

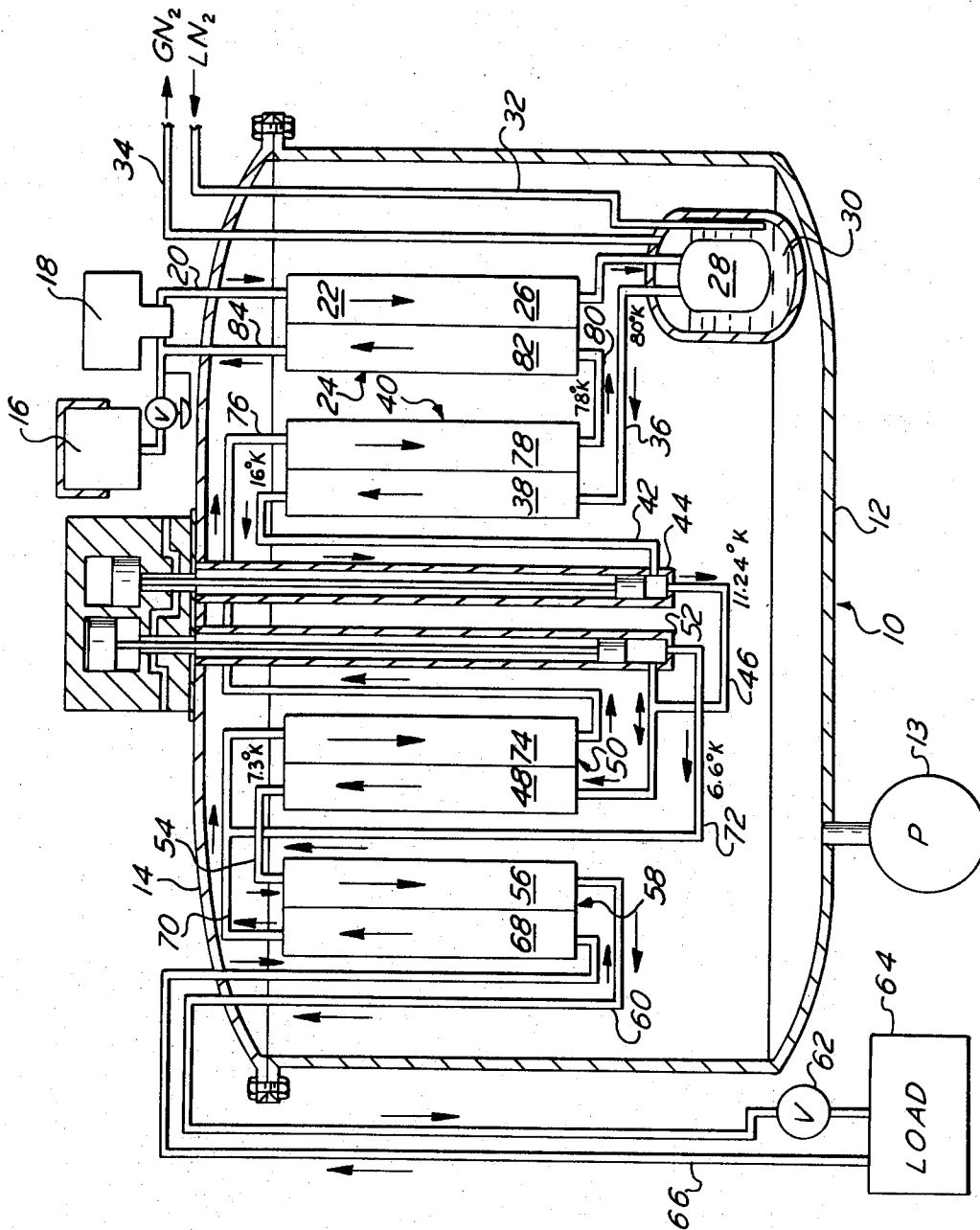
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CRYOGENIC REFRIGERATOR

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CRYOGENIC REFRIGERATOR

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ABSTRACT OF THE DISCLOSURE

A cryogenic refrigerator capable of generating temperatures in the vicinity of the boiling point of liquid helium (4.2° K.) with efficient power input for a given load (4.7 B.t.u./lb. of helium flow). Cooling is attained by a combination of expansion and heat exchange. A pair of expansion devices is provided with all flow going through the first expansion device and less than half of the flow passing through the second expansion device.

The present invention relates to a cryogenic refrigerator, and more particularly, to a helium refrigerator for continuously removing heat from a load at a temperature in the vicinity of the boiling point of liquid helium (4.2° K.). Cooling is attained by a combination of expansion devices and heat exchangers which are more efficient and less costly than other commonly used arrangements. The power input for a given refrigeration load is much lower than that of other devices and the flow rate is greatly reduced, thereby permitting reduction in size of all other major components.

