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

VORRICHTUNG ZUR REKONDENSATION VON FLÜSSIGEM HELIUM UND DAFÜR VERWENDETE TRANSPORTLEITUNG

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

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Description

[0001] 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.

[0002] 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.

[0003] 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.

[0004] Against the background as above-mentioned, there are recent moves to develop liquid hehum 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.

[0005] 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.

[0006] 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.

[0007] Nevertheless, the new circulation system as above-mentioned cannot be free from necessary improvements as follows:

[0008] 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.

[0009] US 4,790,147 discloses a helium cooling apparatus which includes a helium container and a condensation heat exchanger for condensing gas helium into liquid helium. The apparatus also includes a transfer line between the contamer and the exchanger which has two separate pathways, one for liquid helium and one for gas helium.

[0010] US 3,892,106 describes refrigeration circuits which use the vaporized liquid from the cryostat to cool the gas coming in from an external source or from a pump-compressor assembly to a temperature below the Joule-Thomson effect inversion temperature.

[0011] According to a first aspect, the present invention provides a liquid helium circulation system according to claim 1.

[0012] 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.

[0013] Thus, 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 may be 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 may be recovered and liquefied at about 4° K and supplied back to said reservoir. In this manner, the inventory of liquid helium inside said reservoir may be easily replenished by as much as is lost by evaporation.

[0014] Preferably, the second, third and fourth lines are disposed in a same conduit pipe whose periphery is insulated with a vacuum layer.

[0015] In a preferred embodiment, the fourth line is disposed at the center, the third line is disposed around the fourth line and the second line is disposed at the outermost.

[0016] In another preferred embodiment, the second, third and fourth lines are disposed in parallel with one another.

[0017] In the perferred embodiments, each of the second, third and fourth lines has its own surrounding vacuum layer.

[0018] In an alternative preferred embodiment, the second line is surrounded by a first vacuum layer and is disposed separately from the third and fourth lines which are together surrounded by a second vacuum layer.

[0019] In the preferred embodiments, the liquid helium liquefied by said refrigerator is surrounded with low-temperature helium gas and thus isolated from high-temperature parts as it is transported to said reservoir.

[0020] In preferred embodiments of the invention, it is possible to liquefy part of said high-temperature helium gas and supply the liquefied helium to said refrigerator.

[0021] The liquid helium circulation system may include a gas-liquid separator that the liquid helium liquefied by said refrigerator passes through as it is supplied to said reservoir.

[0022] According to a second aspect, the present invention provides a liquid helium circulation method according to claim 10.

[0023] In embodiments of the invention, it is preferred 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.

[0024] 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.

[0025] 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.

[0026] 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.

[0027] Preferred embodiments of the invention will now be described, by way of example only, and with reference to the accompanying drawings in which:

> 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.

[0028] 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:

[0029] 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.

[0030] 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.

[0031] 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.

[0032] 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.

[0033] 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).

[0034] 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).

[0035] The function of the liquid helium circulation system with a construction as above-mentioned is as follow:

[0036] 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.

[0037] 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.

[0038] 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.

[0039] 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.

[0040] As above-mentioned, the liquid helium circulation system according to this invention is designed to perform as follows:

[0041] 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 hehum 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.

[0042] 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.

[0043] 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.

[0044] 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.

[0045] 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.

[0046] According to at least the preferred embodiments of 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.

[0047] 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.

[0048] 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.

[0049] 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.

Claims

1. A liquid helium circulation system having a liquid helium reservoir (1) and a refrigerator (5) that recovers helium gas evaporating in said reservoir and cools and liquefies said helium gas, and being designed to have refrigerated helium gas and liquefied helium returned to said reservoir, wherein said liquid helium circulation system further comprises a first line (12) that supplies high-temperature helium gas (1c) heated up inside said liquid helium reservoir to said refrigerator, where said high-temperature helium gas is made into refrigerated helium gas, a second line (9c) which supplies the refrigerated helium gas to the upper part inside said reservoir, a third line (9b) 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 and a fourth line (9a) which supplies the liquefied helium into said reservoir.

