The empirical correlations for natural convection heat transfer $\text{Al}_2\text{O}_3$ and $\text{ZrO}_2$ nanofluid in vertical sub-channel

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Abstract. Study on convection heat transfer using water-$\text{Al}_2\text{O}_3$ nanofluid as the working fluid in the vertical sub-channel has been conducted. The results of the study have been compared with the water-$\text{ZrO}_2$ nanofluid and pure-water as the working fluid. The equipment used in this experiment is a vertical triangular sub-channel, equipped by primary cooling system, heat exchanger and a secondary cooling system. As a heating source used three vertical cylinders that have a uniform heat flux with a pitch to diameter ratio (P/D) 0:1:16. Cooling is used is water-$\text{Al}_2\text{O}_3$ colloid at 0.05 wt. %. Heat transfer from heating to cooling would occur in natural or forced convection. However, in this study will be discussed only natural convection heat transfer. The results showed that the natural convection heat transfer of water-$\text{Al}_2\text{O}_3$ nanofluid in a triangular sub-channels depending on the position. The results of the correlation as follows,

$$
Nu = 15.97 \left( \frac{Ra D^3}{x} \right)^{0.2778}
$$

1. Introduction

Nanofluid is a fluid containing nano-sized particles. This liquid is made of a colloidal suspension of nanoparticles in the base-fluid\cite{1}. The nanoparticles used in nanofluid are usually made of metal, oxide, carbide, or carbon nanotubes. Nanofluid has special properties that make them potentially useful in many applications in heat transfer\cite{2}. Nanofluid has the properties of thermal conductivity and convective heat transfer coefficient is better than base-fluid.\cite{3} In the analysis using computational fluid dynamics (CFD), nanofluid can be assumed to be single phase fluid. According to the classical theory of single-phase fluid, the physical properties of nanofluid are taken as a function of the constituents and concentrations.\cite{4} Many researchers have conducted research on the heat transfer performance and flow characteristics of various nanofluid with different nanoparticles and base-fluid materials. Several articles published relating to the use of nanofluid are described in the following sections. Chein and Chuang reported experimentally on micro channel heat sink performance using CuO–water nanofluid as coolants. The results showed that the presence of nanoparticles creates greater energy absorption than pure-water at a low flow rate and that there is no contribution from heat absorption when the flow rate is high \cite{5}. Duangthongsuk and Wongwises observed the effect of thermophysical properties models on prediction of the heat transfer coefficient and also reported the heat transfer performance and friction characteristics of nanofluid, respectively. The results also indicated that the heat transfer coefficient of nanofluid is slightly greater than that of pure-water by approximately (6–11) % \cite{6}. Hwang et al. through experiments found of flow and convective heat transfer characteristics of Al$_2$O$_3$–water nanofluid, with convective heat transfer characteristics of Al$_2$O$_3$–water nanofluid with particles varying in the range of 0.01–0.3% in a circular tube with the constant heat flux in fully developed laminar regime reported improvement in convective heat transfer coefficient in the thermally fully developed regime\cite{7}. Li and Xuan studied experimentally the convective heat transfer and flow features...
for Cu–water nanofluid flowing through a straight tube under laminar and turbulent flow regimes with a constant heat flux. The experimental results showed that addition of nanoparticles into the base liquid remarkably enhanced the heat transfer performance of the base liquid. They also proposed new convective heat transfer correlations for calculating the heat transfer coefficients of the nanofluid for both laminar and turbulent flow conditions [8]. Mirmasoumi and Behzadmehr have studied the effects of nanoparticle mean diameter on the heat transfer and flow behavior into a horizontal tube under laminar mixed convection condition. Their calculated results demonstrate that the convection heat transfer coefficient significantly increases with decreasing the nanoparticles means diameter. However, the hydrodynamics parameters are not significantly changed [9]. Sudjatmi et al. has conducted studies to use of ZrO$_2$–water nanofluid as coolant in experimental triangular vertical sub-channel with low concentrations of 0.05 to 0.1%. Their results showed that for low concentrations of the heat transfer coefficient of nanofluid is slightly higher than pure water. But for higher concentrations can reduce the heat transfer coefficient. [10] Zamzamian et al. investigated the effects of forced convective heat transfer coefficient with Al$_2$O$_3$ nanofluid in double pipe and plate heat exchangers. Their results indicate that increasing the nanoparticle concentration and temperature could enhance the convective heat transfer coefficient of nanofluid, leading to a 2–50% enhancement in convective heat transfer coefficient of the nanofluid [11].

