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Correlation Equations of Heat Transfer in Nanofluid Al_2O_3-Water as Cooling Fluid in a Rectangular Sub Channel Based CFD Code

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Abstract - Safety is a major concern in the design, operation and development of a nuclear reactor. One aspect of nuclear reactor safety factor is thermal-hydraulics aspect. In a PWR-type nuclear power plant has been used lighter fluid coolant is water or H_2O. In this research, using nanofluid Al_2O_3-Water with volume fraction of (1%), (2%) and also (3%), used as a cooling fluid in a nuclear reactor core with sub channel PWR fuel element rectangular arrangement. This research was carried out modeling of fuel elements are arranged rectangular, then performed numerical simulations using Computational Fluid Dynamics (CFD) code. In order to obtain the characteristic pattern of flow velocity of each fluid, the fluid temperature distribution along the cylinder wall temperature distribution of the fuel element. Then analyzed the heat transfer in a nuclear reactor core with sub channel PWR fuel element rectangular arrangement, including heat transfer coefficient, Nusselt number (Nu), as well as heat transfer correlations. Heat transfer correlation for nanofluid Al_2O_3-Water (1%), (2%) and also (3%) proved to core of PWR nuclear reactor fuel element sub channel rectangular arrangement with the Reynolds number (Re) is stretched, namely: 404 096 <Re <423 084 and with constant heat flux is 2600 W / m^2, and the composition ratio (pitch / diameter) 1.33.

Keywords - *Nanofluid; Sub Channel; Heat Transfer; Pressurized Water Reactor; CFD*

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I. INTRODUCTION

Safety is a major concern in the design, operation and development of a nuclear reactor. Therefore, the method of analysis used in all these activities must be thorough and reliable so as to predict a wide range of operating conditions of the reactor, both under normal operating conditions and in the event of an accident. [Umar, 2007; Septilarso, 2010; Supriyadi, 2011]

Cooling fluid which is used core nuclear reactor PWR, arrangement of rectangular sub channel is fluid light water (H_2O). In this study used Al_2O_3-Water as a medium heat taker result of nuclear fission reaction. The aim is that the heat is taken and heat transfer that occurs can be optimized. [Pandey, 2011; Li, et al, 2010; Wong, 2010; Putra, 2010]

Nanofluid Al_2O_3-Water used as a blending between Al_2O_3 nanoparticles with fluid water (H_2O), and theoretically nanofluid has a value above the heat transfer fluid is water. The initial step of this study was to determine the characteristics of flow patterns that occur in nanofluid in the composition of the fuel element rectangle in PWR-type nuclear reactor core. [Ramadhan, 2012]. From Fig. 1, in this research examined using modeling the composition of the reactor fuel elements are arranged in a rectangle. So that it can be seen that the analysis of heat transfer occurs between the fuel elements.

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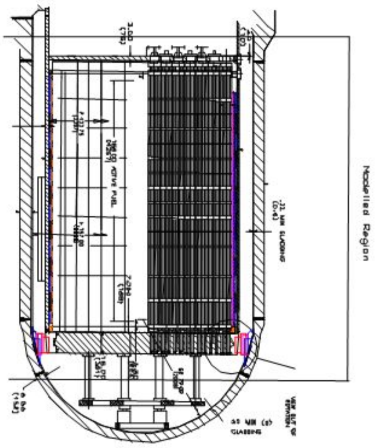

Fig. 1: Cross section of a PWR-type nuclear reactor core [Westinghouse, 2003]

II. METHOD OF RESEARCH

Furthermore, the modeling steps of sub channel rectangular arrangement in PWR reactor core using the fuel elements such as Fig. 2.

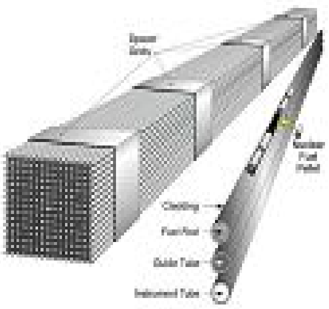

Fig. 2: PWR Fuel Element [Nematollahi, 2011]

Then, based on Fig. 2, made models using modeling programs such as Fig. 3.

