A lower stage chemisorption refrigeration system physically and functionally coupled to an upper stage physical adsorption refrigeration system. Waste heat generated by the lower stage cycle is regenerated to fuel the upper stage cycle thereby greatly improving the energy efficiency of a two-stage sorption refrigerator. The two stages are joined by disposing a first pressurization chamber providing a high pressure flow of a first refrigerant for the lower stage refrigeration cycle within a second pressurization chamber providing a high pressure flow of a second refrigerant for the upper stage refrigeration cycle. The first pressurization chamber is separated from the second pressurization chamber by a gas-gap thermal switch which at times is filled with a thermoconductive fluid to allow conduction of heat from the first pressurization chamber to the second pressurization chamber.
TWO-STAGE SORPTION TYPE CRYOGENIC REFRIGERATOR INCLUDING HEAT REGENERATION SYSTEM

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract, and is subject to the provisions of Public Law 96-517 (35 U.S.C. 202) in which the Contractor has elected not to retain title.

BACKGROUND OF THE INVENTION

The present invention relates to cryogenic sorption refrigeration systems. More specifically, the invention relates to two-stage sorption refrigeration systems.

Sorption refrigeration systems have been developed in the past to provide refrigerators with long lifetimes (e.g., 10 years or more) which will operate with little or no mechanical vibration.

Such refrigerators have been particularly useful in aerospace environments such as on board a space satellite where longevity of the refrigeration is of utmost importance and sensitive equipment must be cooled without vibrational disturbance.

Refrigeration systems employing non-mechanical compressors, generally referred to as sorption refrigerators, employ either a physical adsorption (physisorption) system or a chemical absorption (chemisorption) system.

A chemisorption refrigerator, providing cooling in the temperature range of 55° to 100° K., is disclosed in U.S. Pat. No. 4,697,425 to Jones. The refrigerating unit used in U.S. Pat. No. 4,697,425 is oxygen.

Briefly, in a chemisorption system such as the one disclosed in U.S. Pat. No. 4,697,425, a sorbent material reversibly chemically reacts with oxygen to absorb oxygen at a relatively low first temperature and pressure. When heated to a second temperature, the sorbent releases oxygen at high pressure. A container is provided to contain the oxygen while it is heated. Once an amount of oxygen is adequately pressurized an outlet valve is opened. Oxygen is then directed to direct the pressurized oxygen away from the sorbent material. The oxygen is then subjected to precooling and directed to the high pressure side of a high pressure/low pressure orifice (Joule-Thomson) expansion valve. Heat is absorbed (and cooling takes place) when the pressurized oxygen expands into the low pressure side of the orifice. The oxygen at this point is typically both in liquid and gas phases at a low temperature. A liquid/gas transition chamber is provided for collecting the liquid oxygen. The liquid oxygen is used for cooling such as for the cooling of an infrared sensor. The liquid oxygen, by absorbing heat from the to-be-cooled material, will then boil and leave the transition chamber. On its return path to the container(s) for chemical absorption, the oxygen's temperature will be raised from the low temperature to the first temperature. By providing two containers and alternately heating and cooling the two containers, a continuous source of high pressure high temperature oxygen may be provided.

A. and Blue, G. D., Oxygen Chemisorption Compressor Study for Cryogenic J-T Refrigeration, AIAA 1558 (1987), incorporated herewith by reference. As shown in FIG. 1, a self-contained charcoal/methane upper stage provides precooling to 140° K. for a self-contained oxide chemisorption lower stage. As shown schematically in FIG. 1, the stages operate independently, in a side-by-side fashion. Only the lower temperature portion of the upper stage is in contact with the hot portion of a lower stage 4 to provide precooling of the oxygen.

One of the primary disadvantages of sorption refrigeration systems has been their unusually high power requirements when compared to conventional mechanical refrigeration cooling systems. A two-stage oxide/krypton sorption refrigerator could be expected to require about 155 watts of heat to produce 1 watt of cooling at 65° K. This compares with about 60 watts of power for a mechanical refrigerator.

