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# Experimental investigation on heat transfer enhancement of alumina/water and alumina/water–ethylene glycol nanofluids in thermally developing laminar flow

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ABSTRACT

In this paper, hydrodynamic and thermal behaviors of alumina/water and alumina/water–ethylene glycol 50–50 by volume (WEG50) nanofluids in the thermal entrance region of a circular tube with constant wall temperature were studied experimentally. The flow regime was laminar and only hydrodynamically fully developed. The effects of base fluid, nanoparticles loading and Reynolds number on the convective heat transfer coefficient and pressure drop were studied. The experiments were conducted for 0%, 0.25%, 0.5% and 0.7% nanoparticles volume fractions while Reynolds number varies between 650 and 2300. The dynamic viscosity and the thermal conductivity were measured experimentally. Significant enhancement in nanofluids convective heat transfer coefficient was observed with respect to that of the base fluid. The results indicate that the average convective heat transfer and average Nusselt number increase with increasing volume fraction as well as Reynolds number. But the average Nusselt number ratio was not improves with increasing Reynolds number. Also it is found alumina/WEG50 nanofluids have more heat transfer increment compared to alumina/water nanofluids. The pressure drop behavior was the same as the average convective heat transfer coefficient with the presence of nanoparticles in the base fluid. Finally the energy ratio was defined and showed adding nanoparticle to the base fluid caused increment in energy ratio.



## 1. Introduction

A nanofluid is produced by dispersing some metallic or non-metallic nanometer sized solid particles in a base fluid like water, ethylene glycol or oil. One of the main goals of producing nanofluid is to improve heat transfer characteristics of the base fluid. Suspended nanoparticles have higher thermal conductivity than base fluid, thus nanofluids effective thermal conductivity and convective heat transfer coefficient enhance. Recently, different experimental investigations on nanofluids convection have been performed, in both laminar [1–5] and turbulent regimes [6–9].

Choi and Eastman [10] showed that addition of a small amount of nanoparticles (less than 1% by volume) to conventional heat transfer liquids increase the thermal conductivity of the fluid up to approximately two times. Pak and cho [6] and Li and Xuan [7] provided the first empirical correlation for calculating the Nusselt numbers in laminar and turbulent flows inside a tube using water as a base fluid. Eastman et al. [11] found that with less than 1% volume of CuO nanoparticles, the convective heat transfer coefficient of water increases more than 1%. Wen and Ding [1] showed that the local heat transfer coefficient varies with $\varphi$ and Re at the tube entrance region of laminar flow. Lai et al. [12] studied $Al_2O_3$ (20 nm)-deionized water nanofluids subjected to constant wall heat flux at low Reynolds number (Re < 270). They observed 8% enhancement in the Nusselt number for 1% volume concentration of nanoparticles at Re = 270.

Chandrasekar et al. [13] have found alumina/water nanofluids have higher convective heat transfer coefficient with inserted wire coil in tube. They did experiments with plain tube and two wire coils with pitch ratio 2 and 3 inserted in a tube under fully developed laminar flow and their results indicated the Nusselt number increased 12.24%, 15.91% and 21.53% respectively at Re = 2275. Heris et al. [3] investigated convective heat transfer of CuO and $Al_2O_3$–water nanofluids under laminar flow conditions through a circular copper tube. In their study, the heat transfer coefficient was found to increase with increasing particle volume fraction as well as Peclet number. $Al_2O_3$–water nanofluids showed higher enhancement of the heat transfer coefficient compared with CuO–water nanofluids. Arani and Amani [14] studied heat transfer coefficient and pressure drop of $TiO_2$–water nanofluid in a horizontal double tube counter-flow heat exchanger experimentally. Their experiments were carried out in 0.01 and 0.02 volume concentrations with 10, 20, 30 and 50 nm particle diameters under turbulent

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**Nomenclature**

| | |
|---|---|
| $A$ | cross-sectional area of the tube ($m^2$) |
| $C_P$ | specific heat capacity (J $kg^{-1}$ $K^{-1}$) |
| $D$ | tube diameter (m) |
| $d$ | diameter (m) |
| $f$ | friction factor |
| $h$(exp) | experimental convective heat transfer coefficient of nanofluid (W $m^{-2}$ $K^{-1}$) |
| $k$ | thermal conductivity (W $m^{-1}$ $K^{-1}$) |
| $L$ | tube length (m) |
| $B_c$ | Boltzman constant ($1.3807 \times 10^{-23}$ J/K) |
| $l$ | mean free path (m) |
| $Nu$(exp) | experimental Nusselt number of nanofluid |
| Pr | Prandtl number |
| Re | Reynolds number |
| $T$ | temperature (K) |
| $u_m$ | average fluid velocity (m $s^{-1}$) |

