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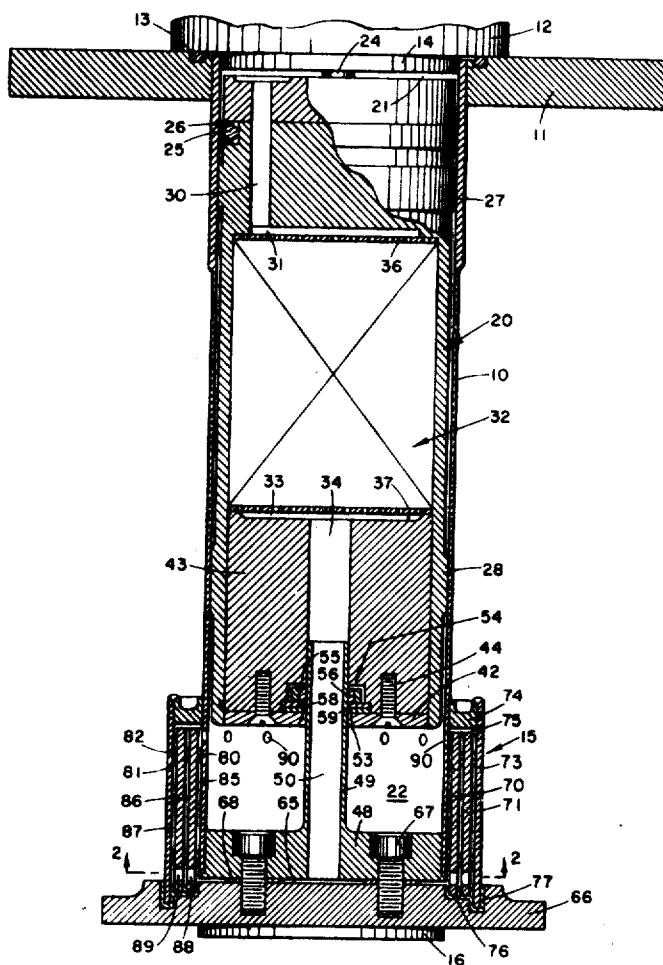
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[54] **CRYOGENIC HEAT STATION AND APPARATUS
 INCORPORATING THE SAME**
 16 Claims, 9 Drawing Figs.

[52] U.S. CL..... 62/6
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 [50] Field of Search..... 62/6

ABSTRACT: An improved heat station for cryogenic apparatus comprising one or more narrow fluid passages in heat exchange relationship with a portion of the external walls which enclose a refrigeration chamber of variable volume. The narrow fluid passages provide an extension of the fluid flow path of the apparatus which in turn provides an increase in heat transfer surface without any appreciable increase in void volume.



