INTERNATIONAL JOURNAL OF REFRIGERATION 35 (2012) 1035–1042

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.elsevier.com/locate/ijrefrig

Performance characteristics of magnetic Brayton refrigeration cycles using Gd, $Gd_{0.74}Tb_{0.26}$ and $(Gd_{3.5}Tb_{1.5})Si_4$ as the working substance

Gildas Diguet, Guoxing Lin, Jincan Chen*

Department of Physics, Xiamen University, Xiamen 361005, PR China

ARTICLE INFO

Article history:
Received 10 October 2011
Received in revised form
5 December 2011
Accepted 12 December 2011
Available online 16 December 2011

Keywords:
Regeneration
Magnetic refrigerator
Brayton cycle
Thermodynamics

ABSTRACT

Based on the experimental characteristics of the iso-field heat capacity changing with temperature for the room-temperature magnetic refrigeration materials Gd, $Gd_{0.74}Tb_{0.26}$, and $(Gd_{3.5}Tb_{1.5})Si_4$, the corresponding entropy versus temperature curves are calculated and presented, the regenerative magnetic Brayton refrigeration cycles, using these magnetic materials as the working substances, are established. The non-perfect regenerative heat quantity, net cooling quantity, released heat quantity, coefficient of performance (COP) and other performance parameters of these magnetic Brayton refrigeration cycles are analyzed and calculated. Furthermore, the performance characteristics of the Brayton refrigeration cycles employing Gd, $Gd_{0.74}Tb_{0.26}$, and $(Gd_{3.5}Tb_{1.5})Si_4$ as the working substance are evaluated and compared, the influence of non-perfect regenerative heat on the performance characteristics of these magnetic Brayton refrigeration cycles is revealed.

Caractéristiques de performance des cycles frigorifiques de Brayton magnétiques utilisant le Gd, le $Gd_{0,74}Tb_{0,26}$ et le $(Gd_{3,5}Tb_{1,5})Si_4$ comme substance active

Mots clés : Régénération ; Réfrigérateur magnétique ; Cycle de Brayton ; Thermodynamique

1. Introduction

Conventional refrigeration technology is based on the cycle of gas expansion/compression. However, scientists and engineers are now searching for some new techniques that are more economic, silent, compact and environmental friendly. Magnetic refrigeration is an environmental-friendly refrigeration technology because it neither use ozone-depleting nor greenhouse gases, and is more efficient and low-carbonic when compared to vapor expansion/compression cycle. Avoiding the necessity of compressor, it is also less noisy. Magnetic refrigeration is one of the important alternative technologies of refrigeration for room-temperature application.

* *Corresponding author*. Tel.: +86 592 2183936; fax: +86 592 2189426.
E-mail address: gxlin@xmu.edu.cn (G. Lin).
0140-7007/$ – see front matter
doi:10.1016/j.ijrefrig.2011.12.004

Nomenclature

Abbreviation

MCE	magneto-caloric effect
Gd	gadolinium

Symbols

H	applied field [T]
T	temperature [K]
S	entropy [J/kgK]
C	heat capacity [J/molK]
Q	heat transfer [J/kg]
COP	coefficient of performance [-]
Wi	work input [J/kg]

Subscript

Magnetic field

H	iso-magnetic field process
0	low magnetic field
1	high magnetic field

Heat transfer

h	to the hot reservoir
c	to the cold reservoir
sr	from working substance to the regenerator
rs	from regenerator to the working substance
L	net quantity

Temperatures

hot	hot reservoir temperature
cold	cold reservoir temperature
0	temperature for maximal iso-field entropy change
Curie	material curie temperature

The magnetic refrigeration is based on the Magneto-Caloric Effect (MCE), which consists in the entropy change of a magnetic material when adiabatically demagnetized, resulting in a heat absorption of magnetic material. This effect was discovered by Warburg in 1881 on iron metal. From 1933, the adiabatic demagnetization technique has been widely used to reach low temperature in the range of mK (Konig, 2000). Later, in 1976, Brown successfully demonstrated the feasibility of a magnetic refrigerator operating at room temperature. His demonstrator was indeed able to decrease the temperature from 320 K to 247 K using a 7T superconducting coil and Gadolinium (Gd) as the magneto-caloric material (Yu et al., 2010). Nowadays, more than 41 prototype machines have been designed; for most of them, Gd has been used as the working substance because it has a large magnetic moment and a Curie temperature near room temperature ($T_{Curie} = 294$ K).

