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Efficiency Analysis for Plate Type Heat Exchangers Using Nanofluids in the Primary Cooling System of the TRIGA 2000 Nuclear Reactor with Computational Fluid Dynamics Code

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ABSTRACT

The TRIGA reactor is equipped with a primary cooling system that transfers heat from the reactor tank water to the secondary cooling system. Heat transfer in this system occurs mainly in plate-type heat exchangers located in the reactor building, using forced convection with the help of primary and secondary pumps. This research aims to evaluate the effectiveness, efficiency, heat transfer rate, and temperature difference. The analysis was carried out through CFD (Computational Fluid Dynamics) modeling using ANSYS Spaceclaim for geometric design and ANSYS FLUENT for simulation. Simulations using ZrO_2-Water Nanofluid with volume concentrations of 0.2%, 0.6%, and 1% and variations in mass flow rates of 15 kg/s, 20 kg/s, and 25 kg/s. The simulation results show the distribution of temperature, pressure and fluid velocity. The theoretical analysis of the plate type heat exchanger shows that the use of ZrO_2 with a concentration of 1% has the highest efficiency, which is 3.39% at a mass flow rate of 25 kg/s, and an efficiency of 64.82% at a mass flow rate. as much as 15 kg/s.

Introduction

The TRIGA 2000 reactor has 2 cooling systems, namely the primary cooling system and the secondary cooling system. The primary cooling system consists of a primary pump, heat exchanger, reactor core [1, 9-14]. All these systems have the function of cooling the reactor produced from the primary cooling system.

The TRIGA 2000 reactor has a primary cooling system that functions to transfer heat from the reactor tank water to the secondary cooling system. Therefore, when the fission reaction occurs, the temperature of the fuel element wall will increase. Heat transfer mechanism in primary cooling system. most of them take place in plate-type heat exchangers placed inside the reactor building and run by forced convection or so-called Forced Convection [2].

Forced convection fluid flow in a plate-type heat exchanger is driven using a centrifugal pump. The heat transfer that occurs along the outer surface of the pipe in the primary cooling system is not taken into account or neglected. The secondary cooling system works to remove heat from the heat exchanger to the environment through two cooling towers [2, 15-19].

Heat Exchanger or known as Plate Heat Exchanger which is equipment that functions to transfer heat energy (enthalpy) between two or more liquids, at different temperatures and thermal contact occurs. A heat exchanger can also function as a heat dissipator, sterilizer, distillation, separation of mixtures, or even to control fluid processes. The plate-type heat exchanger in the TRIGA 2000 reactor functions to transfer heat from the primary cooling water to the secondary cooling water [1].

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The heat exchanger plate acts as a fluid flow divider so that it can flow in opposite directions. The efficiency of the plate type heat exchanger is very important when using a heat exchanger because it is related to the fluid used which is ZrO_2-Water nanofluid as a coolant. Therefore, to determine the effectiveness and efficiency of the plate type heat exchanger, a simulation was carried out using the CFD (Computational Fluid Dynamics) method through ANSYS Space claim software as a geometric design and ANSYS FLUENT as a simulation tool.

According to [3] explaining the effectiveness of the plate type heat exchanger, from this research the effectiveness based on the LMTD method is 83.3%, the thermal effectiveness of the heat exchanger is 55.6% and the effectiveness based on the NTU method is 30.3%.

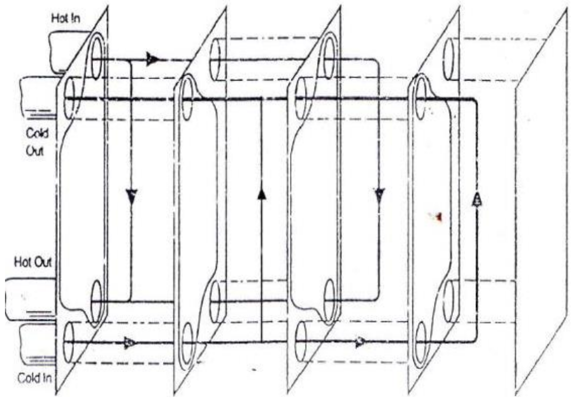

Figure 1. Flow pattern of Plate Type Heat Exchanger

Other research is related to the effectiveness of using ZrO_2-Water nanofluids. This research describes the comparative results of heat transfer experiments on the characteristics of ZrO_2 nanofluids. ZrO_2 nanoparticles were developed using the sol-gel technique. Thermophysical and heat transfer properties were measured in the temperature range 20–60 °C, volume loading range 0.2–1.0% and Reynolds number range 2000– 22000 Results are shown at 1.0% vol. nanofluid loading, thermal conductivity increased by 24.96% at 60 °C; while the viscosity increased by 45.57% at 20 °C, above the base liquid. In addition, the increase in heat transfer coefficient and Nusselt number is 1.0% [4].

The construction of a plate-type heat exchanger consists of an arrangement of corrugated metal plates equipped with inlet and outlet holes at the top and bottom (port holes). These holes serve as fluid channels before flowing to the surface of the plate. The fastening plate and pressure plate are separated by a configuration of metal plates that are tightened using tightening bolts.

A gasket that divides the plate from the other plates serves as a leak barrier and forces the liquid to flow in a different direction. The plate's surface is corrugated to boost eddy current and stabilize the plate in the event of pressure variations. Figure shows the schematic representation of plate-type heat exchangers. There are many different materials that may be used for the plates and gaskets of these heat exchangers, but commonly used materials are SS 304, SS 306, Titanium, Incoloy, and Hastelloy for the plates, and Neoprene and Nitrile rubber for the gaskets. [2].

