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Vander Arend

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[54] **CRYOGENIC HELIUM REFRIGERATION SYSTEM**

[75] Inventor: **Peter C. Vander Arend,** Center Valley, Pa.

[73] Assignee: **Carpenter Technology Corporation,** Reading, Pa.

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[51] **Int. Cl.** **F25b 19/00**

[58] **Field of Search** 62/115, 149, 216, 222, 62/514

[56] **References Cited**

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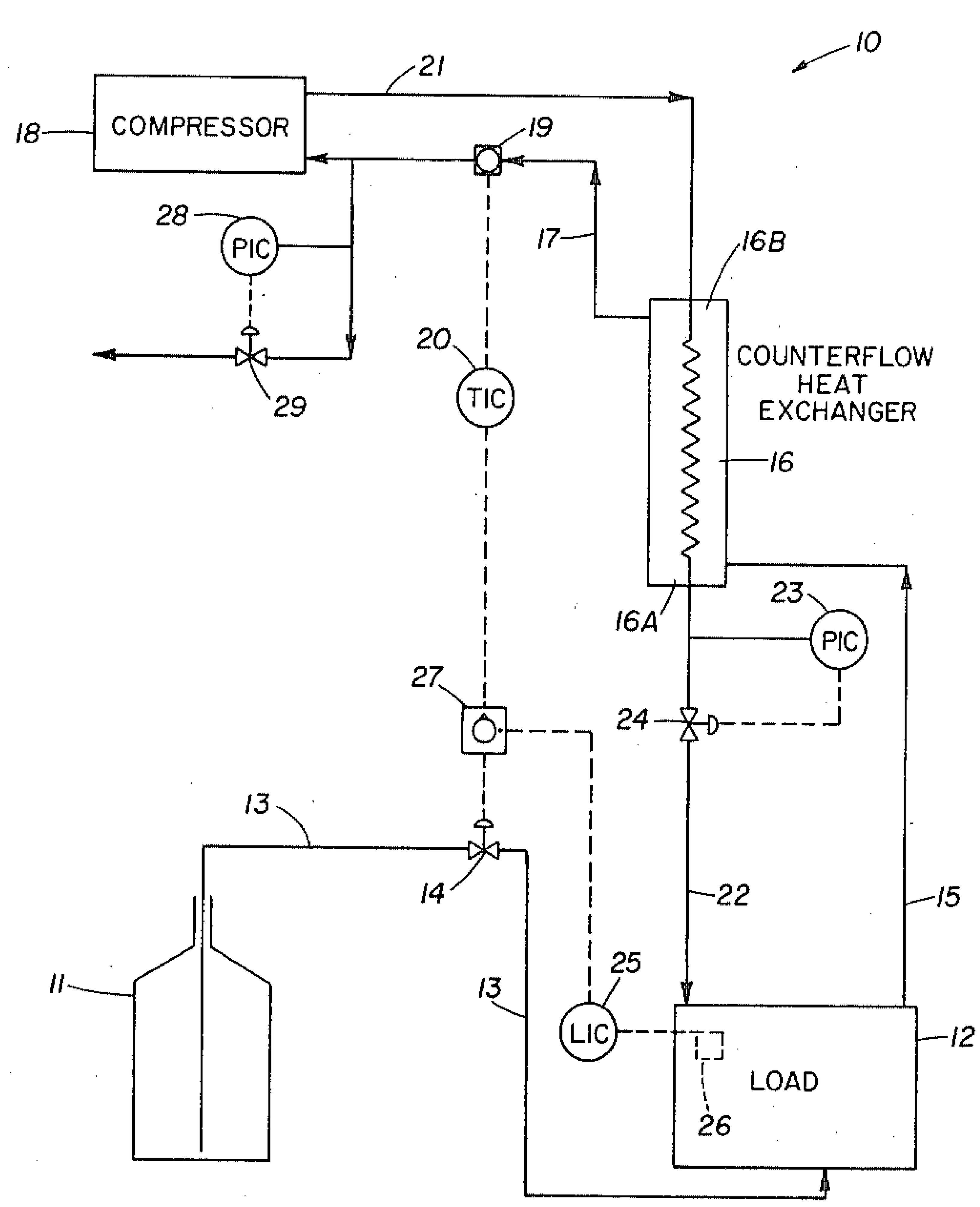
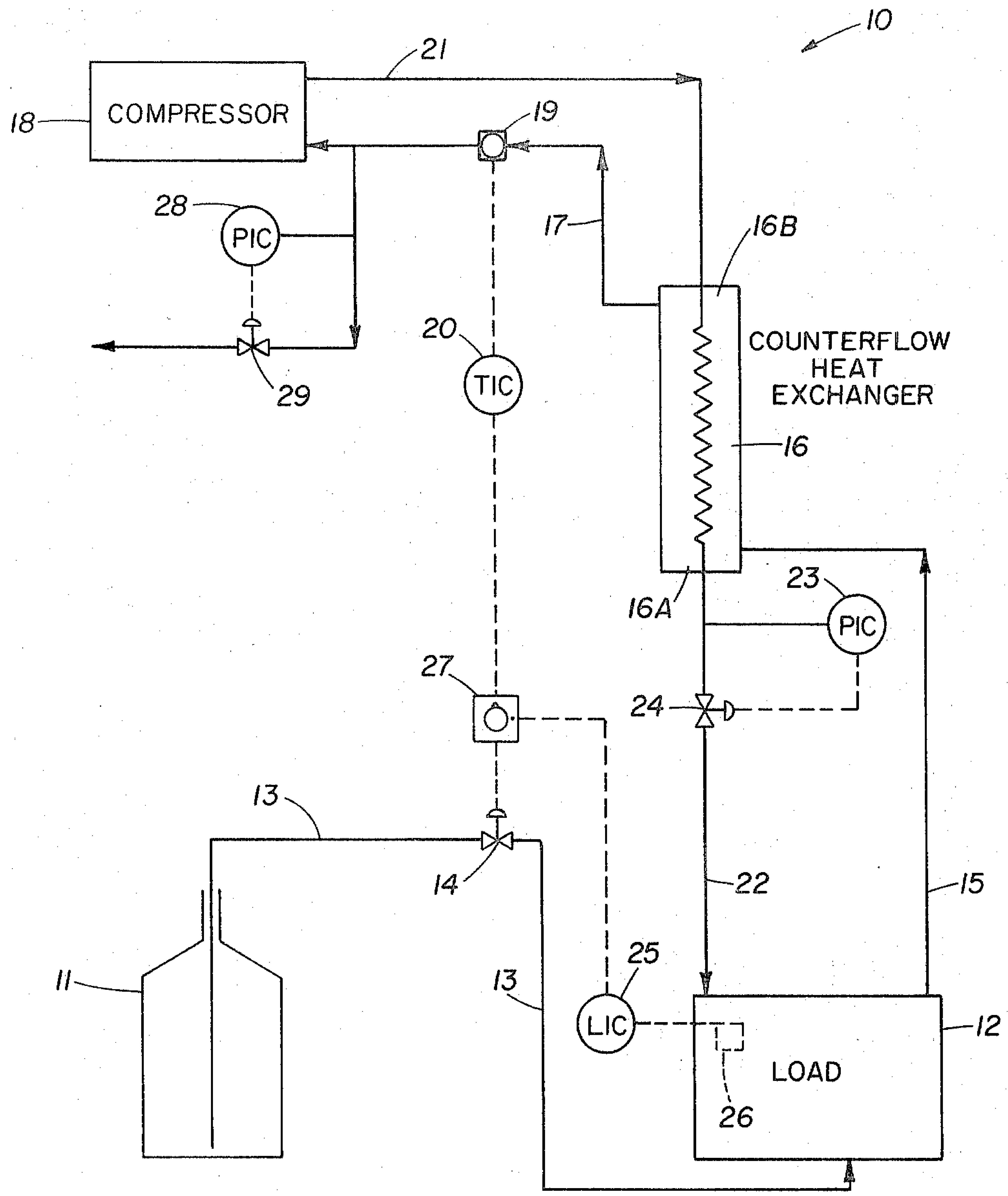
Primary Examiner—Meyer Perlin
Attorney, Agent, or Firm—Edgar N. Jay