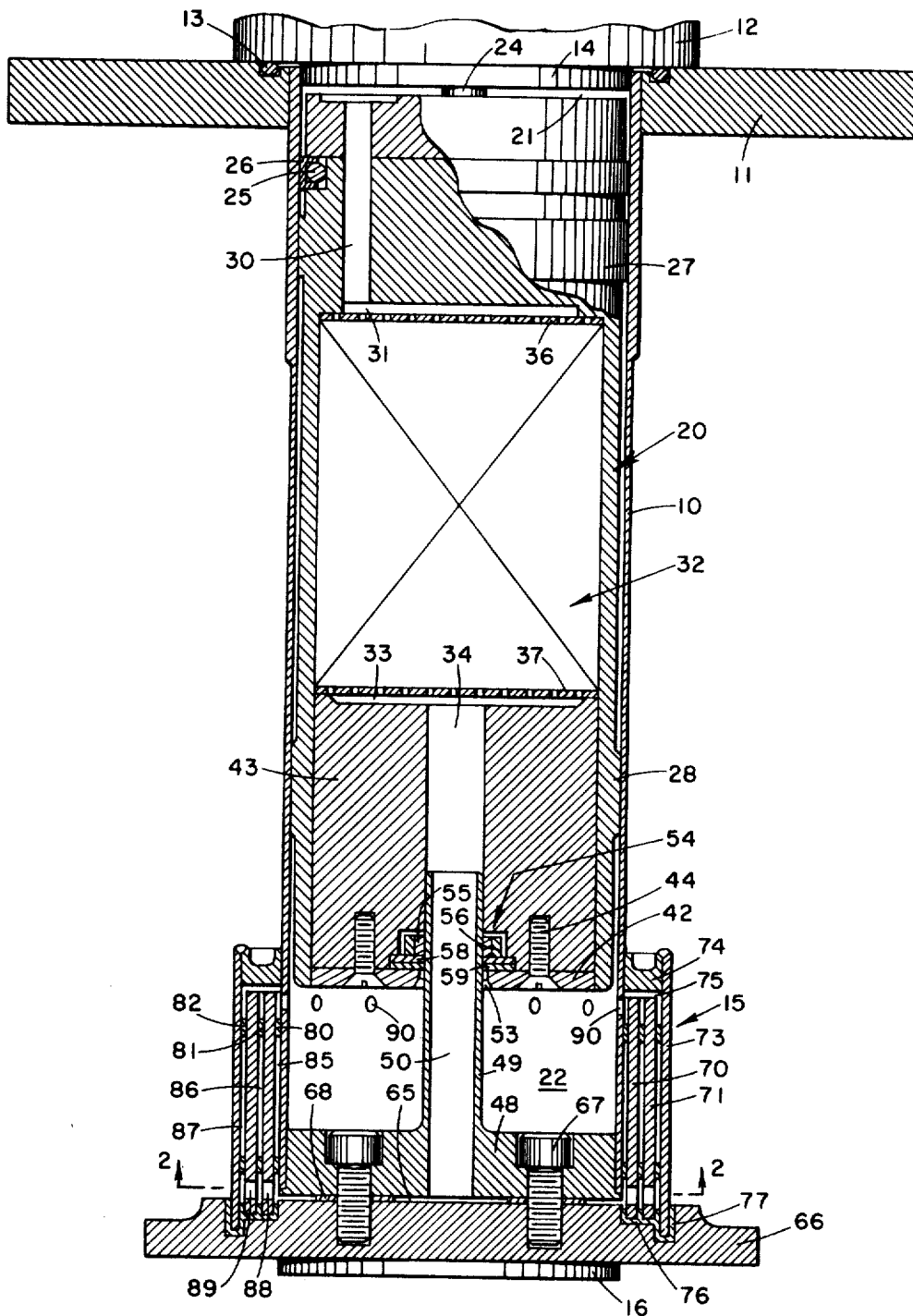


Fig. 1

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CRYOGENIC HEAT STATION AND APPARATUS INCORPORATING THE SAME

This invention relates to refrigerators and liquifiers and, more particularly, to cryogenic apparatus which develop refrigeration through the expansion of a compressed fluid and which may incorporate one or more regenerators.

The refrigeration in such apparatus is typically delivered to a load through a suitable thermal connection which is generally referred to as a heat station. Refrigerators to which the heat station of this invention may be applied include those described in U.S. Pat. Nos. 2,906,101, 2,966,035, 3,188,819, 3,218,815, the well-known Stirling cycle refrigerators, and any other type of cryogenic device which has a moving fluid stream passing through a refrigerating chamber. As examples of the types of refrigerators in which the improved heat station of this invention is designed to be incorporated, we may cite the refrigerators shown in U.S. Pat. No. 3,218,815. Thus, heat station 28 of FIGS. 1 and 4, 85 of FIG. 6 and FIG. 9, 135 of FIG. 10, and 218 and 220 of FIG. 12 of USP 3,218,815 may be constructed in accordance with this invention. It will be seen that in each of the types of apparatus mentioned the cryogenic refrigerator is of a type in which a movable member defines within an enclosure at least one refrigeration chamber of variable volume, and in which a high pressure expansible fluid is introduced through a fluid flow path which may incorporate heat storage means as part of the path. The fluid flow path normally terminates in the refrigeration chamber wherein the fluid is subsequently expanded and then discharged through the same fluid flow path.