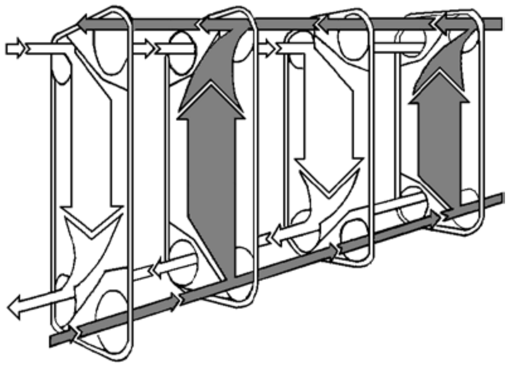

Figure 2. Heat Exchanger Schematic

Reynolds Number

A dimensionless metric known as the Reynolds number is used to assess a fluid's inertial force. The Reynold's Number is dependent on the kind of fluid flow and the frictional forces acting on the surface. The Reynolds number may be computed using the following formula [5] :

$$Re = \frac{G.D_h}{\mu} \tag{8}$$

G Equation 9 can be used to define the mass velocity in one channel of a plate type heat exchanger, where G is the mass velocity in one channel [5].

$$G = \frac{\dot{m}_{cp}}{N_{cp} b L_w} \tag{9}$$

$\dot{m}_{cp}$ The mass flow rate of each channel in a plate type heat exchanger is denoted by mcp. The mass flow rate of each channel may be described using the following equation. [5]

$$\dot{m}_{cp} = \frac{\dot{m}}{N_{cp}} \tag{10}$$

Prandtl Number

The Prandtl number can be defined as the ratio between the kinematic viscosity of a fluid and its thermal diffusivity, the Prandtl number can be defined using the following equation [3]:

$$\mathrm{Pr} = \frac{\mu\, C_p}{k} \tag{11}$$

Nusselt Number

The Nusselt number is the ratio of convective to conductive heat transfer across a boundary. Convection and conduction heat flows are parallel to each other and from the surface normal to the boundary surface, and are all perpendicular to the mean value of the fluid flow [6].

A thermal boundary layer forms when the temperature of the free-flowing fluid and the surface temperature differ. Temperature profiles exist because of the energy exchange that occurs due to temperature differences. So the Nusselt number can be defined using the following equation [7].

$$\overline{\mathrm{Nu}_x} = 2.\,0.332\ \mathrm{Re}_x{}^{1/2}\mathrm{Pr}^{1/3} \tag{12}$$

or,

$$\overline{\mathrm{Nu}_x} = 0.644\ \mathrm{Re}_x{}^{1/2}\ \mathrm{Pr}^{1/3} \tag{13}$$

Coefficient Heat Transfer

The heat transfer coefficient can be calculated after determining the Nusselt number, by defining the following equation [3].

$$h = \frac{Nu.k}{D_h} \tag{14}$$

Coefficient Heat Transfer Overall

The overall heat transfer coefficient can be calculated after determining the heat transfer coefficient of the plate, thereby using the approximation formula of the equation 15 [8].

$$U = \frac{1}{\frac{1}{h_h} + \frac{t}{Kp} + \frac{1}{h_c}} \tag{15}$$

Pressure Drop

In calculating the pressure drop on a plate type heat exchanger, several parameters are used, including calculating the pressure drop on the channel (Δp_c) and the pressure drop on the port (Δp_p), this is done to get the total pressure drop on the channel. plate type heat exchanger (Δp_t), so that To describe the amount of pressure drop the following equation can be used [5].

$$\Delta p_t = \Delta p_c - \Delta p_p \tag{16}$$

pressure drop on to the channel is defined using the following equation [5].

$$\Delta P_{channel} = 4.f.\frac{\rho.u^2}{2}.\frac{L}{D_h} \tag{17}$$

The pressure drop is affected by the friction factor, therefore the friction factor in a plate type heat exchanger can be calculated using the following equation [3].

$$f_{ch} = \frac{K_p}{Re} \tag{18}$$

To calculate the pressure drop at the port it can be defined using the following equation [5].

$$\Delta p_p = 1.4\ N_p.\left(\frac{G_P^2}{2\rho_{c,h}}\right) \tag{19}$$

Temperature Different (LMTD)

The LMTD value (Logarithm Mean Temperature Difference) is a value related to the temperature difference between the hot side and the cold side of the heat exchanger. Assuming that the coolant stream flows at steady state, there is no overall heat loss, no coolant phase change. So the LMTD value can be calculated using the following equation [3].

$$\mathrm{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln(\frac{\Delta T_1}{\Delta T_2})} \tag{20}$$

To calculate ΔT1 and ΔT2 the following equation can be used [7].

$$\Delta T_1 = T_{h,i} - T_{c,o} \tag{21}$$

$$\Delta T_2 = T_{h,o} - T_{c,I} \tag{22}$$

Heat Transfer Rate

To determine the heat transfer rate in a heat exchanger originating from a hot temperature fluid to a cold temperature fluid, the equation to describe the actual heat transfer rate [7].

$$Q_{act} = \dot{m}.cp_c\left(T_{c,out} - T_{c,in}\right) \tag{23}$$

And for the maximum heat transfer $\dot{Q}_{max}$ it can be defined by the following equation [7].

$$\dot{Q}_{max} = (\dot{m}\ cp)_{min}(T_{h\ in} - T_{c\ in}) \tag{24}$$

Total Heat Transfer Rate

To be able to determine the total heat transfer rate in a plate type heat exchanger, the following equation is used to determine the total heat transfer rate [3].