[57] **ABSTRACT**

Liquid helium vaporized in cooling a refrigeration load is counterflowed through a heat exchanger to cool a high pressure flow of helium which is thereby cooled to below the inversion temperature. The outflow from the warm end of the heat exchanger is compressed to form the high-pressure flow. The cooled high-pressure flow of helium is subjected to Joule-Thompson expansion at constant enthalpy to further reduce its temperature and then fed back into the refrigeration load chamber. During cool-down, the system provides a return flow of helium at a temperature below that of the helium withdrawn from the load chamber. When equilibrium is reached, the helium forming the counterflow in the heat exchanger is low enough in temperature so that the cold high-pressure helium output has a less than critical enthalpy so that a major portion of the return flow to the load chamber is liquid helium. Liquid helium is fed into the load chamber from an external source but only at a rate which is a small fraction of the amount of liquid helium required to supercool the load device in normal operation and that amount of helium is removed from the system at the same fractional rate.

14 Claims, 1 Drawing Figure

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CRYOGENIC HELIUM REFRIGERATION SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to the cooling of devices or systems to extremely low temperatures and more particularly to an improved method using helium as the cryogen.

Cryogenic devices which are operated at temperatures near absolute zero, such as superconducting electromagnets, are refrigerated by means of liquid helium which may be supplied directly from an adjacent liquefaction plant or from storage Dewars. As is well known, most effective cooling is accomplished by the vaporization of liquid helium, after which the gaseous helium is removed from the system. This gaseous helium is either vented to the atmosphere or recycled to a liquefaction plant depending upon the cost involved which can be prohibitive.

Heretofore, such systems employing liquid helium as the cryogen have been dependent upon the available supply of liquid helium for their refrigeration. If in a given instance, the available supply of liquid helium was 80 liters per hour and the refrigeration load required a flow of liquid helium at 100 liters per hour then it was necessary to increase the supply rate by an additional 20 liters per hour and usually this was accomplished by the relatively expensive solution of providing a larger liquefaction plant.

Efforts to use the vaporized helium for further cooling of the refrigerated device have not been successful and had often resulted in the use of larger rather than smaller amounts of liquid helium.

SUMMARY OF THE INVENTION

It is, therefore, a principal object of this invention to provide a method for significantly improving the refrigeration of a cryogenic fluid system utilizing helium as the cryogen without increasing the rate at which liquid helium is fed into the system.

Another object of this invention is to provide such a system in which the cooling capacity of a given supply of liquid helium is significantly improved.

In accordance with the present invention the vaporized helium from a refrigeration load cooled by means of liquid helium is led back as the counterflow through a heat exchanger to a compressor. This cold helium gas is used to cool the helium gas fed from the compressor at an elevated pressure to the input on the warm side of the counterflow heat exchanger.

The output from the heat exchanger is expanded through a Joule-Thomson valve and then fed into the cooling chamber to provide further cooling. In operation, the cooling efficiency of the system is improved so long as the temperature of the helium under pressure fed from the heat exchanger to the Joule-Thomson valve is significantly below the inversion temperature of helium which is at about 40°K, and the flow to the heat exchanger from the load is greater than the return flow to load from the heat exchanger.

DESCRIPTION OF THE DRAWING

Further objects as well as advantages of the present invention will be apparent from the following description of a preferred embodiment thereof and the accompanying drawing which is a diagrammatic view of a liquid helium cooling system constructed in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention will now be described in connection with the refrigeration of a device such as a superconducting magnet or solenoid which is intended to be operated at a temperature of about 4°–5°K. While the present invention is especially well suited for and is advantageously used for this purpose it is not intended thereby to limit this invention.

As is well known, such superconducting magnets when being placed into operation are usually initially cooled down to 80°K by cooling with liquid nitrogen. While not essential to the present invention such practice is desirable because it conserves liquid helium. Starting with a superconducting device such as a magnet in the refrigeration or load chamber of the system and, as desired, cooling down initially to 80°K by means of liquid nitrogen, liquid helium is fed to the refrigeration load. In an efficient arrangement, the cooled device is exposed to the liquid helium which is caused thereby to vaporize or boil. For best results, the liquid helium is led into or through the bottom of the load chamber to the load.