This paper focuses on experimental research, particularly with respect to the natural convection of water-Al$_2$O$_3$ nanofluid in vertical sub-channels. Then the results of this study compared with the results of other experiments using water-ZrO$_2$ nanofluid and pure-water as the working fluid.

2. Methodology of the experimental

The experimental equipment is built to conduct the experiments on the vertical triangular sub-channel. This equipment is designed for natural convection flow however it can also be used for forced convection. In addition, this equipment is also equipped with plate type heat exchanger, the primary tank, secondary tank as well as primary and secondary pumps.

At each stage of this experiment, each heating providing electric power is 250 W, 350 W, 500 W, 650 W, 750 W, and 850 W. So the experiment was conducted for six stages of power. Coolant circulation by the primary pump is in constant flow rate of 3 liters/minute and a secondary pump constant flow rate is 20 liters/minute. Heat of the primary cooling system is transferred to the secondary cooling system through a plate type heat exchanger. The amount of heater power at a heater power test section changed by adjusting the voltage on the heater. For each data collection, the surface temperature of the heating and cooling fluids are measured and recorded at 5 points at different height positions. Recording temperature for each experiment was performed after heating run for three hours on the expected steady state has been reached. Thermocouples used for temperature measurement directly connected to the data acquisition equipment. For the experiment associated to this paper, the main test section was configured in the natural convection mode with the triangular configuration as shown in figure 1a and 1b. The main experiment test section and the test box are made of glass sheets so that they are transparent as shown in figure 1c. Cylinder assembly consists of three vertical cylinders, which is equipped with an electric heater and the type-K thermocouple sensors. Each cylinder has an outer diameter of 25.4 mm and length of 340 mm, and arranged with a pitch of 29.5 mm between the two cylinders. In this experiment, the input variable is the power dissipated by each heater cylinder. The output consists of the heater surface temperature and the temperature of the cooling water-Al$_2$O$_3$ nanofluid in a sub-channel.
1. a. Triangular cross section

1. b. Calculated flow sub-channel

1. c. Experiment test section

Figure 1. Cross section of the triangular configuration as main test section

3. Data analysis

Independent input variables for this experiment is the power of electric heater or heat flux on the surface of the heating cylinder, and position of measurement locations along the surface of the heater. The values of the input variables are shown in Table 1. Meanwhile, the output variables are measured or calculated during the experiment is the temperature of the heater surface, the temperature of the water-Al₂O₃ nanofluid in a sub-channel at five points at different height positions the heat transfer coefficient.

Table 1. The values of the input variables

| Variable Name                          | Variable Type | Input Variable Values                      |
|----------------------------------------|---------------|--------------------------------------------|
| Electric Power, Q                      | Input         | 250, 350, 500, 650, 750, and 850 W/cylinder |
| Surface Heat Flux, q''                 | Input         | 9.3, 13.0, 18.6, 24.2, 27.9, and 31.5 kW/m² |
| Distance, x                            | Input         | 1.0, 9.0, 17.0, 25.0, and 33.0 cm          |
| Surface Temperature, Tₛ                | Output        | -                                          |
| Nanofluid bulk Temperature, Tᵇ          | Output        | -                                          |
| Heat Transfer Coefficient, h            | Output        | -                                          |

The main objective of this study is to obtain an empirical equation for natural convective heat transfer correlation of water-Al₂O₃ nanofluid, in the form of equation Nusselt Number, Nu, as a function of the Rayleigh number, Ra, and the non-dimensional position, x/Dₜ⁰, as in the equation below,

\[ Nu = f \left( Ra \frac{D_h}{x} \right) = a \left( Ra \frac{D_h}{x} \right)^b \]  \hspace{1cm} (1)

With x is the measured position of the upstream and Dₚ is the diameter hydraulic cylinder of the sub-channels, whereas a and b are empirical constants to be determined from experiment.
Modified Nusselt number is defined by the following equation,

$$Nu = \frac{q' D_b}{k(T_s - T_b)}$$  \hspace{1cm} (2)

with $q'$, $k$, $T_s$, and $T_b$ are surface heat flux, thermal conductivity of fluid, cylinder heater surface temperature, and bulk temperature of water-Al$_2$O$_3$ nanofluid, respectively.