$$\dot{Q}_T = A.U.\Delta T_m \quad (25)$$

Effectiveness of LMTD

To calculate the effectiveness of LMTD, the following equation can be used [3].

$$\varepsilon = \frac{Ch\,(Th\,out\, - Tc,in)}{Cmin\,(Th,in - Tc,in)} \quad (26)$$

Effectiveness of NTU (*Number Transfer Unit*)

To calculate the effectiveness of NTU, the following equation can be used [3].

$$\varepsilon - \text{NTU} = \frac{\exp[(1-c_r)NTU_{min}]-1}{\exp[(1-c_r)NTU_{min}]-c_r} \quad (27)$$

Methods

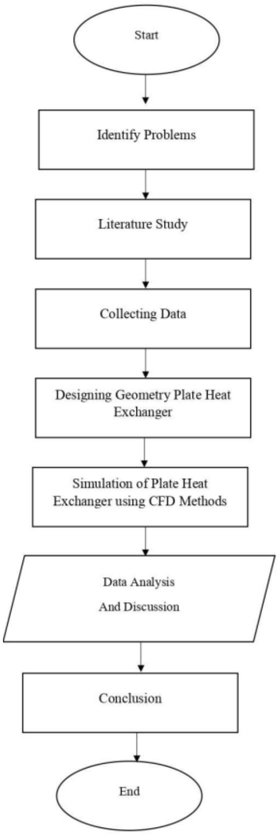

Figure 3. Research flow diagram

The methods used during the research are explained in several stages, including:

1. Literature Review
   This level aims to carry out theoretical research by using references or literature related to the object to be compiled, so that it has a basis that can be justified academically.
2. Collecting data
   In this step, data is collected from the results of conducting heat exchanger tests in the field.
3. Data Processing
   Data processing was carried out with data results from tests and calculations of plate-type heat exchangers in the TRIGA 2000 reactor with variations in 3 nano zirconium fluid concentrations and mass flow rates, temperatures.

Research Activity Series

Time and Place Research

The research process is carried out at BATAN (National Nuclear Energy Agency) or BRIN Bandung. The time required for this research process starts in July 2022.

Data Collection and Processing Techniques

Data Collection Techniques

Data collecting methods are used in several phases, including:

1. Literature Review
   This method aims to carry out a theoretical study by using references or literature related to the object to be compiled, so that it has a basis that can be justified academically.
2. Observation
   Observation is a way to obtain data by observing and recording directly from the research, in this research it is done so that the tool can match what is planned.

Research Variables

In this research, several research variables were used, among them:

1. Independent Variable
   In this research, the independent variable is the type of liquid used which is Water and Zirconium Oxide Nanofluid (ZrO_2-Water) with 3 volume concentrations of 0.2, 0.6 and 1.0%.
2. Dependent Variable
   In this study the dependent variable is the value of the effectiveness and efficiency of the plate type heat exchanger.
3. Control Variable
   Control variables used in this simulation research include:
   a. The temperature determined by the temperature of the hot fluid entering the primary cooling section (Th_{in}) and the cold entering the secondary cooling section (Tc_{in}) are 313.15° K and 295.45° K.
   b. The incoming hot and cold fluid mass flow rates are determined at 15, 20, 25 kg/s.

Data Processing

Data processing is carried out by calculating the results of data collection from heat exchanger simulation tests to calculate the effectiveness and efficiency of Plate Type heat exchangers using ZrO_2-Water in the TRIGA 2000 Nuclear Reactor Main Cooling System Based on CFD (Computational Fluid Dynamics) using ANSYS software, by using mathematical calculations, then the data is expressed in the form of tables and graph.

Material Properties

In the CFD (Computational Fluid Dynamics) simulation research on the Plate Type Heat Exchanger, ZrO_2-Water material is used as the cooling liquid material and SS-304 material as the plate material. The material properties value in the Plate Type Heat Exchanger Analysis is used to simulate and calculate the theoretical heat transfer. Material property values required in this research include thermal conductivity, density, viscosity and specific heat. The material property values for liquid ZrO_2 and SS304 material can be seen in **Table 1**.

Table 1. Material Properties for fluids and Solid Material

Material Properties	Ø (%)	T (°k)	ρ (kg/m^3)	µ (kg/m.s)	*k* (W/ m.K)	Cp (J/kg.k)
Water	0	295.45	997.12	0.00074	0.602	4178
		313.15	995	0.00048	0.631	4179
ZrO_2	0.2	295.45	1006.485	0.00089	0.635	4170.48
		313.15	1004.37	0.00055	0.672	4171.48
	0.6	295.45	1025.215	0.00099	0.654	4155.45
		313.15	1023.11	0.00063	0.714	4156.45
	1	295.45	1043.95	0.00108	0.676	4140.42
		313.15	1041.85	0.00077	0.736	4141.41
SS 304	-	-	8000		16	500

Simulation Procedure

CFD (Computational Fluid Dynamics) simulation on the heat exchanger was carried out by following the procedure carried out from the results of previous studies. The simulation procedures carried out include:

1. Geometry Design

The geometric design carried out for the research is a plate type heat exchanger. Geometric design was carried out using ANSYS Spaceclaim. Stages in the geometry creation process include:

a) Determining the specified unit at the initial stage before the geometric process is carried out, the first step is to determine the unit and determine the direction of the axis as in Figure 4.

