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METHOD OF LIQUEFYING HELIUM

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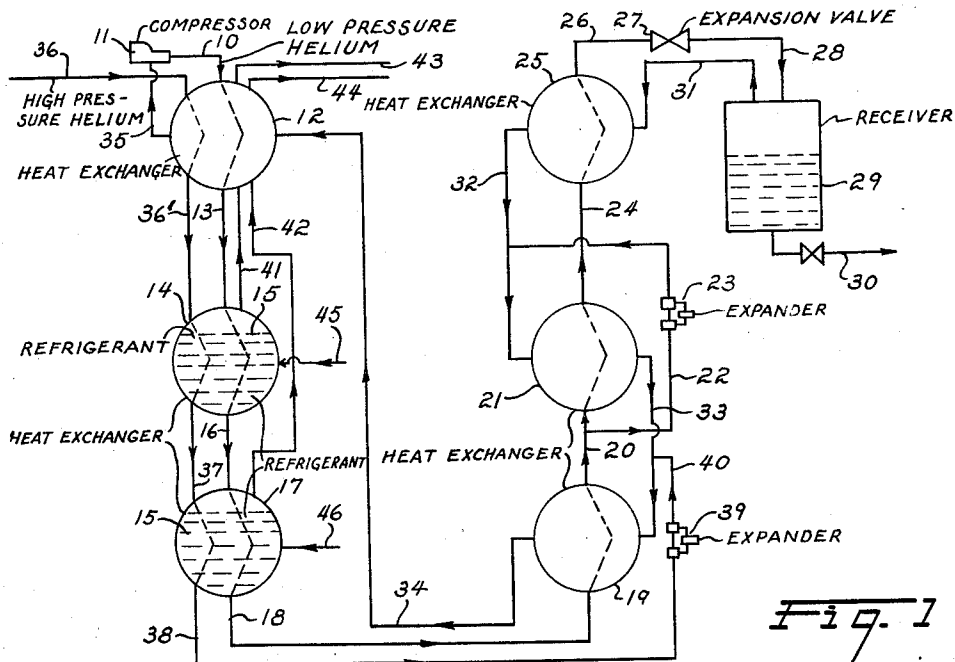


Fig. 1

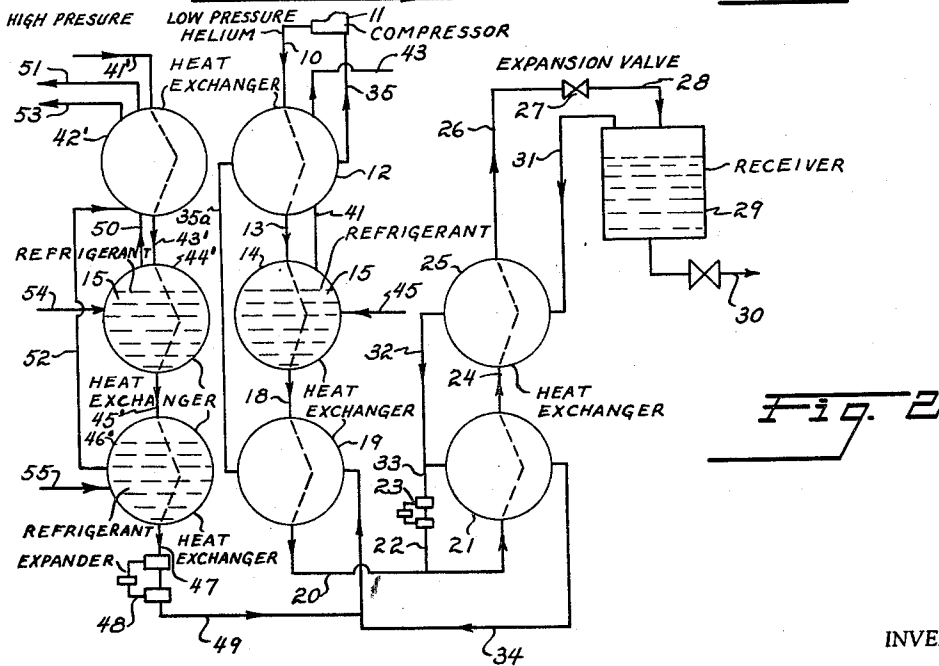


Fig. 2

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METHOD OF LIQUEFYING HELIUM

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1 Claim. (Cl. 62—9)

The present invention relates to the production of helium in a liquid state, and more particularly to a new and novel method for producing liquid helium in a more economical and efficient manner.

