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Dehne

[11] **3,793,846**

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[54] **DECONTAMINATION METHOD AND APPARATUS FOR CRYOGENIC REFRIGERATORS**

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[52] **U.S. Cl.** **62/6,** 62/85, 62/474

[51] **Int. Cl.** **F25b 9/00**

[58] **Field of Search** 62/6, 85, 475, 474

[56] **References Cited**

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[57] **ABSTRACT**

Cryogenic refrigerator system is provided with a contaminant adsorber in the cold region of the refrigerator which can be selectively connected into the cryogen gas circuit in such a position as to receive warm gas passing out of the regenerator to purge the regenerator into the adsorber.

13 Claims, 4 Drawing Figures

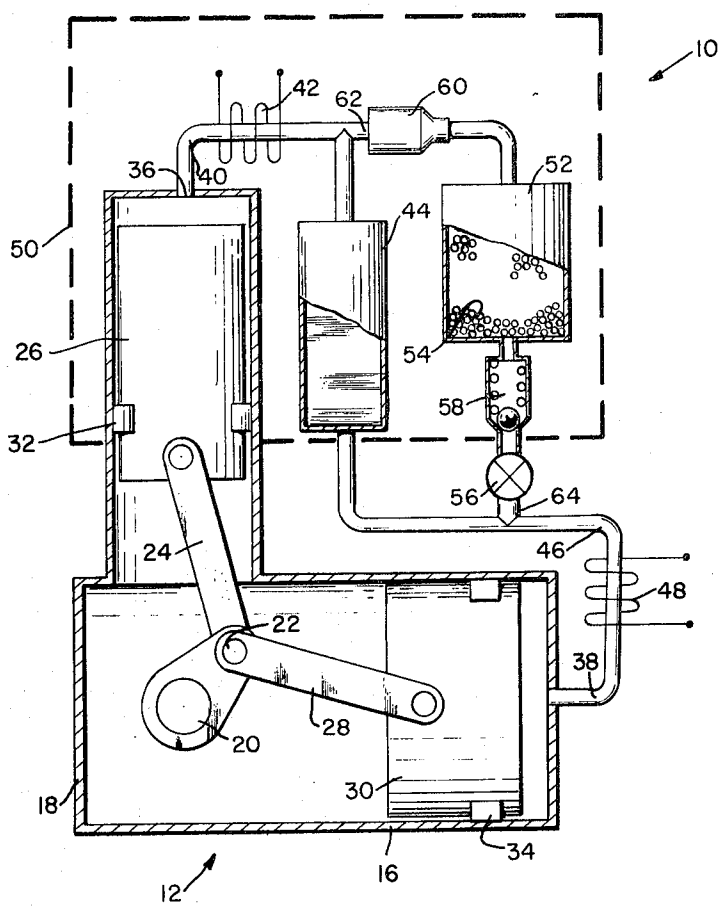


Fig. 1.

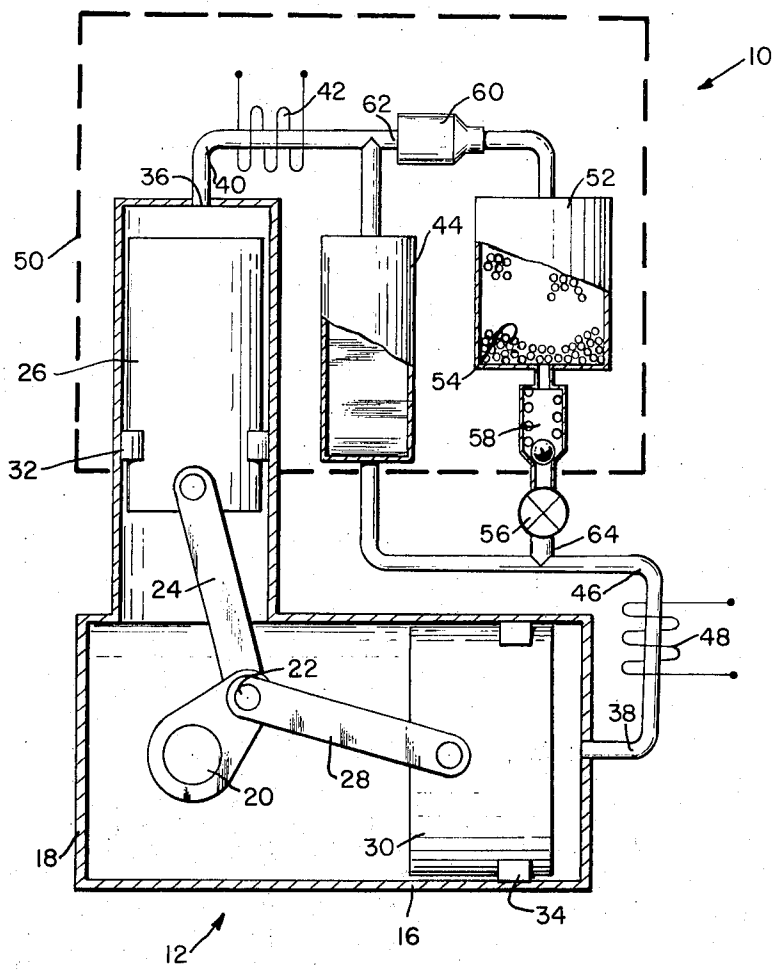

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Fig. 2.