Refrigeration from this moving fluid stream is delivered to an external load through the refrigerator housing, the heat station walls, or a combination of these heat flow paths. In coupling the external load to the moving fluid stream it is highly desirable to provide as much heat transfer surface as is possible. However, in order to make the most effective use of the refrigeration in the fluid, it is also necessary to maintain the void volume as low as possible.

It is, therefore, a primary object of this invention to provide an improved cryogenic heat station of the type which achieves an improved transfer of heat between a fluid stream and an external load. It is another object of this invention to provide a heat station of the character described which achieves the use of a maximum surface area while at the same time maintaining the void volume at a minimum. It is yet another object of this invention to provide a heat station of the character described which is applicable to various refrigeration cycles which involve the expansion of high pressure fluid to achieve refrigeration. It is another object of this invention to provide an improved cryogenic apparatus which incorporates a heat station. Other objects of the invention will, in part, be obvious and will, in part, be apparent hereinafter.

The heat station of this invention may be generally described as comprising means, external of that portion of the apparatus enclosure housing defining the cold or refrigerating chamber, for defining one or more narrow fluid passages which provide indirect fluid communication between the fluid flow path of the apparatus and the refrigerating chamber. The fluid passage or passages may in heat exchange relationship with a portion or essentially all of the external walls defining the refrigerating chambers and valve means may be added to control the flow of fluid through the passage or passages within the heat station.

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

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

FIG. 1 is a longitudinal cross section of a single-stage cryogenic refrigerator constructed with one embodiment of the heat station of this invention;

FIG. 1a is a modification of the heat station embodiment of FIG. 1;

FIG. 2 is a cross section of the heat station taken along line 2-2 of FIG. 1;

FIG. 3 is a modification of a portion of the refrigerator and heat station of FIG. 1 showing the use of one-way check valves to modify the fluid flow path within the refrigerator;

FIG. 4 shows the heat station of FIG. 1 associated with a refrigerator having an external regenerator;

FIG. 5 illustrates another embodiment of the heat station having a single annular passage;

FIG. 6 is a cross section of another embodiment of the heat station of this invention;

FIG. 7 is a longitudinal cross section of a multiple stage refrigerator showing the heat station of this invention affixed to an intermediate stage; and

FIG. 8 is a diagrammatic representation of a complete cryogenic apparatus incorporating a multistage refrigerator having the heat stations of this invention coupled to heat exchangers in a Joule-Thomson loop.

The heat station of this invention is shown in FIG. 1 incorporated in a cryogenic refrigerator which embodies the cycle disclosed in U.S. Pat. No. 2,966,035. In this particular embodiment there is but one refrigeration chamber. It will be shown in FIG. 7 that the heat station of this invention may be used with one or more cold chambers of a temperature-staged cryogenic refrigerator such as described in U.S. Pat. No. 2,966,035.

The refrigerator of FIG. 1 is seen to be comprised of a cylindrical housing section 10 which is attached to a mounting plate 11 for connection with a crosshead 12. Sealing of the crosshead to the plate is accomplished through an O-ring 13. The heat station of this invention is shown generally at numeral 15 and a thermal load at 16.

Within the housing section 10 there is a movable member, such as a displacer 20, which in its movement defines a warm volume 21 at one end of the housing section and a cold volume 22 at the other end. The displacer 20 is attached to a displacer shaft 24 and in keeping with displacer design it has an upper sealing means which comprises an elastomeric ring 25 and a polytetrafluorethylene member 26, as well as an upper land 27 and a lower land 28 which makes sealing contact with the internal walls of the housing 10. Fluid is introduced into the refrigerator and is withdrawn from the refrigerator by means of a passage (not shown) in header 14. The fluid flow path within the refrigerator comprises the warm chamber 21, a first vertical passage 30 within the displacer, an upper plenum chamber 31, a regenerator 32, a lower plenum chamber 33, a lower or second vertical passage 34, the heat station 15 (to be described in detail) and finally the refrigeration chamber 22. The regenerator 32 terminates at its upper end in a perforated plate 36 and in its lower end in a perforated plate 37 which retains the regenerator material such as lead balls, screening or wire within the volume of the regenerator.