Helium gas has been produced in liquefied form heretofore in a variety of ways. However, in general such prior methods have necessitated the use of expensive and complicated equipment which has been undesirable from an economical standpoint. Moreover, in general such methods have not been efficient in their operation, which has further been an economical disadvantage.

It is therefore a principal object in the elimination of the foregoing and related disadvantages to provide a process for producing liquid helium from helium gas in a new and novel process.

Yet another object of the present invention is a process for the production of liquid helium from helium gas which possesses a high yield of liquid helium per unit of helium gas circulated without necessitating a high power consumption.

A still further object of the present invention is a method for producing liquid helium from helium gas in which an intermediate pressure system is employed with a high yield of liquid helium being produced per unit of helium gas circulated.

Still another object of the present invention is a method for producing liquid helium in which the operation is virtually self-contained.

Yet another object of the present invention is a method for producing liquid helium by a continuous operation.

A still further object of the present invention is a method for producing liquid helium without requiring expensive and complicated equipment.

Another object of the present invention is a method for producing liquid helium which reduces the amount of energy required to liquefy the helium gas.

Other and additional objects will become manifest from the ensuing description taken in conjunction with the accompanying drawings.

Broadly stated, the method for producing liquid helium in accordance with the present invention comprises passing helium gas under pressure to a first heat exchange zone to effect a cooling thereof, passing the cooled gas to at least a second refrigerated heat exchange zone to further cool the gas, passing said cooled gas through at least one more heat exchange zone to effect further cooling of said gas, passing the gas leaving the last heat exchange zone through an expansion zone to effect a partial liquefaction of said gas, passing the partially liquefied gas to a receiving zone, and passing the gaseous helium back through at least some of the heat exchange zones to effect the cooling of the incoming gas.

To the accomplishment of the foregoing and related ends, the present invention then consists of the means hereinafter fully described and particularly pointed out in the claims, the annexed drawing and the following description setting forth in detail certain means in the carrying out of the invention, such disclosed means illus-

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trating, however, but one of various ways in which the principle of the invention may be employed.

The present invention is illustrated, by way of example, in the accompanying drawings, in which:

5 Figure 1 is a diagrammatic view of a flow sheet illustrating one method made in accordance with the present invention for producing liquid helium.

Fig. 2 is a diagrammatic view of a flow sheet illustrating a modified form of the method shown in Fig. 1.

10 Reference is now to be had to Figure 1 wherein one illustrative embodiment of a method made in accordance with the present invention is shown by way of a diagrammatic flow sheet. A stream of normal helium gas under pressure, such as, for example, 15 atmospheres, enters line 10 and is passed into a first heat exchanger 12 where an initial cooling of the compressed gas occurs by a heat exchange relationship with cold helium gas. The cold helium gas is obtained from the liquid helium produced by the process and is recycled back through the system in reverse order in a manner which will become more apparent as the description of the process ensues. Further refrigeration for the incoming gas is obtained as from liquid refrigerant, as well as from a high pressure helium gas which itself is subjected to a cooling operation. The operation of such further refrigeration will be described in detail more fully hereinafter.

It is to be noted that low pressure helium gas may be employed by passing same to a compressor 11 which will feed helium under pressure through line 10. When helium gas under pressure is initially employed without requiring compression, the compressor 11 serves to receive low pressure cold helium gas coming from the heat exchanger 12 as a result of the reverse cycle operation, compress same and pass it into the feed-stream line 10 as make-up helium, thereby fully utilizing all of the helium gas put into the system.