*Greek symbols*

| | |
|---|---|
| $\mu$ | dynamic viscosity (Pa s) |
| $\varphi$ | nanoparticle volume fraction |
| $\rho$ | density (kg $m^{-3}$) |
| $\Delta P$ | pressure drop (Pa) |
| $\Delta T_{lm}$ | logarithmic mean temperature difference (K) |

*Subscripts*

| | |
|---|---|
| *ave* | average |
| *bf* | base fluid |
| *nf* | nanofluid |
| *p* | particle |
| *in* | inlet |
| *out* | outlet |

flow regime. They define thermal performance factor with both Nusselt number and pressure drop and showed that 20 nm particle diameter has the highest one. Heyhat et al. [15] performed experimental study on alumina/water nanofluids in a horizontal tube under laminar regime. They measured nanofluids properties experimentally and showed the convection heat transfer coefficient of 2% nanofluids was 32% higher than the base fluid in fully developed region.

In many industrial application the mixture of water and ethylene glycol with different volume or weight percentages are used as coolant. Thus some researches were done for convective heat transfer enhancement of nanofluids with mixture of water and ethylene glycol as base fluid. Kulkarni et al. [16] investigated convective heat transfer enhancement of silicon dioxide–EG/water (60–40% by weight) experimentally. They studied the effect of Reynolds number, volume fraction and three different particle sizes. Their results showed heat transfer coefficient and pressure loss increased with increase in Reynolds number, volume fraction and particle size.

Zamzamian et al. [17] carried out experiments on convective heat transfer of $Al_2O_3$ and CuO ethylene glycol nanofluids in double pipe and plate heat exchangers under turbulent flow. They found convective heat transfer coefficient growth with increasing particle loading and nanofluid temperature. They reported augmentation of convective heat transfer coefficient from 2% to 50% more than base fluid. Yu et al. [18] investigated rheological and heat transfer properties of alumina–water–ethylene glycol (55–45 by volume) experimentally. Their results indicated the thermal conductivity of 2% and 3% nanofluids are 7.7% and 11.6% much more than base fluid. Also the heat transfer coefficient of 1% and 2% nanofluids are 57% and 106% higher than base fluid when Re = 2000.

Raveshi et al. [19], the nucleate boiling heat transfer of alumina–water–ethylene glycol (50–50 by volume) was studied experimentally. Six different volume concentrations of nanofluids were used and results showed the heat transfer coefficient have optimum value in 0.75% volume concentration (64% higher than base fluid).

Main objective of the present study is to find out the effects of base fluid, nanoparticles volume concentrations and Reynolds number on the average convective heat transfer coefficient and pressure drop along a circular tube under constant surface temperature boundary condition. The experiments were carried out for laminar flow regime. It should be noted that the flow was only hydrodynamically fully developed. The obtained results for the Nusselt number of nanofluids were compared with the available equation for thermal length problem.

## 2. Nanofluid preparation

Nanoparticles used in this work are spherical shape $Al_2O_3$ powder with a size range of 20–30 nm and purity of +99%, supplied by DEGUSSA, Germany. A two-step method was used to prepare stable nanofluids. Distilled water and the mixture of distilled water and ethylene glycol by equal volume concentration (WEG50) were used as the base fluid. For stabilizing the nanoparticles, sodium dodecyl benzene sulfonate (SDBS) was used as the dispersant with the amount of one tenth of the mass of nanoparticles. An electronic mass balance with accuracy 0.1 mg (model: Vibra LF 224R) was used to weight suitable amounts of $Al_2O_3$ powder and SDBS dispersant. The dispersant was first added to the base fluid and the mixture was sonicated in ultrasonic bath (model: Elmasonic S80 H) for 2 h. Then, nanoparticles were dispersed into the mixture and sonicated for 4 h. Next, the mixture was agitated with magnetic stirrer (model: Stuart SB 162) for 5 h. Nanofluids were found very stable after 3 days. The nanofluids were made with 0%, 0.25%, 0.5% and 0.7% volume concentrations in each base fluid. Fig. 1 shows the alumina/WEG50 nanofluid samples for 0.25%, 0.5% and 0.7% volume fractions 3 days after preparation.

## 3. Nanofluid properties

Determination of nanofluids thermophysical properties is very important as they are so impressive on the final results. Many

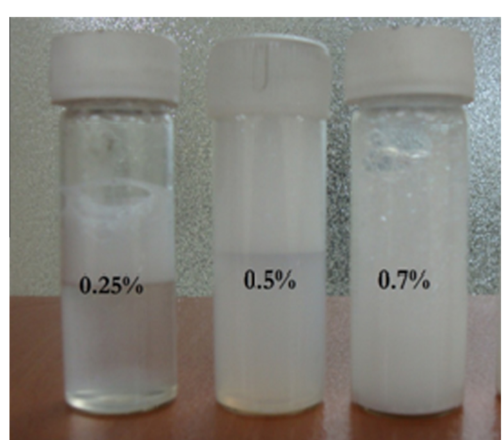


**Fig. 1.** Nanofluids sample after 3 days.