The cycle of the refrigerator of the present invention subsequent to compression of pressure of between 25 and 50 atmospheres comprises counter-current heat exchanger cooling, then cooling by a first expansion device, diverting less than half of the stream through a second expansion device, the remainder of the stream being cooled by counter-current heat exchangers and then expansion through a valve. The final heat exchanger adjacent to the load has a temperature differential of only about one-half degree K. The refrigeration available from the present invention at 4.4° K. is about 4.7 B.t.u./lb. of helium flow through the compressor.

The increase in efficiency over prior refrigerators includes the fact that the same stream is first expanded to a pressure of about 8 atmospheres which is ideal for Joule-Thomson cooling and then cooled to a temperature which maximizes this effect. Since the same stream is subjected to both types of cooling, this double duty effect results in a reduction of horsepower and flow rates over conventional cryogenic refrigerators.

It is an object of the present invention to provide a novel cryogenic refrigerator.

It is another object of the present invention to provide a helium refrigerator capable of generating temperatures in the vicinity of the boiling point of liquid helium with efficient power input for a given load.

It is another object of the present invention to provide a helium refrigerator wherein the temperature differential between the cold path and warm path of the final heat exchanger is only approximately one-half degree K.

It is another object of the present invention to provide a helium refrigerator wherein a stream is first expanded to a pressure of about 8 atmospheres and then cooled to a temperature which maximizes cooling of the stream at that pressure.

Other objects will appear hereinafter.

For the purpose of illustrating the invention, there is shown in the drawings a form which is presently preferred; it being understood, however, that this invention is not limited to the precise arrangements and instrumentalities shown.

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The drawing illustrates a cross-sectional view of a helium refrigerator in accordance with the present invention.

Referring to the drawing in detail, wherein like numerals indicate like elements, there is shown in FIGURE 1 a cryogenic refrigerator in accordance with the present invention designated generally as 10. The refrigerator 10 includes a housing 12 adapted to be evacuated by a vacuum pump 13. The housing 12 may be provided with a removable cover 14. A source of helium gas 16 is connected to the suction side of a compressor 18 by way of a conduit which may contain a pressure regulator. The output side of the compressor 18 is connected to conduit 20.

In conduit 20, the helium gas has a pressure of about 32.5 atmospheres and a temperature of about 300° K. Conduit 20 is connected to the warm path 22 of a counter-current flow heat exchanger 24. The exit from warm path 22 is connected by way of conduit 26 to a refrigerated adsorption purifier 28. Purifier 28 is optional. The purpose of purifier 28 is to freeze out gaseous impurities such as oxygen, nitrogen, or carbon dioxide which would otherwise freeze-out in colder portions of the cycle. As illustrated, purifier 28 is immersed in a bath 30 of liquid nitrogen or some other cryogenic liquid. Liquid nitrogen is introduced into the bath 30 by way of conduit 32 and gaseous nitrogen is removed therefrom by way of conduit 34.

From the purifier 28, the helium stream is transferred by way of conduit 36 at a temperature of 80° K. to the warm path 38 of a counter-current flow heat exchanger 40. From warm path 38, the helium is communicated by way of conduit 42 at a pressure of about 32.3 atmospheres and a temperature of about 16° K. to the suction side of an expansion device 44. Expansion device 44 may be an expansion engine or an expansion turbine, each of which are per se well known to those skilled in the art.

The helium gas stream exits from the expansion device 44 by way of conduit 46 at a pressure of about 8 atmospheres and a temperature of approximately 11.2° K. Approximately seventy-one percent of this stream is communicated directly to the warm path 48 of the counter-current flow heat exchanger 50. The remaining twenty-nine percent of the stream is communicated to a second expansion device 52 which may be identical with expansion device 44. If desired, the expansion devices 44 and 52 may be of different sizes, need not operate off the same crankshaft as shown, and may be of an entirely different type.

From the warm path 48 of heat exchanger 50, the stream is communicated by way of conduit 54 at a temperature of about 7.3° K. while being at the same pressure to the warm path 56 of the final counter-current flow heat exchanger 58. From the warm path 56, the stream is communicated to the load 64 by way of a conduit 60 having a Joule-Thomson expansion valve 62 therein. In conduit 60 the stream is at a pressure of 7.8 atmospheres and 4.8° K. The valve 62 reduces the pressure to 1.2 atmospheres. The refrigerator of the present invention generates a temperature at the load 64 of approximately 4.4° K. From the load 64, the stream recirculates at a temperature of about 4.4° K. and at a pressure of 1.2 atmospheres through conduit 66 to the cold path 68 of the heat exchanger 58. The stream exiting from cold path 68 in conduit 70 has a temperature of about 6.6° K. and therefore there is a temperature differential between conduits 54 and 70 of about one-half degree K. (6.6 versus 7.3).

