CRYOGENIC JOULE-THOMSON HELIUM LIQUEFIER WITH CASCADE HELIUM AND NITROGEN REFRIGERATION CIRCUITS

Filed June 17, 1964 5 Sheets-Sheet 1

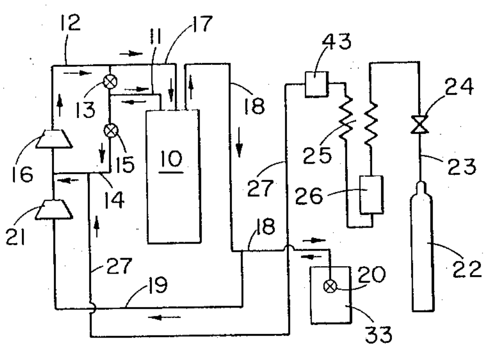

Fig. 1

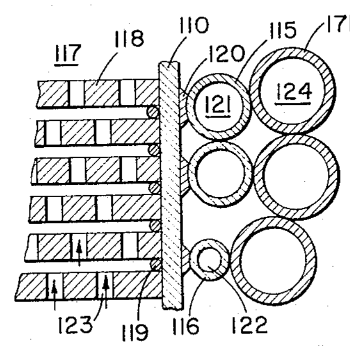

Fig. 6

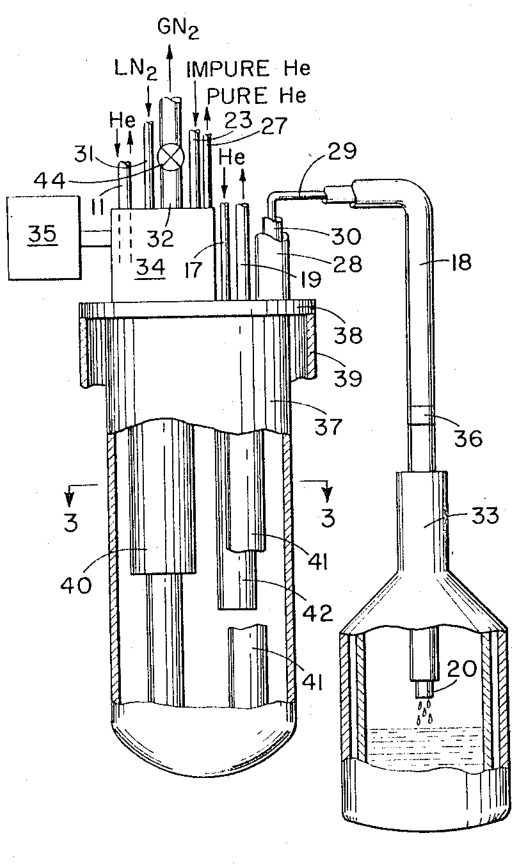

Fig. 2

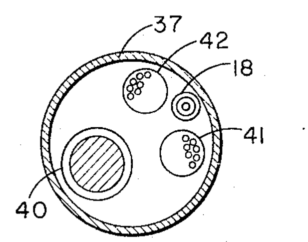

Fig. 3

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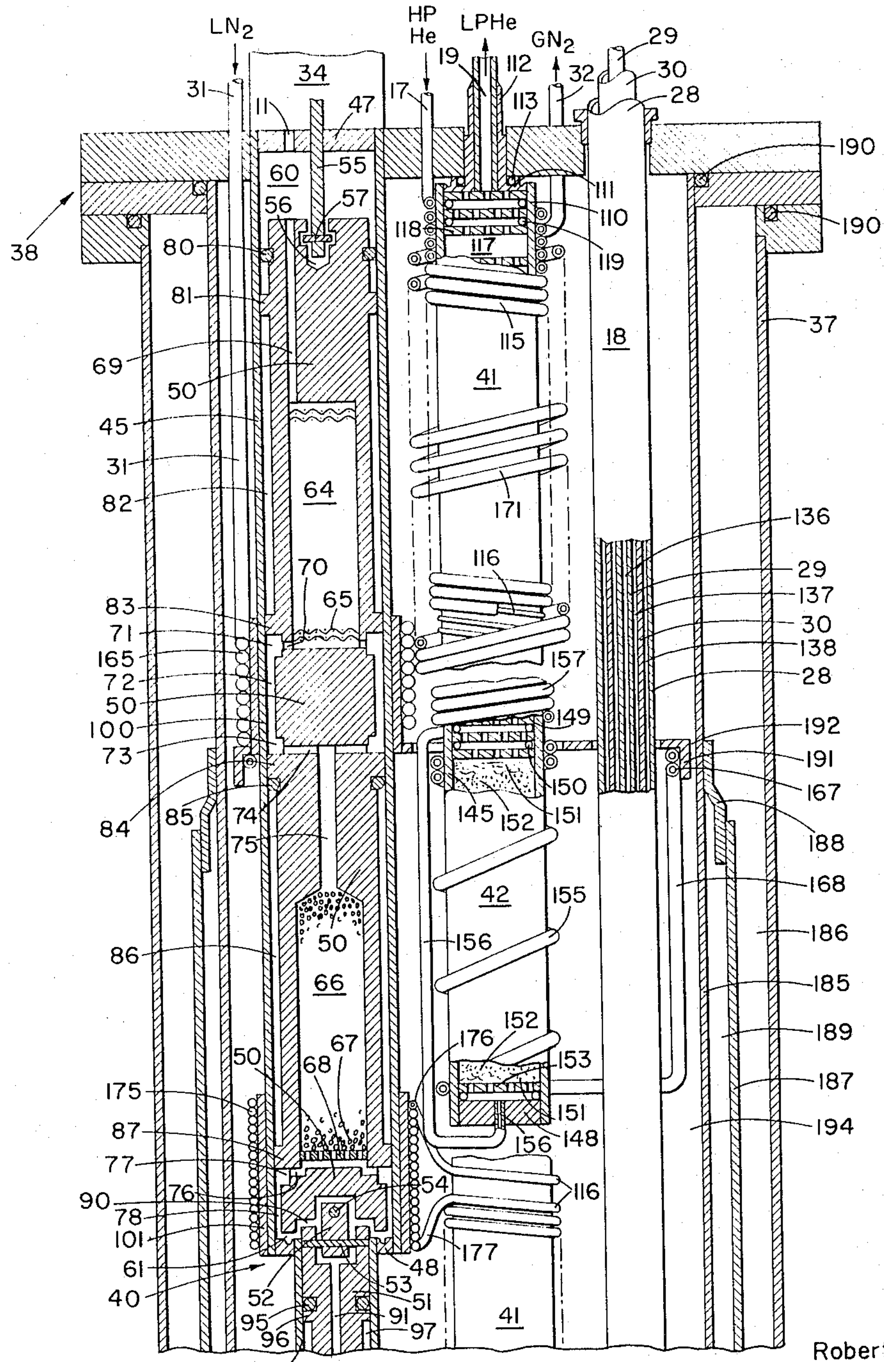

Fig. 4

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CRYOGENIC JOULE-THOMSON HELIUM LIQUEFIER WITH CASCADE HELIUM AND NITROGEN REFRIGERATION CIRCUITS

