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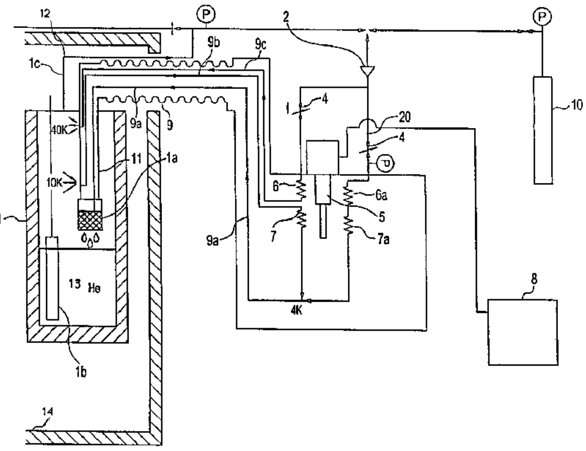
(54) APPAREIL PERMETTANT DE RECONDENSER DE L'HELIUM LIQUIDE ET CONDUITE DE TRANSFERT UTILISEE A CET EFFET

(54) LIQUID HELIUM RECONDENSATION DEVICE AND TRANSFER LINE USED THEREFOR

(57)
A liquid helium recondensation device which includes a liquid helium storage tank (1) and a refrigerating machine (5) that recovers the helium gas vaporized in the storage tank and cools and liquefies the helium gas, and which can return the cooled helium gas cooled by or the liquid helium liquefied by the refrigerating machine to the storage tank, the device comprising a line (9c) whereby the high temperature helium gas elevated in temperature in the liquid helium storage tank is fed to the refrigerating machine and the cooled helium gas from the latter is then fed to the upper region in the storage tank, and lines (9b, 9a) whereby the low temperature helium gas in the vicinity of the liquid level of the liquid helium in the liquid helium storage tank is fed to the refrigerating machine for liquefying and the liquid helium from the latter is fed to the storage tank.



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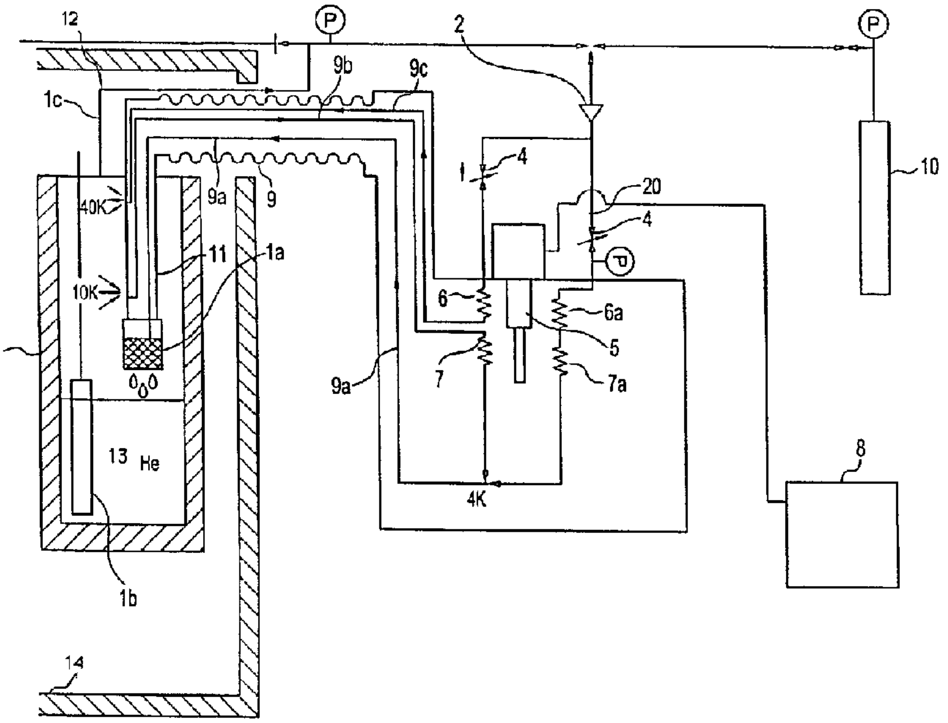
(54) Title: LIQUID HELIUM RECONDENSATION DEVICE AND TRANSFER LINE USED THEREFOR



(57) Abrégé/Abstract:
A liquid helium recondensation device which includes a liquid helium storage tank (1) and a refrigerating machine (5) that recovers the helium gas vaporized in the storage tank and cools and liquefies the helium gas, and which can return the cooled helium gas cooled by or the liquid helium liquefied by the refrigerating machine to the storage tank, the device comprising a line (9c) whereby the high temperature helium gas elevated in temperature in the liquid helium storage tank is fed to the refrigerating machine and the cooled helium gas from the latter is then fed to the upper region in the storage tank, and lines (9b, 9a) whereby the low temperature helium gas in the vicinity of the liquid level of the liquid helium in the liquid helium storage tank is fed to the refrigerating machine for liquefying and the liquid helium from the latter is fed to the storage tank.

