Vacuum jacket 22 which encloses perforated copper radiation shield 8 and the heat sink 18 is evacuated by cryo-pumping. The radiation shield 8 is not liquid nitrogen cooled. This allows the heat sink section to be exposed by removal of the vacuum jacket 22 and radiation shield 8 at flange 24 without breaking the vacuum in the rest of the system. In this manner the object being cooled can be made accessible as soon as the pump 10 is turned off.

A cross-section of the transfer line taken on the line 2—2 is shown in FIG. 2. High pressure helium tubes 16 and 28 are enclosed in perforated copper radiation shield 20. Liquid nitrogen is circulated through tubing 46 to cool the radiation shield and thereby increase its effectiveness as a heat barrier. Teflon spacers 48 and 50 are situated at various points through the system within vacuum jacket 34 to support the components.

It should be noted that the liquid nitrogen tubing which cools the radiation shield makes a loop around the disconnectable connection, as shown in FIG. 3, and does not extend into the heat sink section. The ring 47 is grooved to accommodate the liquid nitrogen tubing and forms an integral part of the disconnectable connection. High pressure helium discharge and return lines 16 and 28 can be seen to extend into ring 47 and downward into the heat sink section. This portion of the apparatus can be seen in FIG. 1 in which the disconnectable connection fits onto radiation shield 8 and is held in place by nut 49. The vacuum is maintained in the heat transfer line at this connection by stainless steel bulkheads 43, the high pressure helium tubes passing through thin stainless steel pantaloons 45 which provide a long heat path between helium and nitrogen temperatures.

An enlarged cross-sectional view of the circulating pump 10 is shown in FIG. 1. High pressure helium is returned to the circulating pump through inlet 52 and forced through outlet 54 through the heat transfer system. Monel bellows 56 is actuated by an iron armature 58 which is driven in reciprocating motion by a superconducting coil 60 surrounding the outside of the pump housing 62 which is a pressure chamber of stainless steel. Helium flow into and out of the pump is controlled by gravity loaded ball valves 64 to insure uni-directional flow. The actuating coil 60 is made of 75% Nb, 25% Zr superconducting wire to eliminate heat dissipation in the liquid bath and is powered by a solid state pulsed current source (not shown) of variable amplitude (0 to 20 amps) and variable frequency (0.2 to 5 c.p.s.). In this manner both the displacement and the cycling rate of the bellows can be controlled continuously to maintain a desired temperature by regulating the flow rate of the helium heat transfer medium through the system.

An important feature of the circulating pump is that it is able to circulate helium at a low circulating pressure

while withstanding a high system pressure. Monel bellows 56 is so designed within the pump structure that the pressure is equalized on both its sides. In this manner the bellows is not placed under an extremely large pressure differential and is able to operate normally under conditions of high pressure. The pump housing 62 is sufficiently strong to withstand the high pressure differential between the pump interior and the atmosphere.

In operation the closed circulation system remains permanently filled with helium at high pressure. The pump unit is immersed in a helium bath in a helium storage Dewar. The flow of liquid nitrogen through the nitrogen shield is started, and the helium circulating pump is turned on. The circulating rate can be regulated by a suitably located temperature sensing device (not shown) so as to maintain the system temperature at any desired level between that of the storage Dewar and room temperature. The storage Dewar can be cooled to below its normal boiling point by vapor pumping or it may contain any cryogenic fluid other than helium if higher temperatures are required. The circulating pump, although shown immersed in the liquid helium storage Dewar, can be located at any other desired position in the circulating system depending upon the particular design requirements and its coil need not be superconducting. Other types of pumps such as piston pumps are equally suitable for this purpose.

The heat exchanger section of the heat transfer system utilizes the high heat content of the helium vapor to take advantage of the total enthalpy of the helium. As shown in FIG. 1, the heat exchanger comprises the circulating pump 10 and the return line 28 which is wrapped around the copper heat exchanger baffles 30. Other means can be employed to increase contact surface between the return line and the helium boil-off vapor. This surface must be sufficiently large to take advantage of the great amount of enthalpy in the boil-off vapor.

The thermal design of a test system was based on an assumed dissipation of 1 watt for a temperature rise of 4° to 5° K. of the helium flowing through the system. The flow required to transport 1 watt at a system pressure of 40 atm. is 7800 cm.³/hr., but would not change much at other pressures. The required circulating pressure for the chosen design is 1 p.s.i. which is substantially independent of system pressure, as the viscosity and density increase little between 10 and 80 atm. In view of the very low kinematic viscosity, flow will be turbulent throughout and quite insensitive to the Reynolds number.