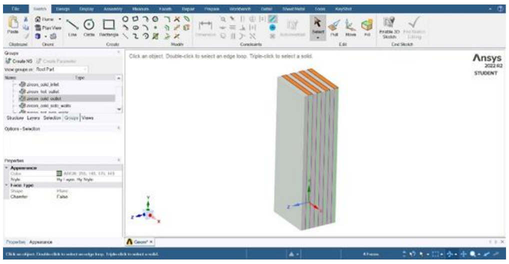

Figure 4. Geometry Plate Heat Exchanger

In **Figure 4**, what is used to make the heat exchanger is to use cm units and the Y axis is used in making the geometry of the plate type heat exchanger. This is intended to represent the position of the fluid flow in a simulated form.

b) Determine Geometry Size

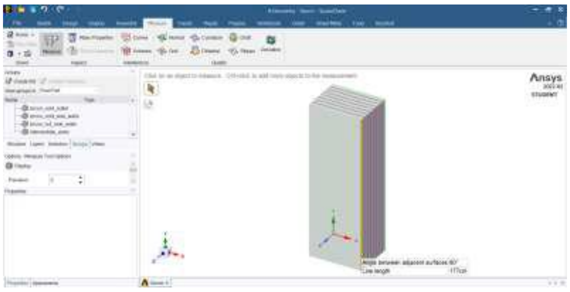

Figure 5. Height Plate

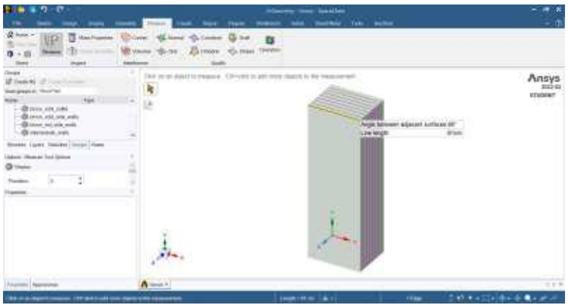

Figure 6. Width Plate

In figure 5 and 6, the geometry of the plate type heat exchanger is designed, in figure 5 the height used in the plate type heat exchanger is 177 cm and in figure 6 the width of the designed plate is 61 cm. The sizes in **Figure 5** and **Figure 6** are designed based on the standards used by LAK TRIGA 2000. Due to the limited number of cells in meshing in the ANSYS Student Version application, the number of plate grids is made from eight to adjust the number of cells.

c) Define Geometry Surface

After going through the geometry creation process, the next step is to determine the position of the geometry part in the plate type heat exchanger.

2. Meshing
After designing the geometry, the next step in the simulation stage is the meshing process. At this stage the geometry will be divided into small elements or what can be called discretization.

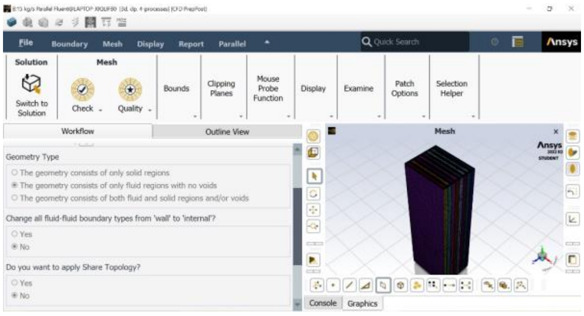

Figure 7. Meshing

The meshing method used in this research is Watertight Workflow in the FLUENT Meshing application.

a) Add Global Sizing
At the stage of the meshing process, the next step is to add a global size to the mesh, more detailed information is shown in table 2.

Table 2. Settings Sizing of Mesh

Minimum Size (m)	0.00172852
Maximum Size (m)	0.019
Size Function	Curvature
Curvature Normal Angle	24

The size in the global size meshing setting is given a minimum size of 0.00172852 m and a maximum size of 0.019 m. This aims to ensure that the number of cells produced can adjust the number of standard cells to the application version but provide good convergent quality decision.

Result and Discussion

Plate Type Heat Exchanger Temperature Distribution

The change in temperature distribution contour in a PHE (Plate Heat Exchanger) fluid flow can be shown in **Figures 8 to 11**.

