World Journal of Nuclear Science and Technology, 2016, 6, 79-88
Published Online January 2016 in SciRes. http://www.scirp.org/journal/wjnst
http://dx.doi.org/10.4236/wjnst.2016.61008

Scientific Research Publishing

Effect Analysis of Volume Fraction of Nanofluid Al_2O_3-Water on Natural Convection Heat Transfer Coefficient in Small Modular Reactor

Anwar Ilmar Ramadhan[1*], Ery Diniardi[1], Rasma[2]

[1]Mechanical Engineering Department, Faculty of Engineering, Universitas Muhammadiyah Jakarta, Jakarta, Indonesia
[2]Automotive and Heavy Equipment Department, Faculty of Engineering, Universitas Muhammadiyah Jakarta, Jakarta, Indonesia
Email: *anwar.ilmar@ftumj.ac.id

Received 1 January 2016; accepted 26 January 2016; published 29 January 2016

Abstract

Development and use of nuclear energy is currently growing very rapidly, in order to achieve increasingly advanced technology, both in terms of design, economic factors and safety factors. Thermal-hydraulics aspects of nuclear reactors should be done with calculation and near-perfect condition. Including today began development of a nuclear reactor with low power below 300 MW, or commonly called the Small Modular Reactor (SMR). One is CAREM-25 developed by Argentina with a power of 25 MW, where in CAREM already using natural circulation system and the use of nanofluid as coolant fluid. In this research, analytic modeling of thermal-hydraulics nuclear reactor SMR CAREM-25, when the nanofluid Al_2O_3-Water used as cooling fluid in the cooling system of a nuclear reactor. Further to this analytic modeling will be done on CFD. Analytic modeling with CFD to determine the flow phenomena and distribution as well as the effect of nano-particles of Al_2O_3-Water based on the volume fraction (1% and 3%) of the coefficient of heat transfer by natural convection.

Keywords

Nanofluid, Nano-Particles, Natural Convection, Thermal-Hydraulic, Coefficient of Heat Transfer

*Corresponding author.

How to cite this paper: Ramadhan, A.I., Diniardi, E. and Rasma (2016) Effect Analysis of Volume Fraction of Nanofluid Al_2O_3-Water on Natural Convection Heat Transfer Coefficient in Small Modular Reactor. *World Journal of Nuclear Science and Technology*, **6**, 79-88. http://dx.doi.org/10.4236/wjnst.2016.61008

1. Introduction

Safety is a major concern in the design, operation and development of a nuclear reactor. Therefore, the analysis method 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 [1]. In addition neutrons aspect, thermal-hydraulic aspect is an important aspect for the safety of the design and operation of a nuclear reactor. Magnitude thermal-hydraulic such as pressure, coolant flow rate and temperature of the fuel needs to be known through predictive calculation [2].

Currently begun development of nuclear power plant or nuclear power plants around the world by type of Small Modular Reactor (SMR) is a mini nuclear reactor with power below 300 MW. Where an excess of Small Modular Reactor (SMR) is more flexible in matters of design, the cheaper the price development and also the price of treatment, as well as the advantages of SMR did pooling system thermal-hydraulic of 2-loop system cooling into the cooling loop in other words the use of integral system loop on SMR. SMR cooling fluid using fluid (H_2O) in the reactor coolant loop integral system. Studies related to the use of other types of nanofluid as coolant into the study and research are interesting and important to optimize heat transfer in the SMR, becoming thermal-hydraulic important aspect in the cooling system in a nuclear reactor [3].

One study that is currently a research priority in the cooling system is the use of nano-particles that are mixed with a fluid to improve the performance of decision-calorific. Theoretically nanofluid including nanoparticles has high thermal conductivity value than ordinary light fluid, so as to absorb and transfer heat better. Buongiorno and his team at the Massachusetts Institute of Technology (MIT) in the United States of America has conducted research related to nanofluid, it has been proven that the value of Critical Heat Flux (CHF) nanofluid greater than fluid water [4].