2. A liquid helium circulation system as claimed in claim 1, wherein said second (9c), third (9b) and fourth (9a) lines are disposed inside a pipe (9A; 9'c) that is insulated with a surrounding vacuum layer (9d).

3. A liquid helium circulation system as claimed in claim 2, wherein the fourth line (9a) is disposed at the center, the third line (9b) is disposed around the fourth line and the second line (9c) is disposed around the combination of the third and fourth lines and is disposed at the outermost.

4. A liquid helium circulation system as claimed in claim 2, wherein the second (9c), third (9b) and fourth (9a) lines are disposed in parallel with one another.

5. A liquid helium circulation system as claimed in claim 3 or 4, wherein each of the second (9c), third (9b) and fourth (9a) lines comprises a pipe that has a surrounding vacuum layer (9d).

6. A liquid helium circulation system as claimed in claim 1, wherein the second line (9c) is surrounded by a first vacuum layer (9d) and is disposed separately from the third (9b) and fourth (9a) lines which are together surround by a second vacuum layer (9d).

7. A liquid helium circulation system as claimed in claim 6, wherein the liquid helium liquefied with the refrigerator (5) is insulated (11) from high-temperature parts, in the atmosphere of low-temperature helium gas, while it is being transported to the reservoir (1).

8. A liquid helium circulation system as claimed in any preceding claim, wherein part of the high-temperature helium gas (1c) is liquefied (6a,7a) within the refrigerator (5) and supplied to the reservoir (1).

9. A liquid helium circulation system as claimed in any preceding claim, wherein the liquid helium liquefied with the refrigerator (5) is supplied into the reservoir (1) via a gas-liquid separator (1a).

10. A liquid helium.circulation method in which helium gas produced in a liquid helium reservoir (1) as the liquid helium evaporates is recovered, cooled down, liquefied and returned to said liquid helium reservoir, wherein high-temperature helium gas heated up inside said liquid helium reservoir is supplied to a refrigerator (5), 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 the refrigerator, where said low-temperature helium gas is liquefied, and the liquefied helium is returned to said reservoir.

11. A liquid helium circulation method as claimed in claim 10, wherein said liquid helium, while being transported to said liquid helium reservoir (1), is protected from direct contact with high-temperature parts at least with either one of low-temperature helium gas or refrigerated helium gas.

Patentansprüche

1. Kreislaufsystem für flüssiges Helium mit einem Behälter (1) für flüssiges Helium und einer Kühleinrichtung (5), die in dem Behälter verdampfendes Heliumgas zurückgewinnt und das Heliumgas kühlt und verflüssigt und ausgelegt ist, das gekühlte Heliumgas und verflüssigte Helium in den Behälter zurückzuführen, wobei das Kreislaufsystem für flüssiges Helium außerdem umfasst: eine erste Leitung (12), die im Inneren des Behälters für flüssiges Helium erwärmtes Heliumgas (1c) hoher Temperatur in die Kühleinrichtung einspeist, wo das Helium hoher Temperatur in ein gekühltes Heliumgas verwandelt wird, eine zweite Leitung (9c), welche das gekühlte Heliumgas in den oberen Bereich im Innern des Behälters einspeist, eine dritte Leitung (9b), welche Heliumgas niedriger Temperatur in der Nähe der Oberfläche des flüssigen Heliums im Inneren des

Behälters zurückgewinnt und das zurückgewonnene Helium in die Kühleinrichtung einspeist, wo das Heliumgas verflüssigt wird, sowie eine vierte Leitung (9a), die das verflüssigte Helium in den Behälter leitet.

2. Kreislaufsystem für flüssiges Helium gemäß Anspruch 1, wobei die zweite (9c), dritte (9b) und vierte (9a) Leitung im Inneren eines Rohrs (9A; 9'c) angeordnet sind, das durch eine umgebende Vakuumschicht (9d) isoliert ist.

