Advanced Powder Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Advanced Powder Technology

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

Original Research Paper

Free convection of hybrid Al_2O_3-Cu water nanofluid in a differentially heated porous cavity

S.A.M. Mehryan [a], Farshad M. Kashkooli [b], Mohammad Ghalambaz [c,*], Ali J. Chamkha [d,e]

[a] Young Researchers Club, Yasuj Branch, Islamic Azad University, Yasuj, Iran
[b] Department of Mechanical Engineering, K. N. Toosi University of Technology, Tehran, Iran
[c] Department of Mechanical Engineering, Dezful Branch, Islamic Azad University, Dezful, Iran
[d] Mechanical Engineering Department, Prince Mohammad Bin Fahd University, Al-Khobar 31952, Saudi Arabia
[e] Prince Sultan Endowment for Energy and Environment, Prince Mohammad Bin Fahd University, Al-Khobar 31952, Saudi Arabia

ARTICLE INFO

Article history:
Received 13 January 2017
Received in revised form 16 May 2017
Accepted 11 June 2017
Available online xxxx

Keywords:
Hybrid nanofluids
Porous media
Al_2O_3-Cu water
Natural convection

ABSTRACT

Hybrid nanofluids are a new type of enhanced working fluids, engineered with enhanced thermo-physical properties. The hybrid nanofluids profit from the thermo-physical properties of more than one type of nanoparticles. The present study aims to address the free convective heat transfer of the Al_2O_3-Cu water hybrid nanofluid in a cavity filled with a porous medium. Two types of important porous media, glass ball and aluminum metal foam, are considered for the porous matrix. The experimental data show dramatic enhancement in the thermal conductivity and dynamic viscosity of the synthesized hybrid nanofluids, and hence, these thermophysical properties could not be modeled using available models of nanofluids. Thus, the actual available experimental data for the thermal conductivity and the dynamic viscosity of hybrid nanofluids are directly utilized in the present theoretical study. Various comparison with results published previously in the literature are performed and the results are found to be in excellent agreement. In most cases, the average Nusselt number Nu_l is decreasing function of the volume fraction of nanoparticles. The results show the reduction of heat transfer using nanoparticles in porous media. The observed reduction of the heat transfer rate is much higher for hybrid nanofluid compared to the single nanofluid.

1. Introduction

Investigation of the natural convective heat transfer in a porous cavity for its engineering usages, include heat removal in heat exchangers [1] and heat storage systems in solar collectors enhanced with porous matrixes [2,3], and active nuclear west disposal systems [4] has been highly regarded. There are also applications for nanofluids, further than heat transfer such as nanoparticles as anti-microbial agents [5,6] or nanoparticles as radiation absorbent agents [7], in which the heat transfer could be the side advantage or disadvantage of utilizing nanoparticles in the host-fluid. The design of using hybrid nanoparticles as nano-additives can be managed in such applications for multi-purpose benefits including enhancement or inhibition of heat transfer. Thus, the current investigation aims to theoretically study the efficacy of the existence of a hybrid nanofluid in a cavity filled with porous media.

Novel kind of engineered fluids introduced by Choi [8] are the nanofluids that consist of well-dispersed solid nanometer-sized particles [9,10]. Nanoparticles existence in the base-fluid influences significantly its properties. On the other hand, the thermophysical characteristics of the host-fluid have modified in the presence of nanoparticles. Due to the experimental results, composed nanofluid's density, viscosity, and thermal conductivity are more than the host-fluid's [11]. So, the existence of nanoparticles within the host-fluid affects the convective heat transfer of nanofluid, and is necessary in usages. Neoteric class of nanofluids is hybrid nanofluids which contain a small amount of metal nanoparticles and also non-metallic nanoparticles. Metallic nanoparticles like Zn, Cu, and Al give high thermal conductivities but their use has restrictions such as stability and reactivity. In contrast, non-metallic nanoparticles such as Al_2O_3, CuO, and Fe_3O_4 present lower thermal conductivity in comparison with metallic; however, they have a lot of desirable properties like stability and chemical inertness. Thus, it

* Corresponding author. Fax: +98 (21) 43854961.
E-mail addresses: a.mansuri1366@gmail.com (S.A.M. Mehryan), farshad.moradi@email.kntu.ac.ir (F.M. Kashkooli), m.ghalambaz@iaud.ac.ir (M. Ghalambaz), achamkha@pmu.edu.sa (A.J. Chamkha).

http://dx.doi.org/10.1016/j.apt.2017.06.011

Nomenclature

Latin symbols

C_p	heat capacity in constant pressure (kJ kg^{-1}K^{-1})
g	gravitational acceleration vector (m s^{-2})
h	local convection coefficient
H	interface heat transfer coefficient parameter
k	thermal conductivity (W m^{-1} K^{-1})
K	permeability of the porous medium (m^2)
L	square cavity size (m)
Nu_x	local Nusselt number
Nu_l	average Nusselt number
p	pressure (Pa)
q''	total interfacial heat flux (W m^{-2})
Ra	Rayleigh number
T	temperature (K)
u, v	velocity components along x, y directions, respectively (m s^{-1})
V	Darcian velocity vector
x, y	Cartesian coordinates (m)

