Forced Convection Heat Transfer of Zirconia-water Nanofluid in Vertical Triangular Sub-channel.

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Abstract. Recently, the researchers in nuclear technology are thinking about the use of nanofluid as an alternative cooler, besides using the base-fluids or water and gas. The idea of using nanofluid is already being considered to be applied in nuclear power plants in the future. This nanofluid is expected to be applied in cooling systems, both primary cooling systems and emergency core cooling systems. Therefore, this study was conducted to determine the characteristics of the thermo-physical properties of ZrO$_2$-water nanofluid in the forced convection flow. Recent studies showed that ZrO$_2$-water nanofluid has a good prospect to be used in the nuclear reactor technology due to its low neutron absorption cross section. Although several papers have reported the physical properties of ZrO$_2$-water nanofluid, practically there is no correlation equation for predicting forced convection heat transfer in a vertical triangular sub-channel in ZrO$_2$-water nanofluid. This experiment used ZrO$_2$–water nanofluid at a constant nanofluid concentration of 0.10 wt.%. The results showed that the average increase in ZrO$_2$-water nanofluid heat transfer coefficient was greater than 20% compared to the base-fluids or water heat transfer coefficient as coolant. It is expected that this nanofluid will support the current trend especially in cooling system applications.

Keywords: ZrO$_2$-water, nanofluid, forced convection, cooling system.

1. Introduction
Along with advances in technological development and lack of world energy sources, nuclear energy sources seem to be one of the energy suppliers that are considered and potential to meet energy needs in Indonesia. As is well known, the national energy policy has launched the transfer of fossil-based energy sources to new energy sources, including nuclear energy [1]. In the viewpoint of energy needs in the present and in the future, some people agree that Indonesia should increase its energy supply, especially electricity that increases its needs. The thoughts that have received much attention and have begun to be applied in the design of new generation nuclear power plants are passive safety systems and applying nanofluid in the cooling system, both the primary cooling system and the emergency core cooling system. The idea of using nanofluid will begin to be applied in nuclear power plants in the future [2]. In this study, nanofluid will be tested is zirconium-oxide nanofluid, this material is very strategic to be used as a substitute for water in the reactor coolant, because it has a small neutron absorption cross section. In the comparison of its conductivity value, the value of thermal conductivity of water is 0.60 W/m.K and the thermal conductivity value of zirconia is 22.7 W/m.K, it can be seen that zirconia-oxide is better in terms of heat transfer than water seen from the aspect of value its thermal conductivity [3].
In the forced convection heat transfer process, an increase in nanofluid thermal conductivity is expected to increase heat transfer in the flow without having a significant impact on energy use. In general there will also be an increase in nanofluid viscosity and this will have an impact on the use of pumping power, so that an increase in heat transfer coefficient competes with increased pumping power due to friction. When the increase in heat transfer is greater than the loss due to increased energy use, then nanofluid is suitable for use as a heat transfer work fluid [4].

The purpose of this study is to determine the forced convection heat transfer coefficient of ZrO$_2$-water nanofluid in the sub-channel with a triangle cylinder arrangement. Likewise for some experimental heat transfer facilities support [5, 6, 7], so that a comparative study on the application of nanofluid is very interesting to do. The application of nanofluid for nuclear reactor cooling systems is not limited to nuclear power plants, but is expected to be used in research reactors, such as the Bandung TRIGA research reactor in Indonesia. In addition, the study of heat transfer at the core of the TRIGA Bandung research nuclear reactor which is a vertical sub-channel and uses water as coolant has been carried out widely. [8, 9, 10, 11]. Many researchers have conducted research on the heat transfer performance and flow characteristics of various nanofluid with different nanoparticles and base fluid materials. 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 result study showed that the natural convective heat transfer coefficient of nanofluid was slightly higher than that of pure-water but for higher concentrations can reduce the heat transfer coefficient compared to using pure-water as cooling [12]. In this study using the similar equipment, but under forced flow conditions.

2. Methodology of the experimental

In this study using an experimental approach, experimental studies were carried out using equipment specifically designed for research purposes. This equipment is designed for forced convection flow. In addition, this equipment is also equipped with plate type heat exchanger, the primary tank, secondary tank as well as primary and secondary pumps.