SUMMARY OF THE INVENTION

The present invention provides a two-stage sorption type cryogenic refrigeration system with greatly improved efficiency.

The present invention further provides a two-stage sorption refrigeration system wherein waste heat generated by a lower stage chemisorption-type cycle fuels an upper stage physisorption-type cycle.

The present invention further provides a two-stage sorption refrigeration system which provides a continuous flow of an upper stage and a lower stage refrigerant.

In the present invention a two-stage sorption refrigeration system includes a container which in turn includes...
a central heater enclosed in sequence by a first pressurization chamber, a gas-gap thermal switch and a second pressurization chamber. The first pressurization chamber contains a first sorbent material which absorbs a first refrigerant at a first temperature and pressure and liberates the refrigerant at a higher temperature. The second pressurization chamber contains a second sorbent material which adsorbs a second refrigerant at a third temperature and pressure and desorbs the second refrigerant at a higher temperature.

In a preferred embodiment of a krypton/oxygen two-stage sorption refrigeration system, two containers each contain central heaters enclosed in sequence by a first pressurization chamber, a first gas-gap thermal switch, a second pressurization chamber, a second gas-gap thermal switch and a radiator. Each of the first pressurization chambers contains a sorbent material which absorbs oxygen gas by chemisorption at a first temperature and pressure and liberates oxygen at a higher temperature. The second pressurization chambers contain a sorbent material which physically adsorbs krypton gas at a third temperature and pressure and desorbs krypton gas at a higher temperature.

Oxygen gas is admitted into the first pressurization chamber of a preselected one of the containers where it is absorbed by the sorbent. The chamber is then heated by the central heater to produce a heated, high pressure oxygen gas which is released into a cooling and expansion system including a precooler chamber where the oxygen’s temperature is reduced to below its critical temperature so as to liquify the oxygen. The liquid oxygen is expanded to provide cooling down to approximately 65°K.

After release of the oxygen from the first pressurization chamber, heat provided by the heater to produce the high pressure oxygen remains in the first pressurization chamber. This waste heat is allowed to conduct across the first gas-gap thermal switch of the preselected container to heat the second pressurization chamber of the preselected container. Krypton gas, previously admitted to the second pressurization chamber and physically adsorbed to the sorbent contained therein, is thereby heated to a temperature where it is desorbed at higher pressure.

Fueled by the heat from the chemisorption stage as described above, high pressure krypton gas is provided with a pressure of 180 atmospheres. The high pressure krypton is released from the second pressurization chamber to a cooling and expansion system where it provides about 135° K. precooling to the flow of oxygen from one of the first pressurization chambers while the oxygen flows through the precooler chamber.

Waste heat from the second pressurization chamber is transmitted across the second gas-gap thermal switch of the preselected container to the radiator of the preselected container so as to allow cooling of the second pressurization chamber.

A preferred embodiment of the present invention in a two-stage oxygen/krypton system thus provides efficient cooling at about 65°K. with additional net cooling at about 135°K.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of the prior art methane/oxygen two-stage sorption refrigeration system as described in Jones, J. A. and Blue, G. D., Oxygen Chemisorption Compressor Study for Cryogenic J-T refrigeration, AIAA 1558 (1987).

FIG. 2 is a schematic diagram of a two-stage sorption refrigeration system according to the preferred embodiment of the present invention.

FIG. 3 is a schematic diagram of a gas-gap thermal switch included in the heat regeneration system utilized by the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The following description is of the best presently contemplated mode for carrying out the present invention. It is to be understood that this description is provided for the purpose of illustrating the general principles of the invention and not for the purpose of limiting the scope of the invention. The scope of the invention is better defined by reference to the accompanying claims.