3. Kreislaufsystem für flüssiges Helium gemäß Anspruch 2, wobei die vierte Leitung (9a) im Zentrum angeordnet ist, während die dritte Leitung (9b) um die vierte Leitung herum angeordnet ist und die zweite Leitung (9c) um die Kombination aus dritter und vierter Leitung herum und damit am weitesten außen angeordnet ist.

4. Kreislaufsystem für flüssiges Helium gemäß Anspruch 2, wobei die zweite (9c), dritte (9b) und vierte (9a) Leitung parallel zueinander angeordnet sind.

5. Kreislaufsystem für flüssiges Helium gemäß einem der Ansprüche 3 oder 4, wobei jede der zweiten (9c), dritten (9b) und vierten (9a) Leitung ein Rohr umfasst, das eine es umgebende Vakuumschicht (9d) aufweist.

6. Kreislaufsystem für flüssiges Helium gemäß Anspruch 1, wobei die zweite Leitung (9c) von einer ersten Vakuumschicht (9d) umgeben und getrennt von der dritten (9b) und vierten (9a) Leitung angeordnet ist, die zusammen von einer zweiten Vakuumschicht (9d) umgeben sind.

7. Kreislaufsystem für flüssiges Helium gemäß Anspruch 6, wobei das durch die Kühleinrichtung (5) verflüssigte flüssige Helium, während es zum Behälter (1) transportiert wird, von den Bauteilen hoher Temperatur durch die Atmosphäre aus Heliumgas niedriger Temperatur isoliert ist (11).

8. Kreislaufsystem für flüssiges Helium gemäß einem der vorhergehenden Ansprüche, wobei ein Teil des Heliumgases höherer Temperatur (1c) innerhalb der Kühleinrichtung (5) verflüssigt (6a, 7a) und in den Behälter (1) eingespeist wird.

9. Kreislaufsystem für flüssiges Helium gemäß einem der vorhergehenden Ansprüche, wobei das durch die Kühleinrichtung (5) verflüssigte flüssige Helium über eine Gas/Flüssigkeit-Trenneinrichtung (1a) in den Behälter (1) geleitet wird.

10. Verfahren zum Umwälzen von flüssigem Helium, wobei man Heliumgas, das in einem Behälter (1) für flüssiges Helium beim Verdampfen von flüssigem Helium entsteht, zurückgewinnt, abkühlt, verflüssigt und in den Behälter für flüssiges Helium zurückleitet, wobei man das in dem Behälter für flüssiges Helium erwärmte Heliumgas hoher Temperatur in eine Kühleinrichtung (5) leitet, wo man das Heliumgas in ein gekühltes Heliumgas umwandelt und man das gekühlte Heliumgas in den oberen Bereich im Innern des Behälters leitet, und außerdem Heliumgas niedriger Temperatur in der Nähe der Oberfläche des flüssigen Heliums im Innern des Behälters für flüssiges Helium in die Kühleinrichtung leitet, wo man das Heliumgas niedriger Temperatur verflüssigt und das verflüssigte Helium in den Behälter zurückführt.

11. Umwälzverfahren für flüssiges Helium gemäß Anspruch 10, wobei das flüssige Helium beim Transport in den Behälter (1) für flüssiges Helium vor einem direkten Kontakt mit Bauteilen höherer Temperatur durch wenigstens entweder Heliumgas niedriger Temperatur oder gekühltes Heliumgas geschützt wird.

