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RESEARCH PAPER

Specific heat capacities and flow resistance of an activated carbon with adsorbed helium as a regenerator material in refrigerators

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Abstract: An ideal regenerator material is characterized by a high specific heat capacity and a low flow resistance, and the specific heat capacity of the working gas must be low. However, the specific heat capacity of a helium working gas is much higher than that of the general regenerator materials in the temperature range 4-30 K, which severely limits the improvement of the refrigerator performance. The helium adsorption capacity of the activated carbon was first evaluated. The heat capacity and flow resistance of the activated carbon with adsorbed helium were measured and compared with the commonly-used regenerator materials such as stainless steel wire mesh, lead, and magnetic Er_3Ni and $HoCu_2$. Results show that the specific heat capacity of the activated carbon with adsorbed helium are higher than those of the other materials investigated at 3.0 MPa and 16-25 K, and its flow resistance is close to that of Er_3Ni, a little bit higher than that of $HoCu_2$, and much less than that of the stainless steel wire mesh. These results confirm that it is feasible to use activated carbon with adsorbed helium as a regenerator material.

Key Words: Activated carbon; Rare-earth material; Adsorbed helium; Specific heat capacity; Flow resistance

1 Introduction

The regenerator is one of the important components in refrigerator. The regenerator alternately repeats two heat transfer processes. During the heat blowing period, the hot working gas helium, coming from the compressor, flow to the regenerator and cooled by the regenerative materials, then enter to the expansion unit, at this time, the temperature of the working gas helium will decrease and the temperature of the regenerative materials will increase. During the cold blowing period, the cold working gas helium, coming out from the expansion unit, reverse flow through the regenerator and cool off the regenerative materials, then enter to the compressor. Therefore, the ideal regenerator is characterized by its high specific heat of regenerative materials, and low specific heat of the working gas. However, as shown in Fig. 1, in the temperature range of 4-30 K, the specific heat of the working gas helium is higher than that of the commonly used regenerative materials, such as the stainless steel wire mesh (SS), lead and magnetic materials Er_3Ni, $HoCu_2$, which severely limits the enhancement of the refrigerator performance [1-4]. To solve this problem, Zhejiang University carried out a series of researches on using ErNi alloy to adsorb hydrogen as regenerative unit [5-7]. In this paper, a part of working gas helium is directly adsorbed by activated carbon with a large specific surface area as the storage unit, and a testing device is set up to investigate the adsorbed helium amount by activated carbon in low temperature, and the specific heat capacity of the adsorbed unit was compared with that of the conventional rare-earth materials. In addition, the flow resistance impedance of the adsorbed unit and the magnetic materials Er_3Ni and $HoCu_2$ were also tested by a self-developed flow resistance testing device.

The presented work is a new exploration on the research of regenerative materials in a refrigerator. Before this, some scholars proposed using activated carbon to adsorb helium as an adsorbent compressor or hydrogen storage medium [8-10], the focus of which is the helium adsorption amounts, while more attention will be given to the specific heat capacities and the flow resistance characteristics of the activated carbon with adsorbed helium in the temperature below 30 K in this work.

2 Experimental

2.1 The developed adsorption capacity test device and its data processing methods

The developed adsorption capacity test device is shown in Fig. 2. It mainly includes the self-developed miniature pulse tube refrigerator (the lowest no-load temperature is 10 K) [2], vacuum systems (the highest vacuum up to 10-5 Pa), adsorption chamber (the volume is 10 cm^3), the calibrated volume (the volume is 611 cm^3), the pressure sensors (JYB,

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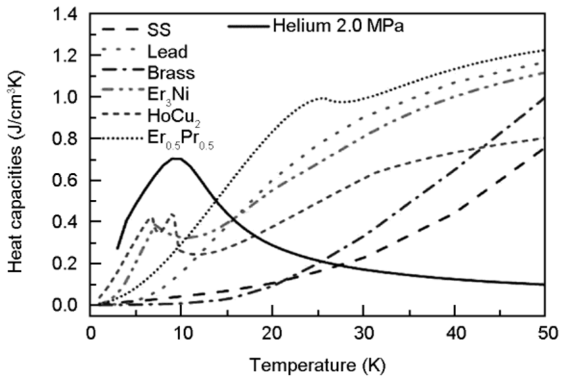

Fig.1 Volumetric heat capacities of the commonly used regenerative materials and working gas helium 4, data from National Institute of Standards and Technology (NIST).

