INTERNATIONAL JOURNAL OF REFRIGERATION 68 (2016) 94–106

Available online at www.sciencedirect.com

ScienceDirect

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

Performance optimisation of room temperature magnetic refrigerator with layered/multi-material microchannel regenerators

Muhammad Sajid Kamran [a,b,*], Hassan Ali [a], Muhammad Farhan [a], Yong Bai Tang [c], Yun Gui Chen [c], Hua Sheng Wang [b]

[a] Department of Mechanical Engineering, University of Engineering and Technology, Lahore, 54890, Pakistan

[b] School of Engineering and Materials Science, Queen Mary, University of London, Mile End Road, London E1 4NS, UK

[c] School of Materials Science and Engineering, Sichuan University, Chengdu 610065, China

ARTICLE INFO

Article history:
Received 3 February 2016
Received in revised form 26 March 2016
Accepted 13 April 2016
Available online 19 April 2016

Keywords:
Magnetic refrigeration
Microchannel regenerator
Numerical modelling
Magnetocaloric material
Multi-material/Layered regenerator

ABSTRACT

A hybrid numerical model of the magnetic refrigerator with multi-material microchannel regenerator has been developed. The magnetocaloric effect was implemented using instantaneous temperature rise/drop (discrete method). Two pipe-in-pipe heat exchangers at two ends of the regenerator were treated using ε-NTU method. The commercially available compounds of $LaFe_{13-x-y}Co_xSi_y$ as well as hypothetical compounds of Gadolinium were considered as the magnetocaloric materials (MCMs) with different Curie temperatures. The predicted results of the present work for parallel-plate regenerators employing different compounds of $LaFe_{13-x-y}Co_xSi_y$ were broadly in good agreement with the available experimental data. The cooling capacity increases as the number of MCMs increase. However, for a given length of regenerator, an optimum number of MCMs was seen yielding the maximum performance of the refrigerator. For a given number of MCMs, a smaller Curie temperature difference ΔT_{Cu} between the MCMs was found to give higher performance.

Optimisation de la performance de réfrigérateur magnétique à température ambiante avec des régénérateurs à microcanaux à multiples couches/matériaux

Mots clés : Froid magnétique ; Régénérateur à microcanaux ; Modélisation numérique ; Matériau magnétocalorique ; Régénérateur à multiples matériaux/couches

* *Corresponding author.* Department of Mechanical Engineering, University of Engineering and Technology, Lahore, 54890, Pakistan. Tel: +92 3311492222.

E-mail address: m.s.kamran@uet.edu.pk (M.S. Kamran).

http://dx.doi.org/10.1016/j.ijrefrig.2016.04.013

Nomenclature

A	heat transfer area
a_p	heat transfer area per unit volume/specific heat transfer area
B	intensity of magnetic field
ΔB	maximum change in intensity of magnetic field
C	ratio of specific heat capacities
c_P	isobaric specific heat capacity
d	diameter
d_i	inside diameter
d_h	hydraulic diameter
d_o	outside diameter
d_p	cross-sectional diameter of piston
f	cycle frequency; rotational frequency; friction factor
l	length
L	length
m	mass; magnetisation
m_r	mass flow rate in regenerator loop
n	number
$\mathbf{n}$	vector normal to boundary
P	pressure
q	heat flux
Q_c	heat exchange at CHEX
Q_h	heat exchange at HHEX
R	radius of crank disk of displacer
t	time
Δt	time step
T	temperature
T_{Cu}	Curie temperature
ΔT_r	temperature span between two ends of regenerator
$\mathbf{u}$	velocity vector
u	velocity in x-direction; mean velocity
U	overall heat-transfer coefficient
V	volume
v	velocity in y-direction
w	velocity in z-direction

Greek symbols

α	thermal diffusivity
δ	spacing; thickness
Δ	change; difference
ε	porosity; effectiveness; error $\varepsilon = (\Delta T_{r,num} - \Delta T_{r,exp})/\Delta T_{r,exp}$ %
λ	thermal conductivity
μ	dynamic viscosity
ρ	density
τ	period of a cycle
ω	angular velocity of the crank disk

Subscripts

ad	adiabatic
b	bulk
c	cold
cf	counter-current flow
ch	channel
ele	electronic
exp	experiment
f	fluid
h	hot, hydraulic
i	inside
init	initial
in	inlet
j	r, h or c
lat	lattice
mag	magnetic
max	maximum
min	minimum
num	numerical
o	outside
out	outlet
pl	plate
r	regenerator
s	solid
tot	total
w	wall

Acronyms

AMR	active magnetocaloric regenerator
CHEX	cold and heat exchanger
COP	coefficient of performance
HHEX	hot end heat exchanger
MCE	magnetocaloric effect
MCM	magnetocaloric material
NTU	number of transferred units
UDF	user-defined function

1. Introduction

Magnetocaloric effect (MCE) is a phenomenon exhibited by certain rare earth metals such as Gd, Mn, Yd, La and their alloys etc. in the form of temperature or entropy change upon their exposure to a changing magnetic field. The materials exhibiting MCE are known as the magnetocaloric materials (MCMs). The severity/magnitude of MCE is strongly reliant upon the change in the magnetic field (ΔB) as well as the temperature of the MCM (Morrish, 1965; Tishin and Spichkin, 2003). The peak MCE is observed when the temperature of the MCM is the same as Curie temperature of the MCM and its value drops as the temperature of the MCM differs from its Curie temperature. Fig. 1 shows the dependence of MCE on the temperature of the MCM and change in magnetic field for different MCMs (Pecharsky and Gschneidner, 1997). Gadolinium (Gd) has Curie temperature of 21 °C and it shows the maximum temperature change per unit change in the magnetic field among the second order magnetic transition (SOMT) materials (up to 3.0 KT^{-1} theoretical value and 1.5–2.0 KT^{-1} experimental (Dan'kov et al., 1998)). It has thus become the most commonly