Filed June 17, 1964 5 Sheets-Sheet 3

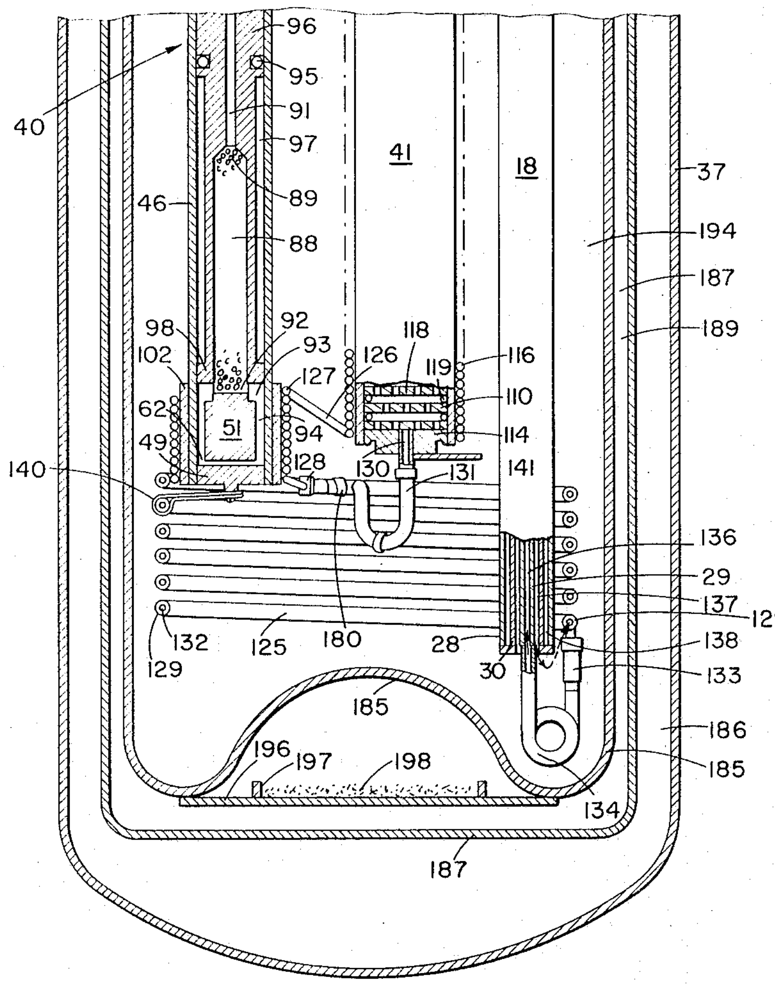

Fig. 5

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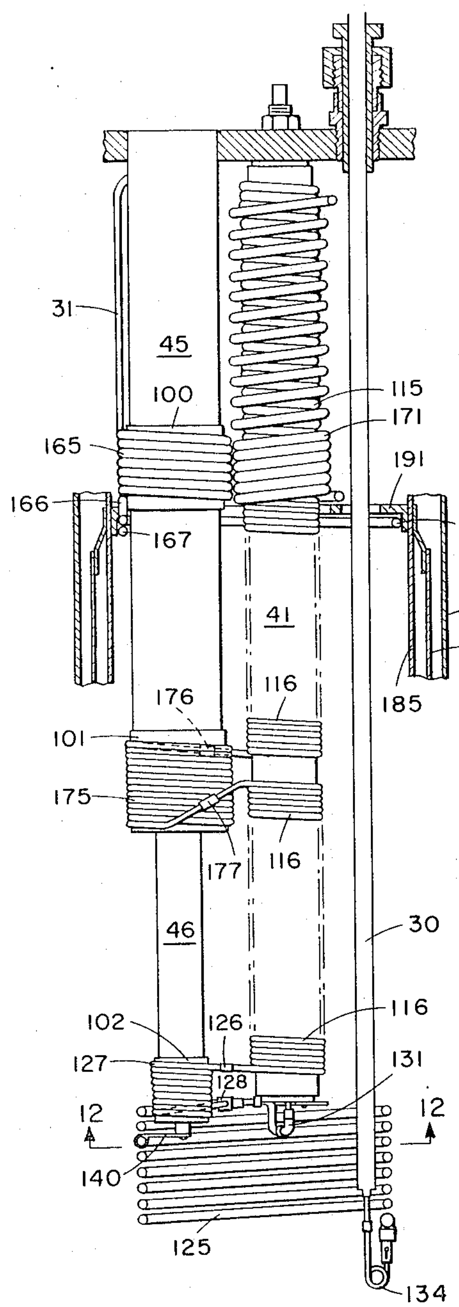

Fig. 7

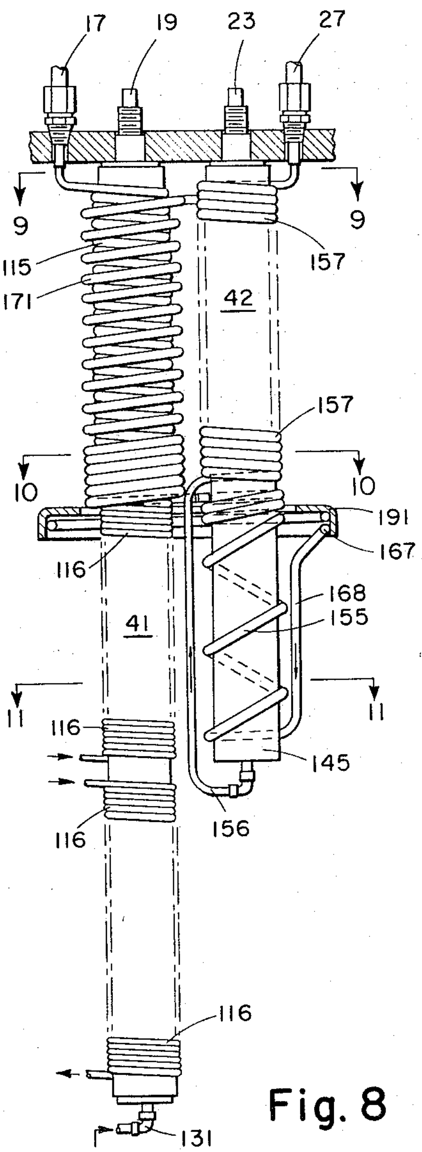

Fig. 8

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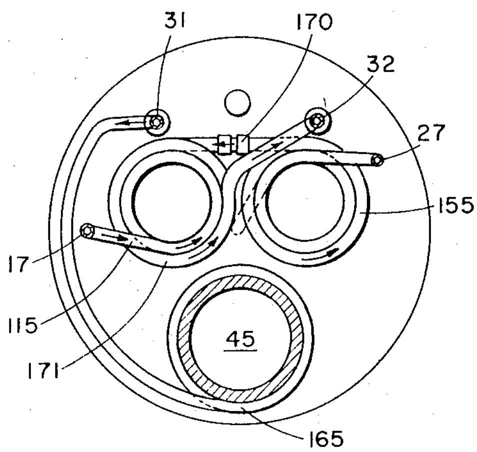

Fig. 9

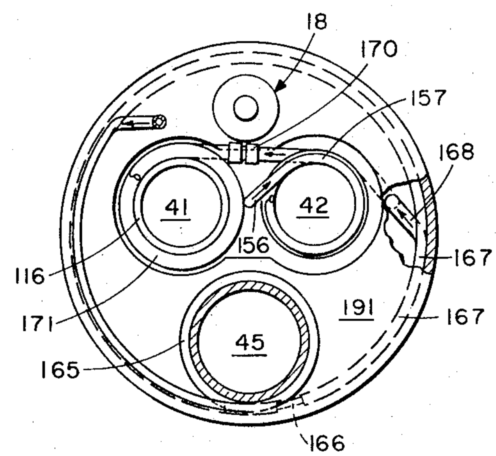

Fig. 10

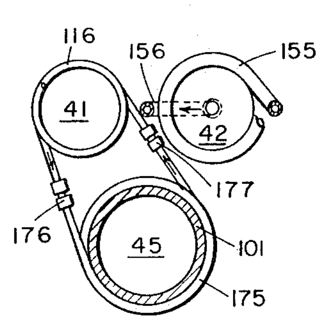

Fig. 11

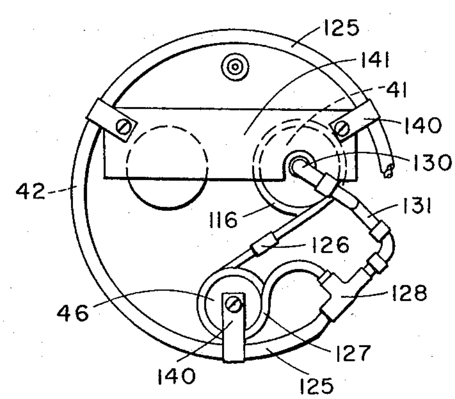

Fig. 12

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United States Patent Office

3,299,646
Patented Jan. 24, 1967

3,299,646

CRYOGENIC JOULE-THOMSON HELIUM LIQUEFIER WITH CASCADE HELIUM AND NITROGEN REFRIGERATION CIRCUITS

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Filed June 17, 1964, Ser. No. 375,854
10 Claims. (Cl. 62—40)

This invention relates to cryogenic equipment and more particularly to a cryogenic device capable of liquefying helium.