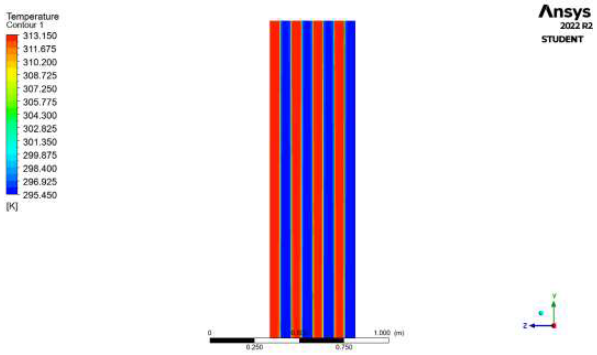

Figure 8. PHE Basefluid temperature distribution contour flow rate 15 kg/s

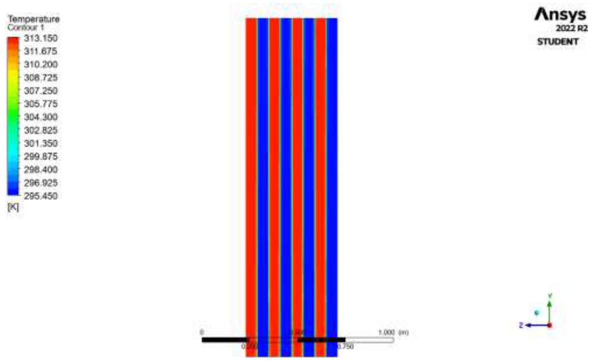

Figure 9. PHE ZrO_2 temperature distribution contour 0.2% flow rate 15 kg/s

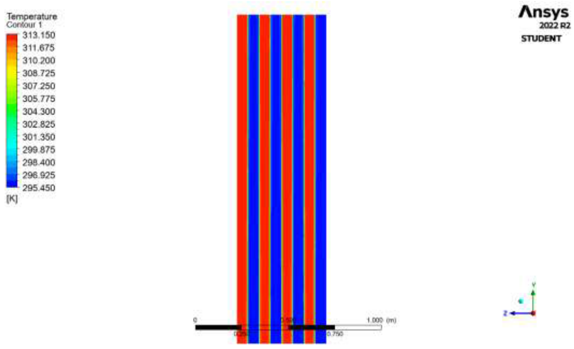

Figure 10. PHE ZrO_2 temperature distribution contour 0.6% flow rate 15 kg/s

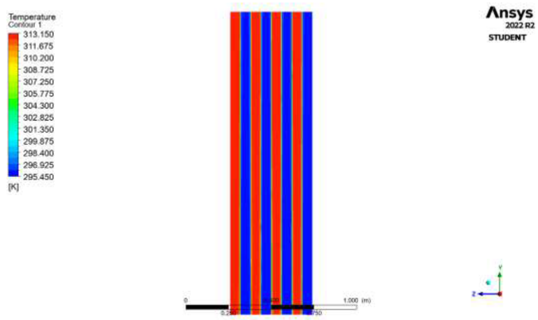

Figure 11. PHE ZrO2 temperature distribution contour 1% flow rate 15 kg/s

Figure 8 shows the state of temperature change in the base fluid when a flow rate of 15 kg/s is given, then Figure 8 shows the state of temperature change in ZrO_2 with a volume fraction of 0.2%, Figure 10 shows the state of ZrO_2 with a volume fraction of 0.6% and Figure 11. is the state temperature change in fluid flow in ZrO_2 at 1% volume fraction.

Figure 8 to Figure 11, these are the initial temperature conditions at the primary and secondary inlet fluid flow, showing the initial contour in red at the top means the initial temperature at the main inlet is 313.15 °K, and the blue color at the bottom indicates the inlet temperature condition in the second part is 295.450 °K. then there is a temperature change in the primary cooling part when using water which is 312,604 °K and the temperature increases in the secondary part by 295,956 °K at a flow rate of 15 kg/s, The temperature change is lower when compared to using ZrO_2 at a concentration of 1% which is 312.65 °K on the primary cooling part and 296.025 °K on the secondary cooling part of the exit part of the plate type heat exchanger. The phenomenon of temperature distribution contour changes in plate-type heat exchangers is caused by the thermal conductivity of the fluid when heat transfer occurs by forced convection.

Pressure Distribution

Changes in pressure distribution contours in PHE (Plate Heat Exchanger) fluid flow can be shown in **Figure 12 to 15**.

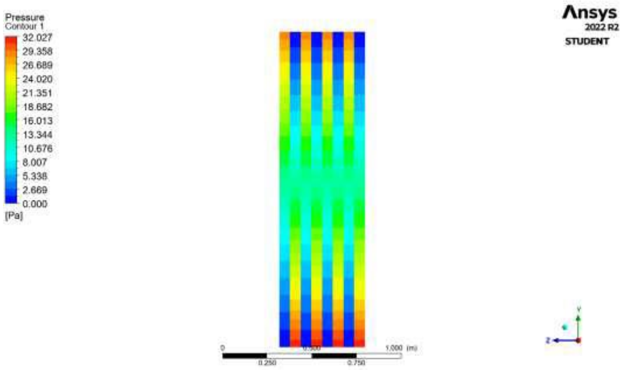

Figure 12. The PHE pressure distribution contour using a water flow rate of 15 kg/s