Summary

The liquid helium circulation system according to this invention is a liquid helium circulation system capable of recycling helium gas evaporating inside its liquid helium reservoir to said reservoir.

This system has a liquid helium reservoir 1 and refrigerator 5 where helium gas boil-off recovered from said reservoir is refrigerated and liquefied, and is designed to have the helium gas refrigerated or liquefied with said refrigerator returned to said reservoir. Said system is equipped with line 9c that supplies high-temperature helium gas heated up inside said liquid helium reservoir to said refrigerator, where said helium gas is made into refrigerated helium gas, and supplies the refrigerated helium gas to the upper part inside said reservoir, lines 9b and 9a that supply low-temperature helium gas in the vicinity to the surface of liquid helium inside said liquid helium reservoir to said refrigerator, where said low-temperature is liquefied, and supply the liquefied helium to said reservoir.

SPECIFICATION

LIQUID HELIUM CIRCULATION SYSTEM AND TRANSFER LINE USED WITH THE SYSTEM

Field of the Invention

This invention relates to liquid helium circulation systems and transfer lines used with the said systems. To be more specific, it relates to the liquid helium circulation system used as part of a brain magnetism measurement system that liquefies helium gas evaporating from its liquid helium reservoir, where an encephalomagnetometer is disposed in an extreme low temperature environment, and to the transfer line used with the system that sends the liquefied helium back to the liquid helium reservoir. Besides brain magnetism measurement systems, the said liquid helium circulation systems and transfer lines are also usable with magnetocardiographs and magnetic resonance imaging (MRI) systems, and in studying and evaluating the properties of a variety of materials at extreme low temperatures.

Background of the Invention

Brain magnetism measurement systems to detect magnetic fields generated by human brains are under development. These systems use super-conducting quantum interference devices (SQUIDs) capable of measuring brain activities with a high space-time resolution and without harming the organs. The SQUID is used in the refrigerated state, dipped in the liquid helium filled in an insulated reservoir.

With most conventional liquid helium reservoirs in those systems, the helium gas evaporating from the reservoir is released into the air. This waste of helium in large quantity makes the systems economically disadvantageous when helium is as expensive as ¥1,200 per liter. Moreover, as the liquid helium in the reservoir is consumed, it has to be replenished with fresh liquid helium from a commercial cylinder. The replenishment however presents problems such that the process is extremely troublesome, or that outsourcing costs are substantial.

Against the background as above-mentioned, there are recent moves to develop liquid helium circulation systems, which may recover, recondense and liquefy the helium gas evaporating from the reservoir in its entirety and send it back to the reservoir.

Referring to Fig.4, briefly shown below, is the schematic configuration of a type of such liquid helium circulation system. 101 stands for a liquid helium reservoir, wherein an encephalomagnetometer is disposed; 102 a drive pump that recovers the helium gas vaporized inside reservoir 101; 103 a dryer that dehydrates the helium gas recovered; 104 a flow regulating valve; 105 a purifier; 106 an auxiliary refrigerator; 107 a heat exchanger No.1 for auxiliary refrigerator 106; 108 a condensing refrigerator and 109 a condensing heat exchanger of condensing refrigerator 108. The helium gas boiling off from liquid helium reservoir 101 and whose temperature is raised to about 300° Kelvin (K) is suctioned with drive pump 102, and sent through dryer 103 and purifier 105 to auxiliary refrigerator 106, where it is cooled down to about 40° K and liquefied. The liquid helium is sent to condensing refrigerator 108, where it is further cooled down to about 4° K as it passes condensing heat exchanger 109. Finally, the extreme low temperature liquid helium is supplied to liquid helium reservoir 101 through transfer line 110.

This prototype helium circulation system is basically a system to recover and recycle entirely the helium gas evaporating from the liquid helium reservoir. Compared with conventional similar systems, whose vaporized helium is released into the air or recovered in a gas bag or the like for reprocessing, it consumes a remarkably smaller quantity of helium, promising benefits of economy and efficiency, which has been spurring recent efforts to put to practical use. In addition, the added feature of the new system demanding little trouble to refill fresh liquid helium would make maintenance of the measurement system easier as a whole.

Nevertheless, the new circulation system as above-mentioned cannot be free from necessary improvements as follows:

While liquid helium is an indispensable medium to keep a SQUID in the refrigerated state, a huge amount of electric energy has to be consumed to run the refrigerator to liquefy helium gas. In addition, a large volume of water is required to cool the compression pump of the refrigerator. Furthermore, as the liquefied helium is transferred from the refrigerator to the liquid helium reservoir through the transfer line, it is difficult to isolate it completely from high-temperature parts, causing a large portion of it to become vaporized, resulting in a poor transfer rate. Such being the case, the running cost as well as insulation measures amount to a huge sum comparable to that in the case of allowing the gas to escape into the air. An economical version of liquid circulation system overcoming such problems needs to be developed.