The cooled compressed helium gas passes from the heat exchanger 12 through line 13 into a pre-cooling second heat exchanger 14 where the gas is cooled further. The cooling of the gas is effected in this form of the invention by providing the heat exchanger 14 with a suitable liquid refrigerant 15, such as, for example, liquid air, liquid hydrogen, liquid oxygen, Freon 14, etc. This enables the helium gas passing therethrough to be cooled to the temperature of the refrigerant. In this form of the invention, no cold helium gas obtained by the reverse cycle operation of the system will be employed to assist in cooling the incoming helium gas. The temperature of the pre-cooled heat exchanger 14 may be varied, if desired, by varying the refrigerant and the pressure at which the refrigerant is maintained.

The cooled compressed helium gas passes from the pre-cooling heat exchanger 14 through line 16 to a pre-cooling third heat exchanger 17 where further cooling of the gas is to be effected. The helium gas is cooled in the third heat exchanger 17 by a liquid refrigerant 15 which is the same as that employed in the pre-cooling second heat exchanger 14. The temperature of the pre-cooling heat exchanger 17 may be varied, if desired, by varying the refrigerant and the pressure at which it is maintained. It is to be noted that, in the same manner as with the pre-cooling heat exchanger 14, no cold helium gas obtained from the produced liquid helium is recycled by the third heat exchanger 17 to provide refrigeration therein. The two-stage cooling operation employing a liquid refrigerant insures a reduction in the temperature of the gas to a very low level, on the order of about 65° K., thereby improving the efficiency of the system in the ultimate liquefaction of the gas.

70 The helium gas leaves the heat exchanger 17 at a very low temperature and passes through line 18 into a fourth heat exchanger 19, where the gas is further cooled by

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heat exchange relationship with the cold helium gas passing therethrough in the reverse cycle operation. The cooled helium gas still under pressure leaves the fourth heat exchanger 19 through line 20 and is split into two feeds, one part of the feed passing through line 20 to a fifth heat exchanger 21, with the remaining part going through line 22 to an expander 23 where it is expanded and passed into the reverse cycle operation side of the system to effect cooling in the heat exchangers in a manner more particularly described hereinafter. The portion of the helium gas passing through line 20 into the fifth heat exchanger 21 is further cooled therein by means of the cold helium gas passing therethrough in the reverse cycle heat exchange operation. The cooling of the helium gas to the desired level in the heat exchanger 21 is materially enhanced since the portion of the incoming helium gas divided out of the feed-stream for passage through the expander into the reverse recycle side of the system is fed thereto at a point just prior to the entry of the outgoing reverse cooling gas stream into the heat exchanger 21.

The helium gas leaves the fifth heat exchanger 21 through line 24 and enters the sixth and final heat exchanger 25 for the final cooling of the gas before effecting liquefaction by heat exchanger relationship with the outgoing helium gas passing therethrough in the reverse cycle operation. The helium gas leaves heat exchanger 25 through line 26 and passes into an expansion valve 27 where a major portion of the cooled helium gas is expanded and thereby liquefied. The liquefied portion and remaining cold helium gas no longer under pressure passes through line 28 into the liquid helium receiver 29. The liquid helium thus produced may be continually withdrawn for storage from the receiver 29 through line 30.

The unliquefied helium gas passing into the receiver 29 from the expansion valve 27 is not liquefied but is passed back through at least some of the heat exchangers of the system in a reverse cycle heat exchange operation to provide part of the desired refrigeration for cooling the incoming gas by heat exchange relationship. The unliquefied helium gas leaves the receiver 29 through line 31 and is passed into the heat exchanger 25 where it serves as a refrigerant for the incoming, compressed helium gas. The helium gas passes from the heat exchanger 25 by line 32 back through the heat exchanger 21 in the reverse cycle phase of the system. During passage from heat exchanger 25 back through heat exchanger 21, the portion of the incoming, compressed helium feed-stream which was separated and passed through line 22 to the expander 23 is fed into line 32 before entry into heat exchanger 21. This operation provides a very cold stream of helium gas to impart the desired refrigeration to the heat exchanger 21.