The displacer 20 terminates at its bottom end in a clamp plate 42 which is attached to the bottom solid portion 43 of the displacer by means of suitable screws 44.

It will be appreciated by those skilled in the art that the displacer may be replaced by a piston such as in a Stirling engine, and the manner in which such a movable member forms sealing contact with the internal walls of the housing may be of a variety of designs and constructions. Therefore, the embodiment illustrated in FIG. 1 is not limiting. Moreover, in the description given the terms "upper" and "lower" are used in a relative sense, and the refrigeration apparatus illustrated may be oriented in any manner. These terms are employed in this description only for convenience and to correspond to the orientation illustrated in the figures.

Affixed to the bottom end of the housing section 10 is a heavy wall support plate 48 which in effect serves as part of the enclosure housing and which is formed integral with a passage-defining extension 49 having a fluid passage 50 which communicates with the second or lower vertical fluid passage 34 of the solid displacer section 43.

In its upward and downward motions, the displacer 20 slides on the passage defining extension 49, the outer wall of which has a sufficiently smooth finish to make a seal with the fluid-sealing means which is represented generally at 54 and which is located just above a central opening 53 in the clamp plate 42. The fluid-sealing means 54 may be made up of one of a number of different types of seal components, the one illustrated in FIG. 1 comprising a sealing ring 55 formed of polytetrafluorethylene, a seal backup ring 56, a spacer washer 58, and finally a Bellville spring washer 59.

The fluid passage 50 which furnishes direct fluid communication with the regenerator terminates in a very narrow or shallow, generally circularly shaped passage 65 defined between the bottom wall of the support plate 48 (serving as the end of the housing section which defines the refrigeration chamber 22) and the top wall of a copper plate 66. The copper plate is affixed to the support plate 48 in space-defining relationship by a plurality of screws 67 and spacer washers 68. By means of this shallow, essentially circularly shaped passage, the fluid is forced to flow beneath the chamber 22.

Positioned around the refrigerator wall are a plurality of annular rings 70 and 71 formed of a material which has good heat conductivity at the temperature at which the refrigerator is to deliver refrigeration. For cryogenic purposes these rings are preferably formed of copper. Surrounding and spaced from the outermost one of these rings is a cylindrical heat station housing 73 formed of a material which has the necessary strength at cryogenic temperatures to support the housing. Typically the housing 73 and the support plate 48 with its integral extension passage-defining means 49 will be formed of stainless steel. An annular ring of stainless steel 74 is welded between the outside wall of housing 10 and the inner wall of the heat station housing 73 to form a fluidtight seal. It is so positioned as to define a narrow fluid flow path 75 between it and the uppermost edges of rings 70 and 71. Along their lower edges the rings 70 and 71 are joined to each other and to the copper plate 66 with a thermal bond 76; while the heat station housing 73 is welded with a strength bond 77 to the copper plate 66.

The annular rings 70 and 71 are maintained in their spaced relationship within the heat station housing by means of a series of spacers 80, 81 and 82 (see also FIG. 2). There is, therefore, defined between the outer wall of refrigerator housing 10, the spacer rings 70 and 71 and the heat station housing wall 73 a series of annular fluid passageways, 85, 86 and 87. Communication with these passageways from the narrow fluid passage 65 is by way of openings 88 and 89 cut in the bottom section of the annular rings 70 and 71 (see also FIG. 2). There is also supplied a means for fluid communication between these annular fluid passages 85, 86 and 87 and the interior of the refrigeration chamber 22, this means being a series of ports 90 drilled in the refrigerator housing below the position of the annular ring 74 but fairly close to the top of the rings 70 and 71.

The particular refrigerator embodiment of FIG. 1 operates on a cycle in which a predetermined quantity of high pressure fluid is introduced by way of the regenerator into the refrigeration chamber 22. As the high pressure fluid passes down through the regenerator 32 it is cooled initially and reaches the refrigeration chamber 22 as high pressure, initially cooled fluid. Subsequently, the supply of high pressure fluid is cut off and the system is opened to a low pressure exhaust reservoir at which point the cold, high pressure fluid expands, is further cooled and gives out refrigeration to the regenerator 32 as it leaves the refrigerator.