Revendications

1. Système de mise en circulation d'hélium liquide ayant un réservoir d'hélium liquide (1) et un réfrigérateur (5) qui récupère le gaz hélium s'évaporant dans ledit réservoir et refroidit et liquéfie ledit gaz hélium, ledit système étant conçu pour que le gaz hélium réfrigéré et l'hélium liquéfié soient renvoyés dans ledit réservoir, dans lequel ledit système de mise en circulation d'hélium liquide comprend en outre une première conduite (12) qui fournit du gaz hélium à température élevée (1c) chauffé à l'intérieur dudit réservoir d'hélium liquide dans ledit réfrigérateur, dans lequel ledit gaz hélium à température élevée est transformé en gaz hélium réfrigéré, une deuxième conduite (9c) qui achemine le gaz hélium réfrigéré dans la partie supérieure à l'intérieur dudit réservoir, une troisième conduite (9b) qui récupère le gaz hélium à basse température à proximité de la surface d'hélium liquide à l'intérieur dudit réservoir et délivre le gaz hélium récupéré audit réfrigérateur, dans lequel ledit gaz hélium est liquéfié, et une quatrième conduite (9a) qui délivre l'hélium liquéfié dans ledit réservoir.

2. Système de mise en circulation d'hélium liquide selon la revendication 1, dans lequel lesdites deuxième (9c), troisième (9b) et quatrième (9a) conduites sont disposées à l'intérieur d'un tuyau (9A ; 9'c) qui est isolé par une couche environnante sous vide (9d).

3. Système de mise en circulation d'hélium liquide selon la revendication 2, dans lequel la quatrième conduite (9a) est disposée au centre, la troisième conduite (9b) est disposée autour de la quatrième conduite, et la deuxième conduite (9c) est disposée autour de la combinaison des troisième et quatrième conduites et est disposée le plus à l'extérieur.

4. Système de mise en circulation d'hélium liquide selon la revendication 2, dans lequel les deuxième (9c), troisième (9b) et quatrième (9a) conduites sont disposées en parallèle l'une avec l'autre.

5. Système de mise en circulation d'hélium liquide selon la revendication 3 ou 4, dans lequel chacune des deuxième (9c), troisième (9b) et quatrième (9a) conduites comprend un tuyau qui a une couche environnante sous vide (9d).

6. Système de mise en circulation d'hélium liquide selon la revendication 1, dans lequel la deuxième conduite (9c) est entourée par une première couche sous-vide (9d) et est disposée séparément des troisième (9b) et quatrième (9a) conduites qui sont conjointement entourées par une deuxième couche sous-vide (9d).

7. Système de mise en circulation d'hélium liquide selon la revendication 6, dans lequel l'hélium liquide liquéfié par le refrigérateur (5) est isolé (11) de parties à température élevée, dans l'atmosphère de gaz hélium à basse température, alors qu'il est transporté vers le réservoir (1).

8. Système de mise en circulation d'hélium liquide selon l'une quelconque des revendications précédentes, dans lequel une partie du gaz hélium à température élevée (1c) est liquéfiée (6a, 7a) dans le réfrigérateur (5) et délivrée au reservoir (1).

9. Système de mise en circulation d'hélium liquide selon l'une quelconque des revendications précédentes, dans lequel l'hélium liquide liquéfié par le réfrigérateur (5) est délivré au réservoir (1) par un séparateur gaz-liquide (1a).

10. Procédé de mise en circulation d'hélium liquide, dans lequel du gaz hélium produit dans un réservoir d'hélium liquide (1) à mesure que l'hélium liquide s'évapore est récupéré, refroidi, liquéfié et renvoyé dans ledit réservoir d'hélium liquide, dans lequel du gaz hélium à température élevée chauffé à l'intérieur dudit réservoir d'hélium liquide est délivré à un réfrigérateur (5), dans lequel ledit gaz hélium est transformé en gaz hélium réfrigéré, et ledit gaz hélium réfrigéré est délivré à la partie supérieure à l'intérieur dudit réservoir, et du gaz hélium à basse température situé à proximité de la surface d'hélium liquide à l'intérieur dudit réservoir d'hélium liquide est également délivré au réfrigérateur, dans lequel ledit gaz hélium à basse température est liquéfié, et l'hélium liquéfié est renvoyé dans ledit réservoir.