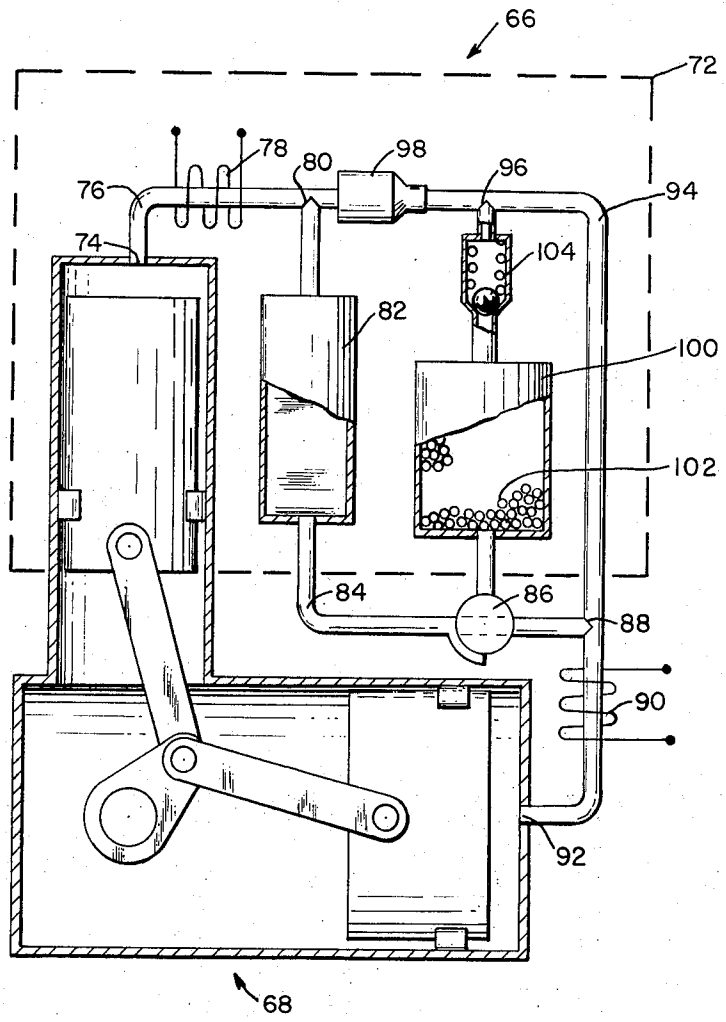


Fig. 3.

