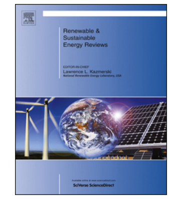
Renewable and Sustainable Energy Reviews 29 (2014) 734–743

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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



A review of forced convection heat transfer enhancement and hydrodynamic characteristics of a nanofluid

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ARTICLE INFO

Article history:
Received 22 May 2013
Received in revised form
5 August 2013
Accepted 11 August 2013
Available online 27 September 2013

Keywords:
Nanofluid
Heat transfer
Nusselt number
Friction factor
Heat exchanger

ABSTRACT

The low thermal properties of liquids have led to investigations into additives of small size (less than 100 nm solid particles) to enhance their heat transfer properties and hydrodynamic flow. To summarise the experimental and numerical studies, this paper reviews these computational simulations and finds that most of them are in agreement with the results of experimental work. Many of the studies report enhancements in the heat transfer coefficient with an increase in the concentration of solid particles. Certain studies with a smaller particle size indicated an increase in the heat transfer enhancement when compared to values obtained with a larger size. Additionally, the effect of the shape of the flow area on the heat transfer enhancement has been explored by a number of studies. All of the studies showed a nominal increase in pressure drop. The significant applications in the engineering field explain why so many investigators have studied heat transfer with augmentation by a nanofluid in the heat exchanger. This article presents a review of the heat transfer applications of nanofluids to develop directions for future work. The high volume fraction of various nanofluids will be useful in car radiators to enhance the heat transfer numerically and experimentally. Correlation equations can expose relationships between the Nusselt number, the Reynolds number, the concentration and the diameter of the nanoparticles. On the other hand, more work is needed to compare the shapes (e.g., circular, elliptical and flat tube) that might enhance the heat transfer with a minimal pressure drop.

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1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2013.08.014

1. Introduction

A nanofluid is a new class of heat transfer fluids engineered by dispersing metallic or non-metallic nanoparticles with a typical size of less than 100 nm in the base fluid (e.g., water, ethylene glycol and oil). The poor thermophysical properties of liquids may have led to the use of suspended solid particles as an additive to enhance the thermal properties and improve the heat transfer characteristics of liquids. The key idea is to improve the thermal conductivity. Because the solid particles have a larger thermal conductivity than the liquids, solid particles suspended in the liquid will improve the thermal conductivity of liquid. For many years, suspensions of millimetre- or micrometre-sized solid particles have been tested to enhance the thermal conductivity of conventional fluids, but problems of sedimentation led to increased pressure drop in the flow channel, as reported by Lee et al. [1]. Recent advances in material technology made it possible to produce innovative heat transfer fluids by suspending nanometre-sized particles that change the transport and thermal properties in base fluids. A solid liquid composite materials consisting of solid nanoparticles with size not large than 100 nm suspended in liquid defined as nanofluids [2]. Nanofluids have attracted significant interest recently because of reports of the enhancement of Thermophysical properties for many industrial applications [3–7].

This review will focus mainly on the hydrodynamic and heat transfer enhancement potential of nanofluids with forced convection flow types (laminar–turbulent) and on the effect of the concentration and diameter of nanoparticles and the shape of cross sectional tubes without much detail about Thermophysical properties. Additionally, this review will give a significant plan for accurate future work.

2. Thermal properties

The thermal conductivity of ultrafine suspensions of alumina, silica and other oxides in a base fluid water was proven to increase up to 30% at a concentration by volume of 4.3% by Masuda et al. [8]. Many researchers have used the mixture relation for estimating the density and specific heat capacity [9–20] of nanofluids with

$$\rho_{nf}=\left(\frac{\phi}{100}\right)\rho_p+\left(1-\frac{\phi}{100}\right)\rho_f \quad (1)$$

$$C_{nf}=\frac{(\phi/100)(\rho C)_p+(1-(\phi/100))(\rho C)_f}{\rho_{nf}} \quad (2)$$

The convection heat transfer coefficient doubled when adding nanoparticles suspended in water as a base fluid in a study by Choi [21]. The thermal conductivity is a significant thermal property for enhancing the heat transfer of liquids by suspending metal or non-metal as shown in Table 1.

The thermal conductivity of nanofluids has been determined experimentally [9–18], and the data of the thermal conductivity for nanofluids of metal and metal oxides, such as Al_2O_3, Fe_3O_4, TiO_2, ZnO, ZrO_2 and CuO, consist of many data points available in the literature for use in the development of the regression Eq. (3) by Sharma et al. [23]

$$k_r=\frac{k_{nf}}{k_f}=\left\{0.8938\left(1+\frac{\phi}{100}\right)^{1.37}\left(1+\frac{T_{nf}}{70}\right)^{0.2777}\left(1+\frac{d_p}{150}\right)^{-0.0336}\left(\frac{\alpha_p}{\alpha_f}\right)^{0.01737}\right. \quad (3)$$

Viscosity is another parameter that influences heat transfer and pressure drop. The experimental study of alumina and copper oxide nanofluid viscosity under ambient conditions with different volume fractions and particle diameters have been conducted by Nguyen et al. [22]. The viscosity of a water–Al_2O_3 nanofluid with particle diameters of 36 and 47 nm and with CuO solid particles of 29 nm diameters were studied by Sharma et al. [23]. The experimental data for viscosity gathered by [24–31] for up to 4% volume concentration consisted of many data points subjected to regression by [23] to obtain the following correlation:

$$\mu_r=\frac{\mu_{nf}}{\mu_f}=\left(1+\frac{\phi}{100}\right)^{11.3}\left(1+\frac{T_{nf}}{70}\right)^{-0.038}\left(1+\frac{d_p}{170}\right)^{-0.061} \quad (4)$$

3. Forced convection heat transfer in a tube

3.1. Experimental studies

The heat transfer coefficients of nanofluids were calculated from the following equations:

$$Nu=\frac{h\times d}{k} \quad (5)$$

$$h=\frac{Q}{T_w-T_f} \quad (6)$$

3.1.1. Laminar flow in a tube

Experimental results illustrated that the convective heat transfer coefficients of nanofluids varied with the flow velocity and

Table 1
Thermal conductivities of various materials [95].

Materials	Thermal conductivity at room temperature (W/m-K)
Silver	429
Copper	401
Aluminium	237
Diamond	3300
Silicon	148
Alumina	40
Water	0.61
Ethylene glycol	0.25
Motor oil	0.15