

United States Patent

Daniels

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[54] THERMAL REGENERATOR

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[52] U.S. Cl. 165/10, 62/6

[51] Int. Cl. F28d 17/00

[58] Field of Search 165/4, 10; 62/6

[56] References Cited

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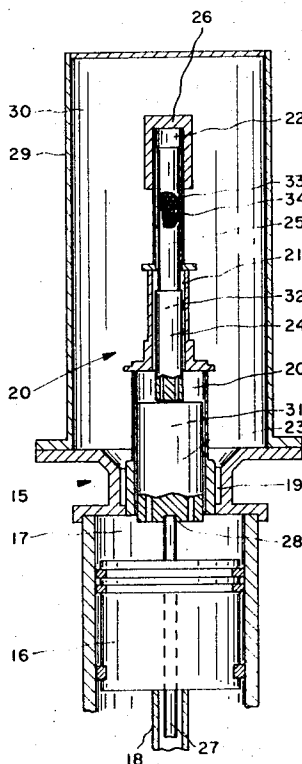
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[57] ABSTRACT

A thermal regenerator having a matrix of a plurality of hollow, carbon, micro-spheres which are permeable to and contain a gas such as helium; the matrix having low heat conductivity between the carbon spheres, but high heat capacity of the helium which increases as temperatures decrease from 40° K. to about 9° K.