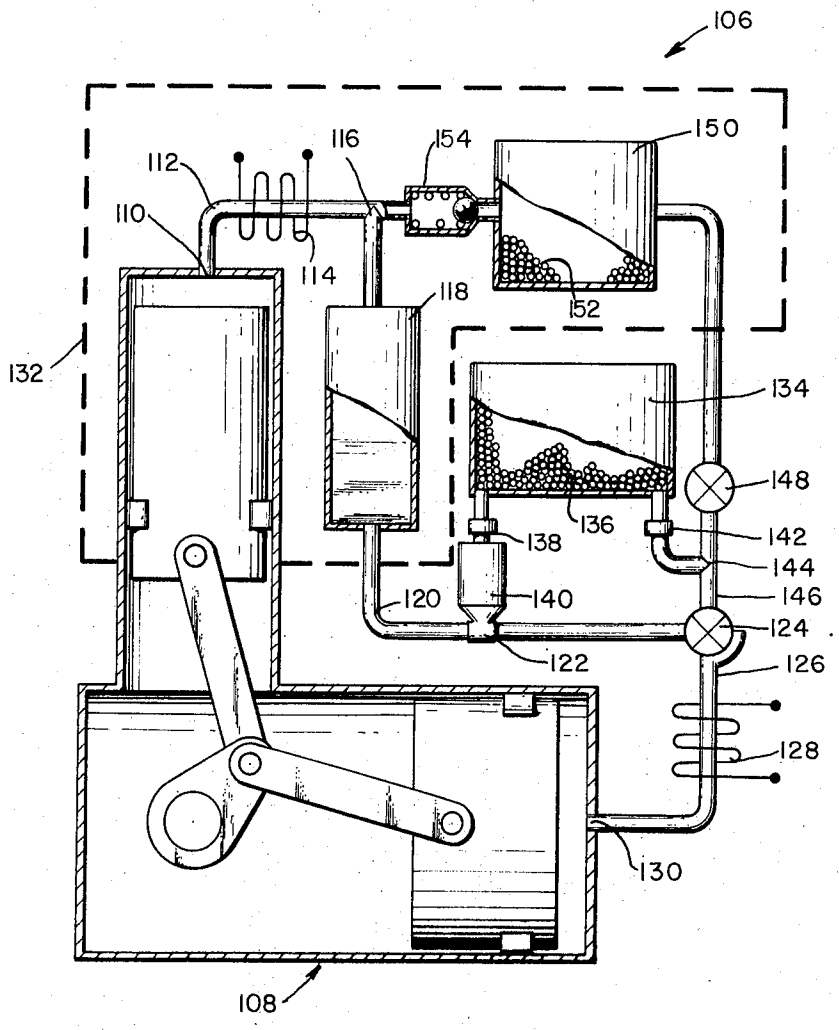
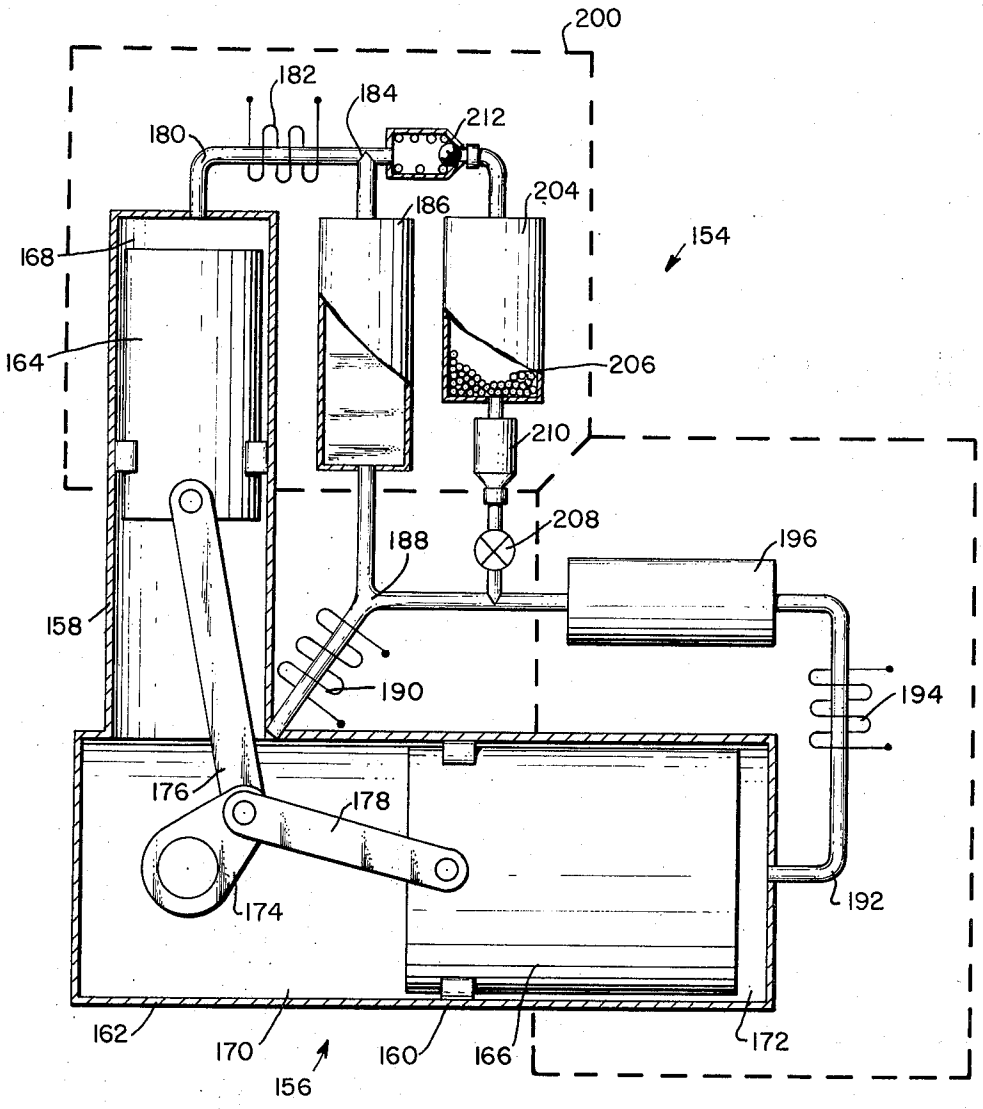

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Fig. 4.