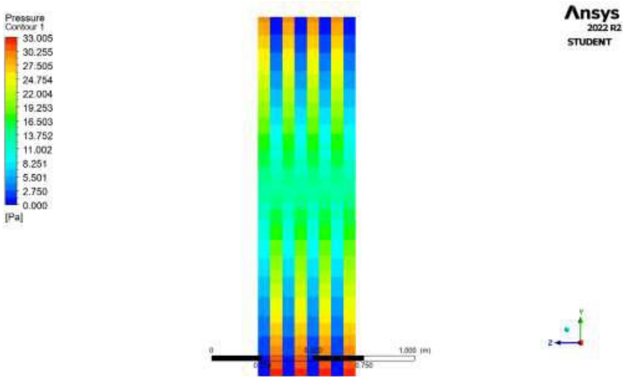

Figure 13. PHE pressure distribution contour using ZrO_2 0.2% flow rate 15 kg/s

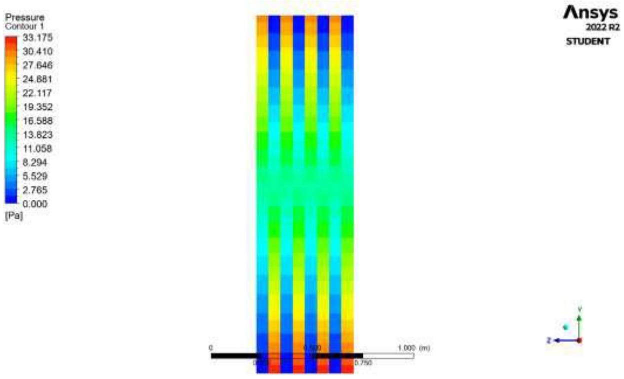

Figure 14. PHE pressure distribution contour using ZrO_2 0.6% flow rate 15 kg/s

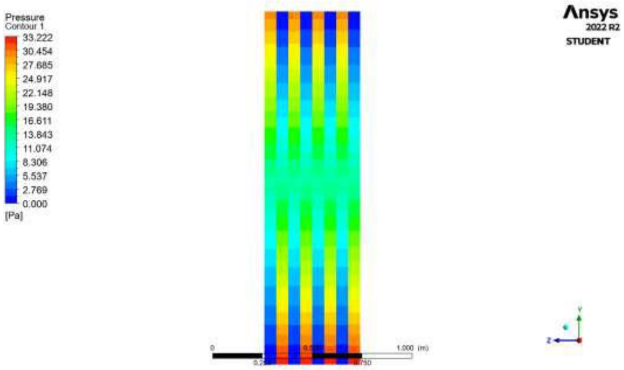

Figure 15. PHE pressure distribution contour using ZrO_2 1% flow rate 15 kg/s

Figure 12 to 15 are the results of the pressure distribution in the plate-type heat exchanger simulation using variations in water and nano-fluids with volume concentrations of 0.2%, 0.6% and 1% at a flow rate of 15 kg/s. The simulation results show the occurrence of a pressure drop or a pressure drop on the plate-type heat exchanger marked by visual contour changes on the primary cooling section and the secondary cooling section. The pressure drop on the plate-type heat exchanger using water in Figure 12 was found to be 14.596 Pa on the primary cooling section and 15.956 Pa on the secondary cooling side, This means that the pressure drop produced using water fluid is lower when compared to the pressure drop produced using ZrO_2 nano liquid with a concentration of 1% which is 15.0862 Pa on the primary cooling side, and 16.553 Pa on the secondary cooling side.

The pressure drop value produced in the plate-type heat exchanger simulation is that the fluid density at cold temperature (secondary cooling side) is greater than the fluid density at hot temperature (primary cooling side), and the fluid mass flow rate. Influence the occurrence of better pressure distribution.

Coefficient Heat Transfer Overall

Based on the simulation of the plate-type heat exchanger, the results obtained are the heat transfer coefficient of the entire plate of the heat exchanger under the conditions of varying flow rates using fluid variation in graphic.

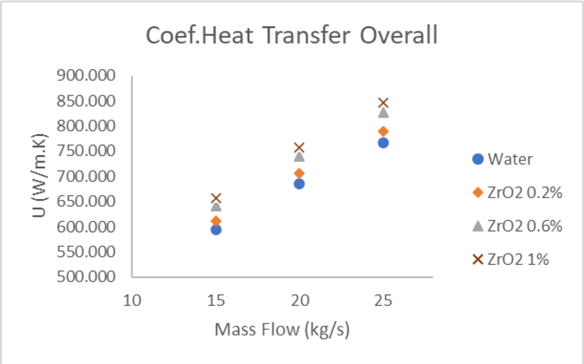

Figure 16. Relationship between overall heat transfer coefficient and flow rate

Figure 16 shows the overall heat transfer coefficient on a plate type heat exchanger using several fluid type variations compared to using water with ZrO_2 with several concentration variations under flow rate conditions. The simulation results on the heat exchanger show that the overall heat transfer coefficient in ZrO_2 nanofluid with 1% concentration is 846.5579 $W/m^2.K$ at a flow rate of 25 kg/s, which is greater when compared to water fluid at the highest level. flow rate of 25 kg/s which amounts to 766.0957 $W/m^2.K$.

The increase that occurs in the overall heat transfer coefficient is influenced by the thermal conductivity of the fluid and the thermal conductivity of the plate, so that the greater the thermal conductivity value of a fluid, the greater the value of the resulting heat transfer coefficient, and the fluid flow rate also affects the increase in the heat transfer coefficient.

Nusselt Number

In the simulation of the plate type heat exchanger, the results are obtained in the form of nusselt number for the plate heat exchanger under the condition of flow rate variation using fluid variation in graphical form.

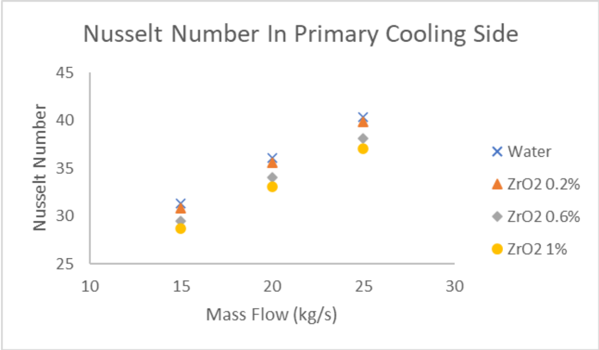

Figure 17. The relationship between the Nusselt number and the flow rate in the primary cooling system

Figure 17 shows the Nusselt number in a plate-type heat exchanger on the primary cooling side using several variations of fluid type compared to using water with ZrO_2 with several variations of concentration under fluid flow rate conditions. These results show that the Nusselt number in water fluid is found to be greater at a flow rate of 25 kg/s which is 40.4141 when compared to using a ZrO_2 concentration of 1% at a maximum flow rate of 25 kg/s which is 37.0344.

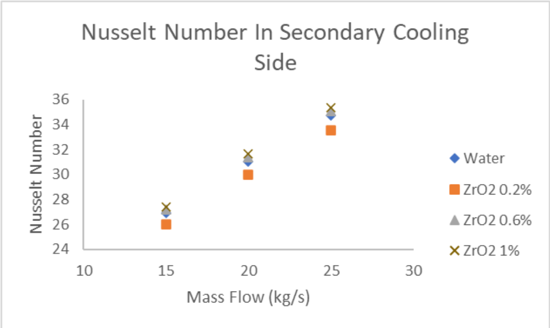

Figure 18. The relationship between the Nusselt number and the flow rate in the secondary cooling system

Figure 18 shows the Nusselt number of a plate type heat exchanger on the secondary cooling section using several variations of fluid type compared to using water with ZrO_2 with several variations of concentration under fluid flow rate conditions. These results show that the Nusselt number in water fluid is found to be greater at a flow rate of 25 kg/s which is 40.4141 when compared to using a ZrO_2 concentration of 1% at a maximum flow rate of 25 kg/s which is 37.0344.