Pressurization chambers 20 and 20' are made of a material that has high strength at high temperature, for example, inconel. The pressurization chambers 20 and 20' function together to provide a continuous flow of a high pressure first refrigerant gas. Each chamber 20 and 20' includes a solid material which acts as a sorbent, preferably praseodymium/cerium oxide (PCO), which will chemically absorb oxygen at low pressures (e.g. 0.023 atmospheres) at approximately 300° C. (573°K.) and will liberate or desorb oxygen at higher pressures (e.g. 22 atmospheres or above) when the material is heated to approximately 600° C. (873°K.). The heaters 14 and 14' are provided to heat the material in subchambers 20 and 20'. A suitable heater includes a heating element which is able to provide the necessary high temperature. Cartridge heaters may be employed.

The refrigeration system of the invention operates so that as one of the pressurization chambers 22 and 22' is being heated, the other chamber is being cooled. Additional chambers may also be added and timed in a staggered fashion. A microprocessor control system is employed to determine the sequence and duration of operation of the heaters. Each of the chambers 20 and 20' is provided with respective inlet check valves 24 and 24' and respective outlet check valves 22 and 22' and respective check valves 24 and 24' of a type well known to those skilled in the art. The outlet valves 24 and 24' are connected to a first side 30a of a first heat exchanger 30 by a suitable length of tubing 32. A suitable heat exchanger may comprise two tubes soldered together. However, the heat exchangers may be formed by any available counterflow structures.

The first heat exchanger side 30a couples as shown to a 200° K. radiator 34 and, thereafter, in series to a first side 36a of a second heat exchanger 36, a precooler chamber 38, a first side 40a of a third heat exchanger 40 and the high pressure side of a first Joule-Thomson (J-T) valve 42. The low pressure side of the J-T valve...
be  

The fourth heat exchanger side of refrigerant, krypton gas. Each chamber contains a mass of sorbent material, such as charcoal, or more preferably, a monolithic porous carbon such as saran carbon type A (the inert pyrolysis product of essentially 100% polyvinylidene chloride, PVDC).

The sorbent material will physically adsorb krypton gas at low pressures (e.g. 3 atm). The krypton gas will be desorbed or liberated at high pressure (e.g. 40 atm) when heated to 300° C. (573° K.).

Each of the chambers 20 and 20' further include third and fourth pressurization chambers 50 and 50', respectively. Chambers 50 and 50' can be made of a lower melting point material than chambers 20 and 20', for example, stainless steel. Chambers 50 and 50' function together to provide a continuous flow of a high pressure second refrigerant, krypton gas. Each chamber contains a mass of sorbent material such as charcoal, or more preferably, a monolithic porous carbon such as saran carbon type A (the inert pyrolysis product of essentially 100% polyvinylidene chloride, PVDC).

The sorbent material will physically adsorb krypton gas at low pressures (e.g. 3 atm). The krypton gas will be desorbed or liberated at high pressure (e.g. 40 atm) when heated to 300° C. (573° K.).

The fourth heat exchanger side of a fourth heat exchanger 60a consists of a continuous flow of a high pressure third refrigerant, krypton gas. Each chamber contains a mass of sorbent material, such as charcoal, or more preferably, a monolithic porous carbon such as saran carbon type A (the inert pyrolysis product of essentially 100% polyvinylidene chloride, PVDC).

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The sorbent material will physically adsorb krypton gas at low pressures (e.g. 3 atm). The krypton gas will be desorbed or liberated at high pressure (e.g. 40 atm) when heated to 300° C. (573° K.).
chamber is pressurized to a desired pressure the outlet valve 24 is automatically opened and the gas is routed to the first heat exchanger 30.

During the time the oxygen and sorbent are being heated in chamber 20, krypton gas is admitted into chamber 50 at a third temperature $T_3$ of, for example, 0°C (273 K) and a third pressure $P_3$ of, for example, 3 atm through the inlet check valve 52. The corresponding outlet check valve 54 is closed at this time and the gas-gap thermal switch 80 remains devoid of gas.