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DECONTAMINATION METHOD AND APPARATUS FOR CRYOGENIC REFRIGERATORS

BACKGROUND

This invention is directed to a cryogenic refrigerator system which includes a contaminant adsorber in the cold part of the system.

The efficiency of cryogenic refrigerators is very critical, because small losses at cryogenic temperature levels cause cycle inefficiency which results in a reduction in refrigeration capability. When the refrigeration system is designed for a particular load, this means that the temperature at the load will increase. In miniaturized equipment, over-design for providing excess capacity to overcome efficiency losses is undesirable.

Regenerators have temperature gradients and, as the cryogen carrying contaminants passes therethrough, the contaminants settle out as liquids or solids along the length of the regenerator. This contamination adversely effects regenerator performance, because it clogs flow passages. The clogged flow passages cause increase in pressure drop and cause reduced heat exchange with the regenerator matrix material. Both degrade efficiency. Furthermore, is some cases the contaminants coat the surfaces of the regenerator matrix to degrade heat exchange. With continually reversing regenerator cycles, the contaminants tend to move toward the cold end where they finally remain located, because the temperature does not sufficiently rise to purge them. During the portion of the cycle where warm gas is leaving the warm end of the regenerator, the contaminants in the regenerator are not swept out, because they are located at a point in the regenerator where the partial pressure thereof is substantially zero.

K. W. Cowans et al., U.S. Pat. No. 3,282,064 illustrates the prior art where a bypass adsorber is connected between the crankcase and warm end of a Stirling cycle refrigerator.

SUMMARY

In order to aid in the understanding of this invention, it can be stated in essentially summary form that it is directed to a decontamination method and apparatus for cryogenic refrigerators. It comprises a cryogenic refrigerator system which includes a contaminant adsorber positioned in the cold portion of the refrigerator and connected to selectively transmit gas to the cold side of the refrigerator so that the regenerator is purged with relatively warm gas from the adsorber.

Accordingly, it is an object of this invention to provide a decontamination method which includes selectively directing, relatively warm cryogen gas through a regenerator to at least partially purge the regenerator and then through a contaminant adsorber which is at sub-atmospheric temperature. It is another object to provide a refrigerator apparatus wherein a contaminant adsorber is positioned within the apparatus so that, when the refrigeration apparatus is operating, the contaminant adsorber is at the sub-atmospheric temperature. It is a further object to provide a contaminant adsorber which is connectable to receive relatively warm gas passing it out of a regenerator to collect the contaminants. It is yet another object to provide a refrigeration apparatus which includes an adsorber for collecting contaminants from the refrigerator system, including contaminants in the refrigeration-producing portion of the cryogen gas cycle. Other objects and advantages of this invention will become apparent from the study of the following portion of this specification, the claims, and the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a Stirling refrigerator system having a contaminant adsorber connected thereto, in accordance with the preferred embodiment of my invention.

FIG. 2 is a second embodiment thereof.

FIG. 3 is a third embodiment thereof.

FIG. 4 is a schematic illustration of a Vuilleumier refrigerator system showing a contaminant adsorber connected therein, in accordance with my invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 schematically illustrates a refrigerator system **10** which includes a refrigerator mechanism **12.** In the embodiment illustrated, the refrigerator mechanism **12** is a unitary structure which has a cold cylinder **14** and a compression cylinder **16** secured to a crankcase **18.** Crankcase **18** has a rotary crankshaft **20** therein which is driven by a power source which provides the motive power to the refrigerator. Crank pin **22** on the crankshaft has a connecting rod **24** which connects to cold piston **26.** Cold piston **26** reciprocates in the bore of cold cylinder **14,** as controlled by the rotation of crankshaft **20.** Similarly, connecting rod **28** is interconnected between crankpin **22** and compressor piston **30.** Compressor piston **30** reciprocates in compression cylinder **16** under the control of crankshaft **20.** Seal rings **32** and **34** are respectively mounted upon pistons **26** and **30** and respectively engage within cylinders **14** and **16** to minimize flow of gas from the working chamber so that pressure changes due to piston operation are not degraded. Any flow of oxygen gas from the working chamber into the crankcase volume can be permitted to build up until the crankcase has a mean pressure therein, or the gas in the crankcase can be returned to the working part of the system by means of a return line, as taught in K. W. Cowans et al. Pat. No. 3,282,064. On the other hand, crankcase pressure can be treated in accordance with A. G. Dehne Pat. No. 3,640,082.

