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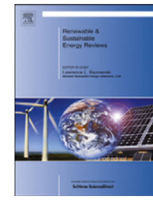

Convective heat transfer and friction factor correlations of nanofluid in a tube and with inserts: A review

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ABSTRACT

In the heat transfer area researches have been carried out over several years for the development of convective heat transfer enhancement techniques. The use of additives in the base fluid like water or ethylene glycol is one of the techniques applied to augment the heat transfer. Recently an innovative nanometer sized particles have been dispersed in the base fluid in heat transfer fluids. The fluids containing the solid nanometer size particle dispersion are called 'nanofluids'. The dispersed solid metallic or nonmetallic nanoparticles change the thermal properties like thermal conductivity, viscosity, specific heat, density, heat transfer and friction factor of the base fluid. Nanofluids are having high thermal conductivity and high heat transfer coefficient compared to single phase fluids. The enhancement in heat transfer coefficient with the effect of Brownian motion of the nanoparticles present in the base fluid. In this paper, a comprehensive literature on the correlations developed for heat transfer and friction factor for different kinds of nanofluids flowing in a plain tube under laminar to turbulent flow conditions have been compiled and reviewed. The review was also extended to the correlations developed for the estimation of heat transfer coefficient and friction factor of nanofluid in a plain tube with inserts under laminar to turbulent flow conditions. However, the conventional correlations for nanofluid heat transfer and friction factor are not suitable and hence various correlations have been developed for the estimation of Nusselt number and friction factor for both laminar and turbulent flow conditions inside a tube with inserts.

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1. Introduction

Thermal loads are increasing in a wide variety of applications like microelectronics, transportation, lighting, utilization of solar energy for power generation etc. The thermal load control technologies with extended surfaces such as fins and micro-channels have already reached their limits. Hence, the management of high thermal loads in high heat flux applications offers challenges and the thermal conductivity of heat transfer fluid have become vital. Traditional heat transfer fluids like water, engine oil, ethylene glycol, propylene glycol are inherently limited heat transfer capability. To overcome the limited heat transfer capabilities of these traditional fluids, micro/millimeter sized particles of high thermal conductivity suspended in them were considered by Ahuja [1]. The major disadvantage is settlement of these course grained particles in the base fluid. To overcome the problem of particle sedimentation, Choi [2] and his team developed nanometer sized particles. Choi et al. [3] observed 160% thermal conductivity enhancement with carbon nanotubes dispersed in engine oil. The similar trend is also observed by Lee et al. [4], Wang et al. [5], Eastman et al. [6,7]. Das et al. [8] have presented temperature dependent thermal conductivity of nanofluid. Sundar and Sharma [9] have observed 6.52% with Al_2O_3 nanofluid, 24.6% with CuO nanofluid thermal conductivity enhancement at 0.8% compared to water. Naik and Sundar [10] have also observed thermal conductivity enhancement with CuO nanoparticles dispersed into glycol and water mixture. Thermal conductivity of some commonly used solids and liquids as shown in Table 1.

Researchers have investigated the convective heat transfer for single-phase fluids and also developed correlations for the estimation of Nusselt number and friction factor. Instead of using single-phase fluids in heat exchangers, now researchers are investigating the convective heat transfer and feasibility of usage of nanofluids in a device. Nanofluid consists of nanosized particle dispersed in a fluids is called 'nanofluid'. Experimental investigation of convective heat transfer of different kind of nanofluids in a tube has been estimated by many researchers. Xuan and Li [11] have experimentally obtained heat transfer enhancement of Cu/water nanofluid in a tube under laminar flow condition and also developed correlation for Nusselt number.

Wen and Ding [12] experimentally obtained 47% heat transfer enhancement with Al_2O_3 nanofluid at 1.6% volume concentration under the Reynolds number of 1600. Experiments with Al_2O_3/water nanofluid in the laminar flow range of $Re=700$ and 2050 has been conducted by Heris et al. [13] and observed heat transfer augmentation with increase in Peclet number and nanoparticle volume fraction. Ding et al. [14] observed 350% heat transfer enhancement with carbon nanotubes (CNT's) flowing in a horizontal tube at 0.5% weight concentration at Reynolds number is 800. Ho et al. [15] have experimentally investigated the convective heat transfer enhancement in Al_2O_3/water nanofluid in micro-channel for a laminar flow.

Experimental convective heat transfer investigations of Al_2O_3, TiO_2 nanofluids in plain tube under turbulent flow condition are undertaken by Pak and Cho [16] and also developed correlation for Nusselt number. Fotukian and Esfahany [17,18] have observed 25% heat transfer enhancement of Al_2O_3/water and 20% pressure drop enhancement. Duangthongsuk and Wongwises [19] performed experimental studies on 0.2% TiO_2 nanofluid in double tube counter flow heat exchanger and obtained 6–11% heat transfer enhancement. Sundar et al. [20] have numerically obtained 2.25% heat transfer enhancement and 1.42% friction factor for Al_2O_3 nanofluid in a tube. Sundar et al. [21] have estimated the magnetic Fe_3O_4 nanofluid heat transfer in a tube and also presented Nusselt number and friction factor correlations.

Nanofluid is having the following advantages compared to single phase fluid: (i) high dispersion stability with predominant Brownian motion of particles (ii) reduced particle clogging as compared to convention slurries, thus promoting system miniaturization (iii) reduced pumping power as compared to pure liquid to achieve equivalent heat transfer intensification (iv) adjustable properties, including thermal conductivity and surface wettability, by varying particle concentrations to suit different applications (v) high specific surface area and therefore more heat transfer surface between particles and fluids. The enhancement in heat transfer of nanofluid cause several reasons such as Brownian motion, Brownian diffusion, friction factor between the fluid layer and the nanoparticle. It also causes dispersion, layering at the liquid/solid interface, ballistic phonon transport and thermophoresis of the nanofluid. Heat transfer experiments are indicating that thermal conductivity is not only the reason for heat transfer augmentation of the nanofluid; it also depends on the Prandtl number. Proper detailed physical mechanism for nanofluid heat transfer augmentation has not been established.

Experimental heat transfer and friction factor of nanofluid in a tube with different kind of inserts is the interesting topic. Researchers are investigating the further heat transfer enhancement for nanofluid flowing in a tube with different kind of inserts. Chandrasekar et al. [22,23] investigated the heat transfer of Al_2O_3/water nanofluids in a circular tube with wire coil inserts and found heat transfer enhancement of up to 15.91%. Pathipakka and Sivashanmugam [24] numerically investigated heat transfer of 1.5% volume concentration of Al_2O_3/water nanofluid in a tube with twisted tape inserts of 2.93 twist ratio and found 31.29% enhancement in the heat transfer at $Re=2039$. Sundar and Sharma [25] have obtained 22.0% heat transfer enhancement for water in tube with longitudinal strip inserts of $AR=1$. Sundar and Sharma [26] investigated convective heat transfer and friction factor of Al_2O_3 nanofluid in circular tube fitted with twisted tape inserts. Sharma et al. [27], Sundar and Sharma [28,29] presented the empirical correlation for the estimation of Nusselt number and friction factor of Al_2O_3 nanofluid flowing in a tube with twisted and longitudinal strip inserts. Sundar et al. [30] have investigated Fe_3O_4/water nanofluid in a tube with twisted tape inserts and also developed Nusselt number and friction factor correlations.

Convective heat transfer and friction factor of nanofluid flowing in a tube and with different kind of inserts have been explained by