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Experimental investigation of convective heat transfer augmentation for car radiator using ZnO–water nanofluids

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ABSTRACT

New experimental data are reported for water based nanofluids to enhance the heat transfer performance of a car radiator. ZnO nanoparticles have been added into base fluid in different volumetric concentrations (0.01%, 0.08%, 0.2% and 0.3%). The effect of these volumetric concentrations on the heat transfer performance for car radiator is determined experimentally. Fluid flow rate has been varied in a range of 7–11 LPM (liter per minute) (corresponding Reynolds number range was 17,500–27,600). Nanofluids showed heat transfer enhancement compared to the base fluid for all concentrations tested. The best heat transfer enhancement up to 46% was found compared to base fluid at 0.2% volumetric concentration. A further increase in volumetric concentration to 0.3% has shown a decrease in heat transfer enhancement compared to 0.2% volumetric concentration. Fluid inlet temperature was kept in a range of 45–55 °C. An increase in fluid inlet temperature from 45 °C to 55 °C showed increase in heat transfer rate up to 4%.

1. Introduction

Heat transfer has been a great challenge for the industrial applications during various operations in order to achieve better performance and efficiency. Many techniques were used in past to enhance heat transfer i.e. pure liquid forced convection and extended surfaces were used to enhance the heat transfer, however due to ever increasing heat flux requirement, these techniques have reached their limits. Nanofluids were developed recently by suspending solid particles (ranging from 10 nm to 100 nm) in a base fluid, these fluids have displayed better thermal characteristics and exhibited excellent heat transfer properties even at low concentration of nano particles in base fluid.

In current era, a large number of experimental investigations are being performed on the properties of nanofluids, it has been found that classical physical models failed to predict the behavior of the nanofluids. Several researches on thermal behavior of nanofluid have resulted in remarkable enhancement in heat transfer in comparison with the conventional mixtures and classical physical model applied could not predict its behavior (Maxwell [1]; Hamilton and Crosser [2]; Xiang and Arun [3]). Thermal conductivity of metallic and oxide nanofluids was measured for a wide range of particle size and volume fraction as a function of temperature. Metallic nanofluids showed higher enhancements compared with the oxide nanofluids (Hrishikesh et al. [4]).

Lee et al. [5] found the thermal conductivity of different nanofluids like Al_2O_3–water, Al_2O_3–EG, CuO–water and CuO–EG using transient hot wire method. The results showed that thermal conductivity is a function of size and shape of particle, and thermo physical properties of base fluid and nanoparticles. Thermal conductivities of both nanofluids were found to be considerably higher than their base fluids. Experimental data of Al_2O_3 nanofluids showed good agreement with previous model (Hamilton and Crosser) to predict thermal conductivity, whereas experimental data of CuO nanofluids showed inadequate agreement. Das et al. [6] found that thermal conductivity is directly proportional to temperature and the values were not obtained from effective model of thermal conductivity. They suggested that greater the number of particles meant greater heat conduction due to increased surface area for heat transfer. Chandrasekar et al. [7] reported that thermal conductivity increased with increasing concentration as viscosity increased with increasing concentration at higher rate. Xuan and Li [8] found that nanofluids have greater thermal conductivity as compared to pure water, they experimentally investigated

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convective heat transfer characteristics of Cu–water nanofluids passing through a straight tube with constant heat flux. It was observed that friction factor of nanofluid at low concentration showed negligible effect on power consumption.

Automotive industry is undergoing continuous improvement in all of its major fields; heat transfer enhancement to improve the performance of the automobile is an important aspect of this industry. Radiator is an important heat exchanger of an automobile which is used for cooling of car engine with water as fluid carrying heat from engine to the radiator, so far less work has been done on the car radiator. In recent years, there has been greater emphasis on heat transfer of nanofluid in different kind of heat exchangers like shell and tube [9], double tube heat exchangers [10], Plate heat exchangers [11], but a handful studies have been done on car radiator investigating the effects of nanofluids.

Choi [12] reported a study regarding fuel saving in automobile by the use of nanofluids and they reported to have heat transfer enhancement by more than 10% at 0.5 vol.% of 2 nm gold nano particles. Esfe et al. [13] conducted an investigation which showed that addition of less than 1% vol. MgO nanoparticles in a base fluid enhanced the heat transfer capability of that fluid. Pressure drop was higher in nanofluid than base fluid; however without significant increment in consumed power nanofluids increased the heat transfer. It was reported that increase in nanoparticle volumetric concentration increases the thermal conductivity of nanofluids, however, this increase also increase the viscosity which leads to an increase in the boundary layer thickness; therefore it may cause a decrease in the convective heat transfer.