The structure thus described comprises the refrigerator mechanism of a Stirling cycle refrigerator. Gas passage **36** in the cold cylinder is connected to gas passage **38** in the compressor cylinder. Line **40** is connected from cold gas passage **36** through cold point **42,** where useful refrigeration is produced. Line **40** is connected to regenerator **44.** The other end of regenerator **44** is connected by line **46** through heat rejection point **48** to hot gas passage **39.** It is at heat rejection point **48** that the heat received at cold point **42** and the heat of compression from system operation is discharged, for example to the ambient. Regenerator **44** is of conventional configuration and, as is appropriate in a miniatured cryogenic systems, may contain metal washers, perforated discs, wire coils, or metal balls.

As described in S. F. Malaker et al. Pat. No. 3,074,244, the system is operated on the Stirling cycle to produce refrigeration. This cycle causes reciprocation of the cryogen gas through regenerator **44,** with a consequent deposition of impurities from the cryogen

gas into the regenerator. While the impurities tend to liquefy or solidify at a particular temperature, which suggests that they move in and out of the warm end of the regenerator, with deposition at a particular cold point in the regenerator, in practice they continually migrate toward the cold end until they are no longer removed by the flow of gas toward the warm end. Thus, the contaminants tend to remain in the regenerator, clog the passages to increase pressure drop, and deposit on the surface, all of which reduce heat transfer. Of course, it is necessary to provide insulation for the cold portions of the system. The dotted box **50** represents the insulated zone which contains the parts at subatmospheric temperature. The insulated zone represented by this box can be in the form of a cold box, dewar, or the like.

The described structure represents a complete Stirling cycle refrigerator which, when operated, produces refrigeration at cold point **42.** Operation is in accordance with the well-known Stirling cycle, as described in Malaker et al. Pat. No. 3,074,244. This includes increase and decrease in gas pressure in the circulating system between passages **36** and **38** and through regenerator **44.** In order to remove contaminants from the system, a contaminant adsorber vessel **52** is provided. It contains adsorber **54** which is a dessicant, molecular sieve, or the like. There are many commercial brands available, such as Linde X13.

Vessel **52** is located within insulated zone **50** so that it is held at cryogenic temperature. At cryogenic temperature, the adsorber material **54** is much more efficient. Vessel **52** is serially connected, with shutoff valve **56** located at ambient temperature and connected to line **46.** Above shutoff valve **56,** in the series connection, is check valve **58,** vessel **52** and check valve **60** connected to line **40.** Shutoff valve **56** can be manually, remotely, or automatically operated. During normal operation of the refrigeration system **10,** valve **56** is closed. The short line **62** between lines **40** and to the check ball in checkvalve **60** and the short line **64** between line **46** and the close valve **56** provide a very small additional volume, with the result that there is little degradation of refrigerator performance, due to additional non-working volume in the system.

Periodically during the normal operation of the refrigerator, when decontamination is desirable, valve **56** is opened. Thereupon, upon the rising pressure portion of the Stirling cycle, checkvalve **56** opens so that vessel **52** receives cryogen therein for adsorption of the contaminants into adsorber **54.** During the decreasing pressure portion of the cycle, the gas in vessel **52** moves through checkvalve **60** and down through regenerator **44.** During the next compression portion of the cycle, gas again moves from line **45** up into the adsorber vessel, with some of the cryogen which has flowed downwardly through the regenerator now passing upwardly through the adsorber. Thus, contaminant adsorption takes place. Furthermore, the gas passing through checkvalve **60** and downward through regenerator **44** during the expansion part of the cycle is relatively warm, as compared to that gas which passes at substantially constant temperature from the cold point **42** into regenerator **44** after the expansion quadrant. Thus, more contaminants are swept downwardly out of the regenerator **44** during this decontamination cycle of operation. While valve **56** is open, refrigeration capability of the refrigerator is degraded, so that the regenerator warms up somewhat to permit purge of the contaminants out of the regenerator into the adsorber.

When as much loss of refrigeration has been caused by the contamination removal cycle as can be tolerated, valve **56** is closed, and the refrigeration system returns to the normal Stirling cycle. Thereupon, it again cools down to the normal operating temperature. Depending upon the thermal mass of the heat load at cold point **42** and its maximum permissible operating temperature, the contaminant removal cycle is periodically actuated for a short time. Operation of the decontaminant removal cycle for not more than 5 seconds does not adversely interfere with the heat load capacity at the cold point, provided that the thermal inertia of the load is sufficiently large. Operation not oftener than once every day is adequate is continuous duty to keep the cryogen gas and the regenerator adequately free of contaminants. Cleanup of the adsorber can be accomplished by purge of hot gas through separate connections when the refrigerator is shut down for other reasons.