14 Claims, 3 Drawing Figures



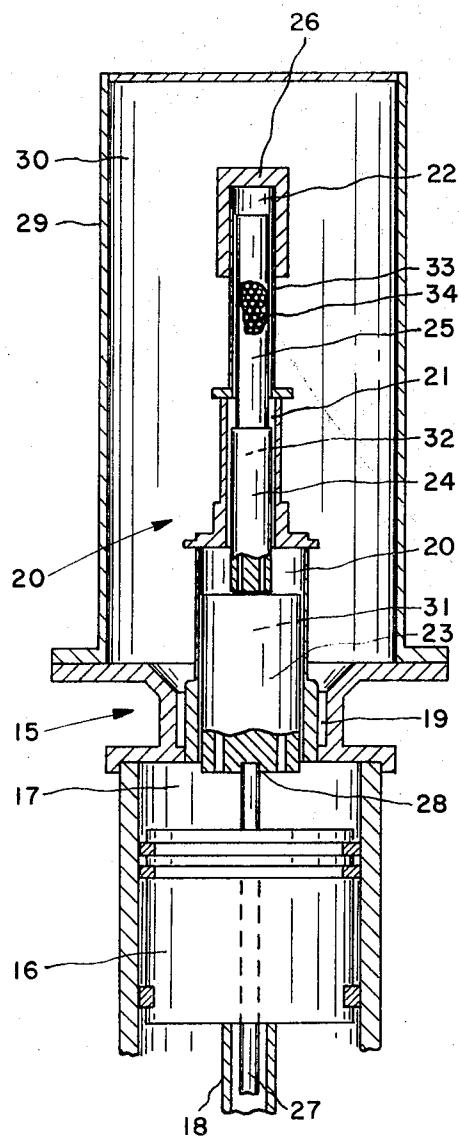


Fig. 2

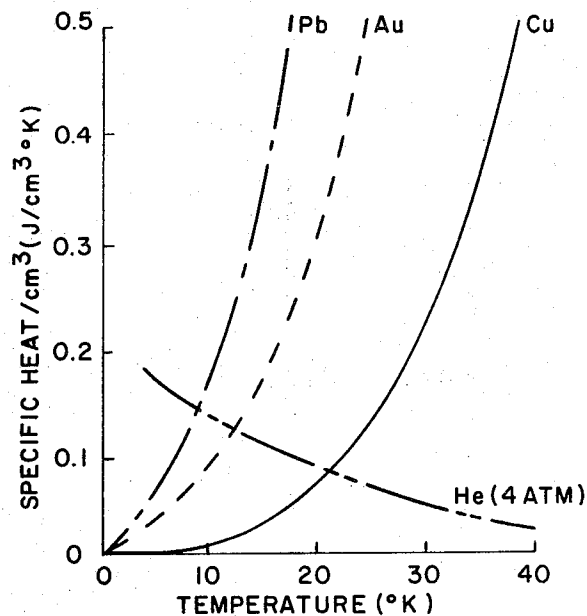


Fig. 1

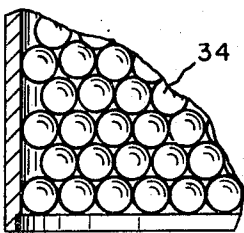


Fig. 3

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AGENT

THERMAL REGENERATOR

BACKGROUND OF THE INVENTION

In cryogenic refrigerators such as those operating on a regenerative cycle, as the Stirling cycle, the essential 'regenerator' component can be a very limiting factor as regards the overall efficiency of the apparatus, the lowest temperature which can be reached, and the cold-production capacity of the apparatus. Typically in these devices a quantity of gas such as helium is transported through a series of stages, namely compression, then cooling to remove heat of compression, followed by flowing the gas through a regenerator where a significant quantity of heat is absorbed from the gas and stored; next there is expansion of the gas to its lowest temperature where cold is produced, and finally re-cycling the gas back through the regenerator where it re-acquires the heat previously stored there, and returning the gas to the compression chamber to begin a new cycle. Regenerators for apparatus as described above have been made of a variety of materials and in a variety of configurations. In each case the design criteria included one or more of the following factors: the regenerator should have high heat-capacity at the cryogenic operating temperatures, but low heat conductivity from the hot side to the cold side; the regenerator should have low resistance to flow, but also be reasonably small and light; and finally cost and complexity should be minimized.

It has been found that materials such as copper, gold and lead have very high heat capacities at temperatures below 40° K., and accordingly these materials have been commonly used in the manufacture of prior art regenerators. More particularly these materials have been formed into matrices comprising wire, mesh or gauze, or a bundle of fibers, or solid spheres, or metal pellets secured to a non-heat-conductive spiral band of paper, with the metal elements absorbing heat upon contact with the gas flowing through or about them. Certain of the above regenerator structures are disclosed in U.S. Pat. Nos. 2,797,539; 3,339,627; and 3,384,157 and in other prior art publications, with complex equations having been evolved in attempts to improve regenerative characteristics; however in all known devices of this general type the ultimate efficiency has been limited by the fact that the specific heat of materials, even including lead, at cryogenic temperatures diminishes as temperatures decrease, and decline to almost zero at temperatures below 10° K. Consequently, despite the many different shapes and arrangements of regenerators, this specific heat limitation has persisted as factor affecting performance of regenerative-cycle devices and refrigerators.

SUMMARY OF THE NEW INVENTION

According to the new invention there is provided a regenerator having a higher specific heat at temperatures below 10° K. than previously available. This invention became possible with the development of hollow carbon spheres and the discovery that a gas such as helium could be diffused into and retained in the spheres. While heat can be stored in the helium within a plurality of adjacent spheres, the heat is not readily transferred between spheres through their carbon walls, so that there is little heat, or cold leakage between the hot and cold sides of the new regenerator.

When the new regenerator is situated either in a movable displacer or at a fixed location in a regenerative-cycle refrigerator, a working gas such as helium is flowed through the regenerator matrix of helium-impregnated carbon microspheres where there is heat transfer through the walls of the carbon spheres, and heat storage by the helium within the walls. Great heat capacity of the new matrix is obtained because of the unique specific heat characteristics of helium gas which increases as temperature decreases; thus the specific heat v. temperature curve of helium gas in generally opposite that of the three commonly used matrix materials, copper, gold and lead. At 6° K. for example, the specific heat of copper declines to almost zero, and lead to about 0.09J/cm³°K., while the specific heat of helium increases to

about 0.165J/cm³°K., or nearly double that of lead. Summarily it can be seen that at a temperature such as 6° K., even lead, one of the best of the known materials for regenerators, has no significant heat capacity left, while helium gas has very substantial heat capacity, which renders the new carbon sphere-helium matrix far more effective than any prior art counterpart.