With the above-mentioned considerations in the background, the inventor has developed the idea of this invention from the phenomena that the quantity of heat (sensible heat) required to raise the temperature of helium gas from about 4° K to about 300° K is much higher than that (vaporization heat) required for the phase change from liquid to gas of helium at about 4° K, and that while the energy required to cool down high-temperature helium to low-temperature helium is moderate, substantial energy is required to liquefy low-temperature helium gas.

Namely, this invention offers a new type of liquid helium circulation system as a solution to the problems conventional circulation systems have had as above-mentioned. With this invention, high-temperature helium gas as high as 300° K boiling off from the liquid helium reservoir is recovered, cooled down to about 40° K, a temperature within the easy reach of a refrigerator, and supplied to the upper part in said reservoir. Also, low-temperature helium gas, say about 10° K, near the surface of liquid helium inside said reservoir is recovered and liquefied at about 4° K and supplied back to said reservoir. In this manner, the inventory of liquid helium inside said reservoir is easily replenished by as much as is lost by evaporation.

Disclosure of the Invention

Solutions this invention has adopted are as follow:

A liquid helium circulation system consisting of a liquid helium reservoir and a refrigerator that cools down and liquefies helium gas evaporating from said reservoir, and being capable of returning refrigerated helium gas or liquefied helium to said reservoir. It is characteristic of a line to supply the high-temperature helium gas heated up inside said reservoir to said refrigerator where it is cooled down, and returns the refrigerated helium to the upper part of said reservoir. It is also characteristic of another line that supplies low-temperature helium gas in the vicinity of the surface of liquid helium inside said reservoir to said refrigerator where it is liquefied, and returns the liquefied helium to said reservoir.

Also, a liquid helium circulation system characteristic of two pipelines—one connecting between said refrigerator and the upper part in said reservoir, and another that supplies said low-temperature gas to said refrigerator where it is liquefied, and returns the liquefied helium to said reservoir—disposed in a same conduit pipe whose periphery is insulated with a vacuum layer.

Also, a liquid helium circulation system characteristic of a triple-pipe construction with a line that supplies liquid helium at the center and a line that supplies low-temperature helium gas to the refrigerator around said central pipe and a line that supplies helium gas refrigerated by the refrigerator at the outermost.

Also, a liquid helium circulation system characteristic of three lines with one that supplies liquid helium, and one that supplies low-temperature helium gas to the refrigerator and one that supplies helium gas refrigerated by the refrigerator disposed in parallel with one another.

Also, a liquid helium circulation system characteristic of said three lines with each one having its own surrounding vacuum layer.

Also, a liquid helium circulation system characteristic of said two lines—one connecting between said refrigerator and the upper part of said reservoir, and another that supplies said low-temperature gas to said refrigerator where it is liquefied, and returns the liquefied helium to said reservoir—disposed separately from one another and each one isolated with a vacuum layer.

Also, a liquid helium circulation system characteristic of a structure that enables the liquid helium liquefied by said refrigerator to be surrounded with low-temperature helium gas and thus isolated from high-temperature parts as it is transported to said reservoir.

Also, a liquid helium circulation system characteristic of a feature that makes it possible to liquefy part of said high-temperature helium gas and supplies the liquefied helium to said refrigerator.

Also, a liquid helium circulation system characteristic of a gas-liquid separator that the liquid helium liquefied by said refrigerator passes through as it is supplied to said reservoir.

Also, in a process to recover helium gas boil-off from a liquid helium reservoir, cool down or liquefy said helium gas and return it to the liquid helium reservoir, a liquid helium circulation method characteristic of supplying high-temperature helium gas heated up inside said liquid helium reservoir to a refrigerator, where it is liquefied, and the liquefied helium to the upper part in said reservoir, and also supplying low-temperature helium gas in the vicinity of the surface of the liquid helium inside said liquid helium reservoir to a refrigerator, where it is liquefied, and the liquefied helium to said reservoir.

Also, a liquid helium circulation method to protect said liquid helium, while being supplied to said liquid helium reservoir, with either low-temperature helium gas or refrigerated helium gas from direct contact with high-temperature parts.

Also, a transfer line characteristic of its construction consisting of a line that supplies liquid helium, a line that supplies low-temperature helium gas, and a line that supplies refrigerated helium gas of a temperature higher than that of said low-temperature helium, with each line surrounded by a vacuum layer and all lines disposed inside a same conduit whose outer surface is insulated with a vacuum layer.

Also, a transfer line characteristic of its triple-pipe design consisting of a line that supplies liquid helium at the center, an intermediate line that supplies low temperature helium gas, and an outermost line that supplies refrigerated helium gas of a temperature higher than that of said low-temperature helium gas, with each line surrounded by a vacuum layer.