In the heat station of this invention, the flow path of the high pressure, initially cooled fluid is so modified as to cause it to

come into contact with a much enlarged heat transfer surface while at the same time maintaining the void volume within the refrigerator at a minimum. The void volume is, of course, comprised of that space which is required for clearances and gas passage purposes and which does not contribute to the development of refrigeration through the expansion of the high pressure gas. Thus in the heat station of this invention heat transfer is maximized without appreciably reducing the efficiency of the apparatus through increase in void volume.

From the regenerator the fluid passes down through the vertical passage 34 and into the passage 50. It is therefore forced through the narrow horizontal fluid passage 65 into the spaced ring system, a portion of it flowing upwardly through annular channel 85, a portion through annular channel 86, and a third portion through annular channel 87, these portions being divided and routed at the bottom end of the refrigerator and passing through the openings 88 and 89. All of the fluid which has passed up through the annular channels 85, 86 and 87 is then collected in passage 75 and enters the refrigeration chamber 22 through the series of ports 90.

In the embodiment of the refrigerator of FIG. 1, after the system has been opened to the low pressure reservoir side of the cycle, the displacer moves downwardly and forces the fluid back through the same flow path by which it entered the refrigeration chamber 22.

In the modification of FIG. 1a, in which like numerals refer to like elements of FIG. 1, a second copper plate 67 is bolted by means of a plurality of screws 69 to copper plate 66. Copper plate 66 has a circular shallow well 91 machined in it, the well being open to refrigeration chamber 22 through a number of passages 92 drilled through the plate. A circular disk 93 is affixed to the end of passage-defining extension 49 and is located within shallow well 91 to define with it and the surface of copper plate 67 a narrow fluid flow path comprising circular passage 94, which is in direct fluid communication with the regenerator through fluid passage 50, and annular passage 95 which is in direct fluid communication with refrigeration chamber 22 through passages 92. If desired a centrally located recess 96 may be drilled in plate 67 better to direct the fluid out through circular passage 94. Finally, a plurality of external conduits 97 may be used with or without passages 92 to provide fluid communication between annular passage 95 and refrigeration chamber 22. A plurality of thermal connecting members 98 provide a heat transfer path among the heat station components.

Under some conditions of operation, it may be desirable to transfer the high pressure incoming fluid directly from the regenerator to the refrigeration chamber 22. A modification of the refrigerator and heat station flow path which accomplishes this is shown in FIG. 3. In this modification, there is provided in the solid bottom section 43 of the displacer an additional fluid channel 100 which has in it a one-way fluid check valve 101, the embodiment shown in FIG. 3 being formed of a ball 102 and a spring 103. Since there will, of course, be some resistance to the fluid flow through valve 101, some of the high pressure fluid will also flow into passage 50 and through the heat station, unless means are provided to check the fluid flow by this route. Therefore, the passage-defining extension 49 may be modified to have an upper inwardly directed flange 104 and an annular ring 105 to hold another one-way check valve 106, shown in FIG. 3, to comprise a ball 107 and spring 108.

In operation, when the high pressure fluid is being introduced into the refrigeration chamber prior to expansion but subsequent to the initial cooling in the regenerator, the fluid flows down through channel 100 directly into chamber 22. However, during discharge the cold fluid cannot flow upward through channel 100 because the valve construction does not permit it to be returned directly into the regenerator. Therefore, the discharging fluid must flow through the flow path indicated in FIG. 1, that is outward through ports 90, then through the annular channels 85, 86 and 87 through ports 88 and 89, fluid channel 65 and then through the fluid passage 50 and valve 106 to be returned to the regenerator 32.

As illustrated in FIG. 4, the regenerator may be located external of the housing section 10, an arrangement which is equally adaptable to single or multiple stage devices. In the apparatus of FIG. 4 (showing the heat station of this invention incorporated into one of the embodiments of U.S. Pat. No. 2,906,101 or 2,966,035), in which like numerals refer to like elements of FIG. 1 of the drawings presented herein, the displacer 115 does not provide any part of the fluid flow path. A regenerator 116, located externally of the housing section, is connected to the fluid passage 65 through an external conduit 117 and a passage 118 drilled in the copper plate 66.