There is available a great variety of equipment capable of liquefying such gases as air, nitrogen and oxygen. However, the liquefaction of the lower boiling gases such as hydrogen and helium has always presented problems in heat transfer, gas purification and the like which are not easy to overcome. The liquefaction of helium which takes place at 4.2° K. is particularly difficult to effect and there are very few classes of equipment commercially available which will accomplish this. One of the most successful helium liquefiers is that which is described in U.S. Patent 2,458,894 and is commercially available as a helium cryostat. This equipment is, however, relatively large and bulky and although it is capable of producing anywhere from 4–8 liters of liquid helium per hour, it is not adaptable for many uses. For example it could not be incorporated in a spacecraft, nor could it conveniently be made part of a compact memory system. Moreover, in most equipment now available, the helium is liquefied within the equipment and thus must be transferred periodically to a remote point where it is to be used. This can be done either through a continuous flow transfer system such as is disclosed for example in copending application Serial No. 100,565 assigned to the same assignee as this application, or it can be done by periodically transferring the liquid helium into a suitable storage vessel such as a Dewar and using it from this vessel. Finally, the helium liquefiers which are now available require a separate purifying unit in order to provide helium of sufficient purity to prevent any contaminant plugging within the heat exchange apparatus or within the Joule-Thomson valve in which liquefaction is finally accomplished.

In the following description of the apparatus the liquefaction of helium will be used as illustrative of the working of the liquefier. However, it is to be understood that the apparatus is equally adaptable to liquefying other cryogenic fluids, particularly hydrogen.

In U.S. Patent 2,966,035 there is described a unique refrigeration cycle which has been designated the "no-work" cycle. FIGS. 10 and 11 of that patent illustrate the possible use of the no-work refrigeration cycle in connection with a Joule-Thomson loop to make possible the liquefaction of helium using that cycle in the active refrigerator of the system. The cycle is broadly defined and claimed therein and the apparatus of this invention represents an improvement of that apparatus. Moreover the apparatus of this invention combines an improved "no-work" refrigerator with a unique Joule-Thomson valve, which permits the liquefaction of the helium remote from the refrigerator, and a purifier which is incorporated in and integral with the refrigerator making it possible to continuously supply make-up helium to com-

pensate for that helium which is removed from the stream as liquid.

The apparatus of this invention therefore provides a compact liquefier that can liquefy a gas at a point remote from where it is cooled to the extent that it is in a condition to pass through a Joule-Thomson valve. It also provides a liquefier in a compact, efficient yet relatively simple form which at the same time includes a helium purifier that makes it possible to continuously supply pure helium to compensate for the quantity of helium which is liquefied. Finally, the apparatus of this invention will be seen to be extremely rugged, and to provide a helium liquefier which can be incorporated into many different devices.

It is therefore the primary object of this invention to provide an improved cryogenic liquefier capable of liquefying helium. It is another object of this invention to provide a cryogenic liquefier of the character described which is thermodynamically efficient. It is yet another object to provide a liquefier which incorporates within it a purefier which takes advantage of refrigeration available to purify the helium and remove contaminants by freezing them. It is another object of this invention to provide a liquefier of the character described which is capable of achieving the final step of liquefaction at a remote point, i.e., within a storage Dewar.

It is another primary object of this invention to provide a cryogenic liquefier capable of liquefying helium which is essentially automatic in that it incorporates within it a helium purifier and a remote Joule-Thomson valve which permits the continuous unattended operation of the liquefier to produce a liquefied gas within a separate storage container. It is another object of this invention to provide such an apparatus which is reliable, and essentially free from any difficulties which may be encountered because of gas leaks within the system. It is another object of this invention to provide such equipment which is compact, durable and easy to construct, and which at the same time is adaptable for incorporation in many different devices such as space vehicles, memory systems, and in satellites where a constant supply of liquid helium or other cryogenic fluid is needed.

Other objects of the invention will in part be obvious and will in part be apparent hereinafter.

The invention accordingly comprises the features of construction, combinations of elements and arrangement of parts which will be exemplified in the constructions hereinafter set forth, and the scope of the invention will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention reference should be had to the following detailed description taken in connection with the accompanying drawings in which

FIG. 1 is a schematic diagram of the flow of the fluids in the apparatus;

FIG. 2 shows the apparatus in a simplified form illustrating the relationship of the various parts;

FIG. 3 is a cross-section along line 3—3 of FIG. 2;

FIG. 4 is a cross-section of the upper portion of the liquefier showing the active refrigerator, the Joule-Thomson loop, the purifier and the transfer tube;

FIG. 5 is a cross-section of the lower portion of the liquefier, being an extension of the drawing in FIG. 4;

FIG. 6 is an enlarged detail cross-section of the heat exchanger in the Joule-Thomson loop;

FIG. 7 shows the heat exchange system as it is associated with the refrigerator and the Joule-Thomson loop;

FIG. 8 shows the heat exchange system as it is associated with the refrigerator and the purifier;

FIG. 9 is a cross-section taken along line **9—9** of FIG. 8;

FIG. 10 is a cross-section taken along line **10—10** of FIG. 8;

FIG. 11 is a cross-section taken along line **11—11** of FIG. 8; and

FIG. 12 is a cross-section taken along line **12—12** of FIG. 7.

For clarity of presentation, the liquefier of this invention will be divided into a number of separate components and the parts of each of the components will be described in detail following a general description of the fluid flow within the system and the relationship of the various parts before each of these is described. Subsequent to the detailed description, the liquefaction cycle along with the interrelationship of components and thermodynamic considerations will be presented. The components can be considered to comprise the active refrigerator, a Joule-Thomson loop, a purifier, an external refrigeration and heat exchange system, and finally the housing and its related insulation and enclosure structure.

GENERAL COMPONENT RELATIONSHIP AND FLUID FLOW

FIGS. 1–3 illustrate in a general way the liquefier of this invention and they show the fluid flow along with the relationship of the various parts within the system. Although liquefaction will normally be accomplished outside the main housing enclosure, the apparatus as a whole will hereinafter be referred to as a "liquefier." Turning now to FIG. 1 it will be seen that there is provided a refrigeration system generally designated by numeral **10**. Refrigeration fluid, e.g., helium, is introduced and withdrawn into the active refrigerator by means of conduit **11** which has a high-pressure branch **12** controlled by high-pressure valve **13**, and a low-pressure branch **14** controlled by low-pressure valve **15**. The flow of fluid in and out of the refrigerator is in accordance with the cycle set forth in U.S. Patent 2,966,035, which is a "no-work" cycle in that sensible heat is removed from the system rather than mechanical energy. The low-pressure fluid discharged from the refrigerator is compressed in compressor **16** and returned to the high-pressure branch conduit **12**. In the diagram of FIG. 1 it will be seen that the same fluid is used in the refrigerator as is used in the Joule-Thomson loop where liquefaction is accomplished and hence there is provided a branch conduit **17** which leads from the high-pressure fluid conduit **12** into the Joule-Thomson loop which can in FIG. 1 be assumed to be in system **10**. Inasmuch as this apparatus provides for the transfer of both high-pressure helium and cold low-pressure helium to and from a Dewar **33** where liquefaction takes place, there is provided a transfer tube **18** which is in effect an extension of the Joule-Thomson loop. In FIG. 1 it will be seen that this transfer tube leads to a "remote" Dewar **33**, and that at this remote point there is a Joule-Thomson valve generally indicated at **20**. From the point of liquefaction, e.g., Dewar **33**, the low-pressure, cold expanded helium is returned by means of conduit **19** into the regular fluid system through a booster pump **21** and thence into the high-pressure side of the fluid flow path. Control of fluid flow through the Joule-Thomson loop is exercised by the manual control of a mechanism **36** designed to open and close the Joule-Thomson valve (FIG. 2.)

The provision of make-up helium to compensate for that quantity which is liquefied is also illustrated in FIG. 1. The make-up helium is supplied from a suitable source such as a pressure flask **22** and is then introduced into the system through a suitable conduit **23** containing a pressure regulating valve **24**. Inasmuch as the contaminants in the make-up helium are to be removed through freezing and absorption there is refrigeration available from the purified helium and this is used to precool the make-up helium from flask **22** in out-of-contact heat exchanger **25**. From there the impure helium is taken into a purifier, which as will be seen below, provides the necessary refrigeration for removing the contaminants. The pure helium is then taken by way of conduit **27** through out-of-contact heat exchanger **25** back into the system to enter the high pressure side of the fluid flow path. The flow of pure helium into the main system is controlled by a valve **43** in conduit **27**. This is preferably a pressure-sensitive solenoid type switch which opens to allow pure helium to enter the system when the pressure in the system falls below a predetermined level due to the removal of some of the fluid through liquefaction.