FIG. **2** illustrates a refrigerator system **66** which includes a refrigerator mechanism **68.** The mechanism **68** is identical to mechanism **12** and is connected within the refrigeration system to operate on the Stirling cycle. The cold cylinder of the refrigeration mechanism is closed in insulation illustrated by the dotted line box **72.** The cold gas passage **74** is connected by line **76** to cold point **78,** at which point the refrigeration load occurs. The cold point **78** is illustrated as a heat exchanger, but the cold point, like the cold point in refrigerator **10,** can appear as a mounting plate on the end of the cold cylinder, or other convenient refrigeration location. Line **76** passes through tee **80** and is connected to regenerator **82.** Again, the regenerator is the same as regenerator **44.** Line **84** out of the warm side of the regenerator is connected through a three-way valve **86** through tee **88** and heat rejection point **90** to the hot gas passage **92** in the hot cylinder of the refrigerator mechanism **68.** This system works as a Stirling refrigerator, as previously described with respect to refrigeration system **10** and refrigerator mechanism **12.**

With respect to the embodiment of FIG. **1,** it was noted that not all gas passing out of the regenerator passes through the adsorber. To provide a full flow contaminant removal system, the structure of the embodiment of FIG. **2** is provided. Warm gas flow line **94** is connected from tee **88** through tee **96** and through checkvalve **98** to tee **80.** The spring loading of the ball on its seat in checkvalve **98** is sufficiently high to prevent flow through hot gas glow line **94** during normal refrigerator operation, when the valve **86** is turned in the direction illustrated in FIG. **2.** Contaminated adsorber vessel **100,** containing adsorber **102,** the same as adsorber **54,** is connected to the side port of three-way valve **86** and through checkvalve **104** to tee **96.** Vessel **100** is within the cold zone within the insulated zone **72** and preferably has a long outlet pipe to provide a low temperature gradient between the adsorber vessel and the ambient at the three-way valve **86.**

When three-way valve **86** is turned to the vertical position, line **84** is connected through three-way valve **86** to the adsorber vessel **100** and is cut off from tee **88.** When the differential pressure of the hot cylinder, as compared to the cold cylinder, is rising, gas flow proceeds up the line **94** and through checkvalve **98** into re-

generator **82.** Flow continues from the regenerator through line **84** and through three-way valve **86** into adsorber **100.** When the pressure in line **94** decreases below that in adsorber vessel **100,** flow from the adsorber goes upoward through checkvalve **104** and back down through line **94.** With the next pressure increasing part of the cycle, gas in line **94** passes through checkvalve **98** and through regenerator **82** into the adsorber vessel. Thus, upon repetition of this cycle, all gas passing through the regenerator **82** passes into and through the adsorber vessel **100.** The same criteria for operation of the refrigerater system **66** in the contaminant removal mode that are applicable to the embodiment in FIG. **1** are applicable to the embodiment of FIG. **2.** Similarly, adsorber purging has the same criteria. Thus, an advantage of the embodiment of FIG. **2** is that all of the relatively warm gas flowing downward through regenerator **82** passes through the contaminant removal vessel. A disadvantage lies in the fact that the volume of line **84** is added to the system during normal operation, thus reducing cycle efficiency for a particular set of machine-operating criteria. However, the volume of line **94** can be kept minimized.

Refrigeration system **106** is also a Stirling cycle refrigerator having a refrigeration mechanism **108,** the same as refrigeration mechanism **12.** It has a cold gas passage **110** to which is connected line **112** which is connected to the cold point **114** at which the net refrigeration is produced. Line **112** passes through tee **116** to regenerator **118.** The regenerator **118** is the same as regenerator **44.** Line **120** passes out of the warm end of regenerator **118** through tee **122** and into three-way valve **124.** The other side of three-way valve is connected by line **126** through heat rejection exchanger **128** to hot gas passage **130.** The cold end of the cold cylinder and the regenerator are enclosed within the insulated zone illustrated by dotted line box **132.**

Adsorber vessel **134** contains adsorber **136** and is located outside of the insulated zone. Vessel **134** is connected on one side by a self-sealing coupling **138** and through checkvalve **140** to tee **122.** The other end of vessel **134** is connected through coupling **142** to tee **144** in line **146.** Line **146** connects the tee to one side of three-way valve **124.** Line **146** is connected through shut-off valve **148** to adsorber vessel **150** positioned within the insulated zone and cryogenically cooled by the refrigeration of the refrigeration system. The adsorber vessel **150** contains adsorber **152.** Vessel **150** is connected through checkvalve **154** to tee **116.**