With the liquid helium circulation system according to this invention, it is possible to minimize liquid helium boil-off from the liquid helium reservoir because therein the sensible heat of refrigerated helium gas removes a large quantity of heat. Also, cooling helium gas from about 300° K down to about 40° K requires an amount of energy much less compared with that when producing liquid helium of about 4° K by liquefying helium gas of about 40° K. Therefore, compared with conventional systems liquefying the entire volume of helium gas recovered, this system offers outstanding economic benefit by lowering remarkably the amount of energy consumed in liquefying helium gas by shortening the running time of the refrigerator, etc.

Also, this system recovers and liquefies low-temperature helium gas in the vicinity of the surface of liquid helium in the liquid helium reservoir, which greatly helps save the amount of energy needed in the process of liquefying helium gas, leading to a large reduction in running cost.

Moreover, this system adapts a method for refrigerated helium gas or low-temperature helium gas to flow around the line supplying liquid helium liquefied by the refrigerator. This feature is to isolate the line from surrounding high-temperature parts and protect the liquid helium from evaporating as it flows though the line, which minimizes the loss of energy in a helium gas liquefying process and makes this system a more efficient liquid helium circulation system.

Brief Description of the Drawing

Fig.1 is a schematic representation of the multi-circulation type liquid helium circulation system according to this invention. Fig. 2 shows an enlarged side view with a broken section of the transfer line according to this invention. Fig.3 are the cross-sectional drawings of two different configurations of transfer lines. Fig.4 shows the schematic configuration of a conventional circulation type liquid helium circulation system.

Optimum System Lineup Demonstrating the Invention

Referring to Fig.1 showing a schematic construction of the multi-circulation type liquid helium circulation system according to this invention, the description is given of the system as follows:

Number 1 stands for a liquid helium reservoir (FRP cryostat) that is disposed inside a magnetic-shield room and wherein a SQUID is placed. 1a a gas-liquid separator disposed in said reservoir; 1b a level gauge measuring the liquid level of liquid helium 13; 1c a pipe for recovery gas line 12 recovering high-temperature helium gas heated up to about 300° K inside said reservoir. Number 2 stands for a flow regulating pump that supplies high-temperature helium gas recovered to a small capacity refrigerator via pipe 1c. 4 a flow regulating valve. 5 a 4 KGM small capacity refrigerator known for its remarkable progress of late. 6 and 7 heat exchangers No.1 and No.2 of said refrigerator. 6a and 7a No.3 and No.4 heat exchangers, which liquefy high-temperature helium gas recovered from the reservoir, or fresh helium supplied from a helium cylinder 10 as it is supplied through line 20 in the event the inventory of liquid helium falls short inside said reservoir. 8 a 6.5KW helium compressor. 9 a transfer line with combined three lines — 9a that supplies liquid helium liquefied with refrigerator 5 to liquid helium reservoir 1; 9b that recovers low-temperature helium gas from inside said reservoir 1 and 9c that supplies helium gas cooled down to about 40° K with refrigerator 5 to liquid helium reservoir 1. 10 a helium cylinder that supplements a fresh batch of helium in an emergency. 11 an insert pipe, which is connected with transfer line 11 and disposed in liquid helium reservoir 1. Above-mentioned component units are interconnected with each other ensuring fluids to flow in the directions as indicated by arrows. In addition, 14 forms the magnetic-shield room of FPR cryostat 1.

Referring to Figs. 2 and 3, the constructions of two different types of transfer lines, among others, are described as follows. Fig.2 is a side view with a broken section of a transfer line. Fig.3 (a) is the section A-A of the transfer line in Fig.2 and Fig.3(b) shows a section of a transfer line of different construction.

The first example of transfer line given in Fig.3 (a) has pipe 9a disposed at the center of a surrounding vacuum layer 9d for flowing liquid helium of about 4° K, pipe 9b disposed at the center of a surrounding vacuum layer 9d for flowing low-temperature helium gas of about 10° K recovered from inside the reservoir and pipe 9c disposed at the center of a surrounding vacuum layer 9d for flowing refrigerated helium gas cooled down to about 40° K with the refrigerator. These pipes 9a, 9b and 9c are lined up in parallel with one another and housed in a large pipe 9A with a surrounding vacuum layer 9d for insulation and an insulation material 13 installed in its inside.

The second example of transfer line is a triple-pipe version of transfer line 9, consisting of a large pipe 9'c surrounded with a vacuum layer 9d at the outermost, a medium size pipe 9'b surrounded with a vacuum layer 9d set at the center of pipe 9'c and a small pipe 9'a surrounded with a vacuum layer set at the center of pipe 9'b. This triple-pipe construction is designed to allow the flow of refrigerated helium gas of about 40° K along the outer surface of medium size pipe 9'b, low-temperature helium gas of about 10° K along the outer surface of small size pipe 9'a and liquid helium of about 4° K through the inside of small size pipe 9'a.

In the case of example (a) of transfer line, three pipes can be bound together, offering an advantage of smaller outer diameter compared with the triple-pipe construction given as example (b).