FIGS. 2 and 3 illustrate in greatly simplified form the general positioning of the components of the liquefier of this invention. In FIG. 2 like numbers refer to like conduits identified in FIG. 1. It will be seen in FIG. 2 that the transfer tube **18** is actually made up of a surrounding insulating channel **28** which contains therein an annular passage **30** for low-pressure helium to be returned from the Dewar **33** where liquefaction takes place and a central high-pressure helium passage **29** which conveys the cold high-pressure helium to the Joule-Thomson valve **20**, located within the Dewar, for liquefaction. In the liquefier of this invention an external refrigerant, e.g., liquid nitrogen is used; and in FIG. 2 it will be seen that the liquid nitrogen (LN_2) is introduced into the system through conduit **31** and is returned, subsequent to its use as a refrigerant, as low-pressure gaseous nitrogen through conduit **32**. In FIG. 2 "GN_2" is used to indicate gaseous nitrogen. This liquid nitrogen may be circulated at a constant rate which may be pressure regulated, or its flow may be regulated by a throttling valve **44** (FIG. 2) on the gaseous nitrogen line which senses the temperature of the gaseous nitrogen leaving the system by conduit **32** and employs this temperature determination to modulate the liquid nitrogen flow and maintain a desired temperature. Finally, there is associated with the refrigerator a suitable means for controlling the introduction of high-pressure fluid into and the delivery of low-pressure fluid from the active refrigerator, and this is accomplished through a valving arrangement indicated generally as a cross-head **34** driven by a motor **35**.

Around the main liquefier enclosure is a protective housing **37** which in turn is attached to a support **38** and is protected by an outer sheath **39**. Within the main refrigerator housing **37** is positioned the active refrigerator **40**, the Joule-Thomson loop **41**, its associated transfer tube **18**, and the purifier **42**.

THE ACTIVE REFRIGERATOR

The active refrigerator which attains temperatures down to about 15° K. embodies the use of the "no-work" cycle as explained in detail in U.S. Patent 2,966,035 and is constructed in accordance with the improved apparatus described in our copending application Serial No. 375,721 assigned to the same assignee as this application. Although the cycle by which the refrigerator of this apparatus develops refrigeration is not a part of this invention, it will be helpful to briefly describe it subsequent to the description of the refrigerator apparatus itself.

The active refrigerator portion of the liquefier of this invention is shown in detail in cross-section in FIGS. 4 and 5. It will be seen to comprise an upper cylinder **45**, a lower cylinder **46**, a top plate **47**, a shoulder **48** which joins the upper and lower cylinders, and a bottom plate 49. In the description of the refrigerator as well as in the other components of the apparatus the terms "upper" and "lower," "top," and "bottom" are used in a relative sense and the refrigeration apparatus may be oriented in any manner. These terms are employed in this description only for convenience and correspond to the orientation illustrated in the figures.

Within the refrigerator enclosure which is defined by the upper and lower cylinders are an upper displacer **50** and a lower displacer **51**. These are preferably joined as illustrated in FIG. 4, the joining comprising a connector piece **52** and two pins **53** and **54** which are placed at 90° angles to each other. It will be appreciated that this arrangement permits the alignment and the operation of two displacers within the enclosure even though the actual enclosure itself is not in precise alignment. Such a joining eliminates any excessive wear in the movement of the displacers up and down within the enclosure. The upper displacer **50** is driven through a rod **55** which extends into a recess **56** in the displacer and is held in position by a pin **57**. This arrangement also permits maintaining proper alignment of the displacer within the upper cylinder **45**. The actual movement of the displacers up and down through rod **55** and the flow of fluid in and out of the refrigerator are achieved through a suitable mechanism in the crosshead **34**, preferably by that mechanism which is described in detail in copending application Serial No. 375,726 filed in the name of Fred F. Chellis and assigned to the same assignee as this application.

The displacers may be pneumatically driven through the use of an additional driving volume as detailed in copending application Serial No. 322,782 and slide valves such as described in copending application Serial No. 359,000 may be employed to control the flow of fluid in and out of the active refrigeration. These applications are assigned to the same assignee as this application and are filed in the names of two of the instant inventors.

Inasmuch as suitable apparatus for controlling the flow of fluid into, within (through displacer movement) and out of the refrigerator has been described in detail in the above-identified copending application, the cross-head **34** (FIG. 2) need not be further detailed except to point out that a preferred embodiment is to use that cross-head assembly disclosed in Serial No. 375,726 and to mount it so that rod **55** of FIG. 4 of this application is that rod designated **22** in FIG. 3 of Serial No. 375,-726, and so the port **11** of FIG. 4 of this application is in fluid communication with both inlet conduit **63** and discharge conduit **64** of the crosshead assembly as illustrated in FIG. 4 of Serial No. 375,726.

The displacers **50** and **51** in their movement within the refrigerator enclosure define a warm variable-volume chamber **60**, a first cold variable-volume chamber **61** and a second cold variable-volume chamber **62**. In FIGS. 4 and 5 the displacers are in their bottom dead center position and so cold chambers **61** and **62** are at their minimum volumes and chamber **60** is at its maximum volume.

The active refrigerator of this liquefier is constructed in accordance with the teaching set forth in copending application Serial No. 375,721, filed in the names of Fred F. Chellis and Walter H. Hogan assigned to the same assignee as this application. The unique features of the refrigerator constructed in accordance with the teaching in this copending application and incorporated in the liquefier of this invention are set forth in detail in application Serial No. 375,721. Briefly, it may be pointed out that the refrigerator incorporates a unique fluid flow heat exchange path associated with heat stations and is characterized by having all of the regenerators located within the displacers.

As will be seen in FIG. 4 the upper displacer **50** contains two regenerators, regenerator **64** which is seen for illustrative purposes to be constructed of stacked screens

65 and regenerator **66** which for illustrative purposes is seen to be comprised of lead balls **67** held in place by a foraminous retaining member **68**. Within the refrigerator there must of course be provided a fluid flow path which will conduct high-pressure fluid from warm chamber **60** to the cold chambers **61** and **62**, and return low-pressure fluid from chambers **62** through **61** to warm chamber **60** and then out of the refrigerator. This fluid flow path may be traced in FIG. 4, and it will be seen that from warm chamber **60** to first cold chamber **61** it is comprised of fluid conduit **69**, communicating between chamber **60** and the upper part of regenerator **64**; radial passage **70**, which leads from the bottom portion of the regenerator **64** and communicates with a peripheral groove **71** in the displacer; a narrow annular heat exchange passage **72** which is defined by the internal wall of cylinder **45** and the surface of displacer **50**; a second peripheral groove **73** located further down in the displacer **50**, and opening into radial passages **74** which are in fluid communication with a conduit **75** leading into the upper part of regenerator **66**; radial passages **76** and associated peripheral groove **77**; and finally, a second narrow annular heat exchange passage **78** which leads into the first cold chamber **61**.

Isolation between chambers **60** and **61**, as well as the minimizing of friction between the internal cylinder wall and the displacer, is attained in the refrigerator through the use of sealing rings **80** and **85**, lands **81**, **83**, **84**, and **87** which are part of the displacer surface, and the dead annular spaces **82** and **86** which are defined between the internal wall of cylinder **45** and the external surface of displacer **50**.

Within the bottom displacer **51** there is also a regenerator **88**, shown in FIG. 5 to be constructed of lead balls **89**. The fluid flow path between the first cold chamber **61** and the second cold chamber **62** can be traced, and it will be seen that it comprises the passage **90** around the connector piece **52** (FIG. 4), the conduit **91** which communicates with the top of the regenerator **88**, radial passages **92**, a peripheral groove **93**, and a narrow annular heat exchange passage **94**. As in the case of the upper displacer there are provided for the lower displacer means for isolating the chambers, and these include a sealing ring **95**, lands **96** and **98** in the surface of the displacer **51**, and an annular dead space **97** comparable to **82** in the upper portion of the refrigerator.

In keeping with the teaching of the novel refrigerator apparatus described and claimed in above-identified Serial No. 375,721, there are associated with the narrow annular heat exchange passages **72**, **78**, and **94** three heat stations **100**, **101**, and **102**, respectively.