In normal Stirling cycle refrigeration operation, valve **148** is closed, and three-way valve **124** connects line **120** to line **126,** as shown on FIG. **3.** When the contaminant removal operating cycle is desired, the shut-off valve **148** is opened, and three-way valve **124** is changed to position where it connects line **126** with line **146.** Now, with an increase in differential pressure in line **126,** as compared to line **112,** warm gas flows up line **146** through adsorber **150,** checkwise **154,** and into regenerator **118.** Now, with a decrease in pressure in line **146** due to the operation of the pistons in the refrigerator mechanism, gas flows from regenerator **118** through line **120** and regenerator vessel **134** out into line **146** and **126.** With the next increase in pressure, warm gas flows upward through line **146,** carrying with it the gas which flowed out of regenerator vessel **134.** The upoward flow again passes through adsorber vessel **150** and checkvalve **154** back into regenerator **118.** With continuous repetition of this cycle, warming gas flows downward through regenerator **118** and successively through contaminant adsorber vessels **134** and **150.** The principle amount of contaminant is removed in vessel **134,** and much of the remainder is removed in vessel **150,** because that second contaminant removal has its adsorber at cryogenic temperatures.

The advantage of a two-adsorber system of this nature is that the major portion of the contaminants can be physically removed by opening couplings **138** and **142** and removal of vessel **134.** A new, clean, prepressurized contaminant adsorber vessel can replace it, or the adsorbent in vessel **134** can be renewed by purging with hot, clean gas.

The refrigeration system **154** of FIG. **4** has some physical resemblance to the Stirling cycle refrigerator described above, by its mechanical structure, interrelationship of parts, and its thermodynamic cycle are quite different. The refrigeration system **154** operates on the Vuilleumier cycle, as taught in Pat. No. 1,275,507. In such a cycle, the refrigeration system has a portion which is at cryogenic temperatures to receive heat from the load to be refrigerated, a portion at temperature above the ambient which serves as the power input to the system, and a portion substantially at ambient, but slightly above ambient to serve as heat rejection to the ambient from both the refrigeration load and the power input heat. A description of the Vuilleumier cycle, as adapted for miniaturized refrigeration equipment, is given in K. W. Cowans reissue Pat. No. RE 27,338.

Referring to FIG. **4,** refrigeration system **154** has a refrigerator mechanism **156** which comprises a cold cylinder **158** and a hot cylinder **160** mounted on a crankcase **162.** Cold displacer **164** is reciprocably mounted in cold cylinder **158** and preferably has a seal ring riding in the cylinder to minimize passage of gas past the displacer. Similarly, hot displacer **166** is reciprocably mounted in hot cylinder **160** with an appropriate seal ring. The displacers divide the volume in the mechanism between cold volume **168,** crankcase volume **170,** and hot volume **172.** Crank **174** has connecting rods **176** and **178** connected to the displacers, in order to maintain their phase relationship. While no power input is required at the crank **174** in a theoretical Vuilleumier machine, a motor is often connected thereto for maintaining the cycle timing and for small amounts of power input or output.

Cold line **180** is connected from cold volume **168** through cold point **182,** which furnishes the refrigeration heat load through tee **184,** regenerator **186,** tee **188,** and heat exchanger **190** which rejects heat to ambient to crankcase volume **170.** On the other side of the machine, hot line **192** connects hot volume **172** through heat input heat exchanger **194,** hot regenerator **196,** and through tee **198** to tee **188.** It is seen that all three volumes are connected together so that, no matter how the displacers are moved, the absolute volume in which the gases are located remains constant. However, increase in pressure is caused by increasing the average temperature of the gas, and this is accomplished by moving the gas through the regenerators into the warmer direction. Similarly, reduction in pressure with a consequent gas expansion and cooling is occasioned by the reduction in temperature caused by moving the gas through the regenerators in the colder direction. As taught in the referenced patents, displacer cy-

cling causes refrigeration. The cold end of the machine is enclosed in cold insulation, represented by the dotted line insulation box **200,** while the hot end of the machine is enclosed in hot insulation, represented by the dotted line insulation box **202.**

Adsorber vessel **204** contains adsorbent **206.** Vessel **204** is serially connected from tee **198** at ambient temperature through shut-off valve **208** and checkvalve **210.** The other end of adsorber vessel **204** is connected through checkvalve **212** to tee **184.** With valve **208** shut off, displacer operation causes flow through cold regenerator **180** and causes increases and decreases in pressure in the system. With valve **208** open, increases in pressure cause flow upward through checkvalve **210** into the adsorber vessel **208.** Following reductions in pressure in the system cause flow from the adsorber vessel **204** and through checkvalve **212** and through tee **184.** Part of this passes downward through regenerator **180** toward tee **190.** On the next pressure increase portion of the cycle, some of this gas moves into vessel **204.** Thus, this is a continuing cycling of cryogen gas downward through cold regenerator **180** and upward through cryogen vessel **204.** By this means, the relatively warm purged gas is supplied to regenerator **180,** and this gas subsequently passes through the adsorber. This system is similar to the system of FIG. **1,** but applied to a different refrigerator cycle. If desired, the systems of FIGS. **2** and **3** could be applied to the refrigerator of FIG. **4,** in similar manner to which they are applied to the Stirling cycle refrigerator of FIGS. **2** and **3.**

This invention having been described in its preferred embodiment, it is clear that it is susceptible to numerous modifications and embodiments within the scope of the invention and without the exercise of the inventive faculty. Accordingly, the scope of this invention is defined by the scope of the following claims.