The invention encompasses the new regenerator and method of making it, and the method of regenerating heat in using this device in a regenerative-cycle thermodynamic refrigerator. For operation at cryogenic temperatures of below 15° K. and particularly at about 6° K., helium is the gas selected for diffusion into the spheres, with some of this gas also adsorbed by the carbon walls of the spheres. In manufacturing these matrices the gas-permeable carbon spheres are first evacuated of air and other gas, and then the helium gas is diffused into the spheres, with evacuation and diffusion both being accelerated if the gas is heated, and diffusion being further accelerated if pressure is applied to the helium.

In a practical application of this invention the new regenerator is incorporated into a regenerative-cycle refrigerator; then working gas is flowed through the regenerator where it contacts the spheres and heat is transferred through the sphere walls into the helium gas where the heat is stored. Subsequently in the thermodynamic cycle, the cooled working gas is flowed back through the regenerator where stored heat is transferred back to the working gas.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a chart showing specific heat vs. temperature curves for helium, lead, gold and copper;

FIG. 2 is a sectional view of a Stirling-cycle refrigerator with a regenerator of this invention, and

FIG. 3 is a fragmentary sectional view of the new regenerator.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The new invention has been developed because of the available properties of helium gas at cryogenic temperatures as shown in FIG. 1, namely high specific heat at low temperature. The specific heats of lead, gold and copper are similar in that they decline steeply with reduced temperature in the range of 0° to 40° K. And, in the area of 6° K., which is of practical interest, the specific heats of gold and copper are almost zero, and that of lead is about 0.08 which is essentially impractical. The chart then shows the remarkably contrasting specific heat curve of helium gas which rises as temperature decreases, and most significantly is about 0.165 at 6° K., or almost double that of lead.

While it was thus known that helium had a high specific heat at the low cryogenic temperatures of interest, there was no known manner of utilizing this property; furthermore since the working gas in typical, Stirling regenerative-cycle refrigerators was also helium, developments in regenerator construction were generally restricted to metal and other solid materials.

By this invention, it was discovered that carbon microspheres having diameter in the range of 90 to 100 microns could be permeated with helium gas after air and any other gas was removed. Then these spheres become the matrix disposed in a housing, to form the regenerator component of a cold-gas refrigerator. By their inherent geometry the spheres will occupy about 63 percent of the volume in which they are housed, as shown in FIGS. 2 and 3. The size of the spheres available, from 5 to 150 microns, and thus the quantity per unit volume of space, affect both potential heat transfer and pressure drop of gas flowing through such a matrix. Smaller spheres permit greater heat transfer, but cause greater pressure drop; while larger spheres result in poorer heat transfer, but a lower pressure drop. These parameters are variable to establish optimum conditions of each refrigerator.

In FIG. 3 the Stirling-cycle refrigerator 15 has a compression piston 16 and compression chamber 17, a piston rod 18,

and a cooler 19. The cold finger 20 has three expansion stages 20, 21, and 22 and correspondingly a displacer with three stepped diameters 23, 24, and 25, and finally freezer 26 adjacent the final expansion stage. A displacer rod 27 extending through the compression piston and rod, 16 and 18, is connected to the base of the displacer at 28, and encompassing the cold finger 20 is outer casing 29 and vacuum space 30.