The vaporized helium is fed as the coolant or cryogen through a heat exchanger to a compressor, the pressurized output of which is in turn fed through the heat exchanger for cooling before it is expanded at substantially constant enthalpy through a Joule-Thomson valve. While any suitable type of heat exchanger can be used, good results have been obtained with a counterflow heat exchanger in which the relatively cold, low-pressure helium vapor from the load chamber is fed counter to the relatively warm, high-pressure helium from the compressor.

It is critical to the operation of the present system that the temperature of the counterflow helium fed to the heat exchanger be reduced below the inversion temperature of helium which is the temperature below which helium on being expanded from a higher to a lower pressure at constant enthalpy undergoes a drop in temperature. When the refrigeration load chamber is well designed to provide efficient cooling of the load by the liquid helium initially fed into the system from the external liquid helium supply, it is evident that initially during early stages of cooling the load from 80°K, the temperature of the vaporized helium (in the absence of some cooling effect by the liquid helium in the chamber) will be at about 80°K. However, as liquid helium is continued to be fed into the system from the external supply, the temperature of the helium vaporized in the load chamber is rapdily reduced below the inversion temperature. That temperature is considered to be at about 40°K (about −233°C). While the precise temperature to which the helium leaving the load chamber must be brought is not critical once it is low enough so that when the high-pressure helium cooled to that temperature is expanded through the Joule-Thomson valve a sensible drop in temperature is obtained. Thus, the helium, though initially returned to the load chamber as gas, is cooler than when withdrawn.

For compressing the helium before it is returned to the heat exchanger to be cooled, any suitable compressor of the desired capacity can be used. A compressor discharge pressure of from 3 to 15 atmospheres can be used although a higher discharge pressure could be used if desired.

During the cooling down portion of the refrigeration cycle when the load device is being cooled down from an initial temperature of say 80°K to its operating temperature of about 4° to 5°K, liquid helium is fed into the load chamber at a rate which is controlled in response to the temperature of the helium vapor after it has left the load chamber and before it enters the compressor rather than in response to the liquid level in the load chamber although the latter can be used. Preferably the liquid helium feed rate to the load chamber is controlled in response to the temperature of the helium leaving the warm side of the heat exchanger. The actual flow rate utilized will depend upon the size and other design factors of the cooldown in response to an increase or decrease in the thus measured temperature; and, for example, could be maintained within a range of about 230° to 270°K.

As cooling down of the load device progresses, the level of the liquid helium in the load chamber will rise. Usually, during operation after cooldown, the load device is fully immersed in the liquid helium and that liquid level is sensed and used to control the further flow rate of liquid helium into the load chamber.

It should be noted that the equilibrium or operating temperature of the load device after cooldown will depend, among other things, upon the pressure of the helium. At one-half atmospheric pressure, the temperature of the helium will be about 3.55°K. At atmospheric pressure, the temperature will be at about 4.22°K. At a pressure of **2** atmospheres, the temperature will be at about 5.0°K. Whatever the selected conditions may be, once equilibrium is reached and is maintained, the temperature of the helium leaving the load chamber should be at essentially the same temperature as the liquid if good cryogenic design practices are observed. The cold helium counterflowing through the heat exchanger cools the high-pressure helium in the load coil of the heat exchanger to a temperature which is low enough so that the enthalpy of the high-pressure helium leaving the cold side of the heat exchanger is at or below its critical value so that Joule-Thomson expansion of the gas results in the formation of liquid helium. Liquid helium returned in this way to the load chamber can be as much as about **80%** of the total amount of liquid helium required to maintain the load device at its operating temperature.

To compensate for the introduction of liquid helium into the system from a storage device such as a Dewar or an adjacent liquefaction plant, the pressure in the system is monitored. This is preferably carried out at the intake to the compressor and excess helium is vented to the atmosphere, or, if desired, is returned to the liquefaction plant.