As pointed out previously, the cycle on which this refrigerator operates is not part of this invention; but it will be helpful to review it very briefly, in order that the over-all thermodynamics and operation of the liquefier may be better understood. The cycle can be considered as being comprised of four distinct steps although it will be appreciated that it would be difficult to point out precisely where one step ended and another began. Assume to begin, however, that the displacers are in their bottom dead center position, as illustrated in FIGS. 4 and 5. High-pressure fluid (in this example assumed to be helium) is introduced by means of conduit **11** into the warm chamber **60**. There remains within this chamber a small quantity of residual helium left over from the preceding cycle. As the displacers are moved upwardly (by means not shown but part of the crosshead **34**) the residual fluid within chamber **60** is compressed and there is developed some heat of compression. However, during this upward movement the introduction of high pressure fluid into chamber **60** is continued, and hence the fluid which flows by means of conduit **69** into regenerator **64** is at an intermediate temperature between the highest temperature reached due to compression and the temperature of the supply fluid entering through port 11. The fluid is caused to flow through regenerator 64 and is there cooled by refrigeration stored from the preceding cycle. It is then forced out through radial passages 70 into peripheral groove 71 and down through the first annular heat exchange passage 72 where it exchanges heat with an external refrigerant circulating in coils as will be explained below in connection with the description of the heat exchange system of the liquefier. The cooled high-pressure helium then enters the second regenerator by the fluid path previously described and finally the first cold chamber 61. Likewise some high-pressure helium is also introduced into cold chamber 62 at the same time through the fluid flow path outlined. During this time the displacers 50 and 51 have been moving upward so that there is built up within cold chambers 61 and 62 a supply of high-pressure initially cooled helium. When the displacers have reached their top dead center position, the high-pressure valve (represented by number 13 in FIG. 1) is closed and the low-pressure valve (represented by number 15 in FIG. 1) is opened, permitting the high-pressure cold helium in chambers 61 and 62 (which are now at their maximum volume) to be discharged and to expand within the system to achieve a final cooling of the fluid in the active refrigerator. In operating the refrigerator apparatus on helium characteristic temperatures in the chambers are 30° K. in chamber 61 and 15° K. in chamber 62. With this expansion the displacers are moved downward thus forcing the cold low-pressure helium back up through the fluid flow path described previously to store refrigeration in the regenerators. In returning back up to chamber 60 the helium is warmed to a temperature approximating that at which it entered the top of regenerator 64. It will be remembered that this temperature was above that at which it was supplied to the refrigerator through conduit 11 and the difference in these two temperatures is substantially equivalent to the refrigeration delivered. Refrigeration is furnished from chambers 61 by way of heat stations 101 and from chamber 62 by way of heat station 102 to external loads. These loads will be further described with reference to the Joule-Thomson loop and the overall heat exchange system of the liquefier.

THE JOULE-THOMSON LOOP

The purpose of what is here referred to as the "Joule-Thomson Loop" is to provide cold, high-pressure fluid to a Joule-Thomson valve which is capable of expanding the fluid to liquefy at least a portion of it. This requires that the helium delivered to the Joule-Thomson valve be below the helium inversion point which is approximately 20° K. Of course the lower the temperature the helium is delivered to the Joule-Thomson valve, the more efficient will be the liquefaction process. The Joule-Thomson loop is shown in detail in FIGS. 4 and 5, a central portion of it being cut away to shown the bottom portion of the helium purifier. However, in that portion which is cut away the details are the same as those in the upper and lower portions shown.

The Joule-Thomson loop can be considered to be comprised of two primary heat exchangers adapted for out-of-contact heat exchange between the fluids flowing within the loop, two secondary out-of-contact heat exchangers in which the high-pressure fluid of the Joule-Thomson loop is the external refrigeration load associated with heat stations 101 and 102 of the active refrigerator, a transfer tube which is in effect an extension of the second out-of-contact exchanger circulating the fluids in the loop, and a Joule-Thomson valve at the end of the transport tube and located within a Dewar.

The first primary or upper heat exchanger 41 adapted to effect out-of-contact heat exchange between warm high-pressure helium and cold low-pressure helium in the loop is shown in FIGS. 4 and 5. It comprises a cylindrical housing 110 which is closed on top with a suitable plate 111 which in turn is integral with a collar 112 extending beyond the liquefier enclosure. Within this extension 112 is located the low-pressure helium discharge line 19. A suitable sealing means 113 is provided to insure that the interior of the liquefier is fluid-tight as will be described subsequently. The bottom portion of this first heat exchanger 41 will be seen in FIG. 5 to terminate in a bottom plate 114. Around the heat exchanger 110 is wrapped high-pressure tubing 115 which partway down in the heat exchanger gives way to a smaller diameter tubing 116. This is a compromise between minimum pressure drop and maximum heat exchange, for by the time the high-pressure helium in tubing 115 reaches the smaller diameter tubing 116 it has cooled to the extent that the decrease in the mass of the helium permits the use of a smaller diameter tubing without any appreciable increase in pressure drop. The low-pressure side of the heat exchanger 41 is the volume 117 within enclosure 110. Within this volume are positioned foraminous discs 118 which are held in spaced relationship by suitable spacing means such as wires 119. The manner in which heat exchange is effected in heat exchanger 41 is described in detail in the subsequent section on heat exchange.

The first of the secondary heat exchangers in which refrigeration from cold chamber 61 of the active refrigerator, by way of heat station 101, is delivered to the high-pressure helium in the Joule-Thomson loop is heat exchanger 175 (see also FIG. 7). High pressure tubing 116 is broken for a very short distance to be joined to heat exchanger 175 and then rejoined to another section of tubing 116 thus returning the high-pressure helium to heat exchanger 41 at a lower temperature, e.g., of the order of about 35° K.

At the bottom and coldest end of heat exchanger 41, the high-pressure fluid is again diverted to the second secondary heat exchanger 127 which is in thermal contact with heat station 102 associated with the coldest chamber 62 of the active refrigerator. This then is the second out-of-contact heat exchanger in which the high-pressure helium in the Joule-Thomson loop is the external refrigeration load for the active refrigerator. From heat exchanger 127 the high-pressure cold helium is then transferred to the final heat exchanger 125, which is the second of the primary heat exchangers, by means of a suitable T-joint 128 which in effect transfers the high-pressure helium into the outer channel 129 of the heat exchanger 125. This heat exchanger 125 is also of course connected with the low-pressure side of the heat exchanger 41 by means of a connecter 131 which effectively joins the inner low-pressure channel 132 of heat exchanger 125 with the interior of heat exchanger 41 through means of the conduit 130 which leads into low-pressure passage 117 of heat exchanger 41.

Connection between the heat exchanger 125 and the transfer tube 18 is effected through another T-joint 133 which in this case, by means of loop 134, connects the high-pressure outer channel 129 of heat exchanger 125 with the high-pressure inner channel 136 (which is defined by tubing 29) of the transfer tube. In the embodiment illustrated in FIG. 5 there is no tubing connection between the low-pressure inlet return 132 of heat exchanger 125 with the low-pressure channel 137 (defined by tubing 30) of the transfer tube 18. It is not necessary to provide this connection inasmuch as the low-pressure fluid returning through channel 137 finds its way into the low-pressure side of heat exchanger 125 without any connection. However, if desired a tubing connection may be supplied. Finally there is around the low-pressure channel 137 an evacuated insulating channel 138 which is defined by tubing 28. A support piece 140 anchors the bottom of the active refrigerator to heat exchanger 125 and similar support pieces hold a support plate 141 (FIG. 12) which anchors heat exchanger 41 in place.

The transfer tubing 18 and the liquefying means is that which is shown in somewhat more detail in FIG. 1 of copending application Serial No. 375,722, filed in the name of Walter H. Hogan and assigned to the same assignee as this invention. At the terminal end of the transfer tube there is located a Joule-Thomson expansion valve which is used to expand and liquefy the high-pressure cold fluid conducted therethrough by way of channel **136**. The Joule-Thomson valve is preferably that which is described and claimed in copending Serial No. 375,722. An examination of FIG. 1 of that application will show that the high-pressure channel **136** corresponds directly to high-pressure channel **13** of that figure; low-pressure channel **137** of FIG. 5 of this application corresponds directly to low-pressure channel **15** of FIG. 1 of application Serial No. 375,722, and the evacuated insulated space **138** corresponds with the evacuated space **17** of FIG. 1 of that application. It is possible of course to use a conventional Joule-Thomson valve at the end of transfer tube **18** (FIG. 1) but the Joule-Thomson expansion valve of Serial No. 375,722 is preferred inasmuch as it provides means for closing off both the high-pressure and low-pressure channels and thus permits removal of the transfer tube from the Dewar without shutting down the liquefier.