This research was developed for the use of nanofluid as coolant fluid in a nuclear reactor with the type SMR CAREM-25, made in Argentina. The research activities focused on assessing the deeper aspects thermal-hydraulic that occurred in the cooling system of a nuclear reactor CAREM-25 using nanofluid Al_2O_3-Water as coolant fluid. So that later acquired the flow characteristics of natural circulation cooling system used by the SMR, heat generation process from the beginning, the temperature distribution in the fuel element, in order to obtain an analytical model for the safety performance of the reactor type CAREM SMR-25.

2. Research Method

2.1. Modeling of Core Nuclear Reactor of Small Modular Reactor (SMR)

It needs to be done first before doing the simulation process is to create a model that happens to sub-channel arrangement of hexagons. In this case the model is made is in the form of volume models. Simplifying assumptions made model that is considered a model sub-channel arrangement of hexagons similar to the SMR reactor core (Small Modular Reactor) type hexagonal and uniform heat flux generated. In the manufacture of this model using CAD program as modeling. And models to be simulated in this research are as follows in **Figure 1**.

2.2. Meshing

Meshing is the process by which the overall geometry is divided into small elements this will act as a control surface or volume in the calculation process and then each of these elements will be input to the element next to it. This will happen over and over again until the fullest domain. In meshing elements that would have been tailored to the needs and geometric shapes. In this thesis meshing application used is CAD. In this study all types of configuration elements are simulated using hybrid or tetrahedron elements. Below are images meshing with volume meshing configuration and size interval by 5 (**Figure 2**).

2.3. Numerical Modeling with CFD

CFD is one type of CAD program that uses finite volume method. CFD mesh provides complete flexibility, so as to resolve the case of fluid flow with unstructured mesh even with a relatively easy way. CFD mesh types supported are the type of triangular-quadrilateral 2D, 3D tetrahedral-hexahedral-pyramid-wedge, and mesh mixture (hybrid). CFD also provides facilities to refine or enlarge an existing mesh. In general, the steps in performing analysis by using CFD.