Within the displacer sections are regenerator 31, 32 and 33, with at least one of these regenerators having a matrix of helium-filled carbon spheres 34 of the new invention. The gaseous working medium of this refrigerator is helium transported from the compression space 17 to the first, second and third expansion spaces 20, 21, and 22. In passing through the new regenerator, the gas contacts the carbon spheres and transfers heat to the helium gas within the spheres. Another significant characteristic of the new regenerator matrix is that there is very low heat flow between spheres, due to the mere point contact between each pair of adjacent spheres, and also because the porous carbon is a poor conductor of heat. Thus, there is small heat flow from the hot to the cold end of the regenerator, and thus very little leakage or loss of cold produced at each expansion stage. Furthermore the heat storage capacity is somewhat enhanced by the fact that helium gas is adsorbed by the carbon walls, in addition to being contained within the spheres.

With the new regenerator low temperatures around 6° K. will be attained, which is a particularly significant achievement in small or miniature cryogenic refrigerators. In the operation of these apparatus other working gas parameters are generally the same, namely a working gas average charging pressure of 50 to 75 psig, and a pressure drop of about 5 psi.

In manufacturing matrices for the new regenerator suitable carbon spheres are sold under the name "Carbo-Spheres" by the General Technologies Corporation, 1821 Michael Faraday Drive, Reston, Va., 22070.

What is claimed:

1. A regenerator comprising a housing and within the housing a plurality of carbon heat-storage elements each having walls which are permeable to gas and which define an interior space into which a quantity of said gas is diffusible and retainable, and a quantity of said gas contained within said spaces.

2. A regenerator according to claim 1 wherein said gas is helium and wherein said walls adsorb a quantity of said helium.

3. A regenerator according to claim 2 wherein said elements have a spherical outer surface with a diameter in the range of about 5 to 150 microns.

4. A regenerator according to claim 3 wherein said spheres have a wall thickness in the range of about 1 to 2 microns.

5. A regenerator according to claim 1 wherein the elements within a housing have bulk density in the range of about 0.13 to 0.14 gm/cc.

6. A regenerator according to claim 1 wherein the housing has an internal volume and said elements are spheres which occupy about 63 percent of the volume.

7. A regenerator comprising a housing having an internal volume, a plurality of hollow, thin-walled carbon spheres having diameter in the range of about 80 to 110 microns and occupying about 63 percent of the volume within the housing, and helium gas diffused into hollows of the spheres and adsorbed into the walls thereof.

8. A regenerator according to claim 2 wherein each element defines a closed geometric outer shape and each element has substantially only single point outer surface contact with each other immediately adjacent element.

9. A method of manufacturing a regenerator according to claim 1 comprising the steps:

a. evacuating air and any other gases from a plurality of said carbon heat-storage elements and subsequently,

b. exposing said evacuated elements to helium gas thus diffusing said gas into the elements and

c. disposing said elements within said housing.

10. A method according to claim 9 comprising the further steps of heating the elements during said evacuating.

11. A method according to claim 9 comprising the further steps of pressurizing said helium gas, while diffusing it into the elements.

12. A regenerative-cycle thermodynamic apparatus such as a refrigerator, wherein the regenerator housing comprises a matrix of a plurality of hollow carbon spheres and a quantity of helium gas contained within the hollows of and adsorbed in the walls of said spheres, the matrix having a specific heat corresponding to that of helium gas.

13. In a regenerative-cycle apparatus such as a refrigerator which includes a regenerator having helium gas contained in hollow, carbon heat-storage elements, and in which a working gas is flowed through the regenerator and is subsequently cooled and flowed back through the regenerator, an improved method of regenerating heat in the working gas comprising:

a. flowing the working gas into contact with said elements,

b. transferring heat from the working gas through the elements into the helium gas,

c. storing the heat in the helium gas,

d. subsequently flowing the cooled working gas again through the regenerator and into contact with said elements, and

e. transferring heat from the helium gas back into the working gas.

14. A regenerator comprising a housing and within the housing a plurality of heat storage elements, each element having walls defining a continuous outer surface and an interior space for containing helium gas, the walls comprising a material (a) through which helium is diffusible into said interior space and (b) into which the helium is adsorbable.

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