In the operation of the Joule-Thomson loop incorporated in the liquefier of this invention high-pressure helium is introduced by means of conduit **17** into heat exchange tubing **115**, and then by means of heat exchange tubing **116** it flows down the heat exchanger **41** in out-of-contact heat exchange with the low-pressure helium returned from Dewar **33** by way of transfer tube **18** into volume **117** and up through foraminous discs **118**. As noted previously it is diverted for out-of-contact further cooling by heat station **101** prior to its leaving tubing **116**. The high-pressure helium then leaves the heat exchanger tubes **116**, is transferred by means of connector tube **126** to be further cooled by out-of-contact heat exchanger tubing **127** with station **102** which is cooled in turn by out-of-contact heat exchange with the cold fluid in refrigerator **40** and more particularly with the refrigerant as it is discharged from the cold chamber **62** of the refrigerator. Subsequent to the cooling in heat exchanger **127** the high pressure cold helium is then introduced into the outer channel **129** of heat exchanger **125** and then into the innermost channel **136** of the transport tube **18** to be carried to the Joule-Thomson expansion valve for liquefaction in a Dewar. The Joule-Thomson valve of Serial No. 375,722 is incorporated by reference in this apparatus as a component part of this liquefier but it is not described in detail inasmuch as this is not deemed necessary.

That part of the cold high-pressure helium which is expanded but not liquefied, as well as the cold low-pressure helium which boils off from the liquefied helium stored in the Dewar, is returned by means of the low-pressure channel **137** and, as explained above, is conducted either by tubing or by means of the atmosphere surrounding it into the inner low-pressure channel **132** of heat exchanger **125**. From there it is transferred to the inner side of heat exchanger **41** and in its passage upwardly through the Joule-Thomson loop it exchanges heat with the incoming high-pressure helium and this serves to refrigerate this high-pressure helium as it enters the loop. The low-pressure helium is then discharged through conduit **19** into the system as illustrated in FIG. 1.

THE PURIFIER

The purpose of the purifier is to remove contaminants from make-up helium as it is supplied from a suitable pressurized tank or other source. This make-up helium is required to compensate for the quantity of helium which is liquefied and thus removed from the system. Such make-up helium will normally contain a number of impurities in the form of the higher boiling gases such as water vapor, methane, hydrogen and the like and it is most convenient to be able to remove these impurities by freezing them out before the helium is introduced into the active refrigerator or into the Joule-Thomson loop. It will be appreciated that if any quantity of these impurities is permitted to build up in the helium in the system it will not be long before the heat exchangers and even more importantly the Joule-Thomson expansion valve will be plugged by these contaminants in solid form. As will be seen in FIG. 3 the purifier occupies a position in line with the Joule-Thomson loop in the enclosure of the liquefier. In order to illustrate the purifier in FIG. 4 the Joule-Thomson loop has been broken away and the bottom portion of the purifier is illustrated in detail. It will be appreciated with this purifier, as seen in FIG. 8, extends to the upper end of the liquefier. The upper portion is identical in construction to that shown in FIG. 4 and need not be detailed further in the drawings.

The purifier **42** is seen to be comprised of a cylindrical enclosure **145** which is sealed at its top and by a means similar to that of a Joule-Thomson heat exchanger **41** and at its bottom end by means of a suitable bottom plate **148**. Within the upper portion of the purifier are positioned stacked foraminous discs **149** which are held in spaced relationship by means of spacers such as wires **150**. The upper portion of the purifier is devoted to the precooling of the helium which is to be purified as illustrated in general by the out-of-contact heat exchanger **25** of FIG. 1. Thus it is necessary to provide suitable fluid flow paths to obtain out-of-contact heat exchange and the incoming impure helium is introduced into the purifier through conduit **23** (FIG. 2) and passes down over the foraminous discs where it is precooled by the discharged pure helium, and where some of the higher boiling contaminants are removed. The lower portion of the helium purifier has a layer of glass wool **151** and then a section of absorbent charcoal **152** which occupies essentially the entire length of the lower portion. At the bottom end is also a layer of glass wool **151** and a foraminous disc **153** which serves to keep the glass wool from blocking the passage leading out of the purifier. A major portion of the contaminants are removed from the helium during its flow through this lower portion of the purifier. Refrigeration is supplied to the charcoal and hence to the helium passing through it from an external refrigerant circulated in coils **155** which are wound around the lower portion of this purifier **42** and serve to provide the necessary refrigeration. The source of the coolant and its path will be described below in conjunction with the heat exchange system and the flow of refrigerant through it. By the time the helium has reached the bottom end of the purifier all of the higher boiling point contaminants have been removed and pure helium is withdrawn from the purifier through line **156** which then becomes integral with heat exchange tubing **157** which is wrapped about the upper portion of the helium purifier to become the other side of the out-of-contact heat exchanger **25**. The pure helium is withdrawn through conduit **27** to be introduced when needed into the refrigerator and Joule-Thomson helium supply as indicated in FIG. 1. Solenoid valve **43** controls the flow of pure helium.

SUPPLEMENTARY REFRIGERATION AND HEAT EXCHANGE SYSTEM

An important aspect of the apparatus of this invention is the use of a secondary or external refrigerant to effect precooling of both the fluid in the refrigerator and that being circulated in the Joule-Thomson loop as well as to provide the refrigeration for the freezing of the contaminants in the purifier. Conveniently this external refrigerant is liquid nitrogen. It is not only readily obtainable but it is extremely safe to use and handle. The flow of the liquid nitrogen within the system may be traced with reference to FIG. 4 and FIGS. 7–11. It will be seen from the simplified FIG. 2 that liquid nitrogen is introduced into the liquefier by means of a suitable conduit **31** from a source not shown. The control of the flow of liquid nitrogen is achieved through pressure or temperature regulation as described above.

FIG. 7 illustrates the introduction of the liquid nitrogen through conduit **31** and its passage first into tubing **165** which is used to effect out-of-contact heat exchange with the incoming refrigeration fluid in the refrigerator **40** and more particularly in the top portion **45**. This out-of-contact heat exchange is effected through heat station **100**, which, as has been described above in connection with FIG. 4, is in turn in heat exchange with the fluid passing through the refrigerator and more particularly through the annular heat exchange passage **72**.

Liquid nitrogen passing through tubing **165** furnishes refrigeration to the refrigerator fluid and hence serves as a means of intercooling the refrigeration fluid as it passes from regenerator **64** to regenerator **66** of the refrigerator (see FIG. 4). The liquid nitrogen is then conducted into tubing **166** and thence into heat exchange tubing **167** to cool the radiation shield **191** which is described in more detail below (FIG. 10). From tubing **167** after cooling the radiation shield the liquid nitrogen is then employed to cool the charcoal in the purifier and hence to condense and solidify the contaminants to be removed from the make-up helium which is being circulated through the purifier **42**. This is made apparent in the drawing in FIGS. 8 and 10 wherein it will be seen that from heat exchange tubing **167** the liquid nitrogen is taken by means of connecting tubing **168** into the heat exchange tubing **155** which is in direct out-of-contact heat exchange with the walls of the purifier **42**. After serving to cool the purifier the liquid nitrogen is then conducted by means of a joining member **170** into heat exchange tubing **171** which is wrapped in out-of-contact heat exchange around the outside of the high-pressure helium tubing **115** which carries the high-pressure incoming helium into the first Joule-Thomson heat exchanger **41**. Thus the incoming high-pressure helium which is to be liquefied is cooled by out-of-contact heat exchange not only by the low-pressure helium being discharged from the Joule-Thomson loop but also by the outgoing liquid and subsequently, gaseous nitrogen which passes through the heat exchange tubing **171** to be delivered to the outside as gaseous nitrogen through conduit **32** (FIG. 4).