Referring now to the drawing in detail, a preferred embodiment of the refrigeration system **10** of the present invention is shown in connection with a load chamber **12** in which a refrigeration load such as a superconducting magnet (not shown) is positioned for supercooling by liquid helium from a suitable source indicated diagrammatically as a Dewar-type storage vessel **11.** Vessel **11** in this instance provides liquid helium at a pressure of about 1.2 atmospheres and a temperature of about 4.4°K through a pipe **13** which includes an electrically controlled valve **14** preferably to the bottom of the load chamber **12.** Vaporized helium is led from the upper portion of the chamber **12** via pipe **15** to the cold side **16**A of counterflow heat exchanger **16** where the helium functions as a refrigerant. The warm side of this primary circuit of heat exchanger **16** is connected by pipe **17** to the input of compressor **18.** A temperature-sending device is included in pipe **17,** as indicated diagrammatically at **19,** which is in turn electrically connected to temperature indicator-controller **20.** The output of compressor **18** is connected by pipe **21** to the secondary or load circuit of heat exchanger **16** at the latter's warm side **16**B. The cold end of the load circuit is connected by pipe **22** to the load chamber **12.** Joule-Thomson expansion of the cooled, high-pressure helium is controlled by pressure indicator-controller **23** which controls expansion valve **24** in response to the pressure in pipe **22** near the output from the heat exchanger **16** to provide isenthalpic expansion of the helium.

A level indicator-controller **25** coupled to liquid helium level sensor **26** for sensing the level of helium in chamber **12** is coupled through switch **27** to flow control valve **14** for controlling the latter in response to the level of helium in chamber **12.** The other side of switch **27** is connected to the output of temperature indicator-controller **20.** Switch **27** in one position couples valve **14** to the temperature indicator-controller **20** and in its other position to the level indicator-controller **25.**

A pressure indicator-controller **28** is coupled to pipe **17** adjacent to the input to the compressor **18.** Output of the pressure indicator-controller **28** controls valve **29.**

The operation of this embodiment will be apparent from the foregoing general description of the present invention. Suffice it to say here, that once the superconducting magnet forming the load in chamber **12** is cooled down to its operating temperature of about 4.4°K, the flow rate from the liquid helium supply **11** will have been reduced to about 20 percent of the rate normally required or 0.2 in absolute units. At the same time, the load chamber **12** will be receiving a flow of helium through pipe **22** at a rate of about **5** times that amount or 1.0 in absolute units, with as much as about 80 percent of this latter flow liquid helium. This is made possible by the fact that the flow of helium to the cold side **16**A of the heat exchanger **16** through the pipe **15** is at a pressure of about 1.2 atmospheres, a temperature of 4.4°K and a flow rate of 1.2, the latter being made up of 1.0 units from the pipe **22** and 0.2 units from pipe **13.** Also, the helium fed into compressor **18** is at about 254°K, at a pressure of 1.0 Atm. and a flow rate of 1.0, 0.2 units being vented from the system by valve **29.** The output from compressor **18** is at a pressure of about 8 Atm., a temperature of about 300°K and at a flow rate of 1.0 units. The output from compressor **18** is adjusted just enough above 8 Atm. to take into account whatever pressure drop may occur in the heat exchanger. The design of the heat exchanger is such as to give an output to pipe **22** at a pressure of about 8 Atm., at a temperature of about 4.8°K and at a flow rate of 1.0.

It is an important advantage of this invention that liquid helium, which is expensive, is conserved. In instances where devices have been rendered inoperative because of the inadequacy of the available supply rate of liquid helium to cool the device to its required temperature, the present invention readily overcomes such difficulties. Indeed, it is evident from the foregoing that a given supply of liquid helium capable of delivering a flow rate of 1.0 can now be used to maintain **5** devices such as superconducting magnets at operating temperature though each had hitherto required liquid helium at the rate of 1.0. In practice, the fraction of the flow to the load provided by the external liquid helium supply **11** may vary between about 5 to 30 percent or it may form an even larger fraction of the total flow with the system of the present invention still providing a significant advantage. Preferably, the ratio of the helium flow from the heat exhanger to the flow from the external source of liquid helium is greater than about 1, although a smaller ratio as little as 0.25 may also be useful.

The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed.