Greek symbols

α	effective thermal diffusivity (m^2 s^{-1})
β	thermal expansion coefficient of the fluid (K^{-1})
ε	porosity of the porous medium
θ	dimensionless temperature
μ	dynamic viscosity (kg m^{-1} s^{-1})
ρ	density (kg m^{-3})
(ρc)	effective heat capacity (J K^{-1} m^{-3})
φ	relative nanoparticle volume fraction
ψ	dimensionless stream function

Subscripts

bf	base-fluid
c	cold
h	hot
hnf	hybrid nanofluid
l	liquid phase
m	effective
max	maximum
nf	nanofluid
r	relative
s	solid porous matrix
x	in x-direction

is hoped that adding Cu to an Al_2O_3-based nanofluid can increase the thermophysical characteristics of the resulting mixture without reducing the nanofluid stability [12,13].

Recently, a lot of experimental studies [12,14–19] and numerical investigations [13,20–25] have been conducted on hybrid nanofluid as a novel technology concept. The thermal conductivity and viscosity of the Al_2O_3–Cu/H_2O hybrid nanofluid have been measured by Suresh et al. [12]. The results demonstrated that both parameters of the hybrid nanofluid enhance with the volume concentrations of nanoparticles. Moghadassi et al. [24] studied the influences of the nanofluid (water-based Al_2O_3) and hybrid nanofluid (Al_2O_3-Cu) and indicated that the hybrid nanofluid has a much larger coefficient of convection heat transfer. Esfe et al. [19] measured the thermal conductivity of SWCNTs-MgO/EG hybrid nanofluids and modeled the experimental data using artificial neural network. Sarkar et al. [26] conducted a comprehensive review briefing recent challenges and investigations in the area of hybrid nanofluids such as heat transfer, synthesis, thermodynamic properties, etc. Tayebi and Chamkha [13] studied numerically the heat transfer in an annulus between two confocal elliptic cylinders filled with Cu-Al_2O_3/water hybrid nanofluid. Three-dimensional hybrid nanofluid boundary-layer flow passing a stretching sheet under the effects of Newtonian heating and Lorentz force has been accomplished by Devi and Anjali [23]. Laminar convective heat transfer of using different base fluids and a hybrid nanofluid in a uniformly heated circular tube is numerically investigated by Takabi et al. [21].

Many researchers have studied experimentally and numerically the influence of the nanofluid on convective heat transfer within enclosures for various conditions and case studies [27–37]. In enclosures, because of no requirement to an exterior power supplies such as electrical source for inducing convective heat transfer, this mechanism of heat transfer is significant. Free convection has some advantages including the decrease of magnetic noise, fee, and sound due to the absence of power sources. These benefits cause the enclosures as an attractive subject for the researchers and various industrials. Baïri et al. [1] have presented a great review on the free convection mechanism in cavities for industrial usages. Most of the time, the cavities are filled by porous media that is saturated with a fluid or a nanofluid. Recent advances in the field of heat transfer and nanofluid flow in a porous medium have been conducted with an excellent review by Kasaeian et al. [38]. Lately, a number of authors have focused on various thermal boundary conditions in cavities. Uniform, non-uniform, and sinusoidal temperature distribution in some or all of the walls and also insulated and adiabatic boundary conditions have used in these problems [39–42]. Use of local thermal equilibrium [43] (when the fluid and solid temperature is equals) and local thermal non-equilibrium (where the fluid and solid temperature is varied) [42,44] models for porous media is another challenging subjects in enclosure filled with nanofluid investigations. Most recently, a number of scholars concentrated on conjugate natural convections in cavities [9,45,46] for its important applications in electrical parts cooling, collectors of solar energy, production of material, etc. Ghalambaz et al. [37] have considered the presence of viscous dissipation and radiation influences on the free convective heat transfer within a square enclosure filled by porous media saturated with nanofluid. Free convection in a differentially heated and partially-layered porous cavity filled by a nanoliquid is examined by Chamkha and Ismael [30]. Al-Zamily [47] conducted a review about the latest progresses in free convection and entropy generation in an enclosure filled by multi-layer porous media, and nanoliquid with considering heat generation. Mansour et al. [33] and Sheremet et al. [35] checked out the influence of the presence of nanoparticles on the magnetohydrodynamic convection heat transfer of nanofluids in a cavity.

Investigation of using a hybrid nanofluid in cavity problems has newly conducted by some of the researchers [48–50] but to the best of author's knowledge, the free convective heat transfer of hybrid nanofluids in a cavity filled by a porous media has not been addressed yet. As a case study, Al_2O_3-Cu water nanofluid is adopted as a synthesized hybrid nanofluid, as its thermophysical data are available in the literature [12,21,23,24]. The thermal conductivity values of the glass balls and aluminum foam are 1.05 and 205, respectively [27]; hence, the glass balls and aluminum porous foams are adopted as low and high thermal conductive porous matrixes, respectively. The effect of using the hybrid nanofluid on the natural convective behavior of the hybrid nanofluid and the

Please cite this article in press as: S.A.M. Mehryan et al., Free convection of hybrid Al_2O_3-Cu water nanofluid in a differentially heated porous cavity, Advanced Powder Technology (2017), http://dx.doi.org/10.1016/j.apt.2017.06.011