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Experimental investigation of oxide nanofluids laminar flow convective heat transfer ☆

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Abstract

In the present investigation nanofluids containing CuO and Al_2O_3 oxide nanoparticles in water as base fluid in different concentrations produced and the laminar flow convective heat transfer through circular tube with constant wall temperature boundary condition were examined. The experimental results emphasize that the single phase correlation with nanofluids properties (Homogeneous Model) is not able to predict heat transfer coefficient enhancement of nanofluids. The comparison between experimental results obtained for CuO/water and Al_2O_3/water nanofluids indicates that heat transfer coefficient ratios for nanofluid to homogeneous model in low concentration are close to each other but by increasing the volume fraction, higher heat transfer enhancement for Al_2O_3/water can be observed.

Keywords: Laminar flow; Heat transfer enhancement; Forced convection; Nanofluid; Oxide nanoparticles

1. Introduction

Fluids, such as water, ethylene glycol and engine oil have poor heat transfer performance and therefore high compactness and effectiveness of heat transfer systems are necessary to achieve the required heat transfer. Among the efforts for enhancement of heat transfer the application of additives to liquids is noticeable [1,2]. These earlier studies, however used suspensions of millimeter or micrometer sized particles, which although showed some enhancement, experienced problems such as poor suspension stability and channel clogging, extra pressure drop and erosion.

The term of nanofluids refers to a new kind of fluids by suspending nanoparticles in base fluids. This term was used by Choi (1995) [3]. Nanofluids found to possess long time stability and large efficient thermal conductivity [4]. For example Lee [5] reported that suspension of 4% volume CuO 35 nm particles in ethylene glycol shows 20% increase in thermal conductivity. Since the theoretical models such as Maxwell and Hamilton–Crosser [6–8] cannot determine exactly the thermal conductivity of nanofluids, therefore it is necessary to study about thermal conductivity enhancement mechanisms of this kind of fluids.

There are only few previous studies involved in describing fluid flow and convective heat transfer performance of the nanofluids [9–11]. Li and Xuan [9] studied convective heat transfer of 35 nm Cu/deionized water nanofluid

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Nomenclature

A	Tube cross section area (m^2)
Cp	Specific heat ($kJ\ kg^{-1}\ K^{-1}$)
D	Tube diameter (m)
$\overline{h}_{nf}(\exp)$	Nanofluid experimentally average heat transfer coefficient ($Wm^{-2}\ K^{-1}$)
k	Thermal conductivity ($Wm^{-2}\ K^{-1}$)
L	Tube length (m)
$\overline{Nu}_{nf}(\exp)$	Nanofluid experimentally average Nusselt number
$\overline{Nu}_{nf}(\mathrm{th})$	Nanofluid Nusselt number calculated form Seider–Tate equation
Pe	Peclet number
Pr	Prandtl number
Re	Reynolds number
Tb_1	Inlet bulk temperature (K)
Tb_2	Exit bulk temperature (K)
$\overline{Tb}$	Average bulk temperature (K)
Tw	Tube wall temperature (K)
$\bar{U}$	Average fluid velocity ($m\ s^{-1}$)

Greek letters

μ	Viscosity (Pa s)
μ_{wnf}	Nanofluid viscosity at tube wall temperature (Pa s)
v	Nanoparticle volume fraction
ρ	Density ($kg\ m^{-3}$)

Subscripts

nf	Nanofluid
s	Solid nanoparticles
w	Water

and showed that the suspended nanoparticles remarkably enhance heat transfer process with smaller volume fraction of Cu nanoparticles.

Some other experimental or theoretical investigations indicated that the Nusselt number of the nanofluids increases with increasing volume fraction of the nanoparticles [12–14]. However Pak and Cho [15] expressed that the convective heat transfer coefficient of Al_2O_3/water and TiO_2/water nanofluids with concentration of 3.0% volume was 12.0% smaller than that of pure water. Putra [16] reported suppression of natural convection heat transfer by nanofluid of Al_2O_3/water and CuO/water and concluded that this could be due to nanoparticles settling and velocity difference between nanoparticles and main fluid. Nanofluid boiling process was investigated experimentally by several researchers [17,18]. Das et al. [17] observed nanofluids boiling performance deterioration.

The objective of this study is to compare laminar flow convective heat transfer and rheological properties of CuO/water and Al_2O_3/water nanofluids under constant wall temperature boundary condition and different concentration of nanoparticles.

2. Experimental setup

The experimental apparatus with constant wall temperature boundary condition is shown schematically in Fig. 1. The test chamber constructed of 1 m annular tube with 6 mm diameter inner copper tube and with 0.5 mm thickness and 32 mm diameter outer stainless steel tube. Nanofluid flows inside the inner tube while saturated steam enters annular section, which creates constant wall temperature boundary condition. The fluid