A substantial amount of the krypton entering the chamber 50 is adsorbed by the sorbent material in chamber 50. After a predetermined length of time has elapsed and/or a predetermined amount of krypton gas is adsorbed, the inlet valve 52 is automatically closed. The vacuum and gold-plated walls of the gas-gap thermal switch 80 minimize conduction and/or radiation of heat from the chamber 20 to the chamber 50. Therefore, the krypton gas remains at the third temperature $T_3$. To ensure that minimal heat radiates across the gas-gap thermal switch, a number of thin shields coated with a reflective material may additionally be disposed throughout the switch 80. Again gold is the preferred reflective material since it will withstand high temperatures and is unlikely to oxidize and is therefore especially suitable for placement in harsh environments or for use in applications where parts may not readily be replaced.

After all or substantially all of the high pressure oxygen has been released from the chamber 20, the inlet valve 100 of gas-gap thermal switch 80 is automatically triggered to open. The valve may be triggered by a timer or alternatively by a temperature sensor located in pressurization chamber 20, which triggers the valve when the sorbent with absorbed oxygen has reached its second temperature $T_2$. Once the inlet valve 100 is opened, a small amount of gas from the fluid supply bottle 104 enters the switch 80 at a pressure of approximately 10 torr. The outlet valve 102 is closed at this time. After a predetermined amount of gas has entered the switch 80 or after expiration of a predetermined length of time, the inlet valve 100 is automatically closed and the gas is trapped in the switch 80 for a predetermined length of time. Presence of a gas having good thermal conductivity in the switch 80 allows an amount of heat $Q_1$ from pressurization chamber 20 to conduct across the switch 80 to pressurization chamber 50 where it will raise the temperature of the second sorbent surface and raises its pressure from the third pressure $P_3$ of approximately 3 atm to a higher fourth pressure $P_4$ of, for example, 40 atm. Once the selected adsorption chamber 50 is pressurized to a desired pressure $P_4$, its outlet check valve 54 is opened automatically and the pressurized krypton gas is routed to the fourth heat exchanger 60.

After all or substantially all of the high pressure krypton gas has been released from the chamber 50, the inlet valve 100 of the second gas-gap thermal switch 82 is automatically triggered to open. Again the valve may be triggered by a timer or a temperature sensor. Once the inlet valve is opened, a small amount of gas from the fluid supply bottle 104 enters the switch 82 at a low pressure of approximately 10 torr. The outlet valve 102 is closed at this time. The inlet valve 100 is automatically closed after a predetermined amount of gas has entered the switch 82 or after expiration of a predetermined length of time, and the gas is trapped in the switch 82 for a predetermined length of time. Presence of the gas in the switch 82 allows an amount of heat $Q_2$ from the pressurization chamber 50 to conduct across the switch 82 to radiator saddle 90a of the 0°C (273 K) radiator 90. Chamber 50 is thereby cooled.

After expiration of a predetermined length of time, i.e. the time necessary for the temperature of chamber 50 to drop down to the third temperature $T_3$ of approximately 0°C (273 K), the outlet valve 102 is automatically opened and the gas is evacuated from the switch 82 through a pipe 108 directly to the vacuum of space or, if used on earth, with a mechanical vacuum pump. After all of the thermoconductive gas has been evacuated from the switch 82, outlet valve 102 is closed and switch 82 is again devoid of gas, in a state of vacuum. Any heat entering chamber 50 subsequently will not be lost to radiator 90 by radiation across switch 82 until thermoconductive gas is again admitted to switch 82.

Once the sorbate in chamber 50 has been cooled to the third temperature $T_3$, check valve 52 will again be triggered to open, an amount of krypton will be admitted and the upper stage sorption cycle will be repeated.

The pressurized krypton gas released from chamber 50 and routed to the fourth heat exchanger 60 is liquefied at 200°K as it travels through the 200°K radiator 64. The gas then flows through the fifth heat exchanger 66 and the J-T valve 68 where it is expanded to provide
cooling at approximately 135° K. The krypton is collected in the second liquid/gas transition chamber 70 where it acts as a refrigeration upper stage for 135° K. precooling of the oxygen flowing through precooling chamber 38. At 135° K. and 22 atm pressure the oxygen will be liquefied.