Xie et al. [14] reported heat transfer enhancement using nanofluids of Al_2O_3, ZnO, TiO_2 and MgO with a mixture of water and ethylene glycol of 55% and 45% respectively. Al_2O_3, MgO and ZnO nanofluids showed superior increment in heat transfer compared to TiO_2 nanofluids (which was the lowest, less than 10% enhancement compared to base fluid). In the case of MgO nanofluids at 1000 Reynolds number up to 252% enhancement was reported. Fotukian and Esfahany [15] experimentally investigated convective heat transfer of CuO–Water nanofluid in circular fin tube, 25% increase in heat transfer was observed using 0.3% vol. fraction of nano particle. Peyghambarzadeh et al. [16] tested a car radiator using Al_2O_3/water based nanofluids. The volumetric concentrations were varied in a range of 0.1–1%. A maximum heat transfer enhancement up to 45% at 1% volumetric concentration was recorded. Leong et al. [17] showed that overall heat transfer coefficient and convective heat transfer coefficient was greater than pure water by using copper/water nanofluid in shell and tube heat exchanger. With 1% copper nanoparticles in ethylene glycol, 16.9% enhancement in heat transfer was observed. Jung et al. [18] conducted experiments to determine the convective heat transfer of Al_20_3 nanofluid. Three volumetric concentrations of 0.6%, 1.2% and 1.8% were tested. They reported a heat transfer enhancement of about 32% at 1.8% volume concentration. Heris et al. [19] conducted experiment of Al_2O_3 with water based nanofluid under laminar flow, heat transfer enhancement was found to be as high as 40%.

Hussein et al. [20] tested TiO_2 and SiO_2 water based nanofluids in a car radiator under laminar flow regime. Volumetric concentration and fluid inlet temperature was changed in a range of 1–2% and 60–80 °C. Maximum enhancements of 11% and 22.5% in comparison with pure water were obtained for TiO_2 and SiO_2 nanofluids respectively. Elias et al. [21] reported findings about thermal conductivity, viscosity, specific heat and density of Al_2O_3 nanofluids in water and ethylene glycol used as coolant in car radiator. Volume concentration and coolant temperature were kept up to 1% and 50 °C respectively. Viscosity, thermal conductivity and density of the nanofluids were found to increase whereas specific heat of nanofluid was found to decrease with increasing volumetric concentrations. Peyghambarzadeh et al. [22] tested a car radiator for CuO and Fe_2O_3 water based nanofluids at three volumetric concentrations of 0.15, 0.4 and 0.65%. Reynolds number was varied from 50 to 1000 and coolant inlet temperature was changed from 50 to 80 °C. Both nanofluids showed a 9% increase in overall heat transfer coefficient compared with water. Increasing the nanofluids inlet temperature decreased the overall heat transfer coefficient. Vermahmoudi et al. [23] further investigated the above [22] study for Fe_2O_3 water based nanofluids only. Increasing the inlet temperature was found to have a negative effect on overall heat transfer coefficient and a positive effect on heat transfer rate. Naraki et al. [24] reported experimental results for CuO/water nanofluids tested under laminar flow regime in a car radiator. Volumetric concentration was varied from 0 to 0.4% and inlet temperature was changed from 50 to 80 °C. An 8% increase in overall heat transfer coefficient compared with water was reported for 0.4% vol. nanofluids. Peyghambarzadeh et al. [25] experimentally investigated the effect of Al_2O_3 nanoparticles in the fluids of water and ethylene glycol. 0.1–1 % vol. nanofluids were prepared. Coolant flow rate was varied from 2 to 6 LPM (liter per minute). For water based and ethylene glycol based nanofluids inlet temperatures were varied in the range of 35–50 °C and 45–60 °C respectively. Reynolds number was kept in the range of 1200–2500 and 9000–23,000 for ethylene glycol and water based nanofluids respectively. By the addition of 1% vol. nanoparticles in the base fluid of water or ethylene glycol, a 40% increase in Nusselt number was recorded compared to the base fluids.

Kole and Dey [26] prepared ZnO–ethylene glycol nanofluids using sonication. A maximum 40% thermal conductivity enhancement compared to base fluid was reported for 3.75% vol. of ZnO particles in ethylene glycol. Nucleate pool boiling heat transfer measurements were performed using a cylindrical polished copper heater surface. Up to 22% increase in boiling heat transfer coefficient was found at a volumetric concentration of 1.6% nanofluids. Shoghl and Bahrami [27] reported pool boiling data using ZnO–-water nanofluids. 0.01–0.02% by weight ZnO nanofluids were prepared using different combinations of 0.01–0.02% by weight surfactant SDS (sodium dodecyl sulfate). Nanofluid with 0.01 wt% ZnO and 0.02 wt% SDS showed the best enhancement about 30% in convective heat transfer coefficient compared to pure water. Ferrouillat et al. [28] carried out an experimental study of SiO_2 and ZnO nanofluids flowing inside a horizontal tube with a wall temperature. Two shapes of each nanoparticle were used. Two different inlet temperatures of 20 °C and 50 °C were imposed and flow rates were kept in a Reynolds number range of 200–15,000. For SiO_2 both nanofluids with different shaped particles showed about 4% enhancement in Nusselt number compared to pure water. For ZnO, nanofluids with polygonal nano particles showed 8% and nanofluids with rod-like nanoparticles showed 3% Nusselt number enhancements compared to pure water.

Above literature review reveals the enhancing heat transfer effects of nanofluids for many applications. A very few studies so far are reported for nanofluids heat transfer enhancement for car radiators. In this investigation, ZnO/water nanofluids are prepared for different volumetric concentrations (i.e. 0.01%, 0.08%, 0.2% and 0.3) to find the optimum heat transfer enhancement for car radiator.

2. Experimental setup and methodology

Preparing a stable and homogenous nanofluid holds a great importance in heat transfer characteristics. Two main factors play important role in the stability of nanofluid i.e. particles agglomeration and particles suspension in base fluid. Failing to achieve these factors will result in poor performance of the nanofluid. Particle agglomeration may eliminate the nano related discussions as