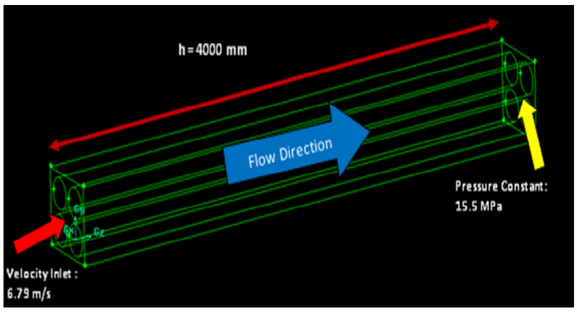

Fig. 3: Modeling sub channel rectangular arrangement in PWR reactor core

With the dimensions of the model above is:

a. Diameter (D) fuel elements: 9.5 mm
b. Height (h) fuel elements: 4000 mm
c. Pitch (P) between the fuel elements: 12.65 mm

Then the next step is done mesh on the model, can be seen in Fig. 4.

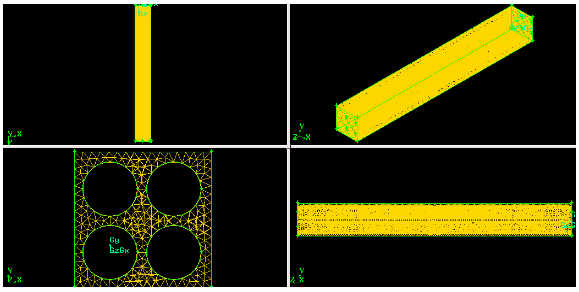

Fig. 4: The results of the model mesh on fuel element of sub channel rectangular

PWR design data and also the condition of the cooling fluid used in this study are described in Table 1:

Table 1. PWR design and condition of the cooling fluid [Nematollahi, 2011]

Power	Fuel	Coolant
Thermal 3800 MW Electrical 1280 MW	Rod, OD 9.5 mm Rod lattice pitch 12.65	Pressure 15.5 MPa Inlet Temp. 292°C Outlet Temp. 324°C Inlet Velocity 6.79 m/s
Core		
Length 3.81 m Diameter 3.66 m		

Table 1 describes for input conditions in the numerical simulation using the equation k-ε standard, namely, k-ε standard model is a model-based semi-empirical model of the transport equation for the turbulent kinetic energy (k) and the dissipation rate (ε), which was developed by launder and Spalding. Turbulent kinetic energy (k) and the dissipation rate (ε), obtained from the following transport equation:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \quad (1)$$

And,

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \quad (2)$$

In these equations G_k declared the formation of turbulent kinetic energy with a mean velocity gradient. G_b is the formation of turbulent kinetic energy due to buoyancy forces. Y_m states contribution dilatation fluctuations in the turbulent flow are not compressed against the overall dissipation rate.

While the value $C_{1\varepsilon}$, $C_{2\varepsilon}$, $C_{3\varepsilon}$ are constants, σ_k and σ_ε respectively turbulent Prandtl numbers for k and ε. To S_k and S_ε defined as tribal sources. $C_{1\varepsilon}$ = 1.44, $C_{2\varepsilon}$ = 1.92, $C_{3\varepsilon}$ = 0.09, σ_k and σ_ε = 1.0 = 1.3. Standard k-ε model is used for

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the Reynolds number (Re) is high.

Nanofluid used is Nanofluid Al_2O_3-Water with volume fraction of 1%, 2% and 3%, so as to Table fluid properties are as in Table 2.

Table 2. Properties of Nanofluid Al_2O_3 -Water (1%, 2% and 3%) [Pandey, 2011]

	$\emptyset - 1\%$	$\emptyset = 2\%$	$\emptyset = 3\%$
k_{nf} (W/mK)	0.620	0.638	0.656
ρ_{nf} (kg/m^3)	1021.7	1047.7	1073.8
$_{nf}$ (kg/ms)	8.17×10^{-4}	8.376×10^{-4}	8.576×10^{-4}
$C_{p,nf}$ (kJ/kgK)	4.149	4.115	4.081

III. RESULTS AND DISCUSSIONS

The results of numerical simulation modeling in sub channel fuel elements with rectangular arrangement can be seen in the flow pattern along the z direction of the fuel element can be seen in Fig. 5-8.