The exit side of the expansion device 52 communicates directly with conduit 70 by way of conduit 72. In conduit 72, the stream is at a pressure of about 1.19 atmospheres and a temperature of about 6.6° K. Conduit 70

communicates with the cold path 74 of heat exchanger 59. From cold path 74, the stream communicates by way of conduit 76 to the cold path 78 of heat exchanger 49. In conduit 76, the stream has a temperature of about 10.6° K. It is to be noted that the temperature differential between the streams in conduit 76 and conduit 46 is only slightly more than one-half degree K. (10.6 versus 11.24).

The exit side of cold path 78 communicates with the inlet side of cold path 82 of heat exchanger 24 by way of conduit 80 at a temperature of 78° K. The exit side of cold path 82 communicates with the suction side of the compressor 18 by way of conduit 84. In conduit 84, the gas is at a pressure of about 1.09 atmospheres and a temperature less than that of conduit 20 according to the size and efficiency of heat exchanger 24. This difference in temperature is not essential to the operation of the system as long as purifier 28 is held at 80° K. with liquid nitrogen. Thus, it will be noted that the temperature differential between the streams in conduits 36 and 80 is approximately 2° K.

The refrigeration available at the load 64 at a temperature of about 4.4° K. is about 4.7 B.t.u./lb. of helium flowing through the compressor 18. Efficiency can be expressed in terms of power input divided by refrigeration available, which in this case is 244. Also, efficiency may be expressed in terms of Carnot efficiency which in this case is about 28%. This increase in efficiency lies in the fact that the stream is first expanded to a pressure of about 8 atmospheres which is the ideal temperature for Joule-Thomson cooling. Then the helium is cooled to the proper temperature when passing through heat exchangers 50 and 58 by the streams in conduits 66, 70 and 72 for maximum effect by the expansion valve 62. Since the helium stream flowing to the load as described above is subjected to expansion cooling as well as heat exchanger cooling, there is reduction in horsepower and flow rate over conventional cryogenic refrigerators.

When a purifier 28 immersed in LN₂ is used, it fixes the temperature in conduit 36, regardless of the performance of cold path 82 in heat exchanger 24. If the purifier is not used, the cold path 82 of heat exchanger 24 must maintain the 2° K. temperature difference, which will appear at conduits 84 and 20. Hence, heat exchangers 24 and 40 then become one heat exchanger. It would be possible to operate the purifier 28 without liquid nitrogen, in which case its temperature would be determined by the size and efficiency of the cold paths 38 and 82 of heat exchangers 40 and 24. The purifier 28 may also be cooled by other means, such as a separate stream of helium, etc.

In view of the above description, a more detailed description of the operation is not deemed necessary since the same will be readily apparent to those skilled in the art to which the present invention pertains. Hereinafter, either or both of the heat exchangers 24 and 40 may be referred to as first heat exchanger means, heat exchanger 50 may be referred to as a second heat ex-

changer means, and heat exchanger 58 may be referred to as a third heat exchanger means.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof and, accordingly, reference should be made to the appended claims, rather than to the foregoing specification as indicating the scope of the invention.

It is claimed:

1. A cryogenic refrigerator comprising a compressor having its outlet communicating with the inlet of the warm side of a first counter-current flow heat exchanger means, the outlet of the warm side of said first heat exchanger means communicating with the inlet of a first expansion device, the outlet of said first expansion device communicating with the inlet of a second expansion device and the inlet of the warm side of a second counter-current flow heat exchanger means, the outlet of the warm side of said second heat exchanger means communicating with the inlet of the warm side of a third counter-current flow heat exchanger means, the outlet of the warm side of said third heat exchanger means communicating with the inlet of an expansion valve, the outlet of the expansion valve communicating with a load, said load communicating with the inlet of the cold side of said third heat exchanger means, the outlet of said cold side of the third heat exchanger means and the outlet of said second expansion device each communicating with the inlet of the cold side of said second heat exchanger means, the outlet of the cold side of said second heat exchanger means communicating with the inlet of the cold side of the first heat exchanger means, and the outlet of the cold side of the first heat exchanger means communicating with the suction side of the compressor.

2. A refrigerator in accordance with claim 1 including a supply of helium gas selectively communicating with the suction side of the compressor.

3. A refrigerator in accordance with claim 1 including a source of helium gas communicating with the suction side of the compressor, the pressure of the helium stream on the outlet side of said first expansion device being approximately 8 atmospheres, the temperature of the helium stream on the outlet side of said valve being approximately 4.4° K., and the temperature differential across the third heat exchanger means between the warm and cold sides thereof being less than 1° K.

4. A refrigerator in accordance with claim 1 including a cryogenic purifier positioned between the compressor and the inlet of the first expansion device.

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