An important aspect of the apparatus of this invention is the effective cooling of the high-pressure helium as it passes downwardly through the Joule-Thomson loop, first through tubing **115** and then through tubing **116**. The manner in which refrigeration is transferred to the high-pressure helium is illustrated in detail in FIG. 6 which is a fragmentary cross-section of heat exchanger **41** at the point where large diameter tubing **115** gives way to the smaller diameter tubing **116**. Heat exchange tubings **115** and **116** are preferably constructed of stainless steel having a copper coating approximately 0.002 inch thick. These tubings may also be made of cupronickel, the one requirement of the tubing being that it is a relatively good conductor without possessing such a high thermal conductivity that the heat will be conducted around the tubing rather than from it through the brazed joint **120** to the cylindrical housing **110**. The heat flow path can be seen in FIG. 6 to be from the high-pressure helium circulating downwardly first in channels **121** and then in channels **122** through the walls of tubings **115** and **116**, the brazed joints **120**, the cylinder walls **110** to the foraminous discs **118**, then to the passageways **123** in the foraminous discs and finally to the cold-low pressure helium moving upwardly as indicated by the arrows. Heat is also transferred between the cold liquid/gaseous nitrogen moving upwardly in channels **124** of heat exchange tubing **171**. The heat exchange structure will thus be seen to effect extremely efficient transfer of refrigeration from cold low-pressure helium in volume **117** and cold liquid/gaseous nitrogen in channels **124**. This heat exchanger is relatively simple to construct but is extremely efficient.

In cooling the refrigerating fluid which is passing through annular passage **72** in the refrigerator (FIG. 4) prior to its entrance into the second regenerator of the upper displacer, the liquid nitrogen provides refrigeration to overcome the losses associated with the cooling of the operating fluid in the refrigerator. It then serves to cool the radiation shield in order to better protect the interior of the liquefier from the transmission of radiant energy inward from the outside atmosphere. In cooling the purifier, the liquid nitrogen serves to furnish the necessary refrigeration to solidify the contaminants from the make-up helium. Finally, in cooling the upper portion of the Joule-Thomson heat exchanger the liquid, and subsequently gaseous, nitrogen provides refrigeration to the high-pressure helium to overcome the temperature differential required for heat exchange between incoming high-pressure helium and discharging low-pressure helium. This differential is brought about by the fact that there is more helium entering the Joule-Thomson valve than there is returning through it since a portion of the helium is liquefied and is retained in the Dewar where liquefaction takes place. Although by the time the nitrogen refrigerant reaches the upper portion of coils **171** it is vaporized, and it is possible to recover some of the helium is liquefied and is retained in the Dewar stream and thus to reduce the amount of liquid nitrogen that must be used in the external refrigeration system thus described.

FIG. 7 illustrates the heat exchange relationship that exists between the refrigerator and the Joule-Thomson loop. The purpose of heat stations **101** and **102** which are associated with the cold chambers **61** and **62**, respectively, and which obtain their refrigeration by out-of-contact heat exchange with cold fluid passing through narrow annular heat exchange passages **78** and **94** is to furnish refrigeration to the high-pressure helium which is to be liquefied. This is done by diverting the flow of high-pressure helium in the outside tubing **116** to out-of-contact heat exchange with the heat stations. As will be seen in FIGS. 7 and 11 the first such diversion is accomplished in connection with heat station **101** and this is done by causing the high-pressure helium to flow through heat exchange tubing **175** which is connected with heat exchange tubing **116** of the Joule-Thomson heat exchanger by means of suitable connectors **176** and is returned to tubing **116** through a suitable connector **177**. In like manner the even colder high-pressure helium as it reaches the bottom end of the heat exchange tubing **116** is diverted by means of connection **126** to the out-of-contact heat exchange tubing **127** prior to its entrance into T-joint **128** to pass into the Joule-Thomson heat exchanger **125** as described in detail in connection with FIGS. 5 and 12. Thus, in this manner the refrigerator provides refrigeration to the high-pressure helium which is to be liquefied, and the helium is delivered to heat exchanger **125** at a temperature of about 15° K. Further heat transfer between this high-pressure helium and the low-pressure returning helium from the Dewar is of course accomplished in the transfer tube **18** as explained above.

HOUSING AND INSULATING STRUCTURE

The housing and protective enclosure for the liquefier is illustrated in detail in FIGS. 4 and 5. The overall enclosure is seen to be comprised of an outer enclosure **37** and an inner housing **185** which define between them an evacuated space **186** which serves as insulation. Within this space is a radiation shield **187** which is joined to the inner housing **185** through the use of a connecting support piece **189**. The volume **188** between the inner housing **185** and the radiation shield **187** is also evacuated. The entire top portion of the liquefier is of course sealed by means of a suitable closure assembly generally indicated by the numeral **38**, the sections of which are made fluid tight through the use of suitable rings **190**. A horizontal radiation shielding **191** is placed between the warmer and colder sections of the liquefier, these terms being used in a relative sense. This horizontal radiation shielding **191** is cooled by out-of-contract heat exchange with the liquid nitrogen circulating in coils **167**. It in turn transfers refrigeration to the radiation shield **187** through a very narrow annular heat transfer passage **192** and then through the inner housing **185** and the connecting support **188**.

The interior **194** of the liquefier is filled with helium gas. This is done to minimize the effect of any possible gas leaks within the system. The presence of helium gas within the liquefier stabilizes the conditions therein and limits any heat transfer through convective currents to a minimum. The presence of the helium gas within the volume **194** therefore necessitates the heat transfer from horizontal shield **192** to radiation shield **187** through the mechanism described, i.e., the narrow passage **192**.

Inasmuch as the temperature within the area defined by the concave portion of the lower end of inner housing **185** is about 5° K. it is possible to take advantage of this refrigeration to achieve cryosorption of any residual gases which may be contained in the evacuated volume **189**. To do this a horizontal copper plate **196** is sealed to the bottom portion of the inner housing **185** and in it is a shallow container **197** in which absorbing charcoal **198** is placed. Thus there is some cryopumping achieved within this area which results in better insulation brought about through a better vacuum.

RELATIONSHIP OF COMPONENT PARTS AND THERMODYNAMIC CONSIDERATIONS

In the construction of a refrigerator which will be suitable as the active refrigerator of this liquefier, consideration must be given to performance requirements which in turn require consideration of temperature levels and chamber volumes. Such considerations follow from the basic thermodynamics associated with the refrigeration process and they are traced briefly here to set forth the relationships which preferably obtain in the active refrigerator of this liquefier.

Normally, a refrigerator, as distinct from a liquefier, is required to develop refrigeration at a single temperature level and the refrigeration produced must be large enough to meet the requirement of its load plus the losses associated with the device. Since the refrigeration produced is directly related to the refrigeration sizing or displacement (i.e., chamber volume) it is possible to define the cold chamber volume of a single-stage refrigerator as

$$V_c = K_1[Q_{load} + Q_{losses}] \qquad (1)$$

where K_1 is a proportionality constant relating volume to refrigeration requirements and is a function of the temperature level, fluid flow rate and efficiency of the expansion device.

The losses inherent in the refrigerator can in turn be related to operational conditions in the following manner:

$$Q_{losses} = K_2(T_w - T_c) \qquad (2)$$

where K_2 is a proportionality constant relating losses in the refrigerator to the operational temperature level, including the losses due to radiation and heat exchanger efficiency; and T_w and T_c are the ambient (warm) temperature and cold volume temperature, respectively.

Substituting the expression of equation (2) for Q losses in equation (1), the volume of the cold chamber may be defined as

$$V_c = K_1[Q_{load} + K_2(T_w - T_c)] \qquad (3)$$

This is in effect a restatement of the fact that the cold chamber volume is directly proportional to the load which must be sustained by the refrigerator plus the losses inherent in the refrigerator.

This load can, however, be sustained more efficiently if the refrigerator is staged, i.e., there are two or more cold chambers at successively colder temperatures. Where the refrigerator is designed to deliver refrigeration only at its coldest temperature, i.e., from the last and coldest chamber, the volume of the coldest stage is still proportional to the load and to the losses associated with that stage. The volume of any intermediate temperature chamber is, however, that which is required to produce refrigeration only sufficient to overcome the losses associated with that stage. Therefore it is possible to write the equations expressing the volume of the coldest chamber, V_c and the volume of the intermediate chamber, V_i

$$V_c = K_1[Q_{load} + K_2(T_i - T_c] \qquad (4)$$

and

$$V_i = K_1[K_2(T_w - T_i] \qquad (5)$$

Since the refrigerator described by equations (4) and (5) intercepts some of its losses at the intermediate temperature, level, T_i, the displacement (cold chamber volumes) can be smaller than that for the single-stage device for a given load sustaining capability. This in turn means that a staged refrigerator requires less power input for a given refrigeration load.