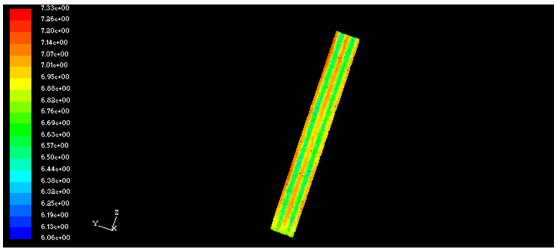

Fig. 5: Contours of the flow pattern in sub channel with fuel element rectangular arrangement using light water (H_2O)

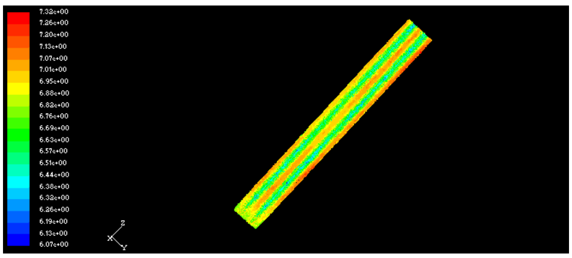

Fig. 6: Contour flow patterns in sub channel with fuel element rectangular arrangement using nanofluid Al_2O_3-water (1%)

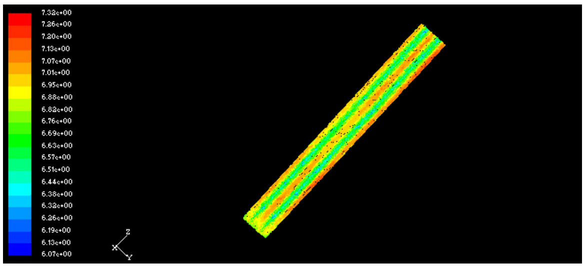

Fig. 7: Contour flow patterns in sub channel with fuel element rectangular arrangement using nanofluid Al_2O_3-water (2%)

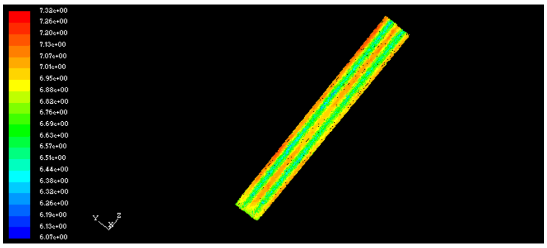

Fig. 8: Contour flow patterns in sub channel with fuel element rectangular arrangement using nanofluid Al_2O_3-water (3%)

Fig. 5-8 shown that the flow pattern based on the contours of fluid flow that occur in sub channel element in the flow of fuel is almost evenly along the z direction in the fuel elements. Also seen along the right and left edges of the sub channel fuel elements seen the pattern of fluid flow are almost evenly anyway.

In Fig. also shows a pattern of cross flow between sub channel fuel elements. This cross flow occurs when the beginning of the flow between the sub channel fill the fuel element transfer occurs following the flow of the fluid temperatures are rising, then fell back to its home position as the height of the cylinder fuel elements.

Seen on the contour Fig. 5-8 fluid temperature distribution pattern great beginning and then decreased and the fluid temperature rising, this is caused by the cross flow. It occurs in both the fluid light water (H_2O) as well as for nanofluid Al_2O_3-Water (1%, 2%, 3%).

It shows the flow pattern based on the contour in both fluid water and nanofluid has a tendency that the flow pattern is almost the same, whether at the beginning, the middle and upper part of the fuel element when fed by the fluid.