The dual containers 10 and 10’ are preferably operated in alternating fashion so that while oxygen is being admitted into the cooled chamber 20 for absorption and heating, pressurized oxygen gas is being released from chamber 20 and while krypton gas is being admitted into chamber 50 for adsorption and heating, pressurized krypton gas is being released from chamber 50. In order to allow for differences in timing between the krypton gas entering chamber 50 and the krypton gas leaving chamber 50, a high pressure surge volume chamber 59c and a low pressure surge volume chamber 59b may be employed. These allow either high pressure or low pressure krypton to be stored temporarily if there are any absorbing/desorbing cycle mismatches. In this fashion, a substantially continuous flow of oxygen and krypton refrigerants can be maintained to thereby provide a substantially constant refrigeration capacity.

The refrigeration adsorption cycle as described above provides 1 watt of precooling to the oxygen stage plus an additional approximately 0.5 watt of cooling at 135° K. The precooled, liquefied oxygen will in turn be expanded to provide 1 watt of cooling at 65° K. as it flows through the third heat exchanger 49, the first J-T valve 42 into the first liquid/gas transition chamber 44. Table 1 (below) summarizes the approximate net power requirements, i.e. watts required to be input to produce 1 watt of cooling, of each of the stages of a two-stage sorption refrigeration system operated side-by-side and of a system utilizing the dual container arrangement with regeneration of heat system as provided by the present invention.

### Table 1

<table>
<thead>
<tr>
<th>Stage</th>
<th>Net Power Required (watts per each watt of cooling)</th>
<th>System of Present Invention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Stage</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>Adsorption Cycle</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>Lower Stage</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>Chemosorption Cycle</td>
<td>155</td>
<td>95</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>155</strong></td>
<td><strong>95</strong></td>
</tr>
</tbody>
</table>

It has been calculated that the side-by-side arrangement of a two-stage sorption refrigeration system has total power requirement, excluding precooling at 200° K. of about 155 watts of heat for production of 1 watt of cooling at 65° K. The dual container arrangement with heat regeneration system, on the other hand, has been calculated to have a total power requirement, excluding precooling at 200° K., of about 95 watts of heat for production of 1 watt of cooling at 65° K. plus production of 0.5 watt of excess cooling at 135° K. Thus, the present invention provides a substantial net power saving of approximately 60 watts per watt of cooling by virtue of its unique arrangement of the pressurization chambers allowing utilization of a heat regeneration system.

The unique design of the present invention has approximately the same power requirements as mechanical refrigeration systems for one watt of cooling at 65° K. plus 0.5 watt of cooling at 135° K. However, the sorption refrigerator of the present invention has the multiple advantages of employing essentially no wear-related moving parts and therefore having a potentially very long life and operating with no measurable vibration.

In addition to the above described preferred embodiment, the heat regeneration system may be expanded to include a higher temperature gas cycle (600° C. to 900° C.) to fuel with its waste heat a lower stage sorption refrigeration cycle, which, in turn, fuels with its waste heat an upper stage sorption refrigeration cycle.

For example, a manganese nitride-nitrogen cycle may be added to the system. In such a system, the first and second containers 10 and 10’ each include a third pressurization chamber. These third pressurization chambers are made of a very high strength material, such as MAR-M-26 alloy, and function together to provide a continuous flow of a high pressure third refrigerant, nitrogen. Each of the third pressurization chambers includes a material which acts as a sorbent, preferably manganese nitride, which will chemically absorb nitrogen at low pressures (e.g. 0.2 atm) at approximately 625° C. (998° K.) and will liberate or desorb nitrogen at higher pressures (e.g. 63 atm) when the material is heated to approximately 950° C. (1223° K.).