In each case of transfer line 9, the reservoir-side end of the transfer line is connected with an insert pipe 11 disposed in liquid helium reservoir 1, and a gas-liquid separator 1a is installed at the end of insert pipe 11. While this gas-liquid separator does not constitute an essential part of this invention, it is desirable to install it where it is necessary to prevent the disturbance of temperature equilibrium in the reservoir due to a paucity of helium gas generating from liquid helium in transit. Of three pipes placed inside transfer line 9, an end of pipe 9a that supplies the liquid helium liquefied with the refrigerator to liquid helium reservoir 1 is connected with gas-liquid separator 1a, an end of pipe 9b that recovers low-temperature helium gas from inside reservoir 1 and supplies it to the refrigerator is located close to the gas-liquid separator 1a of insert pipe 11 or in the vicinity of the surface of liquid helium inside reservoir 1 so that low-temperature helium gas can be collected from an area of the lowest available temperature (close to 4° K) inside reservoir 1, and an end of pipe 9c that supplies refrigerated helium gas, cooled down to 40° K with the refrigerator, to reservoir 1 is opened over insert pipe 11 (the inner upper part of reservoir 1).

The function of the liquid helium circulation system with a construction as above-mentioned is as follow:

The liquid helium pooled inside liquid helium reservoir 1 starts to gasify at a temperature of about 4° K inside said reservoir and keeps refrigerating the inner space of said refrigerator until its temperature rises to a room temperature of about 300° K by sensible heat. The high-temperature helium gas of about 300° K is suctioned out with flow-regulating pump 2 via helium gas recovery pipe 1c installed at the upper part of reservoir 1. The entire helium gas recovered is sent to heat exchanger No. 6 of small-capacity refrigerator 5, where the helium gas is cooled down to about 40° K. The refrigerated helium is supplied via pipe 9c disposed inside the transfer line to the upper part inside reservoir 1 and cools down efficiently the inner space of reservoir 1 by sensible heat until its temperature rises to 300° K. While the lower space inside reservoir 1 is kept at constant 4° K as the liquid helium inside reservoir 1 evaporates, the evaporation is slowed down because the shrouding helium gas of about 40° K as above-mentioned inhibits heat infiltration from above to the liquid helium. Meanwhile, although, in order to raise the cooling performance of reservoir 1, it is desirable to supply refrigerated helium gas cooled down as low as possible below about 40° K to the reservoir, it is economically unfavorable since it demands a system with a much higher refrigeration capacity.

Also, pipe 9c with its opening close to the surface of liquid helium inside reservoir 1 recovers low-temperature helium gas of about 40° K, which is liquefied with the heat exchanger 7 of small capacity refrigerator 5. The liquefied helium is returned to reservoir 1 via pipe 9a inside transfer line 9, and via gas-liquid separator 1a if necessary. This method of liquefying low-temperature helium gas of about 10° K using a small capacity refrigerator is instrumental in replenishing constantly the reducing inventory of liquid helium due to evaporation inside said reservoir at a lower energy cost. Moreover, liquefied helium flowing inside transfer line 9 is protected with refrigerated helium gas or low-temperature helium gas flowing also inside said transfer line against high-temperature parts, which helps restrict the liquid helium in transit from evaporating. Meanwhile, liquefying helium gas of the lowest available temperature drawn out from inside reservoir 1 helps raise the liquefying efficiency of refrigerator used, making it possible to use a small capacity refrigerator with an ensuing reduction in running cost.

Described above is a transfer line that consists of pipe 9c that supplies refrigerated helium gas, cooled down to about 40° K, to reservoir 1, pipe 9b that transports low-temperature helium gas of about 10° K recovered from reservoir 1 and pipe 9a that transports liquefied helium. Unlike this design, it is possible to design pipe 9c that supplies refrigerated helium gas to reservoir 1 as an insulated pipe independent from the transfer line.

Aforementioned is an operational system where the entire volume of high-temperature helium gas of about 300° K recovered from reservoir 1 is cooled down to about 40° K, and the refrigerated helium gas is sent to the inner upper part of said reservoir. It is also possible, by operating flow-regulating valve 4, to supply part of high-temperature helium gas through the line indicated as 20 in the drawing to the heat exchangers No.1 6a and No.2 7a (different from those aforementioned) of refrigerator 5 for liquefying and to return the liquefied helium to reservoir 1 via aforementioned pipe 9a

As above-mentioned, the liquid helium circulation system according to this invention is designed to perform as follows:

First, the helium gas whose temperature is about 300° K from inside the liquid helium reservoir, and the recovered helium gas is cooled down to about 40° K in its entirety taking advantage of the first-stage refrigeration cycle of the refrigerator and the refrigerated helium gas is sent back to the liquid helium reservoir. Second, low-temperature helium gas of about 40° K is recovered through a pipe with its opening close to the surface of liquid helium inside the reservoir. The recovered low-temperature helium gas is supplied to the heat exchangers No. 2 7 of the small capacity refrigerator where the helium gas is liquefied, and the liquefied helium is returned to the reservoir to add to the reducing inventory of liquid helium. Owing to these design features, the helium gas of 40° K can cool the liquid helium reservoir because a large quantity of heat is removed as the helium gas is heated up to about 300° K., and the lower space inside the reservoir is kept at about 4° K., which makes the system comparable with conventional systems in terms of cooling effect. Also, the inventory of liquid helium inside the reservoir is reduced as it evaporates. The design feature to recover and liquefy low-temperature helium gas in the vicinity of the surface of liquid helium inside the reservoir and return the liquefied helium into the reservoir helps minimize energy loss in producing liquid helium, paving the way for designing a liquid helium circulation system with high efficiency at a low cost.

Also, the design feature to have helium gas cooled down with the refrigerator or low-temperature helium gas recovered from the reservoir protects the liquid helium liquefied with said refrigerator in transit greatly helping to reduce the volume of the liquid helium lost by evaporation.

Also, while condensing helium gas of about 40° K to produce liquid helium of about 4° K demands a huge amount of energy, the design feature of this invention to condense helium gas of about 10° K helps minimize the liquefying energy, making it possible to use a small capacity refrigerator.

Meanwhile, it goes without saying that another type of refrigerator can replace the refrigerator described above. Using a multi-stage refrigerator would make it possible to have helium gas of different temperatures flow at one time. Also, in designing, a controller, though it is not shown in the drawing, that is activated with signals from a sensor such as level gauge disposed inside the liquid helium reservoir can be included to control the flow-regulating valve used in replenishing the inventory of liquid helium. Also, optional component units, materials etc. are selectable to suit the purpose of the system.

While the system described above uses one unit of small capacity refrigerator for producing liquid helium and refrigerated helium gas, instead, it is possible to use two or more units of smaller capacity refrigerators, each one assigned with a specific function. Furthermore, while the temperature of helium gas supplied to the refrigerator of the system described above for refrigeration is about 40° K, this temperature is not binding and helium gas at a variety of temperatures may be used depending upon the purpose of the work.

The application of this invention is diversified without deviating from its spirit as well as its principal features. This description of system performance is nothing but one application, among others, and should not be construed as a one and only application.

Usability of the Invention in Various Industrial Fields

According to this invention;

Because of its design feature of recovering low-temperature helium (about 10° K) by means of a pipe with its opening close to the liquid helium inside the reservoir, liquefying the recovered gas with a small capacity refrigerator and returning the liquefied helium to said reservoir to replenish the inventory of liquid helium, the loss of energy in producing liquid helium can be minimized, paving the way for designing highly efficient liquid helium circulation systems operating at a low running cost.

Its design feature ensuring the effective use of a large quantity of sensible heat required while helium gas of about 40° K is raised to 300° K for cooling the liquid helium circulation system dismisses the conventional need of liquefying the entire volume of helium gas with ensuing benefits of saving measurable energy and running cost.

Its design feature to recover and recycle helium in its entirety dismisses the conventional method of troublesome helium replenishment and reduces largely the cost involving liquid helium.

Its feature to transport the liquid helium liquefied with the refrigerator without allowing it to contact high-temperature parts prevents it from evaporating while in transit and ensures its stabilized return to the reservoir.

Range of Claim

1. In the category of liquid helium circulation system that has a liquid helium reservoir and a refrigerator that recovers helium gas evaporating in said reservoir and cools and liquefies said helium gas, and is designed to have the refrigerated helium gas or liquefied helium returned to said reservoir:

A liquid helium circulation system characteristic of its construction consisting of a line that supplies high-temperature helium gas heated up inside said liquid helium reservoir to said refrigerator, where said helium gas is made into refrigerated helium gas, and supplies the refrigerated helium gas to the upper part inside said reservoir, and a line that recovers low-temperature helium gas in the vicinity of the surface of liquid helium inside said reservoir and supplies the recovered helium gas to said refrigerator, where said helium gas is liquefied into helium gas, and supplies the liquefied helium into said reservoir.

2. A liquid helium circulation system described in Claim 1, characteristic of the disposition of the both lines—one that connects between said refrigerator and the upper part inside said reservoir and the other that supplies said low-temperature helium gas to said refrigerator, where said helium gas is liquefied, and supplies the liquefied helium into said reservoir—inside a pipe that is insulated with a surrounding vacuum layer.

3. A liquid helium circulation system described in Claim 2, characteristic of a triple-pipe formation of three lines, related to said disposition, with the one that supplies liquid helium disposed at the center, the second one that supplies low-temperature helium gas to the refrigerator disposed around said central line and the third line that supplies the refrigerated helium gas cooled down with the refrigerator disposed around the combination of said two lines and at the outermost.