11. Procédé de mise en circulation d'hélium liquide selon la revendication 10, dans lequel ledit hélium liquide, pendant son transport dans ledit réservoir d'hélium liquide (1), est protégé d'un contact direct avec des parties à température élevée au moins avec l'un ou l'autre du gaz hélium à basse température et du gaz hélium réfrigéré.

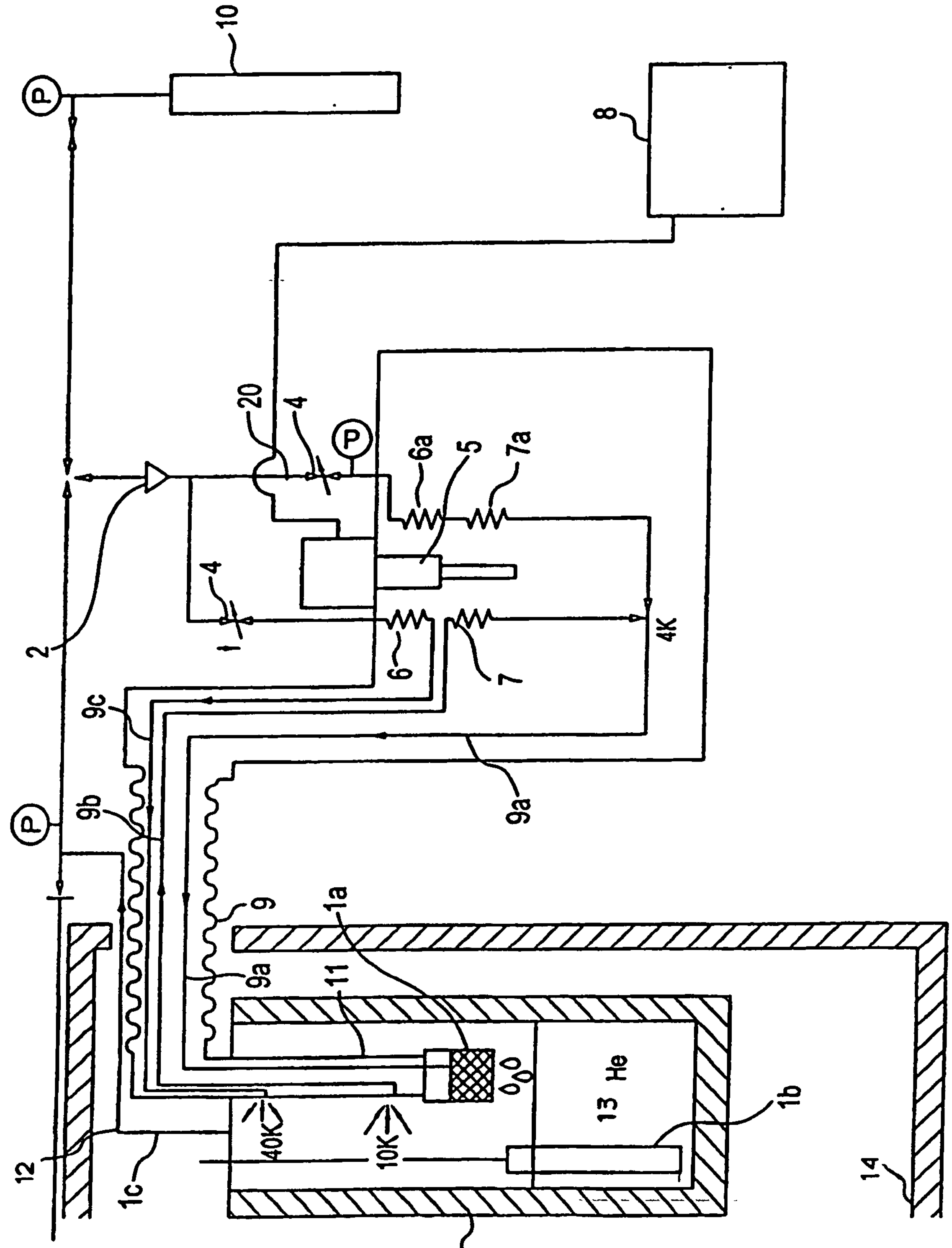
10
P
8
20
4
P
6a
5
7a
2
4
6
7
4K
9c
9a
P
9b
9
1a
9a
11
12
1c
40K
10K
13 He
1b
14
1