In a system including three pressurization chambers, the third pressurization chamber directly surrounds a central heater having a heating element able to provide temperatures to approximately 950° C. The third pressurization chamber is surrounded in sequence by a first gas-gap thermal switch, the first pressurization chamber, a second gas-gap thermal switch, the second pressurization chamber, a third gas gap thermal switch and a radiator providing cooling at approximately 9° C. The high pressure flow of nitrogen generated by the third pressurization chamber is expanded by an expansion system similar to the expansion system provided for expanding the high pressure flow of oxygen from the first pressurization chamber to provide one watt of cooling at approximately 80° K. As in the oxygen expansion system, the expanded krypton provides precooling of the nitrogen to 135° K. After the high pressure flow of nitrogen has been released from the third pressurization chamber, the remaining waste heat is allowed to conduct across the first gas-gap thermal switch, in a manner described previously, to heat the first sorbent in the adjacent first pressurization chamber. Inclusion of the manganese nitride-nitrogen cycle as described has been calculated to offer an additional net power savings of approximately 15%.

Other changes in the details of the preferred embodiment described may be made and such alternate embodiments are within the scope of the present invention. Therefore, the scope of the present invention should not be limited to the above detailed description but should rather be defined more broadly in light of its spirit, the accompanying claims and equivalents thereof.

We claim:

1. A two-stage sorption cryogenic refrigeration system adapted for use with a first refrigerant and a second refrigerant comprising:
   (a) a first container comprising:
      (i) a first pressurization chamber and a second pressurization chamber, the first pressurization chamber being disposed within the second pressurization chamber and the first pressurization chamber containing a first sorbent material for sorbing the first refrigerant, the second pressur-
The refrigeration system of claim 7 wherein the means for cooling the respective second pressurization chambers are interconnected and are disposed around the respective second gas-gap thermal switches.

9. The refrigeration system of claim 8 wherein the first and second sorbent materials contained in the respective second pressurization chambers is capable of chemically absorbing the first refrigerant at a first pressure and a first temperature and is capable of desorbing the first refrigerant at a second pressure when heated to a higher second temperature, wherein the first sorbent material is heated to the second temperature by conduction and radiation of a first amount of heat from the heating means and wherein said first sorbent material is cooled to the first temperature when a second amount of heat is conducted across the first gas-gap thermal switch to the second pressurization chamber while said first gas-gap thermal switch is filled with a small amount of thermoconductive fluid from the fluid supply means.

10. The refrigeration system of claim 6 wherein the first sorbent material contained in the first pressurization chamber is capable of chemically absorbing the first refrigerant at a first pressure and a first temperature and is capable of desorbing the first refrigerant at a second pressure when heated to a higher second temperature, wherein the first sorbent material is heated to the second temperature by conduction and radiation of a first amount of heat from the heating means and wherein said first sorbent material is cooled to the first temperature when a second amount of heat is conducted across the first gas-gap thermal switch to the second pressurization chamber while said first gas-gap thermal switch is filled with a small amount of thermoconductive fluid from the fluid supply means.

11. The refrigeration system of claim 10 wherein the first sorbent material contained in the second pressurization chamber is capable of physically adsorbing the second refrigerant at a first pressure and a first temperature and is capable of desorbing the second refrigerant at a second pressure when heated to a higher second temperature, wherein the second sorbent material contained in the second pressurization chamber is heated to the second temperature by conduction and radiation of a first amount of heat from the heating means and wherein said second sorbent material is cooled to the first temperature when a second amount of heat is conducted across the first gas-gap thermal switch to the second pressurization chamber while said second gas-gap thermal switch is filled with a small amount of thermoconductive fluid from the fluid supply means.