Recently, the discovery of some giant MCE materials, which is a coupling between the magnetic and structural transition, has enhanced the interest of investigators on new and giant MCE materials which are cheaper, easier to be produced or have better physical and chemical properties than Gd in order to find potential candidates for commercial room-temperature magnetic refrigerators. These novel materials belong to several families like Gd-based alloys as $Gd_{0.74}Tb_{0.26}$, $Gd_5(Si_xGe_{1-x})_4$ and so on; manganites compounds as $MnFeP_xAs_{1-x}$, etc.; peroskites as $La(Fe_{1-x}Si_x)_{13}H_y$ and so on. A full description involving these materials is provided by Gschneidner and Pecharsky (2008). To evaluate these materials, the theoretical and experimental papers have mostly focused on their isothermal entropy change and adiabatic temperature change characteristics (Oesterreicher and Parker, 1984; Hashimoto et al., 1981a,b; Balli et al., 2007; Spichkin et al., 2001; Wang et al., 2005; Phan et al., 2003). The performances of refrigeration cycles presented by these materials have rarely been investigated. In fact, for a room-temperature magnetic refrigerator, it is an important and useful investigation to make clear the cyclic performance of involved magnetic refrigeration materials.

In this article, on the basis of the experimental characteristics of the iso-field heat capacity and the magnetic entropy changing with temperature for the materials Gd, $Gd_{0.74}Tb_{0.26}$ or $(Gd_{3.5}Tb_{1.5})Si_4$, the related Brayton refrigeration cycle employing these materials as the working substance are designed. By using thermodynamic analysis and numerical value calculation methods, the non-perfect regeneration quantity, net cooling quantity, and COP of these magnetic Brayton refrigeration cycles are analyzed and calculated. Moreover, the performance characteristics of these Brayton refrigeration cycles are evaluated and compared. The results obtained in the present paper may provide some new message for the optimal design of real room-temperature magnetic refrigerators.

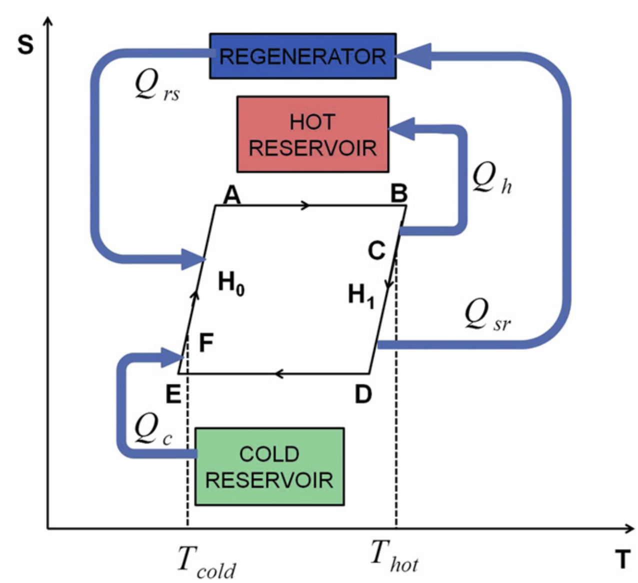

Fig. 1 – S–T diagram and heat flows between the working substance and hot, cold reservoirs and regenerator for regenerative magnetic Brayton refrigeration cycle, where T_{hot} and T_{cold} are the temperatures of hot and cold reservoirs respectively.