Figure 17 and 18 show that there is an increase in the Nusselt number in the plate type heat exchanger simulation. The increase in Nusselt number that occurs in the simulation of the plate type heat exchanger is due to the fluid viscosity (μ) and mass velocity in a channel (*G*) produced at the Reynolds number as well as the thermal conductivity (*k*) and specific heat (C_p) produced at the Prandtl number (Pr). So the larger the Reynolds number and the Prandtl number, the larger the Nusselt number produced in a plate type heat exchanger.

Friction Factor

The simulation results of the plate type heat exchanger show the relationship between the friction factor of the heat exchanger plate versus the Reynolds number in the variation of the fluid in graphic form.

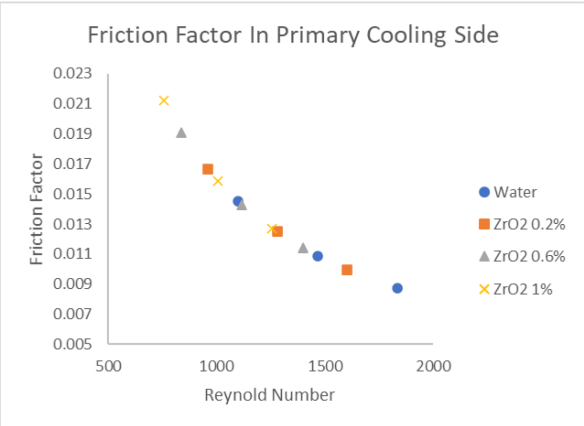

Figure 19. Relationship between friction factor and Reynolds number in the primary cooling side

Figure 19 shows the friction factor in a plate type heat exchanger on the primary cooling side using several variations in fluid type compared to using water with ZrO_2 with several concentration variations under fluid flow rate conditions. These results show that the friction factor in water fluid is found to be greater at a flow rate of 25 k/s which is 40.4141 when compared to using a ZrO_2 concentration of 1% at a maximum flow rate of 25 kg/s which is 37.0344.

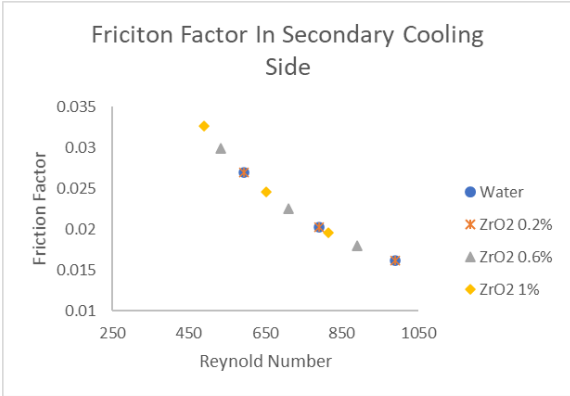

Figure 20. Relationship between the friction factor and the Reynolds number in the secondary cooling side

Figure 20 shows the friction factor that occurs in the secondary cooling section in fluid variations. It can be seen that the friction factor for ZrO2 at a volume concentration of 1% is found to be greater which is 0.03268608 at a mass flow rate of 15 kg/s, and the lowest friction factor is obtained for water fluid at mass flow rate of 25 kg/s, which is 0.0161615.

Figure 19 and 20 show that the friction factor in the plate-type heat exchanger simulation decreases with increasing mass flow rate. The reduction of the friction factor is affected by the mass velocity in a channel (*G*) and the resulting fluid viscosity (μ) at the Reynolds number, so that the greater the Reynolds number, the lower the resulting friction factor.

Effectiveness LMTD

In the simulation research of plate type heat exchanger, results were obtained in the form of LMTD plate heat exchanger effectiveness under the condition of flow rate variation using fluid variation in graphical form.

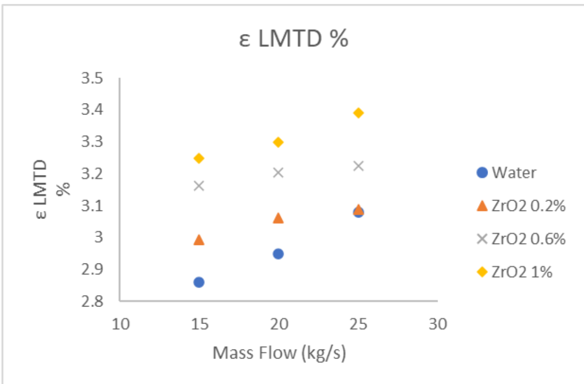

Figure 21. Relationship between LMTD effectiveness and flow rate

Figure 21 shows the effectiveness of the LMTD occurring on the secondary cooling section in fluid variations. It can be seen that the effectiveness of ZrO_2 at a volume concentration of 1% is found to be greater, which is 3.39%, at a mass flow rate of 25 kg/s, and the lowest effectiveness is obtained for water fluid at mass flow rate of 15 kg/s, which is 2.86%.

In **Figure 21**, it can be seen that there is an increase in the effectiveness of LMTD as the mass flow rate increases. The increase in efficiency is due to the specific heat (C_p) in the fluid and the mass flow rate ($\dot{m}$) produced at the actual heat transfer rate (Q_{act}) and the maximum heat transfer rate (Q_{max}), so that the greater the value of the specific heat and the mass flow rate produced, greater the resulting effectiveness.