In a similar fashion, equations may be written for refrigerators having three or more stages.

The above considerations have been directed to a refrigeration device where a load is sustained at only one level of a staged refrigerator. If, however, it is desired to liquefy gas as in the apparatus of this invention and to derive refrigeration from more than one stage for the gas to be liquefied, then the volume relationships must be adjusted since it is necessary to provide an additonal amount of refrigeration for the precooling of the gas, that is to overcome its sensible heat. This sensible heat is preferably intercepted at all of the intermediate temperature levels at which refrigeration is produced. In the active refrigerator of this liquefier these two points of interception are represented by heat stations **101** and **102** where the high-pressure helium in heat exchanger **116** is diverted for out-of-contact heat exchange with the refrigerator (FIGS. 4 and 5).

In the active refrigerator of this liquefier the additional factors of latent heat of vaporization, and the necessity to remove the sensible heat of the gas must be taken into consideration, and so equations (4) and (5) for the staged refrigerator must be modified for the staged active refrigerator which is to form a component part of the liquefier. Under these conditons the volumes of the cold and intermediate temperature volumes may be written as follows:

$$V_c = K_1[M\lambda + (MC_p + K_2)(T_i - T_c)] \qquad (6)$$

and

$$V_i = K_1[(MC_p + K_2)(T_w - T_i)] \qquad (7)$$

where M is the liquefaction rate, λ is the latent heat of vaporization and C_p is the specific heat of the gas at constant pressure.

An example may be cited to illustrate the volume ratios which have been found to be optimum for a typical refrigerator having three cold volumes when it is used to deliver refrigeration only at its coldest level and when it is used as an active refrigerator in a liquefier such as the apparatus of this invention. In the first case, i.e., as a refrigerator these volume ratios are preferably 8:1.5:1 (in order of decreasing temperature). In the second case, i.e., in a liquefier these ratios are preferably 10:3:1.

This ratio of 10:3:1 then becomes the preferred one for an active refrigerator such as that shown in FIGS. 4 and 5 where the volume of chamber **61** is V_i and that of chamber **62** is V_c. In the refrigerator of this liquefier the first intermediate chamber has been replaced by externally supplied refrigeration, i.e., the liquid nitrogen circulating in coils **165** which are in out-of-contact heat exchange through heat station **100** and cylinder wall **45** with the fluid flowing in narrow annular heat exchange passage **72**. Thus this leaves for consideration the ratio of the volumes of chambers **61** and **62** which is preferably about 3:1. However, this ratio may range from about 1.5:1 to 4:1 with some attendant sacrifice in efficiency when the extremes of these ratios are employed.

In the liquefier of this invention the use of liquid nitrogen at the first or upper intermediate temperature level contributes materially to the economics of operating the liquefier. Liquid nitrogen is relatively inexpensive and readily available, and its use in the role of an external refrigerant in the manner described effectively halves the compressor work required and therefore reduces the power input by this same amount.

It is thus apparent that the liquefier of this invention attains a thermodynamic balance among the fluids in the refrigerator, in the Joule-Thomson loop, in the purifier and in the externally supplied refrigerant. The result is an efficient, compact and versatile liquefier capable of liquefying helium and of substantially automatic operation.

It will thus be seen that the objectives set forth above, among these made apparent from the preceding description, are efficiently attained, and since certain changes may be made in the above construction without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

We claim:

1. A cryogenic liquefier, comprising in combination

(a) an active refrigerator in which refrigeration is developed by initially cooling a high-pressure fluid and then expanding and further cooling it, and including first, second and third heat stations adapted to effect out-of-contact heat exchange with said fluid in said refrigerator;

(b) a Joule-Thomson loop comprised of first and second primary out-of-contact heat exchangers adapted to effect heat exchange between incoming high-pressure fluid and discharging low-pressure fluid, and first and second secondary out-of-contact heat exchangers adapted to effect heat exchange between said high-pressure fluid and said second and third heat stations of said active refrigerator;

(c) a transfer tube in fluid communication with said second primary heat exchanger, characterized by having an inner high-pressure passage, an intermediate low-pressure channel and an outer insulation, and extending externally of said liquefier;

(d) a Joule-Thomson expansion valve terminating said transfer tube adapted to expand and liquefy said high-pressure fluid and to return said low-pressure fluid in said Joule-Thomson loop;

(e) a purifier adapted to remove contaminants from said fluid prior to introduction into said active refrigerator and said Joule-Thomson loop and comprising means for removing said contaminants through solidification and absorption;

(f) radiation shielding means surrounding the colder end of said active refrigerator, said Joule-Thomson loop, and said purifier;

(g) heat exchange means adapted to circulate an externally supplied refrigerant in out-of-contact heat exchange with said first heat station of said active refrigerator, said radiation shielding means, said purifier, and said first primary heat exchanger of said Joule-Thomson loop; and

(h) housing means enclosing said active refrigerator, said Joule-Thomson loop, a portion of said transfer tube, and said purifier.

2. A cryogenic liquefier in accordance with claim **1** wherein said active refrigerator is further characterized by having first and second fluid expansion chambers associated with said second and third heat stations, respectively, wherein refrigeration is developed for sustaining the refrigeration load represented by said high-pressure fluid circulating in said first and second secondary heat exchangers of said Joule-Thomson loop.

3. A cryogenic liquefier in accordance with claim **2** wherein the ratio of the volume of said first expansion chamber to that of said second expansion chamber ranges between 1.5:1 and 4:1.

4. A cryogenic liquefier in accordance with claim **3** wherein said ratio is 3:1.

5. A cryogenic liquefier in accordance with claim **1** wherein said first primary heat exchanger of said Joule-Thomson loop comprises

(1) a central passage containing stacked and spaced foraminous discs as the low-pressure side of said heat exchanger,

(2) high-pressure tubing helically wound around and brazed to the external wall defining said central passage; and

(3) tubing wound around and in thermal contact with that portion of said high-pressure tubing positioned outside said radiation shielding means and adapted to circulate said externally supplied refrigerant.

6. A cryogenic liquefier in accordance with claim **1** wherein said purifier comprises

(1) a central passage adapted to receive impure fluid and divided into a first precooling section and a second absorbing section, said first precooling section comprising stacked and spaced foraminous discs and said second absorbing section containing an absorbent material.

(2) heat exchange tubing in thermal contact with said second absorbing section adapted to circulate said externally supplied refrigerant thereby to cool said fluid within said second section to a sufficiently low temperature to solidify and cause said contaminants to remain within said purifier, and

(3) heat exchange means adapted to circulate pure cold fluid discharged from said second section in out-of-contact heat exchange with the fluid in said first section thereby to precool the incoming impure fluid.

7. A cryogenic liquefier in accordance with claim **1** wherein said housing means comprises an inner fluid-tight housing, and an outer fluid-tight housing which define between them an evacuable space in which a portion of said radiation shielding means is located.

8. A cryogenic liquefier in accordance with claim **7** wherein said fluid-tight housing contains the same fluid which is circulated in said liquefier whereby the effects of any minor fluid leak in the system are minimized.

9. A cryogenic liquefier in accordance with claim **7** wherein said evacuable space in its coldest region contains a quantity of a material capable of cryosorption.

10. A cryogenic liquefier in accordance with claim **1** wherein said radiation shielding means comprises

(1) a horizontal member through which said active refrigerator, said Joule-Thomson loop and said purifier pass, and having a peripheral skirt to which refrigeration is delivered from said externally applied refrigerant, said skirt defining with the internal wall of said inner housing a narrow heat exchange passage,

(2) a cylindrdical member within said evacuable space, and having a peripheral skirt to which refrigeration is delivered from said externally supplied refrigerant,

(3) connecting support means adapted to attach said cylindrical member to said inner housing and to suspend said cylindrical member within said evacuable space, whereby there is established a thermal con-

nection between said horizontal and cylindrical members comprising said connecting support means, said inner housing and said narrow heat exchange passage.

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