It is, of course, within the scope of this invention to construct the heat station with one or more annular rings and FIG. 5 illustrates another embodiment of the heat station in which a single annular passageway is provided around the side of the refrigeration chamber 22 and direct fluid communication is provided between the narrow horizontal fluid passage below the refrigeration chamber and the interior volume of the refrigeration chamber. In FIG. 5 like reference numbers are used to identify like elements as shown in FIG. 1.

In the embodiment of FIG. 5 the refrigeration chamber 22 is closed on the bottom by a cap 120 which extends upwardly to encase that part of the housing section 10 which is enclosed within the heat station housing 121 formed of a material, e.g., copper, having good heat conductivity at the cryogenic temperatures involved. The cap 120 provides the bottom wall for the enclosure housing and is typically formed of copper. Cap 120 has a fluid port 122 which provides fluid communication with the very shallow, circular-shaped horizontal chamber 123 and a plurality of fluid ports 124 which are aligned with ports 90 in the housing 10. An annular fluid passage 125 connects the shallow chamber 123 to ports 124 and ports 90, and a plurality of thermal connecting members 126 provide a direct heat transfer path between cap 120 and housing 121.

Regenerator 32 is connected at its lower end to a plurality of radial passages 128 which open into a narrow annular passageway 129 defined between the outer wall of the lower displacer section 43 and the inner wall of housing 10. This passageway 129 provides continuous fluid communication between the regenerator and passage 125 (by way of ports 90 and 124) throughout the entire travel distance of the displacer. A seal 130 prevents any direct fluid communication between the regenerator and the refrigeration chamber 22. The embodiment of FIG. 5 may be constructed as in FIG. 1 to have additional copper rings and spacers located between the annular extension of cap 120 and the heat station housing 121, thereby to provide additional heat transfer surface.

In the embodiments of FIGS. 1-5 (except for FIG. 1a) the heat station is positioned to surround the refrigerator housing and extends up to about the point which corresponds to the maximum volume of refrigeration chamber 22. Although it is preferable for the heat station to occupy this position and relationship with respect to the refrigeration chamber and housing, it is possible for the heat station to extend either beyond the height of displacer travel or to extend over only a portion of this distance; and it is also possible in apparatus housing the regenerator in the displacer to provide a heat station which extends only over a very short length of the housing and has an extension beyond the housing as shown in FIG. 6.

The heat station of FIG. 6 comprises a fluid passage around housing 10 in the form of a manifold 135, which communicates with annular passage 129 through a plurality of ports 90, and a small diameter tubing 136 which connects manifold 135 with chamber 22. Tubing 136 is adapted to extend the passage and to deliver refrigeration to a load 137, and it may comprise one or more parallel tubings corresponding in function to the one or more annular passages (e.g., 85, 86 and 87 of FIGS. 1 and 3 or 125 of FIG. 5) and to the narrow horizontal passage (e.g., 65 of FIG. 1 or 126 of FIG. 5). The sealing member 130 prevents direct fluid communication between the annular passage 129 and refrigeration chamber 22 and forces the fluid to flow through the small diameter tubing 136 which is typically formed of copper.

It is, of course, to be understood that at least the colder end of the cryogenic apparatus is to be suitably insulated and that the heat station (whether attached to the housing or positioned as in FIG. 6) will be protected by such thermal insulation.

The embodiments of FIGS. 1, 3, 4 and 5 will be seen to include one or more narrow fluid passages essentially surrounding all of that portion of the housing wall corresponding to the maximum volume of the chamber 22. In FIGS. 1, 3 and 4 there are a plurality of annular passages while in FIG. 5 there is a single annular passage. In FIG. 1a passages are limited to those associated with the bottom end of the housing and the several external connecting conduits 97.