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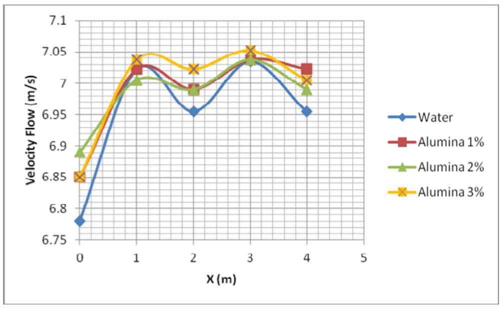

Fig. 9: Distribution of the speed of the fluid occurs in sub channel rectangular arrangement

In Fig. 9, can be seen also at the beginning of an increase in the fluid flow, this happens due to the turbulent flow at the beginning of the flow, along with the altitude factor fuel element gradually declining pattern of fluid flow. This occurs in the cooling water using a fluid water and nanofluid.

From Fig. 9, shown that the velocity of fluid flow in each of the different cooling fluid, nanofluid with 3% Alumina nanoparticles have a pattern of fluid flow velocity above of Alumina 2% or 1%, and also the pattern of flow of fluid to the fluid flow rate of water light (H_2O) is lower than the third nanofluid. This relates to the relationship with the density and viscosity of each fluid. Density of nanofluid greater than the fluid water, resulting in the magnitude of the velocity distribution of the fluid nanofluid compared with fluid water.

Similarly, the nanofluid viscosity of the fluid is smaller than ordinary water, so the buoyant force of nanofluid lighter so that after being exposed to the style of the beginning of the turbulent flow causes the flow of fluid flow velocity of nanofluid used is greater than the usual light-water fluid.

To determine the heat transfer occurs in the sub rectangular channel using nanofluid Al_2O_3-Water can be graphed fluid temperature distribution and the temperature distribution of the cylinder wall heater, as shown in Fig. 10 and Fig. 11:

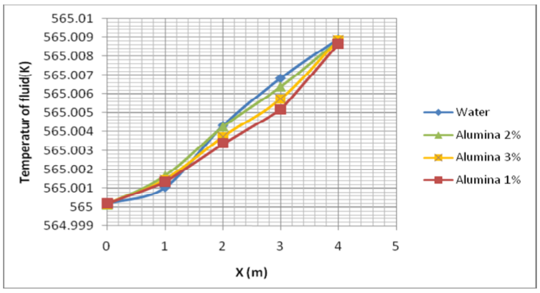

Fig. 10: Distribution of the temperature of the fluid that occurs in sub channel rectangular arrangement

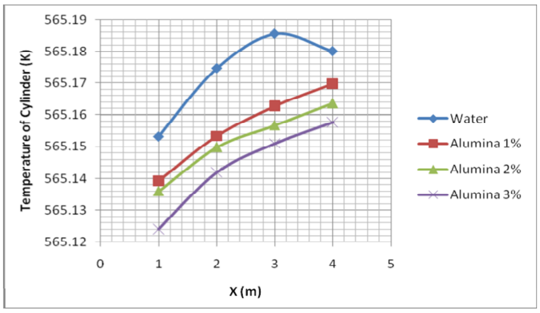

Fig.11: Distribution of temperature in the cylinder wall heater in the sub channel rectangular arrangement

Fig. 10 shown that the temperature distribution is influenced by the temperature of the fluid or fluid cooling to fixed heat flux, while Fig. 11 shows that when the heat flux with a fixed amount given to the cylindrical fuel elements each using a different fluid (fluid light water and nanolfuid), will be seen the increasing influence of each fluid. Due to differences in the value of the properties of the fluid itself, such as thermal conductivity, viscosity and density.

Furthermore, it can be calculated the amount of heat transfer coefficient (*h*) that occurs in the cylinder fuel elements in the sub channel rectangle for each fluid light water or by using nanofluid. Can be seen in Fig. 12 as follows:

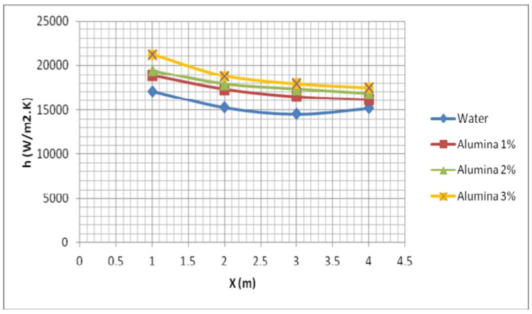

Fig. 12: Coefficient of heat transfer fluid in a rectangular arrangement of sub channel

Fig. 12 shows that nanofluid alumina 3% has a coefficient of thermal transfer of greater than Alumina 2%, 1% and light water. This is due to the influence of the larger thermal conductivity is owned by Alumina 3% compared to 1% and 2%, and mild water.