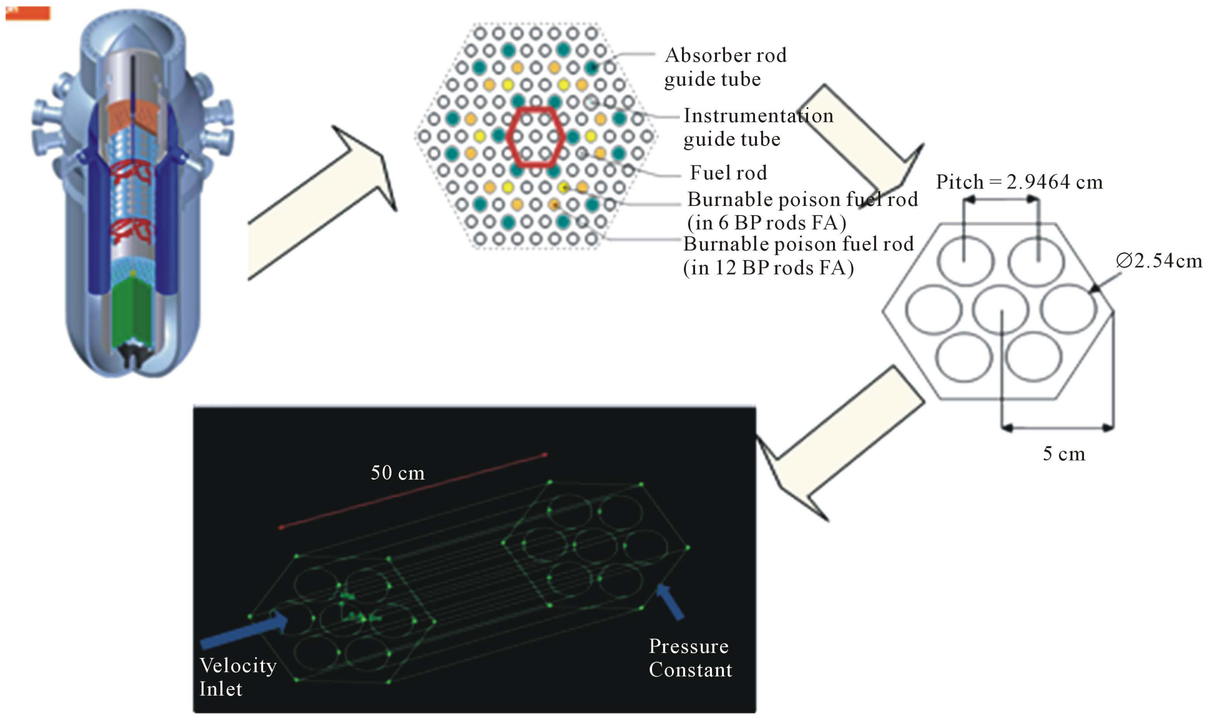


Figure 1. Modeling the SMR reactor sub channel of hexagon.

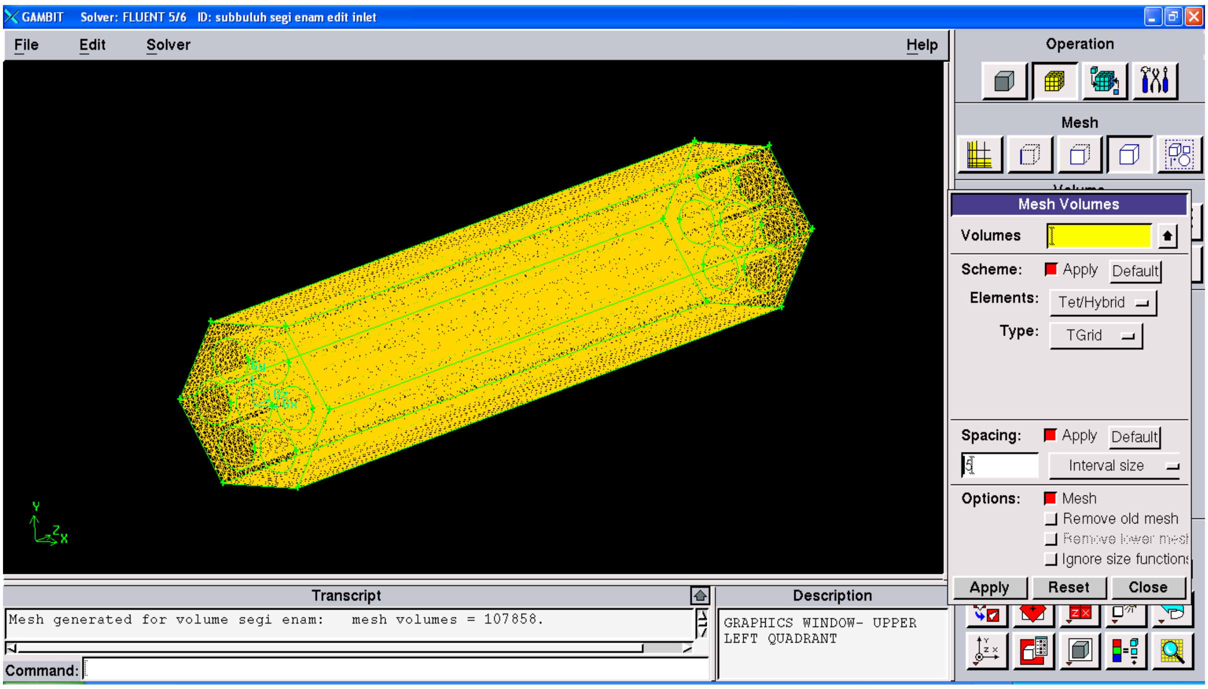


Figure 2. Results meshing in CAD.