Effectiveness of Number Transfer Unit (ε-NTU)

In **Figure 22** from a simulation of a plate type heat exchanger, which shows the results in terms of NTU (Number Transfer Unit) plate heat exchanger effectiveness under varying flow rate conditions using fluid variations in graphical form. In the graph, it can be seen that the NTU effectiveness using a volume concentration of ZrO_2 of 1% at a flow rate of 15 kg/s resulted in an effectiveness of 64.82%, and the lowest NTU effectiveness was produced in liquid water at a flow rate. by 25 kg/s, which is 58.27%.

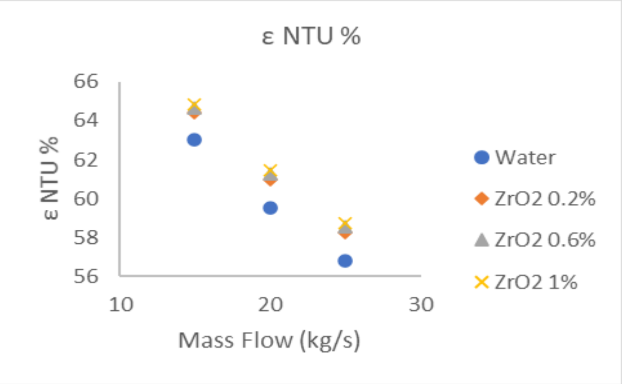

Figure 22. Relationship between NTU effectiveness and flow rate

Based on the simulation results, it shows that the NTU effectiveness value tends to decrease at the maximum mass flow rate, the decrease in NTU effectiveness is affected by the minimum heat capacity rate (C_{min}) and the overall heat transfer coefficient (U) resulting from the NTU-Minimum which is getting lower as the speed increases in plate type heat exchanger.

Conclusion

After carrying out a series of stages of the simulation process up to the stage of heat transfer analysis in a counter-flow plate type heat exchanger using ZrO_2-Water fluid, the following conclusions can be drawn from the results of the study:

1. The use of ZrO_2 nanofluid at a concentration of 1% has a greater effectiveness and efficiency value that is; The effectiveness of ZrO_2 was found to be 3.249% at a mass flow rate of 15 kg/s and increased by 3.39% when given a flow rate of 25 kg/s, while the efficiency value of the result of the calculation of the NTU method obtained a value of 64.12% in the state of mass flow rate of 15 kg/s but there was a decrease when the state of mass flow rate of 25 kg/s which is 57.99%. The increase in the effectiveness of the heat exchanger is influenced by the value of the actual heat transfer rate ($\dot{Q}_{act}$) and the maximum heat transfer rate ($\dot{Q}_{maks}$) when the mass flow rate increases, the resulting effectiveness increases), while the decrease in the efficiency value of the heat exchanger is influenced NTU-Minimum and the minimum heat capacity (C_{min}).
2. The use of ZrO_2 at a concentration of 1% results in a greater total heat transfer rate of 1901.938534 kW in the condition of a mass flow rate of 15 kg/s and there is an increase when given the condition of a mass flow rate of 25 kg /s amounting to 2449.951469 kW, the results obtained are greater if compared to using water and ZrO_2 at concentrations of 0.2% and 0.6%. The total heat transfer rate is affected by the value of the overall heat transfer rate coefficient (U), and ΔT LMTD values. The values of the actual heat transfer rate using ZrO_2 with a concentration of 1% obtains a greater result when compared to using water and ZrO_2 with a concentration of 0.2% and 0.6% which is 35,711 kW when the mass flow rate is 15 kg/s, and the value of the actual heat transfer rate Increase occurs when the mass flow rate is 25 kg/s, that is 62,106 kW. Factors that affect the increase in heat transfer rates include; fluid mass flow rate, thermal conductivity in bulk fluid, and temperature difference resulting from nanofluid ZrO_2 at 1% concentration.
3. The value of the maximum heat transfer rate in a plate type heat exchanger using ZrO_2 at a concentration of 1% has a lower maximum heat transfer rate when compared to using water and ZrO_2 with a concentration of 0.2% and 0.6% which is 1099.28 kW at a mass flow rate of 15 kg/s, but there is an increase when the mass flow

rate is 25 kg/s, which is 1832.14 kW. This is impacted by the magnitude of the mass flow rate condition and the specific heat value in the fluid resulting from the minimum heat capacity (C_{min}).

4. The total pressure drop value in the plate type heat exchanger increases with increasing concentration when using ZrO_2 in the primary and secondary parts. Using ZrO_2 with a concentration of 1.0% results in a large amount of pressure drop when compared to using water and ZrO_2 at a concentration of 0.2% and 0.6% which is 791.1312 Pa in the primary cooling side, and 1224.8410 Pa in the secondary cooling side at a mass flow rate of 15 kg/s, there is an increase when a mass flow rate of 25 kg/s is given, which is 1305.9906 Pa in the primary cooling side, and 2027.8351 Pa in the secondary cooling section. The increase that occurs in the pressure drop of the heat exchanger is affected by the density and average speed of the flow in the fluid.

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Author Contributions

The authors' contributions to the paper are as follows: study conception, design, analysis, and interpretation of results: AIR, EU, WHA; data collection: Y, RF, F; draft manuscript preparation: Y and AIR. All authors have reviewed the results and approved the final version of the manuscript.

Conflicts of Interest

All authors declare that they have no conflicts of interest.

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