The helium gas leaves the heat exchanger 21 through line 33 and is carried back through the heat exchanger 19 to provide the necessary refrigeration to effect the desired cooling of the incoming helium stream. The helium gas leaves the heat exchanger 19 through line 34 and is passed back into the first heat exchanger 12 where it provides at least part of the refrigeration by heat exchange relationship for the initial cooling of the incoming compressed helium gas.

It is to be noted in this form of the invention the low pressure helium gas used in the reverse cycle operation by-passes the pre-cooling heat exchangers 14 and 17, since in general the refrigerant used in the heat exchangers will provide adequate cooling of the incoming helium gas at this stage of the process. The low pressure helium gas leaves the heat exchanger 12 through line 35 and is carried to the compressor 11 where it is compressed and then added to the incoming helium gas under pressure. Alternatively, if all of the incoming helium gas is not under pressure and must first be compressed by compressor 11, the helium gas from the heat exchanger 12 will be employed as make-up gas. In either operation,

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the helium gas from the reverse cycle operation will insure the maintaining of the system in a balanced state.

It is to be noted that an expanded stream of refrigerating cold gas is passed into the reverse cycle side of the system between the fourth and fifth heat exchangers to add additional refrigerant for assisting in cooling the fourth and first heat exchangers in that order. This operation will be discussed more in detail hereinafter in describing the auxiliary refrigeration to be used in assisting the reverse cycle side of the outgoing cold gas to cool the incoming gas.

The auxiliary refrigeration system is obtained by providing high pressure helium gas which, in addition to assisting in refrigerating points of the system, will also serve to balance the system by providing make-up feed to replace the liquefied gas. The make-up helium at a high pressure, such as, for example, 200 atmospheres, enters through line 36 and passes through the first heat exchanger 12 to be initially cooled therein. The cooled compressed helium gas leaves through line 36' and passes through the pre-cooling second heat exchanger 14 for further cooling therein by means of the refrigerant 15. The helium gas leaves the second heat exchanger 14 for passage through line 37 through the pre-cooling third heat exchanger 17, which likewise is provided with a liquid refrigerant 15.

The high pressure helium gas is cooled at this point to a temperature of about 65° K. and leaves the pre-cooled third heat exchanger 17 through line 38 for passage through an expander 39. The expansion of the high pressure gas through the expander 39 results in considerable cooling of the already cold gas by removal of energy therefrom during the expansion. The expanded cold helium gas leaves the expander 39 through line 40 and is added to the reverse cycle side of the system at line 33 between the fourth and fifth heat exchangers 19 and 21. The gas serves as a make-up gas for the helium liquefied in order to balance the system as well as providing, in addition to the gas recycle from the liquefied helium, cold refrigerant to assist in cooling the incoming gas in the fourth and first heat exchangers 19 and 12, respectively.

To further aid in cooling the initial heat exchange zone as well as providing a closed system for maintaining the refrigerant 15 in a cold, liquefied state, the pre-cooling second and third heat exchangers 14 and 17 are provided with return lines 41 and 42, respectively, which connect with the first heat exchanger 12. The lines 41 and 42 will carry off the volatilized refrigerant from each of the pre-cooled heat exchangers 14 and 17 to assist in providing additional cooling for the heat exchanger 12 in the initial cooling of the incoming helium. The volatilized refrigerant leaves the heat exchanger 12 by lines 43 and 44, with each line being connected to a cooling and pumping system for liquefying the vaporized refrigerant and repassing same back into the pre-cooling second and third heat exchangers through lines 45 and 46, respectively. Alternatively, the volatilized refrigerant may be passed to the atmosphere through lines 43 and 44 with liquid refrigerant serving as a make-up for the lost refrigerant in each of the pre-cooling heat exchangers 14 and 17 by passing the refrigerant thereinto through lines 45 and 46, respectively.