12. The refrigeration system of claim 11 wherein the first refrigerant is comprised essentially of oxygen.

13. The refrigeration system of claim 12 wherein the second refrigerant is comprised essentially of krypton.

14. The refrigeration system of claim 13 wherein the first temperature is approximately 753° K., the first pressure is approximately 0.023 atm, the second temperature is approximately 873° K., the second pressure is approximately 22 atm, the third temperature is approximately 273° K., the third pressure is approximately 3

15. The refrigeration system of claim 14 wherein the first temperature is approximately 753° K., the first pressure is approximately 0.023 atm, the second temperature is approximately 873° K., the second pressure is approximately 22 atm, the third temperature is approximately 273° K., the third pressure is approximately 3

16. The refrigeration system of claim 15 wherein the first and second pressurization chambers is capable of chemically absorbing the first refrigerant at a first pressure and a first temperature and is capable of desorbing the first refrigerant at a second pressure when heated to a higher second temperature, wherein the first sorbent material is heated to the second temperature by conduction and radiation of a first amount of heat from the heating means and wherein said first sorbent material is cooled to the first temperature when a second amount of heat is conducted across the first gas-gap thermal switch to the second pressurization chamber while said first gas-gap thermal switch is filled with a small amount of thermoconductive fluid from the fluid supply means.

17. The refrigeration system of claim 16 wherein the first sorbent material contained in the second pressurization chamber is capable of physically adsorbing the second refrigerant at a first pressure and a first temperature and is capable of desorbing the second refrigerant at a second pressure when heated to a higher second temperature, wherein the second sorbent material contained in the second pressurization chamber is heated to the second temperature by conduction and radiation of a first amount of heat from the heating means and wherein said second sorbent material is cooled to the first temperature when a second amount of heat is conducted across the first gas-gap thermal switch to the second pressurization chamber while said second gas-gap thermal switch is filled with a small amount of thermoconductive fluid from the fluid supply means.

18. The refrigeration system of claim 17 wherein the first refrigerant is comprised essentially of oxygen.

19. The refrigeration system of claim 18 wherein the second refrigerant is comprised essentially of krypton.
atm, the fourth temperature is approximately 555° K. and the fourth pressure is approximately 40 atm.

15. The refrigeration system of claim 14 wherein the first refrigerant generated by the first pressurization chamber provides cooling at 55° to 90° K.

16. The refrigeration system of claim 15 wherein the second refrigerant generated by the second pressurization chamber provides precooling of the first refrigerant at 130° to 150° K.

17. The refrigeration system of claim 16 wherein the thermoconductive fluid in the fluid supply means which fills the first and second gas-gap thermal switches to allow conduction of heat across said switches is selected from the group consisting of helium, nitrogen, oxygen and hydrogen.

18. In a method for providing cryogenic cooling by a two-stage sorption refrigerator wherein a first refrigerant is generated by a lower stage sorption cycle when a first sorbent is heated after sorbing the first refrigerant and a second refrigerant is generated by an upper stage sorption cycle when a second sorbent is heated after sorbing the second refrigerant and wherein the second refrigerant generated by the upper stage sorption cycle precools the first refrigerant generated by the lower stage sorption cycle, the improvement comprising the steps of:

(a) regenerating waste heat used for heating the first sorbent while the first refrigerant was sorbed thereon by providing the waste heat via thermal conduction means to heat the second sorbent while the second refrigerant is sorbed thereon, whereby the second refrigerant is desorbed at high pressure; and

(b) the step of expanding the high pressure second refrigerant to provide precooling of the lower stage sorption cycle.

19. The method of claim 17 wherein the step of regenerating the heat comprises passing the heat through a gas-gap thermal switch by filling the switch with a conductive fluid whereby the conductive fluid conducts heat to the second sorbent material.

* * * * *
UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,875,346
DATED : October 24, 1989
INVENTOR(S) : Jack A. Jones, Liang-Chi Wen and Steven Bard

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, item [54] and column 1, lines 2, 3 and 4:
Title should be: TWO-STAGE SORPTION TYPE CRYOGENIC REFRIGERATOR INCLUDING HEAT REGENERATION SYSTEM

Signed and Sealed this
Twenty-seventh Day of November, 1990

Attest:
HARRY F. MANBECK, JR.
Attesting Officer
Commissioner of Patents and Trademarks