What is claimed is:

1. An apparatus for decontamination of a cryogenic refrigerator in combination with a cryogenic refrigerator, said cryogenic refrigerator comprising:

a cold cylinder in which refrigerant gas is expanded to produce refrigeration;

a regenerator connected to receive in its cold end cold refrigerant gas from said cold cylinder, said regenerator having a warm refrigerant gas connection on its warm end opposite said cold end;

a refrigerated insulated zone, the improvement comprising:

an adsorber vessel containing an adsorbent for adsorbing contaminants from the refrigerant gas at cryogenic temperatures, a control valve serially connected with said adsorber vessel, said adsorber vessel and control valve combination being connected in parallel to said regenerator, said adsorber vessel being positioned within said insulated zone so that, when said control valve is opened, refrigerant gas flowing from the warm end of said regenerator passes into said refrigerated adsorber vessel.

2. The apparatus of claim **1** wherein said control valve is outside of said insulated zone so that said control valve is substantially unrefrigerated.

3. The apparatus of claim **2** wherein said control valve is a shut-off valve and further including a checkvalve in series with said adsorber vessel and connected to said regenerator.

4. The apparatus of claim **3** wherein said checkvalve is connected between the adsorber vessel and the cold end of said regenerator and is positioned so that refrigerant gas flow can proceed from said adsorber vessel toward the cold end of said regenerator.

5. The apparatus of claim **4** wherein said adsorber vessel is connected to be refrigerated by said cold cylinder.

6. The apparatus of claim **4** wherein there is a second checkvalve in series with said shut-off valve connected therebetween, said adsorber vessel and the warm end of said regenerator, said second checkvalve being positioned to pass refrigerant flow from the warm end of said regenerator into said adsorber vessel.

7. The apparatus of claim **4** wherein said refrigerator apparatus includes a warm cylinder, said control valve being a three-way valve, said three-way valve being connected to the warm end of said regenerator, being connected to said adsorber vessel and being connected to said warm cylinder.

8. The apparatus of claim **7** further including a refrigerant gas line connected between said warm cylinder in parallel to said adsorber vessel and to said checkvalve so that, upon switching said three-way valve from a connection between said warm cylinder and the warm end of said regenerator to a connection between said adsorber vessel and the warm end of said regenerator, warm gas flows said warm cylinder through said by-pass line and through said checkvalve into the cold end of said regenerator and thence into said regenerator vessel.

9. The apparatus of claim **8** wherein said checkvalve is a first checkvalve and there is a second checkvalve, said second checkvalve being positioned between said adsorber vessel and said first checkvalve.

10. The apparatus of claim **4** wherein said adsorber vessel is a first adsorber vessel and wherein there is a second adsorber vessel positioned outside of said insulated zone, said second adsorber vessel being connected between the warm end of said regenerator and said first adsorber so that adsorption of contaminants from the refrigerant gas first occurs into the second adsorber vessel at ambient temperature and then the refrigerant gas flows through said first adsorber vessel or adsorption at cryogenic temperature.

11. The apparatus of claim **4** wherein said refrigerator apparatus is a Stirling refrigerator.

12. The apparatus of claim **4** wherein said refrigerator apparatus is a Vuilleumier cycle refrigerator.

13. The method of removing contaminants from the refrigerant gas in a cryogen refrigerator where the refrigerator includes a cold cylinder, a regenerator connected on one end to the cold cylinder to receive cold refrigerant gas from the cold cylinder and thereby define a cold end on the regenerator, the regenerator also having a warm end connected to ambient temperature, an adsorber vessel serially connected with a control valve and connected in parallel to the regenerator and connected to be refrigerated by the cold cylinder, the process comprising the steps of:

maintaining the control valve closed so that refrigeration is produced at the cold end of the cold cylinder and the adjacent end of the regenerator is cooled, together with reciprocation of refrigerant gas through the regenerator with heat exchange between the refrigerant gas and the regenerator resulting in deposition of contaminants from the re-

frigerant gas in the regenerator, and cooling of the contaminant adsorber vessel; and

opening the control valve so that refrigerant gas passes out of the warm end of the regenerator into the adsorber vessel and from the adsorber vessel through the regenerator from the cold into the warm end thereof so that the regenerator has its contaminants flushed out by relatively warm refrigerant gas passing from the cold end to the warm end of the regenerator and then into the contaminant adsorber vessel.

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