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# Comparison of CFD simulations to experiment for heat transfer characteristics with aqueous $Al_2O_3$ nanofluid in heat exchanger tube

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ABSTRACT

In this paper, the convective heat transfer and flow characteristics of nanofluids consisting of distilled water and 0.25, 0.5 wt% and 1 wt% $Al_2O_3$ nanoparticles were studied experimentally and compared to predicted results using computational fluid dynamics (CFD) that using laminar model was performed to examine the heat transfer characteristics. The $Al_2O_3$ nanoparicles with a nominal diameter of 40 nm are dispersed in distilled water to form stable suspensions containing various kind of volume concentrations of nanoparticles. For the even dispersion of the nanoparticles in the base liquid, ultrasound was applied for 3 h. The nanoparticle dispersion on alumina concentration was measured using UV spectroscopy. Thermal conductivities of nanofluid solutions are measured by the transient hot wire method. Heat transfer characteristics were investigated by changing pressure pulsation at each concentration. Finally, calculated heat transfer characteristics results using CFD are compared to experimental results and discussed successfully. Results indicate that the heat transfer coefficient and Nusselt number increase with increasing the Reynolds number and it is also seen that the Prandtl number is getting down when the concentration of nanofluids enlarge and showed the equation by the linear method of the result value.

## 1. Introduction

Nanofluids are a great part of nanotechnology-based heat transfer fluids produced by well-dispersing of some species of metallic and nonmetallic nanoparticles in convective heat transfer fluids. Nanoparticles size is typically smaller than 50 nm in traditional heat-transfer fluids such as water, glycol, or oil in many industry processes, including chemical, heating and cooling system [1–4]. It has developed new strategies in order to improve the effective way of heat transfer area in conventional fluids [5–9]. Maxwell [10,11] offered for enhancing heat transfer for the first time. But the main problem was that it is getting sunk down of these particles in fluids because of using such large particles like a micrometer or millimeter. Maxwell's concept is old, but what is new and innovative in the concept of nanofluids is the idea that particle size is primary importance in developing stable and highly conductive nanofluids. Choi [12], Masuda et al. [13] are the first researcher who investigated suspending nanoparticles in the base fluid. They found the effective thermal conductivity of mixtures with $Al_2O_3$ nanoparticles. Heris et al. [14,15] investigated the convective heat transfer coefficient of $Al_2O_3$–water and CuO–water nanofluids for laminar flow in an annular tube under a constant wall temperature boundary condition. And the results showed that the heat transfer coefficient increased with an increasing Peclet number as well as volume fraction and the $Al_2O_3$–water nanofluid showed larger enhancement than CuO–water nanofluid. Nguyen et al. [16] investigated the heat transfer enhancement and behaviour of the $Al_2O_3$–water nanofluid flowing under a turbulent flow regime inside the cooling system of microprocessors or other electronic components. Their results showed that the nanofluid gave a larger heat transfer coefficient than the base fluid and that the nanofluid with a 36 nm particle diameter provided a higher heat transfer coefficient than the nanofluid which had particles of 47 nm in size. Actually, the smaller the particle size, the higher the thermal conductivity of the nanofluid [17,18]. And $Al_2O_3$ nanoparticles are generally known for having a great stability dispersion and large heat transfer area than other nanoparticles. The thermal conductivities of various nanoparticle/fluid mixtures were reported by Eastman et al. [19] and Artus [20]. Adding a small fraction of metal oxide powder increased the thermal conductivity of the mixture over the base fluid. As mentioned above, many researchers have studied for the nanoparticles such as copper, aluminium, graphene and their oxides

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**Fig. 1.** Photograph of $Al_2O_3$ nanofluids (0.25 wt%, 0.5 wt%, and 1.0 wt%).

[21–23]. In this study, nanofluids using alumina were produced for the experiment in copper tube and compare by changing pulsation at each concentration to examine for the various Reynolds number and in order to figure out alumina nanofluid thermal characteristics and identify the Nusselt number and Prandtl number at each Reynolds number experimentally and computationally using computational fluid dynamics (CFD) that using laminar model was performed to examine the heat transfer characteristics.

## 2. Experimental details

### 2.1. Preparation and properties of nanoparticles

In this experiment, $\gamma$-$Al_2O_3$ nanoparticles with a nominal average particle diameter of 40 nm and the density 3.9 g/cm$^3$ was used to disperse into distilled water with variable weight ratios 0.25 wt%, 0.5 wt% and 1 wt% which made as shown Fig. 1. The properties of alumina nanoparticles are shown in Table 1. The preparation processes of nanofluids that firstly, nanofluids were made by ultrasonication bath approach. Ultrasonication is helpful for dispersion nanofluids with higher stability [24]. Madhusree Kole et al. [25] performed 4 h to 100 h of ultrasonication for checking proper time of sonication for producing ZnO-EG nanofluids and reported that if the duration of sonication is too long, the particles coalesce again. Mahabubul et al. [26] experimentally studied the effect of ultrasonication duration on colloidal structure and viscosity of alumina-water nanofluid where they used ultrasonic homogenizer for various durations from 0 to 180 min. They reported that more stable and lower viscosity nanofluids can be obtained by applying ultrasonic treatment for durations of 90 min or longer. Hafiz et al. [27] experimentally studied the sedimentation and dispersion behavior of alumina-water nanofluids with dependence of time and reported that 3 wt% and 5 wt% alumina nanofluids with 3 h ultrasonic time have best dispersion results in comparison. For that reason, the nanofluids were sonicated for 3 h using ultrasonic vibration at sound frequency of 42 kHz to produce uniform dispersion of nanoparticles in distilled water. Fig. 2 shows the scanning electron microscope (SEM) image of the untreated nanoparticles and after ultrasound. It can be seen more divide finely after ultrasound.

**Table 1**
Properties of the spherical $Al_2O_3$ nanoparticles at 293 K.

| Density (kg/m$^3$) | Heat conductivity (W/mK) | Specific heat (J/kg K) | Diameter (nm) |
|---|---|---|---|
| 3900 | 42.34 | 880 | 40 |

### 2.2. Nanofluids properties

The properties of nanofluid should be known exactly before the study of convective heat transfer characteristics.

#### 2.2.1. Density

The density of nanofluid is calculated by the mixing theory as:

$$\rho = \varphi\rho_p + (1-\varphi)\rho_{bf} \tag{1}$$

#### 2.2.2. Specific heat

Similarly, in the absence of experimental data relative to nanofluids, it has been suggested that the effective specific heat can be calculated using the following equation as reported in [28–31].

$$C_{p\cdot nf} = \frac{\varphi(\rho C_P)_n + (1-\varphi)(\rho C_P)_{bf}}{\varphi\rho_n + (1-\varphi)\rho_{bf}} \tag{2}$$

#### 2.2.3. Dynamic viscosity

In order to evaluate nanofluid dynamic viscosity, a least square curve fitting, based on some scarce experimental data available in [32–34] was performed by Maiga et al. [35,36], leading to the following equation:

$$\mu_r = \frac{\mu_{nf}}{\mu_{bf}} = 123\varphi^2 + 7.3\varphi + 1 \tag{3}$$

### 2.3. Experimental apparatus

The apparatus assembled to identify the DW and alumina nanofluid heat-transfer characteristics is shown in Fig. 3. The test section is a smooth horizontal copper tube with an inner diameter (ID) of 4.5 mm