From the foregoing description of one form of the invention shown in Fig. 1, it is seen that the compressed helium gas is cooled in a stepwise relationship by passage through a plurality of heat exchangers with each heat exchanger having a temperature lower than the preceding one. Conversely, the helium gas which is not under pressure and which is obtained from the vaporization of the liquid product produced as well as splitting off and expanding a portion of the cooled helium feedstock, in addition to the high pressure expanded make-up helium gas, passes through at least a portion of the heat exchanger to provide the necessary

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refrigeration. It will be noted that the gas leaving each heat exchanger in reference order gradually becomes warm. It is to be understood that in the present form of the invention, together with subsequent additional forms to be described, the number of heat exchangers may vary. The number of heat exchangers should be sufficient to permit a stepwise cooling of the incoming gas in an efficient manner with most of the refrigeration being derived from the feedstock itself by a reverse cycle operation.

Reference is now to be had to Fig. 2 wherein a modified form of the method shown in Fig. 1 is represented. Corresponding parts in the flow sheets of Figs. 1 and 2 will be designated by like reference numerals. In the form of the invention illustrated in the flow sheet of Fig. 2, a stream of helium gas, either under pressure or compressed by compressor 11, will be passed through line 10 to the first heat exchanger 12 to effect its initial cooling. The partially cooled helium gas is next passed through line 13 into the pre-cooling first heat exchanger 14 where it is subjected to further cooling by heat transfer with the liquid refrigerant present therein.

In the modified form shown in Fig. 2, the pre-cooling third heat exchanger 17 in which liquid refrigerant 15 is present is not needed. Rather, an auxiliary refrigerating medium is employed which will be described more fully hereinafter.

The cooled gas leaves the pre-cooled second heat exchanger 14 through line 18 for passage through a third heat exchanger 19 wherein the gas is further cooled by heat exchange relationship with the cold gas passing therethrough in a reverse cycle operation. The gas leaves the heat exchanger 19 through line 20. The gas is divided after leaving the third heat exchanger 19 with a part passing through line 22 to an expander 23 where the gas is expanded to further cool same and is added to the reverse cycle side of the system to add further refrigerant thereto to cool the incoming gas as well as assisting in maintaining a proper balance in the overall system. The gas passes from heat exchanger 21 through line 24 into the final heat exchanger 25 wherein the helium gas receives its final cooling by heat exchange relationship with the reverse cycle phase of the cold gas passing therethrough in the manner described hereinbefore. The cooled gas passes from the heat exchanger 25 through line 26 into an expansion valve 27 where the gas is liquefied by the expansion. The liquefied gas and that portion which has not been liquefied passes through line 28 into the receiver 29. The liquid helium may be drawn off through line 30.

The unliquefied portion of the helium gas leaves the receiver 29 through line 31 for passage through the heat exchanger 25. The gas leaves the heat exchanger 25 through line 32 for passage back through the heat exchanger 21. The expanded portion of the incoming gas taken off of line 20 is received from the expander 23 through line 33. Thus the gas entering the heat exchanger 21 on the return or reverse cycle side of the system is a combination of the expanded portion of the incoming stream and the unliquefied portion of the helium coming from the produced liquid helium. The gas leaves the heat exchanger 21 through line 34 and is passed back through heat exchanger 19 to aid in the cooling of the incoming gas therein by heat exchange relationship. The gas then leaves the heat exchanger 19 in the reverse cycle operation of the system through line 35a and passes through the first heat exchanger 12 to aid in the initial cooling of the incoming helium gas by heat transfer relationship therewith. The gas leaves the first heat exchanger 12 through line 35 where it is carried to the compressor 10 for compression and reuse in the system. The first heat exchanger is further cooled by vaporized refrigerant leaving the pre-cooling heat exchanger 14 through line 41 which passes

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therethrough and is carried out by line 43. The vaporized refrigerant may be re-liquefied and carried back to the pre-cooling heat exchanger 14 by line 45.

