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Two types of natural graphite host matrix for composite activated carbon adsorbents

L.W. Wang [a,b], S.J. Metcalf [b], R.E. Critoph [b,*], Z. Tamainot-Telto [b], R. Thorpe [b]

[a] Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai 200240, China
[b] School of Engineering, University of Warwick, Coventry CV4 7AL, United Kingdom

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ABSTRACT

Two types of host for activated carbon (AC) adsorbents intended for use in compressed systems are studied: expanded natural graphite (ENG) and expanded natural graphite treated with acid (ENG-TA). Results show that compressed ENG-TA has much higher thermal conductivity than the compressed ENG. For a density of 830 kg/m^3 the thermal conductivity of compressed ENG-TA is 336 W/(mK), and it is of the order of one hundred times higher compared with compressed ENG having similar density. The permeability of compressed ENG-TA is much more critical than the compressed ENG. For example for similar density of 300 kg/m^3, the permeability of compressed ENG-TA is 2.01×10^{-15} m^2 while the permeability of compressed ENG is 1.07×10^{-13} m^2. Compressed composite adsorbents of AC with ENG as host were produced with a high density in the range 700–720 kg/m^3. Considering that the permeability will be too low using composite AC with ENG-TA as host in high density, the density range was restricted to less than 500 kg/m^3. The thermal conductivity of AC/ENG-TA composite is much higher than the thermal conductivity of AC/ENG composite, and it is about 7 times higher than the optimal value of AC/ENG composite.

1. Introduction

Adsorption refrigeration, which is powered by low grade heat such as waste heat or solar energy and utilizes green refrigerants such as methanol, ammonia and water, is an energy saving and environmentally benign technology [1]. Adsorption refrigeration consists of two principal phases, i.e. desorption and adsorption. In desorption the adsorbents are heated by the driving heat, and the refrigerants are desorbed from the adsorbents by the heating process. In adsorption the adsorbents are cooled by the cooling media, reducing the pressure in the adsorbents, causing refrigerant to evaporate and be adsorbed. The evaporation of the refrigerant generates the cooling effect. There are principally two types of adsorbent used for refrigeration, i.e. physical adsorbents and chemical adsorbents. Activated carbon (AC) is a physical adsorbent, and has the advantages of high mass transfer performance, stable adsorption performance, and no corrosion problems with metal containers if compared with chemical adsorbents such as chlorides. The main disadvantage of physical adsorbents is the low adsorption quantity. For example, the maximum adsorption quantity of AC is about 0.3 kg/kg, which is only 1/4 of that of calcium chloride, which has the highest adsorption quantity of 1.225 kg/kg [2]. The refrigeration power of an adsorption refrigeration system mainly relates to the adsorption rate, which is the cyclic mass adsorbed and desorbed divided the cycle time. Although the adsorption quantity of AC is low, a high adsorption refrigeration power can be obtained if the cycle time is short. The cycle time is mainly related to the heat and mass transfer performance of the adsorbers. In order to get high refrigeration powers per unit volume or mass, consolidated adsorbents, which have higher thermal conductivity, have been studied by different researchers [3]. AC consolidated adsorbents have been developed using mixtures of AC with chemical binders [4,5]. For such materials the thermal conductivity can be improved, but the mass transfer performance can be impaired. Expanded graphite, which is a type of porous material, is thought to be a good host matrix for the heat and mass transfer intensification of adsorbents [6,7]. In order to develop a type of composite consolidated adsorbent with better heat and mass transfer performance, two types of host, i.e. expanded natural graphite (ENG) and expanded natural graphite treated with acid (ENG-TA, marketed by Mersen as Papyex™) have been studied as a host matrix for AC.

Results and methods for the ENG [8,9] reported previously are repeated here for the convenience of comparison but the results

* Corresponding author. Tel./fax: +44 2476 418922.
E-mail address: R.E.Critoph@warwick.ac.uk (R.E. Critoph).

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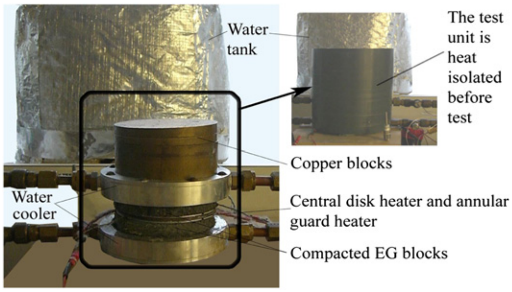

Fig. 1. Thermal conductivity test equipment used for ENG.

(and method of measuring conductivity) for ENG-TA are new. ENG-TA offers much better performance.