In this test section each heater power was given each 250 W, 350 W, 500 W, 650 W, 750 W, and 850 W. Cooling fluid is circulated by a pump in the flow rate of 6, 8, 10, 12 and 14 liters/minute and a constant secondary flow rate of 20 liters/minute. Heat of the primary cooling system is transferred to the secondary cooling system through a plate type heat exchanger. The configuration of the test equipment is made based on fuel configuration in the Bandung TRIGA reactor core.
In accordance with the composition of the fuel in the reactor core, it is made an experimental test equipment is made as in Figure 3. and the sub-channel is calculated based on Figure 4. The hydraulic diameter for the vertical hexagonal sub-channel is expressed in the following equation:

\[
D_h = \left(\frac{2\sqrt{3}}{\pi}\right)\left(\frac{P}{D}\right)^2 - 1
\]  

(1)

\(D = \) heater diameter (m)
\(P = \) Pitch (m)
\(D_h = \) hydraulic diameter or characteristic length parameter (m)

For nanofluid density and viscosity values are determined as follows:

\[
\rho_{nf} = (1 - \varphi)\rho_{bf} + \varphi\rho_p
\]  

(2)

\[
\mu_{nf} = (1 + 2.5\varphi)\mu_{bf}
\]  

(3)

\[
k_{nf} = \frac{k_p + 2k_{bf} - 2\varphi(k_{bf} - k_p)}{k_p + 2k_{bf} + \varphi(k_{bf} - k_p)}
\]  

(4)

\(\rho_{nf} = \) nanofluid density (kg/m\(^3\))
\(\rho_{bf} = \) base-fluid density (water) (kg/m\(^3\))
\(\rho_p = \) nanoparticles density (kg/m\(^3\))
\(\varphi = \) nanoparticles volume concentration (%)
\(\mu_{nf} = \) nanofluid viscosity (N.s/m\(^2\))
\(\mu_{bf} = \) base fluid viscosity (water) (N.s/m\(^2\))

The specific mass of nanofluid and nanofluid-specific heat is obtained based on research conducted by Mr. and Cho [13]. The viscosity of nanofluid was calculated using the equations obtained based on a study conducted by Drew and Passman suggesting using the Eisten equation for viscosity calculations that can be used for nanofluid with a volume fraction below 5% [14]. However, for nanofluid conductivity values were calculated using the Wasp equation [15].
Cylinder assembly consists of three vertical cylinders, which is equipped with an electric heater and 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. Sub-channel is explored in this study is a sub-channel that is formed by the three-cylinder for a triangle configuration.

Data analysis
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 cylinder surface and the temperature of the ZrO2 nanofluid in a triangular sub-channel. The temperature is measured in five heights along the cylinder and the heat transfer coefficient. The diameter size nanoparticles are used in the present study about 20-30 nm.

| Variable Name                  | Variable Type | Input Variable Values                        |
|--------------------------------|---------------|----------------------------------------------|
| Electric Power, Q              | Input         | 250, 350, 500, 650, 750, and 850 W/cylinder  |
| Primary coolant flow rate      | Input         | 6, 8, 10, 12 and 14 liters/minute             |
| Secondary flow rate            | Input         | 20 liters/minute                              |
| Distance, x                    | Input         | 1.0, 9.0, 17.0, 25.0, and 33.0 cm             |
| Surface Temperature, $T_s$     | Output        | -                                            |
| Nanofluid bulk Temperature, $T_b$ | Output        | -                                            |
| Heat Transfer Coefficient, $h$ | Output        | -                                            |

3. Experiment results
Below is shown three graphs of the relationship between the magnitudes of the power, the primary coolant flow rate of the ZrO$_2$-water nanofluid fluid and the ZrO$_2$-water nanofluid heat transfer coefficient.

Figure 5. Value of heat transfer coefficient at the primary coolant flow rate 6 liters/minute
In Figures 5 and 6 there is almost no increase in the value heat transfer coefficient from ZrO$_2$-water nanofluid. So at a flow rate of 6 liters minute and 8 liters/minute the primary coolant has a heat transfer coefficient close to the same value. However, for the primary cooling flow rate of 12 liters/minute has a heat transfer coefficient higher than the two previous conditions. So for a higher flow rate it will produce a higher heat transfer coefficient, but eventually it will reach a certain maximum limit, this needs to be observed.

4. Conclusions

Heat transfer coefficient of ZrO$_2$-water nanofluid increases with the increase in power and flow rate. The increase in the heat transfer coefficient of ZrO2 nanofluid is not proportional to the given heating power. The increase in heat transfer coefficient is relatively large for higher power. The average heat transfer coefficient values of ZrO$_2$-water nanofluid of 0.1 wt.% concentrations is relatively increase about 20% of the average heat transfer coefficient of base water. So from this
The experiment can be concluded that ZrO$_2$-water nanofluid can be used as a cooling fluid in various heat transfer systems. However, it is still necessary to further analyze the effect of heating and a higher flow rate, because the equipment used has limitations in the ability of heating power and flow rate.

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