Fig. 1

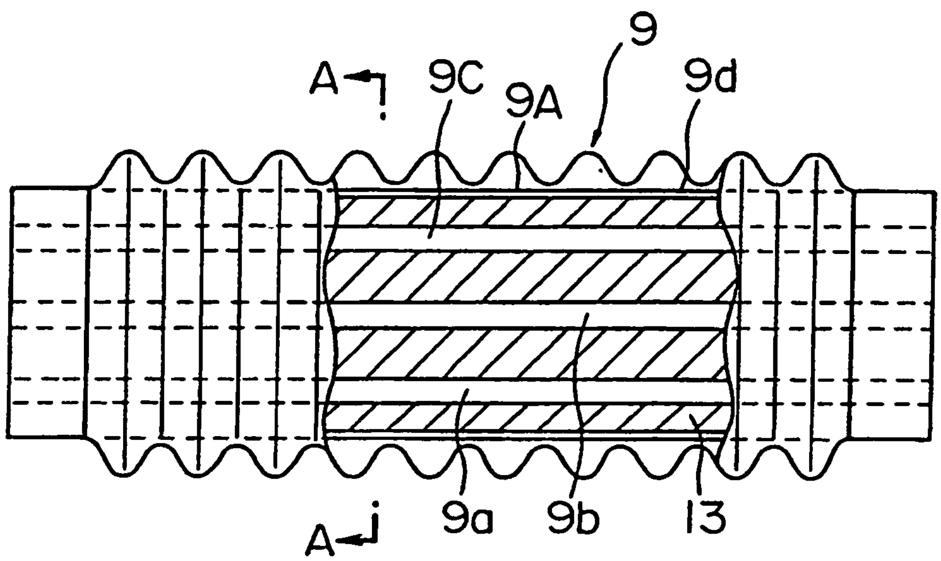

Fig. 2

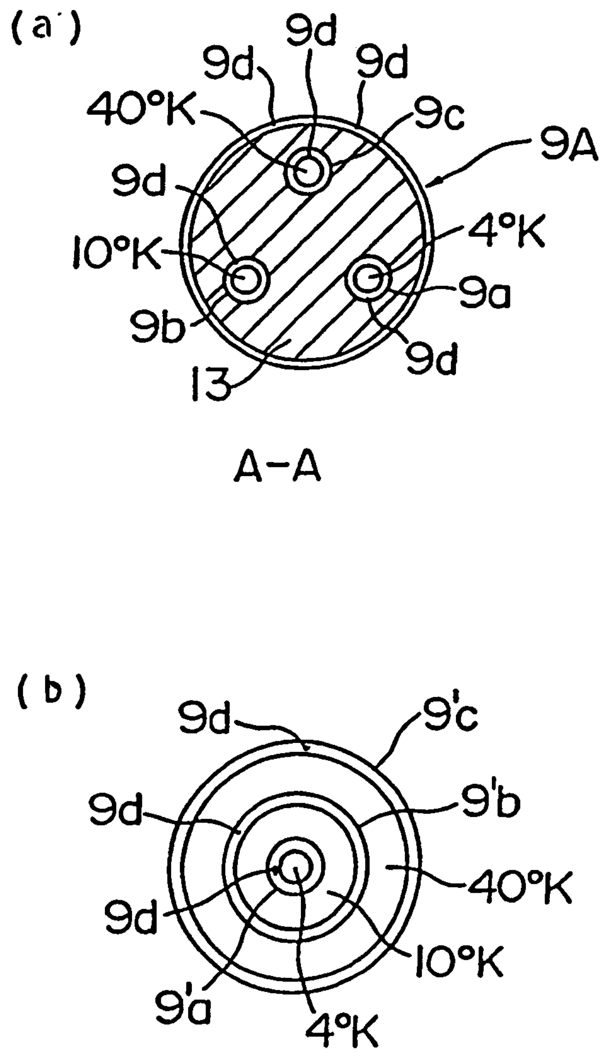
(a')
9d
9d
9d
40°K
9c
9A
9d
4°K
10°K
9a
9b
9d
13
A-A
(b)
9d
9'c
9d
9'b
40°K
9d
10°K
9'a
4°K