FIG. 7 illustrates the application of the heat station of this invention to a multistate refrigerator or liquefier. The colder or lower stage is constructed as shown in cross section in FIG. 1 in which like numbers refer to like elements. In adapting the heat station to an intermediate refrigeration stage, it is necessary, as in the embodiment of FIG. 5, to provide for continuous fluid communication between the regenerator and the heat station passages during the entire stroke of the displacer.

The main refrigerator housing comprises an upper section 145 and a lower section 146; and the displacer likewise comprises an upper section 147 and lower section 148, each section containing a regenerator 149 and 150. High pressure fluid is introduced into the upper chamber 21 through line 152 and low pressure fluid discharged through line 153. Fluid passage 154 connects chamber 21 with regenerator 149 and fluid passage 155 connects regenerators 149 and 150. A portion of the high pressure fluid which passes through regenerator 149 enters the first refrigeration chamber 156 through heat station 157 while the remainder enters regenerator 150 for passage through heat station 15 to enter the colder refrigeration chamber 22 (FIG. 1).

Heat station 157 is formed of a housing 158, a heavy copper bottom wall 159, the lower portion of refrigerator housing 145, a plurality of annular copper rings 161 and 162, and spacers 163, 164 and 165. The flow path joining regenerator 149 and refrigeration chamber 156 therefore comprises passageway 155, radial passages 170, the shallow circular passage 171, ports 172 and 173, annular passages 170, the shallow circular passage 171, ports 172 and 173, annular passages 174, 175 and 176, upper passage 177, and finally ports 178. As the displacer moves downwardly, sealing ring 180 serves as a means to terminate an annular passage 181 between the lower displacer section 148 and lower housing section 146. This passage 181 maintains fluid communication between radial passages 170 and circular passage 171 throughout the displacer travel. Sealing ring 182 prevents any direct fluid communication between passage 171 and chamber 156.

FIG. 8 is a diagrammatic representation of a cryogenic apparatus 192 (refrigerator or liquefier) incorporating heat stations of this invention used to cool a fluid circulating in a Joule-Thomson loop 193. The cryogenic apparatus as shown is constructed in three stages 194, 195 and 196, each succeeding stage delivering refrigeration at a lower temperature through heat stations 197, 198 and 199. In the modification illustrated, the same fluid is used in both the cryogenic apparatus 192 and the Joule-Thomson loop 193, an arrangement which permits the use of a single high pressure fluid source 200 and low pressure discharge reservoir 201. If desirable, a compressor 202 is incorporated in the fluid line between the high pressure and low pressure sides. It is, of course, within the scope of this disclosure to use separate fluids in the refrigerator 192 and in the Joule-Thomson loop 193, in which case separate high pressure fluid sources and low pressure fluid reservoirs would be provided. The high pressure line 205 in the Joule-Thomson loop passes through heat exchangers 206, 207 and 208 for indirect heat exchange with the cold fluid in heat stations 197, 198 and 199 and then through Joule-Thomson heat exchanger 209 prior to expansion in a Joule-Thomson valve 210. The finally cooled fluid (partially liquefied if

desired) is discharged into reservoir 211 and at least a portion of it is returned as cold low pressure gas through the low pressure side 212 of the Joule-Thomson loop where it is used to indirectly precool the high pressure fluid in heat exchangers 209, 215, 216 and 217.

It will be seen that by providing the unique flow path in the heat station, it is possible to obtain more effective transfer of heat between the moving fluid stream and the components of the heat station which, in turn, are used to transfer the heat to a load, such as a maser or infrared detection device or to fluid in a Joule-Thomson loop. Since there is no material increase in the size or void volume, it will be seen that it is possible to obtain improved heat transferability within essentially the same structure of the system. In summary, therefore, it is possible to couple a heat load to a moving gas stream and obtain the maximum refrigeration at a minimum temperature penalty.

We claim:

1. In a cryogenic apparatus in which a refrigerating chamber of variable volume is defined within a fluid tight enclosure housing and is in fluid communication with a fluid flow path in which a fluid stream is circulated, a heat station adapted to effect indirect heat transfer between at least a portion of said fluid stream circulating in said fluid flow path and an external load and comprising means external of said enclosure housing defining narrow fluid passage means around at least a portion of said refrigerating chamber, said narrow fluid passage means within said heat station providing fluid communication between said fluid flow path and said refrigerating chamber.