4. A liquid helium circulation system described in Claim 2, characteristic of three lines, related to said disposition, —one that supplies liquid helium, one that supplies low-temperature helium gas to the refrigerator and one that supplies refrigerated helium gas cooled down with said refrigerator disposed in parallel with one another.

5. A liquid helium circulation system described in Claim 3 or Claim 4, characteristic of the formation of said lines with each one formed with a pipe that has a surrounding vacuum layer.

6. A liquid helium circulation system described in Claim 1, characteristic of said two lines—one that connects between said refrigerator and the upper part in said reservoir and the other that supplies low-temperature helium gas to said refrigerator, where said helium gas is liquefied, and supplies said liquefied helium to said reservoir—disposed separated from each other and with each one surrounded with a vacuum layer.

7. A liquid helium circulation system described in Claim 6, characteristic of the design to have the liquid helium liquefied with said refrigerator, while being transported to said reservoir, insulated in the atmosphere of low-temperature helium gas from high-temperature parts.

8. A liquid helium circulation system described in either one of Claims 1 to 7, characteristic of the design enabling part of said high-temperature helium gas to be liquefied with a refrigerator and supplied to said reservoir.

9. A liquid helium circulation system described in Claims 1 to 8, characteristic of the design to have the liquid helium liquefied with said refrigerator and supplied into the reservoir via a gas-liquid separator.

10. In the category of helium circulation process that the helium gas produced in the liquid helium reservoir as the liquid helium evaporates is recovered, and said helium gas is cooled down and liquefied and the liquefied helium is returned to said liquid helium reservoir;

A liquid helium circulation method characteristic of the process, with which the high-temperature helium gas heated up inside said liquid helium reservoir is supplied to a refrigerator, where said helium gas is made into refrigerated helium gas, and said refrigerated helium gas is supplied to the upper part inside said reservoir, and also low-temperature helium gas in the vicinity of the surface of liquid helium inside said liquid helium reservoir is supplied to a refrigerator, where the said helium gas is liquefied, and the liquefied helium is returned to said reservoir.

11. A liquid helium circulation method described in Claim 10, characteristic of the process with which said liquid helium, while being transported to said liquid helium reservoir, is protected at

least with either one of low-temperature helium gas or refrigerated helium gas from direct contact with high-temperature parts.

12. A transfer line characteristic of the construction consisting of three lines supplying liquid helium, low-temperature helium gas and refrigerated helium gas whose temperature is higher than that of said low-temperature helium gas respectively, with each line formed with a pipe surrounded with a vacuum layer and all of them disposed in a pipe insulated with a surrounding vacuum layer.

13. A transfer line characteristic of the construction consisting of three lines—the one supplying liquid helium disposed at the center, the second line supplying low-temperature helium gas disposed around said central line and the third one supplying refrigerated helium gas whose temperature is higher than that of said low-temperature helium gas disposed around said second line and at the outermost, with each line formed with a pipe surrounded with a vacuum layer.