2. Adsorbents with ENG as host

ENG is prepared by heating untreated natural graphite in an oven at the temperature of 600–700 °C for 12–15 min. The graphite is manufactured by Shanghai YiFan Graphite Company in China, and is 50–80 mesh and greater than 99% pure.

Anisotropic thermal conductivity exists for different directions of compressed composite adsorbent [8], and the direction perpendicular to the pressing direction has better heat and mass transfer performance than the direction parallel to the pressing direction. Thus the direction perpendicular to the pressing direction is that selected for study.

2.1. Thermal conductivity of compressed ENG

The thermal conductivity was investigated by using the guarded hot plate method [5]. It is an absolute method for determining the steady state thermal conductivity of materials. The experimental set-up is based on British Standard BS-874 [5]. The test unit is shown in Fig. 1. The main components are: a central disc heater sandwiched between two compressed ENG blocks, two water coolers symmetrically above and below the central disc heater, an annular guard heater radially beyond the central disc heater, and a water tank from which water is pumped through the coolers. Copper blocks provide a clamping force on the whole test unit. The test unit is thermally insulated before experiments.

The determination of the effective thermal conductivity λ is based on the measurement of the average temperature gradient ΔT produced through the compressed blocks by a known axial heat flux Q under steady-state conditions. When the working conditions

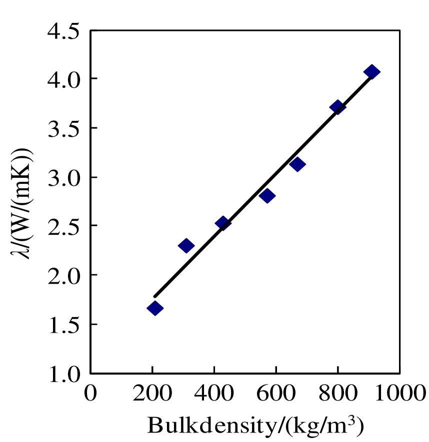

Fig. 2. Thermal conductivity vs. bulk density of ENG.

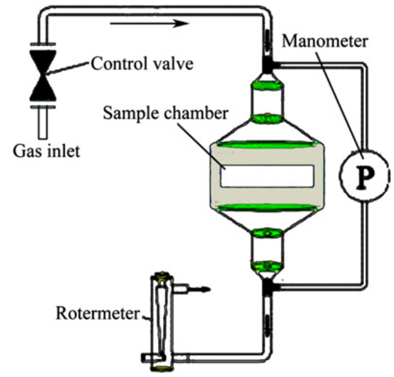

Fig. 3. Permeability test schematic.

(heat flux determined by the electric current and electric resistance of central disc heater, water flow rate and temperatures) are set up and the equilibrium is reached, the effective thermal conductivity λ (W/(mK)) is given by the following expression:

$$\lambda = \frac{Q \times \Delta z}{2S\Delta T} \tag{1}$$

where Q is the measured central disc heater heating power (W), Δz is the thickness of the compressed expanded graphite blocks (m), ΔT is the temperature difference across the blocks and S is the effective heating area of the central plate heater (m^2). The intrinsic thermal conductivity is determined by combining the effective thermal conductivity with the contact resistance as deduced from experiments on discs of different thickness but the same assumed contact resistance [5].

For such a device, the error of thermal conductivity measurements is mainly related to temperatures, electric current and resistance, and the thickness of the samples. Temperatures are measured using thermocouples with a measurement error of ± 0.7 °C. The heat flux is calculated using the electric current and electric resistance, in which the electric resistance has the relative error of $\pm 1\%$ after calibration, and the electric current is controlled by a stabilized current supply which has the relative error of $\pm 1\%$. The depth of the sample is measured using a micrometer with an error of 0.01 mm, and the smallest thickness in the experiments is 10 mm, corresponding to the largest relative error of $\pm 0.1\%$. The average value of temperature difference is about 11 °C, and so the average relative error of heat conductivity in the experiments is 11%.

The thermal conductivity is shown in Fig. 2. The thermal conductivity increases linearly with the density, and the maximum value is about 4 W m^{-1} K^{-1} when the density is 910 kg/m^3.

2.2. Permeability of compressed ENG

The permeability test unit is shown in Fig. 3. The main components are a specimen chamber, a differential manometer,

Table 1
Permeability of compressed ENG.

Density (kg/m^3)	Permeability of CENG (m^2)
100	8.91×10^{-12}
150	2.61×10^{-12}
200	6.84×10^{-13}
250	4.37×10^{-13}
300	1.07×10^{-13}
350	4.39×10^{-14}
400	2.92×10^{-14}
450	1.51×10^{-14}
500	8.39×10^{-15}