International Communications in Heat and Mass Transfer 38 (2011) 533–542

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

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

# A numerical investigation of conjugated-natural convection heat transfer enhancement of a nanofluid in an annular tube driven by inner heat generating solid cylinder ☆

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ARTICLE INFO

Available online 8 January 2011

*Keywords:*
Annular tube
Volumetric heat generation
Conjugated- Natural convection heat transfer
Nanofluid
Heat generating solid rod
Solid concentration
Numerical method

ABSTRACT

Laminar conjugate heat transfer by natural convection and conduction in a vertical annulus formed between an inner heat generating solid circular cylinder and an outer isothermal cylindrical boundary has been studied by a numerical method. It is assumed that the two sealed ends of the tube to be adiabatic. Governing equations are derived based on the conceptual model in the cylindrical coordinate system. The governing equations have been solved using the finite volume approach, using SIMPLE algorithm on the collocated arrangement. Results are presented for the flow and temperature distributions and Nusselt numbers on different cross sectional planes and longitudinal sections for Rayleigh number ranging from $10^5$ to $10^8$, solid volume fraction of $0‹\varphi‹0.05$ with copper-water nanofluid as the working medium. Considering that the driven flow in the annular tube is strongly influenced by orientation of tube, study has been carried out for different inclination angles.



## 1. Introduction

Nanofluid is a fluid containing nanometer-sized particles; these fluids are engineered colloidal suspensions of nanoparticles in a base fluid, which have a better suspension stability compared to millimeter or micrometer sized ones.

Nanofluids have novel properties that make them potentially useful in many applications. They exhibit enhanced thermal conductivity and the convective heat transfer coefficient compared to the base fluid [1], so the nanofluids transfer heat at a higher rate than ordinary fluids (for example, water) which allows for more efficient heating or cooling while reducing energy consumption. Since nanofluid consists of very small sized solid particles, therefore in low solid concentration it is reasonable to consider nanofluid as a single phase flow [2].

First Choi [3] introduced an inventive technique of using a mixture of nanoparticles and the base fluid in order to develop advanced heat transfer fluids with substantially higher conductivities. Lee et al. [4] measured the thermal conductivity of $Al_2o_3$–water and Cu–water nanofluids and indicated that the thermal conductivity of nanofluids increases with solid volume fraction. They concluded that any new models of nanofluid thermal conductivity should contain the effect of surface area and structure dependent behavior as well as the size effect. Some of theoretical and experimental studies have been reported on convective heat transfer coefficient [5–8].

Study of natural convection heat transfer in differentially heated enclosures within systems using nanofluids has been conducted by many researchers. A numerical study of natural convection of copper–water nanofluid in a two-dimensional enclosure was conducted by Khanafer et al. [9]. The nanofluid in the enclosure was assumed to be in single phase. It was found in any given Grashof number, heat transfer in the enclosure increased with the volumetric fraction of the copper nanoparticles in water. Ho et al. [10] presented two-dimensional numerical simulation of buoyancy-driven convection in the enclosure filled with alumina–water nanofluid.

In contrast to the numerous experimental, numerical and analytical studies performed on natural convection of a nanofluid in rectangular enclosures [11–16], just a few literatures can be found about the convection heat transfer of nanofluid in the circular tube [17–23]. Akbari et al. [21] analyzed numerically the mixed convection heat transfer of a nanofluid consisting of water and $Al_2O_3$ in horizontal and inclined tubes. They investigated the effects of nanoparticles concentration and tube inclinations on the hydrodynamics and thermal parameters. Numerical study of convective heat transfer of nanofluid in a circular tube with constant wall temperature boundary condition was conducted by Zeinali Heris et al. [22]. They estimated the effects of nanoparticles size on the heat transfer behavior and eventually found decreasing at a specific concentration leads to the increase in the heat transfer coefficients. Recently Authors [23] have

☆ Communicated by W.J. Minkowycz.

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0735-1933/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.icheatmasstransfer.2010.12.022