The operation just described is, in general, the same operation employed in the form of the invention described in connection with Fig. 1, the difference being the omission of the pre-cooling second liquid refrigerant 17 as well as omitting the high pressure helium passage through the first and second heat exchangers 12 and 14. A separate refrigeration operation is substituted for the two omitted operations.

The separate and auxiliary system is obtained by passing high pressure helium through line 41', which passes through the heat exchanger 42' for cooling therein by heat transfer relationship. The heating gas leaves the heat exchanger 42' through line 43' for passage through a pre-cooling heat exchanger 44' which has a liquid refrigerant 15 present therein. The further cooled helium gas leaves the heat exchanger 44' through line 45' for passage through a second pre-cooling heat exchanger 46'. Gas at this stage is cooled to a temperature of about 65° K. and leaves the heat exchanger 46' through line 47 for passage through an expander 48. The gas is expanded and is further cooled by such expansion and is passed through line 49 into line 34 on the reverse cycle side of the main system between the third and fourth heat exchangers 19 and 21. This results in providing make-up gas to insure a proper balance of the system by replacing the helium liquefied as well as providing very cold refrigerant to cool the incoming gas.

The pre-cooling heat exchanger 44' is provided with a line 50 which extends to the heat exchanger 42' to permit the vaporized liquid refrigerant to pass therethrough to assist in cooling the incoming high pressure helium and passes out therefrom through line 51. The second pre-cooling heat exchanger 46' is provided with a line 52 connected likewise to the heat exchanger 42' through which the vaporized refrigerant is likewise passed therethrough to provide the refrigerant for the first heat exchanger and out through line 53. The liquid refrigerant passing out through lines 51 and 53 may be refrigerated again and passed back into the pre-cooling heat exchangers 44' and 46' through lines 54 and 55. Alternatively, the vaporized refrigerant gas may pass to the atmosphere with fresh liquid refrigerant being passed into the respective heat exchangers through lines 54 and 55.

While there have been described herein what are at present considered preferred embodiments of the invention, it will be obvious to those skilled in the art that modifications and changes may be made therein without departing from the essence of the invention. It is therefore to be understood that the exemplary embodiments are illustrative and not restrictive of the invention, the scope of which is defined in the appended claim, and that all modifications that come within the meaning and range of equivalency of the claim are intended to be included therein.

We claim:

A method for producing liquid helium comprising passing two separate streams of helium gas, one being under intermediate pressure and the other being under high pressure, to a first heat exchange zone to effect a cooling of the two separate gaseous streams, passing the cooled high pressure gas stream and the intermediate pressure gas stream to at least a second refrigerated heat exchange zone to further cool the gas, passing the separate intermediate pressure gas stream through a plurality of heat exchange zones to effect stepwise cooling of said intermediate pressure gas stream, dividing the incoming intermediate pressure gas stream during the stepwise cooling and before its exit from the last heat exchange zone into a first stream and a second

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stream, passing the first stream of the intermediate pressure stream through the last heat exchange zone of said plurality of heat exchange zones, passing the first stream after its exit from the last heat exchange zone through an expansion zone to effect at least a partial liquefaction thereof, passing the at least partially liquefied gas stream to a receiving zone wherein the resulting liquid helium is collected, passing the second stream of said intermediate gas pressure helium stream through an expansion zone to cool same and reduce the pressure, taking the unliquefied gaseous helium of the first stream from the receiving zone, combining it with the expanded gas of said second stream, passing the combined gases at reduced pressure back through at least some of the heat exchange zones to effect the cooling of the incoming gas, passing the high pressure gas helium stream from said refrigerated zone to an expansion zone to effect a cooling thereof and

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reduce the pressure thereon, passing the expanded high pressure gas back through at least some of the heat exchange zones to provide refrigeration to cool the incoming intermediate pressure gas stream.

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