Under the above steady-state conditions, evaporation from the storage Dewar will amount to about 1.4 liters of liquid helium per hour. A counterflow heat exchanger in the neck of the Dewar is designed to utilize the available enthalpy of this vapor to recool the returning fluid, even if its temperature should be as high as 77° K. during cool-down. Losses in the 5 foot transfer line are less than 10 milliwatts. In addition to its convenience, the system should offer substantial economy of helium as compared to the conventional procedure of transferring helium into an open Dewar. Thus, to operate the system it is merely necessary to immerse the heat exchanger assembly into a helium storage Dewar (unless it is designed to remain permanently in the Dewar, as would be the case in large systems) and to turn on the circulating pump. The object to be cooled will very quickly reach any desired temperature which can be stabilized by automatically controlling the circulation rate. When low temperature is no longer needed the pump is turned off and immediately thereafter the separate vacuum jacket surrounding the heat sink can be removed for access to the cooled object.

There has been described a unique helium heat transfer system in which heat transfer is accomplished by means of the circulation of helium at high pressure in a closed system. The system, which has significant and numerous advantages over immersion techniques, permits rapid and uniform cooling of even the most massive objects such

as large superconducting magnets without the usual loss of vapor enthalpy due to vapor blow-off during cool-down. In the case of massive objects, the high pressure tubing may be connected to a channel system permeating the entire mass rather than contacting only its external surface.

Having thus described the invention it will be apparent that numerous modifications to suit various applications may be made by those skilled in the art without departing from the scope contemplated by the invention. Consequently the invention herein described is to be construed as limited only by the scope of the following claims.

What is claimed is:

1. A heat transfer apparatus for cooling a heat sink of the type comprising,
 - a closed circulation loop containing helium under pressure,
 - means for circulating said helium through said loop,
 - means for cooling said helium in a portion of said loop,
 - means for transferring heat into said helium in a different portion of said loop from said heat sink,
 - wherein the improvement comprises,
 - means for providing said helium in said loop at a pressure in excess of its critical pressure throughout said loop.
2. Apparatus as in claim 1 in which the means for cooling said super-critical helium is by immersion of a portion of said loop in a reservoir of a cooling medium.
3. Apparatus as in claim 2 in which the cooling medium is liquid helium,
 - heat exchanger baffles,
 - said baffles in thermal contact with the boil-off vapor from said liquid helium in said reservoir,
 - said baffles also making thermal contact with the helium in said closed circulation loop,
 - said helium circulation in said loop being in a direction to make thermal contact with said baffles prior to making thermal contact with the liquid helium in said reservoir.
4. Apparatus as in claim 2 wherein said heat sink is maintained at a desired cryogenic temperature comprising in addition,
 - means for controlling the rate of circulation of said helium through said loop.
5. In a heat transfer apparatus utilizing helium as the heat exchange medium,
 - a closed circulation loop,
 - a fill of helium in said loop,
 - a pump connected into said loop for circulating said helium through said loop,
 - a source of liquid helium, a portion of said loop cooled by said liquid helium, and
 - a heat sink thermally connected to said loop,
 - said helium in said loop being at a pressure in excess of its critical point,
 - said pump comprising,
 - a housing provided with an inlet and an outlet, said inlet and said outlet connected in series with said circulation loop,
 - a bellows mounted within said housing,
 - means for obtaining a uni-directional flow of said helium through said pump,
 - means for actuating said bellows,
 - said helium within said housing being pumped through said outlet by said bellows when said bellows is actuated by said housing means,
 - whereby helium in said housing both within and without said bellows is substantially equalized in pressure, thus allowing said pump to operate normally under conditions of high pressure.
6. In a heat transfer apparatus utilizing helium as the heat exchange medium,
 - a closed circulation loop of stainless steel tubing,
 - a fill of helium in said loop,

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a pump connected into said loop for circulating said helium through said loop,
 a reservoir of liquid helium, a portion of said loop immersed in said reservoir and cooled thereby,
 a heat sink thermally connected to a portion of said loop remote from the cooled portion of said loop,
 insulation surrounding a portion of said loop, said insulation comprising a perforated radiation shield and an outer vacuum jacket, said radiation shield provided with tubes through which liquid nitrogen is circulated thereby cooling said radiation shield, said cooled portion of said loop not being insulated, and
 a buffer volume maintained at a relatively constant temperature connected into said loop to reduce pressure fluctuations in said loop as the temperature of the heat exchange medium varies,
 said helium in said loop being at a pressure in excess of its critical point,

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said insulation comprising a first section and a second section,
 said second section independent from said first section and removably connected thereto,
 said first section capable of retaining a vacuum when said second section is disconnected therefrom,
 said heat sink surrounded by said second section whereby said second section may be disconnected from said first section to permit ready access to said heat sink while said first section is capable of retaining a vacuum.

References Cited

UNITED STATES PATENTS

3,025,680	3/1962	Brosse et al.	62—514 X
3,125,863	3/1964	Hood	62—45 X
3,162,716	12/1964	Silver	62—45 X

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