And also the existence of a factor in the turbulence at the beginning of the flow, resulting in the value of the coefficient of heat transfer in the fuel elements in the sub rectangular channel, then with increases in the direction of the height of the fuel elements will decrease coefficient of heat transfer fluid for light water and nanofluid.

Then, to determine the heat transfer phenomena occurring in sub channel rectangular arrangement using light water coolant fluid and nanofluid can be graphed the relationship between the Nusselt number (Nu) with Re * Pr [Dh / x], is shown as Fig. 13 as follows:

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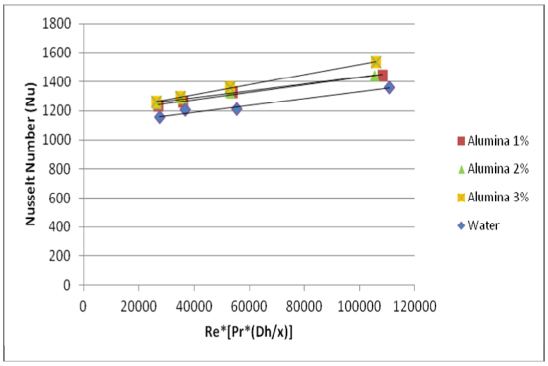

Fig. 13: Relationship Nusselt number (Nu) of the Re * Pr [Dh / x] on the sub channel rectangular arrangement

Thus obtained heat transfer correlation in Table 3:

Table 3. Correlation equation heat transfer

Item	Convection Correlation
Fluid Water (H_2O)	Nu = 2.57 [Re*Pr (Dh/x)] $^{0.11}$
Al_2O_3 (1%)	Nu = 2.58 [Re*Pr (Dh/x)] $^{0.11}$
Al_2O_3 (2%)	Nu = 2.63 [Re*Pr (Dh/x)] $^{0.10}$
Al_2O_3 (3%)	Nu = 2.46 [Re*Pr (Dh/x)]$^{0.14}$

Table 3 is valid for nanofluid Al_2O_3 with volume fraction of (1%, 2% and 3%) with turbulent flow with the Reynolds number (Re) is 404 096 < Re < 423 084 with constant heat flux is 2600 W / m^2, and the composition ratio (Pitch / diameter) 1.33 and used for fuel element in sub channel rectangular arrangement.

IV. CONCLUSION

Numerical simulation modeling in sub channel fuel element of the rectangle by using different cooling fluid, namely: fluid light water (H_2O), and nanofluid Al_2O_3 – Water (alumina) with a composition volume fraction of 1%, 2% and 3%. The cooling fluid used has a flow velocity pattern which is almost the same in every sub channel fuel element rectangular arrangement, and nanofluid has a considerable influence on the heat transfer that occurs in the cylinder wall fuel elements become more prevalent as compared with light-water fluid.

Simulation modeling has gained value of heat transfer coefficient and Nusselt number by using fluid light water (H_2O), and nanofluid Al_2O_3 (alumina) with a composition of 1%, 2% and 3% of the axial direction.

Heat transfer correlations obtained in this study are as follows:

A. Fluid water (H_2O): Nu = 2.57 [Re * Pr (Dh / x)] $^{0.11}$
B. Al_2O_3 (1%): Nu = 2.58 [Re * Pr (Dh / x)] $^{0.11}$
C. Al_2O_3 (2%): Nu = 2.63 [Re * Pr (Dh / x)] $^{0.10}$
D. Al_2O_3 (3%): Nu = 2.46 [Re * Pr (Dh / x)] $^{0.14}$

Heat transfer correlations above applied to nanofluid Al_2O_3 with volume fraction of (1%, 2% and 3%) for the Reynolds number (Re) is: 404 096 < Re <423 084 and with a constant heat flux is 2600 W / m2, and the composition ratio (Pitch / Diameter) 1.33 and used for fuel sub channel element rectangular arrangement.

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