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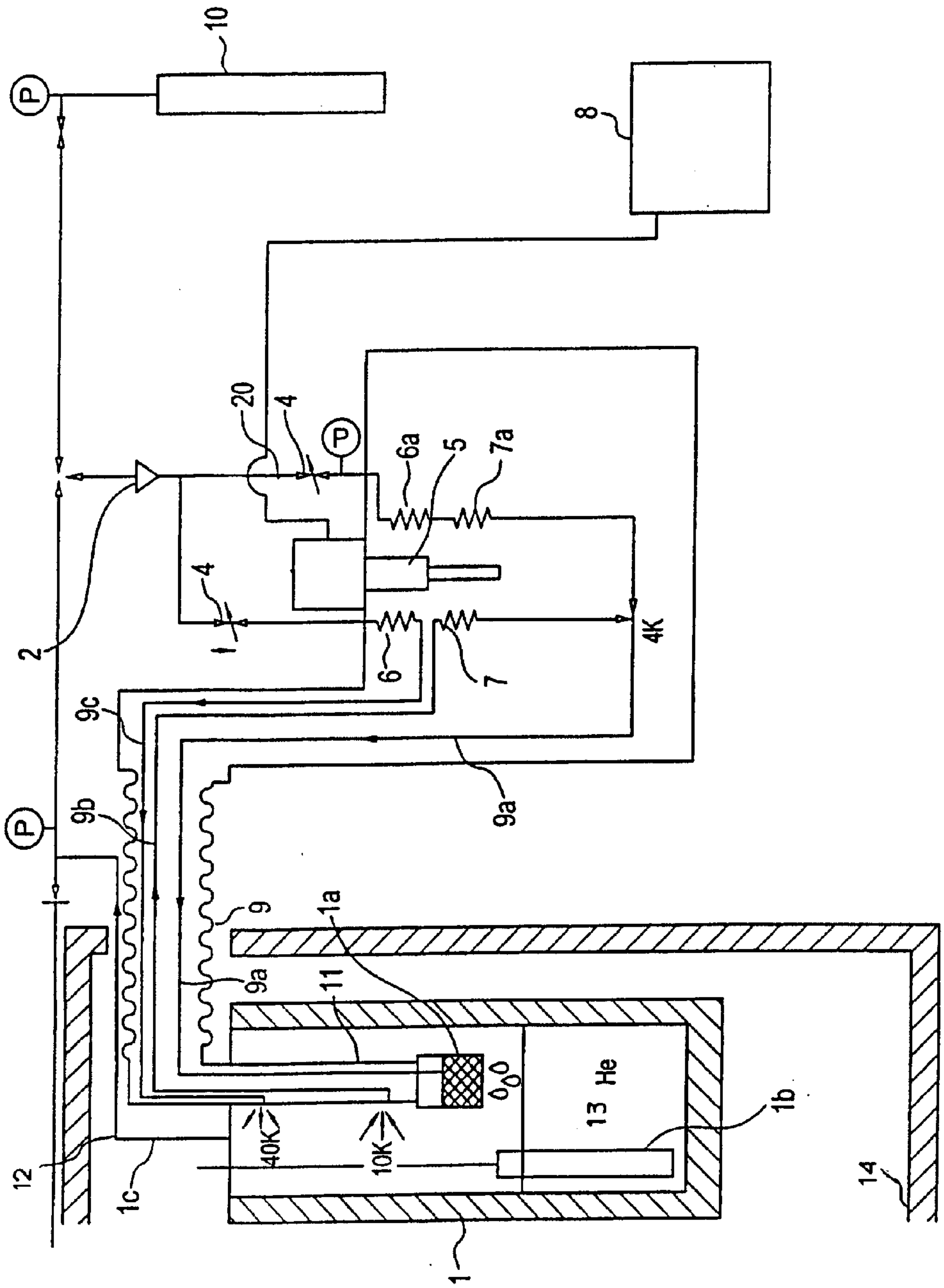
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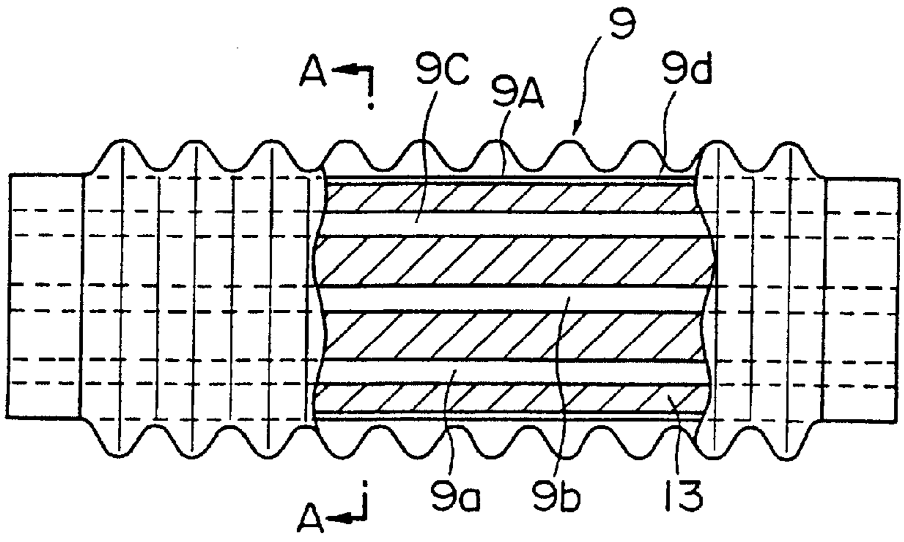
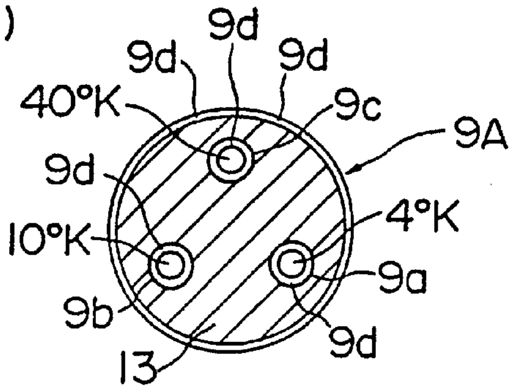
14

第２図



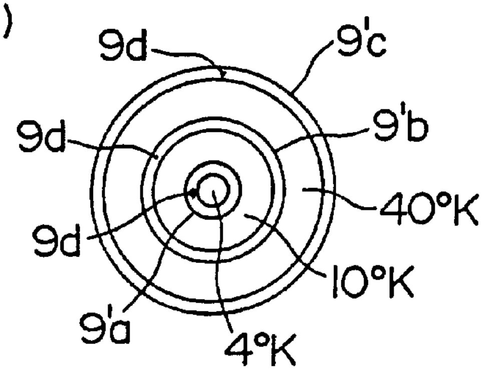
第3図

(a)



A-A

(b)



第4図