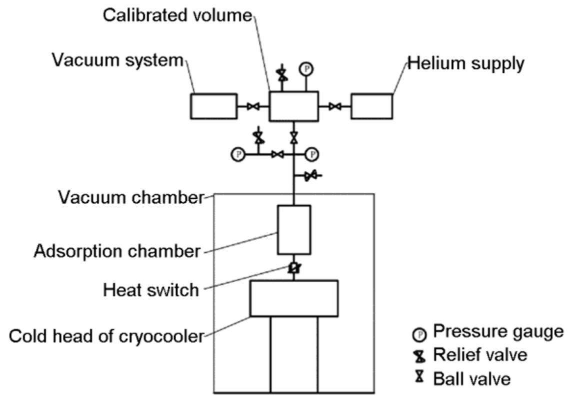

Fig. 2 A schematic illustration of the developed adsorption capacity test device.

0-4 MPa) and the temperature sensors (pt100 is employed to measure room temperature, and calibrated rhodium-iron resistance thermometer is used to measure the cryogenic temperature).

The specific testing procedure is as follow. Firstly, a vacuum operation was performed to reduce the system vacuum to 10-4 Pa. Secondly, the calibrated volume and the adsorption volume was filled with a certain pressure of helium, and the pressure P1 and room temperature T1 were recorded. Thirdly, the refrigerator was started to cool off the adsorption chamber to the set temperature, and the temperature of the adsorption Tc, the room temperature T2 and the pressure of the calibrated volume P2 were recorded.

The data processing procedure is as follows. The density and heat capacities of the helium at a certain temperature and pressure can be achieved by the REFPROP database of NIST. And the mass of helium is the product of density and volume. Then the amount of helium adsorbed to the adsorption chamber is equal to the mass difference of the calibrated volume before and after cooling. The helium in the adsorption chamber contains two parts. The helium adsorbed by the activated carbon and the helium filled in the macroscopic volume between the activated carbon particles. Noticed that the macroscopic volume is equal to the product of the porosity and the total volume of the adsorption chamber, so the helium mass filled in the macroscopic volume can be achieved according to the test temperature and pressure of the adsorption chamber. Then the mass of helium adsorbed in the activated carbon is equal to the total helium mass in the adsorption chamber minus the helium mass filled in the macroscopic volume.

In order to determine the heat capacities of the adsorbed helium in activated carbon, the temperature and the density should be given. For the temperature of the adsorbed helium, it is equal to that of the adsorption chamber. For the density of the adsorbed helium, the tested temperature and pressure in the presented work is much higher than the helium critical parameters (Tc=5.2 K, Pc=0.23 MPa), i.e., it is an above-critical adsorption process. However, the mechanism of above-critical adsorption is not clear, there is no mature method to determine the density of the adsorbed phase at present [11]. The density of the adsorbed phase is roughly determined by a simplified method here. The total volume of the activated carbon and its microscopic volume is equal to the volume of the adsorption chamber minus the volume of the macroscopic volume between the activated carbon particles, while the mass of activated carbon can be tested and its absolute density is equal to that of graphite (2.2 g/cm^3) [12], then the volume of the adsorbed helium and its density can be determined further.

2.2 The developed flow resistance test device

Fig. 3 shows a schematic illustration of the flow resistance test device. It mainly includes pressure source, pressure sensors, flowmeter and the sample unit. To make the test results more conducive to improve the design of a refrigerator, a coaxial pulse tube cold head was used to serve as the sample test system (outer diameter 18 mm, inner diameter 8.9 mm and length 60 mm). The flow resistance test procedure is as follows. The pressure of the gas entering into the sample test system was controlled by a pressure relief valve and a needle valve. Then the gas passed through the

Table 1 The information of the samples in the tests.

Item	Values	Item	Values
Activated carbon material	Coconut shell	Er_3Ni size (mm)	0.15-0.35
Total BET surface area (m^2/g)	1100	$HoCu_2$ size (mm)	0.15-0.35
Ball Pan Hardness	98	Stainless steel mesh	635
Activated carbon size (mm)	0.15-0.35	Helium purity	99.999%
Calibrated volume	611 cm^3	Porosity	0.4
Adsorption chamber volume	10 cm^3	Activated carbon mass (g)	6.0