2. A cryogenic apparatus in accordance with claim 1 wherein said narrow fluid passage means comprises a fluid passage associated with the end of said enclosure housing.

3. A cryogenic apparatus in accordance with claim 1 wherein said narrow fluid passage means comprises at least one annular passage around said enclosure housing.

4. A cryogenic apparatus in accordance with claim 1 wherein said narrow fluid passage means comprises a fluid passage associated with the end of said enclosure housing and a plurality of concentric connected fluid passages around the side of said enclosure housing.

5. A cryogenic apparatus in accordance with claim 1 further characterized by having fluid communication means providing a direct fluid connection between said fluid flow path and said refrigeration chamber and having fluid flow control means.

6. A cryogenic apparatus in which a movable member defines within an enclosure a chamber of variable volume and in which a high pressure expansible fluid is introduced through a fluid flow path into said chamber and then discharged into a low pressure reservoir through said flow path, said flow path incorporating heat storage means as an integral part thereof; said flow path being characterized by including heat station means comprising means external of said enclosure defining narrow fluid passage means around at least a portion of said refrigerating chamber, said narrow fluid passage means providing at least a portion of a fluid connection between said heat storage means and said refrigeration chamber.

7. A cryogenic apparatus in accordance with claim 5 wherein said heat storage means is located within said movable member.

8. A cryogenic apparatus in accordance with claim 7 further characterized by having a fluid channel incorporating check valve means adapted to provide direct fluid communication between said heat storage means and said chamber for high pressure fluid entering said chamber.

9. A cryogenic apparatus in which a movable member defines within one end of a cylindrical enclosure a chamber of variable volume and in which a high pressure expansible fluid is introduced through a fluid flow path into said chamber to be expanded and then discharged through said flow path, said flow path incorporating heat storage means as an integral part thereof, and including heat station means, said heat station means comprising in combination

a. a heat station housing surrounding at least portion of said one end of said enclosure and defining with the external walls of said enclosure annular passage means and a substantially circular passage at the end of said enclosure in fluid communication with said annular passage means;

b. fluid communication means between said heat storage means and said substantially circular passage; and

c. a plurality of fluid ports in said enclosure wall providing fluid communication between said annular passage means and said expansion chamber.

10. A cryogenic device in accordance with claim 9 wherein said annular passage means comprises a plurality of concentric annular passages in fluid communication with each other.

11. A cryogenic apparatus in accordance with claim 9 wherein said heat station housing comprises an annular stainless steel ring, a stainless steel sleeve and a copper plate joined in fluidtight relationship.

12. A cryogenic apparatus in accordance with claim 9 wherein said annular passage means and said circular passage substantially surround that portion of said wall which defines said chamber at maximum volume.

13. A cryogenic apparatus, comprising in combination

a. a cryogenic multistage refrigerator, in each stage of which is a movable member defining within one end of a cylindrical enclosure a chamber of variable volume and in which a high pressure expansible fluid is introduced through fluid flow path means into each of said chambers to be expanded and then discharged through said flow path means, said flow path means incorporating heat storage means as an integral part thereof;

b. separate heat station means associated with each of said chambers and forming an integral part of said flow path means, each of said heat station means comprising in combination

1. a heat station housing surrounding at least a portion of said one end of said enclosure and defining with the external walls of said enclosure narrow fluid passage means, and

2. fluid communication means between said heat storage means and said narrow fluid passage means and between said narrow fluid passage means and said chamber with which said heat station means are associated.

14. A cryogenic apparatus in accordance with claim 13 wherein said narrow fluid passage means comprise annular passage means surrounding each of said enclosures and passage means essentially corresponding to the bottom portion of said external wall of each of said enclosures.

15. A cryogenic apparatus in accordance with claim 13 including heat exchange means associated with each of said heat stations means and adapted to effect indirect heat exchange with a fluid circulating through said heat exchange means.

16. An apparatus in accordance with claim 15 wherein said heat exchange means are integral parts of a Joule-Thomson loop.