I claim:

1. In a cyrogenic helium refrigeration system for cooling a refrigeration load to a predetermined temperature by means of liquid helium at a predetermined pressure, said refrigeration load requiring liquid helium at said pressure at a predetermined flow rate to maintain its normal operating temperature, the steps of feeding liquid helium at said pressure to said refrigeration load from an external supply, feeding helium vaporized by said load through the primary circuit of a heat exchanger as a coolant, compressing the outflow from the primary circuit, then feeding the pressurized helium through the secondary circuit of said heat exchanger and cooling the same below the helium inversion temperature, expanding the cooled highpressure helium isenthalpically to further lower its temperature, then feeding the expanded and cooled helium to said refrigeration load at about said predetermined pressure and at a rate which is less than the rate at which helium is fed from said load to said heat exchanger primary circuit, and removing warm helium from said system at a rate substantially equal to said flow rate from said external supply.

2. The system as set forth in claim **1** in which the ratio of (a) the flow rate of cooled helium from said heat exchanger to said refrigeration load to (b) the flow rate from said external supply to said refrigeration load is maintained greater than one.

3. The system as set forth in claim **2** in which said ratio is equal to about **5.**

4. The system as set forth in claim **1** in which the rate of flow of liquid helium from said external supply to said refrigeration load is controlled in response to the level of liquid helium at said refrigeration load.

5. The system as set forth in claim **4** in which the rate of flow of liquid helium from said external supply is initially controlled in response to the temperature of the warm helium fed from the heat exchanger to be compressed.

6. The system as set forth in claim **5** in which the rate of flow of liquid helium from said external supply to said refrigeration load is adjusted to maintain the temperature of the warm helium from said heat exchanger at a temperature of about 230° to 270°K.

7. The system as set forth in claim **1** in which the rate of flow of liquid helium from said external supply to said refrigeration load during cooldown of the latter is controlled in response to the temperature of the warm helium fed from the heat exchanger to be compressed.

8. A cryogenic helium refrigeration system for cooling a refrigeration load to a predetermined temperature by means of liquid helium from an external supply thereof, said refrigeration load requiring liquid helium at a predetermined pressure and flow rate to maintain its normal operating temperature, comprising means for feeding liquid helium at said pressure to said refrigeration load from said external supply, a heat exchanger having a primary circuit and a secondary circuit, means for feeding helium vaporized by said load through said primary circuit of said heat exchanger as a coolant, means for compressing the helium outflow from said primary circuit, means for feeding the pressurized helium through said secondary circuit of said heat exchanger and cooling the same below the helium inversion temperature, means for expanding the cooled high-pressure helium isenthalpically to further lower its temperature, means for feeding the expanded and cooled helium to said refrigeration load at about said predetermined pressure and at a rate which is less than the rate at which helium is fed from said load to said heat exchanger primary circuit, and means for removing warm helium from said system at a rate substantially equal to said flow rate from said external supply.

9. The system as set forth in claim **8** which further comprises means for maintaining the ratio of (a) the flow rate of cooled helium from said heat exchanger to said refrigeration load to (b) the flow rate from said external supply to said refrigeration load greater than one.

10. The system as set forth in claim **9** in which said ratio is equal to about **5.**

11. The system as set forth in claim **8** which includes means for controlling the rate of flow of liquid helium from said external supply to said refrigeration load in response to the level of liquid helium at said refrigeration load.

12. The system as set forth in claim **11** which includes means for initially controlling the rate of flow of liquid helium from said external supply in response to the temperature of the warm helium fed from the heat exchanger.

13. The system as set forth in claim **12** which includes means for controlling the rate of flow of liquid helium from said external supply to said refrigeration load so as to maintain the temperature of the warm helium from said heat exchanger at a temperature of about 230° to 270°K.

14. The system as set forth in claim **8** which includes means for controlling the rate of flow of liquid helium from said external supply to said refrigeration load during cooldown of the latter in response to the temperature of the warm helium fed from the heat exchanger.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,850,004 Dated November 26, 1974

Inventor(s) Peter C. Vander Arend

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 3, line 16, after "the", insert -- system, but is conveniently increased or decreased during --.

Signed and sealed this 15th day of April 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks