International Journal of Heat and Mass Transfer 118 (2018) 40–47

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Heat transfer measurment in water based nanofluids

Masoudeh Ahmadi, Gerold Willing *

Department of Chemical Engineering, University of Louisville, Louisville, KY 40292, United States

ARTICLE INFO

Article history:
Received 4 November 2016
Received in revised form 5 April 2017
Accepted 22 October 2017
Available online 28 October 2017

Keywords:
Nanofluids
Copper oxide
Heat transfer enhancement
Heat transfer coefficient
CFD

ABSTRACT

Nanofluids are a class of heat transport fluids created by suspending nano-scaled metallic or nonmetallic particles into a base fluid. Some experimental investigations have revealed that the nanofluids have remarkably higher thermal conductivities than those of conventional pure fluids and are more suited for practical application than the existing techniques of heat transfer enhancement using millimeter and/or micrometer-sized particles in fluids. Use of nanoparticles reduces pressure drop, system wear, and overall mass of the system leading to a reduction in costs over existing enhancement techniques. The focus of this study is to determine the role of nanoparticle motion in the enhancement of the overall heat transfer coefficient of a nanofluid at different nanoparticle loadings. The enhancement of the heat transfer coefficient is determined experimentally by dispersing CuO nanoparticles (40 nm) with different particle loadings (0.25 wt% and 1 wt%) into water and then flowing the resulting nanofluid through a heated copper tube. The experimental results illustrated that numerous factors including Reynolds number and particle concentration are all capable of impacting the enhancement ratio. To further explain the impact of these variables on the hydrodynamic and thermal parameters of a nanofluid, we developed a CFD model using a Eulerian-Lagrangian approach to study the nature of both the laminar and turbulent flow fields of the fluid phase as well as kinematic and dynamic motion of the dispersed nanoparticles. The main goal is to provide additional information about the fluid and particle dynamics to explain the observed behavior in the experimentally observed trends of the heat transfer coefficient enhancement relative to both nanoparticle concentrations and fluid flow behavior. Our results indicate that heat transfer enhancement significantly depends on particle motion within the system and is highly dependent upon the position of nanoparticles relative to the tube wall.

1. Introduction

One method of enhancing the thermal conductivity, and hence the heat transfer coefficient of a fluid is to add nanoparticles to the fluid creating what is commonly known as a nanofluid. The heat transfer coefficient, the proportionality constant between the heat flux and the thermodynamic driving force for the flow of heat, shows how effectively heat can be transferred within a system. The coefficient can be passively enhanced by changing flow geometry, system parameters (temperature, velocity, etc.), or by enhancing the thermal conductivity of the fluid. In most existing systems, the first two of these are set by design, which leaves enhancement of the heat transfer properties of the fluid as the only method to enhance heat transfer within an existing system [1].

Many researchers have considered using nanofluids in heat exchange systems to replace conventional thermal working fluids such as water, ethylene glycol (EG) and engine oil. Nanoparticle suspensions based on these fluids containing a small amount of metal nanoparticles such as Cu, or nonmetal nanoparticles like SiC, Al_2O_3, CuO have been reported recently because they have higher thermal conductivity as compared to conventional thermal fluids [2–5]. In general, the results indicate that the heat transfer coefficient is increased by adding nanoparticles to the conventional fluid. This can be explained by the fact that metals with their higher thermal conductivity when compared to the conventional fluids could lead to increases in the overall heat transfer coefficient when added to the conventional fluids [6–8].

Numerous works regarding the thermal performance of nanofluids have been published in the recent decades based on both experimental and theoretical evaluation. Many of the works point to the fact that the addition of small amounts of nanoparticles to fluids tends to enhance the heat transfer capabilities of the base fluid. However, due to the often contradictory results within the research conclusions of these works, nanofluid research work is still under heavy investigation. Some of the current experimentation is reviewed in the following paragraphs.

* Corresponding author.
E-mail address: gerold.willing@louisville.edu (G. Willing).

https://doi.org/10.1016/j.ijheatmasstransfer.2017.10.090
0017-9310/

Nomenclature

h	heat transfer coefficient (J/m^2 K)
T_{out}	outlet temperature of heat exchange section (K)
T_{in}	inlet temperature of heat exchange section
Cp	specific heat (J/kg K)
ρ	density (kg/m^3)
Q	volumetric flow rate (m^3/s)
L	length (m)
d	diameter (m)
ΔT	average temperature difference between surface of the tube and the fluid (K)
ϕ	volume fraction of the nanoparticles
V	mean velocity (m/s)
μ	dynamic viscosity (kg/ms)
Re	Reynolds number

Subscripts

bf	base fluid
nf	nanofluid
p	CuO nanoparticles

Namburu et al. studied the turbulent flow and heat transfer characteristics of several nanofluids (CuO, Al_2O_3 and SiO_2) in an ethylene glycol and water mixture flowing through a circular tube under a constant heat flux condition. They showed that nanofluids containing smaller diameter nanoparticles, regardless of the material, had higher viscosities and higher Nusselt numbers. This suggests that as nanoparticle size decreases, the importance of convective heat transfer increases [9]. Nguyen et al. reported on the heat transfer coefficient of Al_2O_3/water nanofluids flowing through a microprocessor liquid cooling system under turbulent flow conditions. They reported that the heat transfer coefficient of the nanofluid is higher than the base fluid. They also found that the nanofluid with smaller nanoparticles gave a higher heat transfer coefficient [10]. Both of these studies indicated that heat transfer coefficient increased by decreasing particle size.

Jalal et al. performed an experimental study on the impact of a CuO/water nanofluid on the convective heat transfer over a heat sink in the laminar flow regime. They found that the heat transfer coefficient increased with increasing volume percentage of the CuO nanoparticles [6]. Fotukian and Esfahani also studied the heat transfer coefficient of a CuO/water nanofluid. In this case, their focus was on the heat transfer within a circular tube under turbulent flow conditions. They found that the heat transfer coefficient was enhanced by 25% at nanoparticle loadings of 0.236% (on a volume basis) [11]. Therefore, in both studies heat transfer enhancement increased with increasing CuO concentration.

Other groups studied effect of *Re* and particle concentration on the heat transfer coefficient and Nusselt number of different types of nanofluids (Al_2O_3, TiO_2 and CuO). Most of them reported similar conclusions under both laminar and turbulent flow regimes. Heyhat et al. studied the convective heat transfer and friction factor of Al_2O_3/water nanofluids in a circular tube with a constant wall temperature under turbulent flow conditions. They found that the heat transfer coefficient of nanofluids was higher than the base liquid (water) and increased with increasing nanoparticle concentration. Their results indicated that in this system the heat transfer coefficient did not change significantly with Reynolds number [12]. Wen and Ding have studied Al_2O_3/water nanofluid in laminar flow and indicated that the convective heat transfer coefficient of a nanofluid will increase with Reynolds number and nanoparticle concentration [13]. Heris et al. studied the heat transfer of both Al_2O_3/water and CuO/water nanofluids through a circular tube under laminar flow conditions and reported an enhancement in the convective heat transfer coefficient over that of pure water (41% and 38% at 3% by volume of Al_2O_3 and CuO nanoparticles, respectively) [7,8]. Pak and Cho also studied heat transfer performance of Al_2O_3/water and TiO_2/water nanofluids flowing in a horizontal circular tube with a constant heat flux under turbulent flow conditions. Their results showed that the Nusselt number for the nanofluid increased with increasing Reynolds number and volume fraction. However, they found that the heat transfer coefficient of the nanofluid with 3% volume fraction nanoparticles was 12% lower than that of pure water [14] so in this case the results are in direct contradiction with the other studies.

Overall, adding nanoparticles to heat transfer fluids seems to improve the heat transfer properties of the fluid. It seems that in most cases the heat transfer coefficient enhancement increased with decreasing nanoparticles size, increasing *Re*, and increasing volume fraction. However, in some cases no changes were observed and even negative enhancements have been observed by increasing either Reynolds number or volume fraction. Due to the inconsistencies within the research conclusions of these experimental works, a number of groups have turned to theoretical and simulation studies to address these observed inconsistencies.

To better understand how the nanoparticles influence the thermal physical properties of nanofluids, the kinematics and dynamics of the nanoparticles have been investigated in a number of simulations. Akbarnia and Behzadmehr reported a CFD model for the investigation of laminar convection of a water/Al_2O_3 nanofluid in a horizontal curved tube. The focus of their study was on the impact of nanoparticle concentration. Specifically, it was found that for a given Reynolds number, the nanoparticle concentration has a positive effect on the heat transfer enhancement [15]. Mirmasoumi and Bezadmehr used a two-phase model for the prediction of turbulent forced convection of a nanofluid in a tube with uniform heat flux. In the CFD simulation the effect of nanoparticle volume fraction on both the hydrodynamic and thermal parameters was investigated. Their results showed that increasing the nanoparticle volume fraction augments the molecular thermal diffusion, which significantly enhances the heat transfer enhancement. In addition, their comparison with the experimental results showed that the mixture model is more precise than the single-phase model [16]. Aminfar and Motallebzadeh investigated the concentration distribution and velocity field of nanoparticles of water/Al_2O_3 nanofluid in a pipe with a constant heat flux based on a Lagrangian-Eulerian model in the laminar regime. They reported that Brownian forces have the most impact on the nanoparticles concentration distribution and the velocity field when compared to the other forces such as thermophoretic and gravitational forces [17].

Kumar investigated the heat transfer enhancement numerically using the single-phase approach for a constant wall temperature boundary condition in both laminar and turbulent flow regime in pipe flow by Al_2O_3 nanofluid. Both the experimental values and the numerical predictions showed that heat transfer enhancement in the laminar regime is not as significant as in the turbulent regime. It was pointed out that single-phase approach does not predict heat transfer coefficient in the laminar regime as accurately as in the turbulent regime [18]. More research needs to be done to