Fig. 3

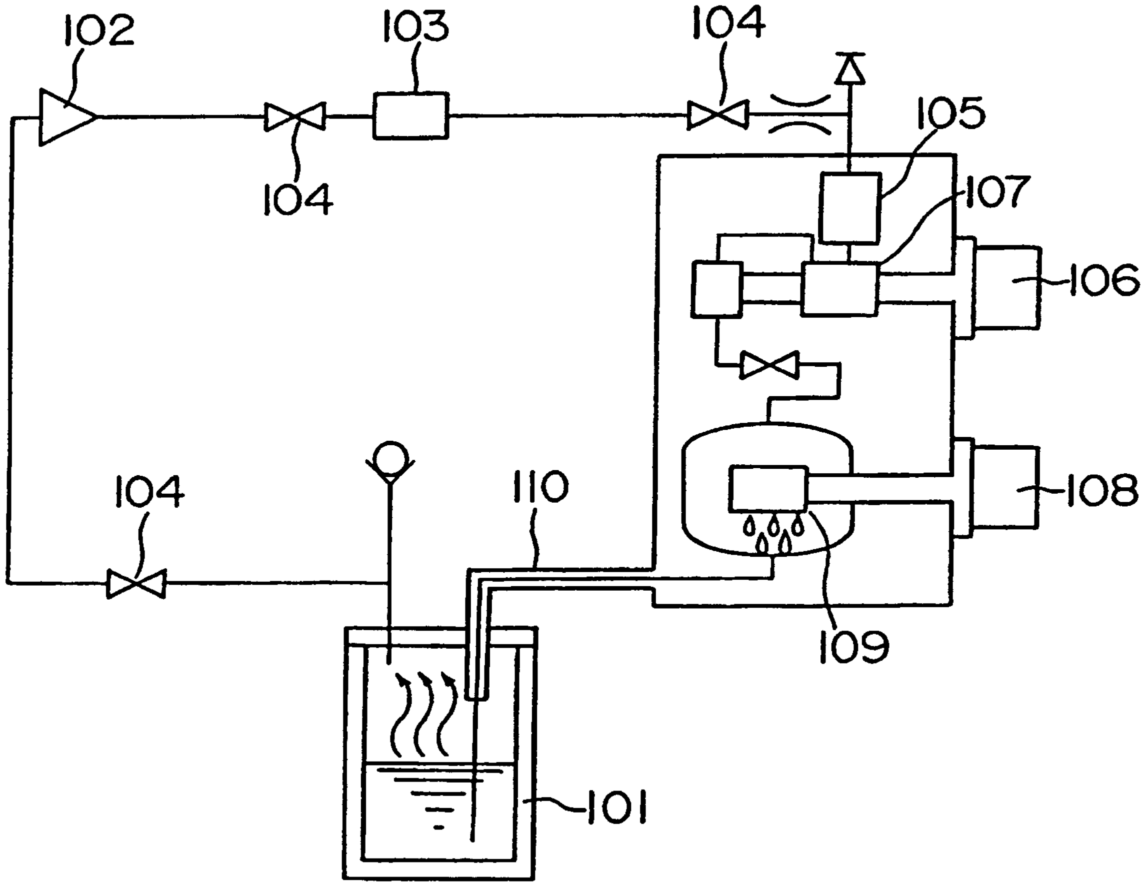

Fig. 4