The modified Rayleigh number is defined by the following equation,

$$Ra = \frac{g \rho \beta c_p D_b^4}{k^2 \nu}$$  \hspace{1cm} (3)

Where $g$ is gravity, $\rho$ is density, $\beta$ is coefficient of expansion, $c_p$ is heat capacity, and $\nu$ is kinematic viscosity of the nanofluid water-Al$_2$O$_3$ film near the cylinder surface.

All physical and transport properties are evaluated at the film temperature, $T_f$, as in below,

$$T_f = \frac{T_s + T_b}{2}$$  \hspace{1cm} (4)

By using the heating cylinder geometry data, all input variables in table 1, and all measured temperatures, $T_s$ and $T_b$, modified Nusselt and Rayleigh numbers for all measurement locations can be calculated. The relationship among the Nusselt number, Rayleigh number, and the location of the measurement can be determined using linear regression analysis.

4. Experiment results

The Al$_2$O$_3$ nanoparticles of about 20 nm diameter are used in the present study. Distribution of average wall temperature and water-Al$_2$O$_3$ nanofluid temperature distribution along the heater cylinder length at several of heat flux for triangular sub channel at various heat fluxes are shown in figure 2 and 3, respectively. The trend lines shown on these figures are just intended to emphasize the trends of the data. From the figures shown very clearly that the heating cylinder wall temperature tends polynomial shape and temperature of the water-Al$_2$O$_3$ nanofluid always increasing along sub channel, so that the line of linear approach. The general trend shows that the temperature curves in the figure are realistic and acceptable.

![Figure 2. Wall temperature distribution at various heat fluxes](image-url)
From these figures it is clear that the water-Al$_2$O$_3$ nanofluid temperature triangular sub channel increase as the heat flux increases. Since the heater cylinder surface temperature and the water-Al$_2$O$_3$ nanofluid temperature were known from the measurements, then the film temperature can be calculated by using Equation 4, so that thermal conductivity and other physical properties of the water-Al$_2$O$_3$ nanofluid can be determined. These physical properties were evaluated at the film temperature. Meanwhile, the hydraulic diameter can be calculated from the know geometry of the heater cylinder arrangement. By knowing these variables and using equation 2 and 3 the modified Nusselt and Rayleigh number can be calculated. A linear regression analysis gave an empirical correlation of natural convective heat transfer for water-Al$_2$O$_3$ nanofluid in the triangular sub channel between the Nusselt number, Rayleigh number and non-dimensional position as expressed by the following equations:

$$\text{Nu} = \frac{D_x}{x} \left( \frac{\text{Ra}}{D_x} \right)^{0.2778} \quad \text{or} \quad 1 + \frac{1}{1.2035}$$

Meanwhile, a linear regression analysis gave an empirical correlation of natural convective heat transfer for water-ZrO$_2$ nanofluid in the sub channel between the Nusselt number, Rayleigh number and non-dimensional position as expressed by the following equations:

$$\text{Nu} = \frac{D_x}{x} \left( \frac{\text{Ra}}{D_x} \right)^{0.0606} \quad \text{or} \quad 1 + \frac{1}{1.2102}$$

If the result of the experiment using water-Al$_2$O$_3$ nanofluid were compared with the results of the experiments using water-ZrO$_2$ and pure-water as the working fluid for the triangular sub-channel obtained graphs in figure 3 and 4. Based on the result, it was found that, for water Al$_2$O$_3$ and water-ZrO$_2$ the heat transfer coefficient can be up to 5 – 10 % higher than that of pure-water.

Figure 3. Nanofluid temperature distribution at various heat fluxes

Figure 4. Linear regression for water-Al$_2$O$_3$, water-ZrO$_2$ nanofluid and pure-water
5. Conclusions

Based on the current experimental study, the following important points need to be highlighted as conclusions of this study.

1. It was obtained that on the vertical triangular sub-channel geometry, water-Al$_2$O$_3$ nanofluid heat transfer coefficient can be up to 5 - 10 % higher than that of pure-water.

2. A natural convective heat transfer equation for water-Al$_2$O$_3$ nanofluid in the vertical triangular sub-channel that depends on the position was obtained from the current study. The equation can be written as: $Nu_q = 15.97 \left( \frac{Ra_q D_a}{X} \right)^{0.2778}$

3. The linear regression between water-Al$_2$O$_3$ and water-ZrO$_2$ nanofluid as working fluid is not much different, and the slope of the graph for the linear regression of water-Al$_2$O$_3$ slightly steeper.

4. The linear regression graph of water-Al$_2$O$_3$ and ZrO$_2$ nanofluid are above of that of the pure-water as a working fluid.

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