2.4. Input Parameters on CFD

Numerical modeling in this study is done by using the CFD. Numerical simulations of the volume set have been created with the CAD program carried out for steady state. In the numerical modeling, it takes some assumptions, among others:

- Heat conduction to the walls inside and outside the sub model of channel hexagonal ignored.
- Radiation heat transfer from the walls inside and outside the sub model of channel hexagonal ignored.

The stages are carried out in numerical modeling is as follows:

1) Defining of model

- Solver

In this experiment, based pressure because the flow is analyzed incompressible at low velocity.

- Energy

Energy equation must be enabled in order to model the heat transfer process that occurs in the system.

2) Determine the properties of the material

The type of fluid used is nanofluid. Nanofluid physical properties such as density, viscosity, thermal conductivity, and thermal types are modeled as a function of temperature (**Table 1**).

3) Determine the operating conditions

The influence of the gravitational acceleration is also included in the system with values 9.8 m/s. Gauge Pressure = 0 Pa.

4) Determine of boundary condition

In the numerical modeling, setting the boundary conditions on the volume set is done by inserting a quantitative value of the parameters related to the type of boundary, such as a large heat flux on the surface of the heating cylinder. Configuration of heat on the surface approximated by a constant heat flux. The values of the parameters as set the volume boundary conditions are shown in **Table 2**.

3. Results and Discussions

3.1. Velocity Flow Characteristics on Nuclear Reactor Core of Small Modular Nuclear Reactor

Characteristic patterns of movement flow of nanofluid as coolant fluid by convection naturally occurring in a nuclear reactor core types Small Modular Reactor (SMR) with sub channel hexagon, can be seen in **Figures 3-5**.

Figure 3 shows the condition of nanofluid of Al_2O_3-Water treatment for the condition is given heat flux of 1000 W/m^2 with a volume fraction of 1%, and for **Figure 4**. A nanofluid of Al_2O_3-Water with the volume fraction of 3%, and for **Figure 5** shows a comparison of cooling fluid usually used in nuclear reactor cooling water is H_2O. **Figure 3** and **Figure 5** is a flow velocity contour of nanofluid of Al_2O_3-Water and fluid H_2O water at the center position of the sub channel on the hexagon in a nuclear reactor core types Small Modular Reactor (SMR).

Table 1. Properties of nanofluid Al_2O_3-Water [5].

Properties	Al_2O_3-Water (1%)	Al_2O_3-Water (3%)
Density [kg/m^3]	1021.7	1073.8
C_p (Heat Capacity) [J/kgK]	4.149	4.081
Thermal Conductivity [W/mK]	0.620	0.656
Viscosity [kg/ms]	8.17×10^{-4}	8.56×10^{-4}

Table 2. Input parameters values boundary conditions.

Type of Boundary	Parameter	Value
Inlet	Velocity inlet	0.1 m/s
	Temperature	300 K
Outlet	Gauge Pressure	0 Pa
	Backflow temperature	300 K
Wall of Cylinder	Heat Flux	100; 1000 W/m^2

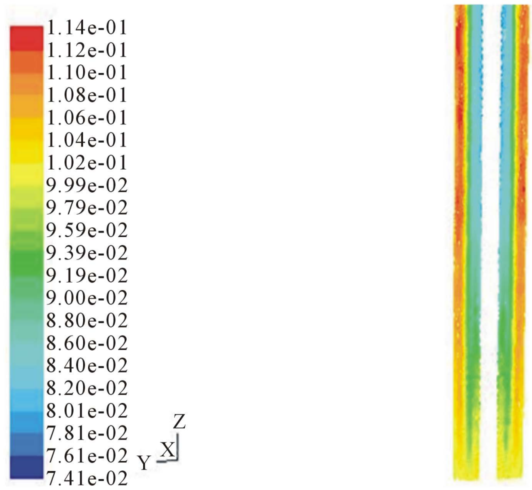


Figure 3. Contour of fluid flow of nanofluid Al_2O_3-Water (1%) with heat flux of 1000 W/m^2.

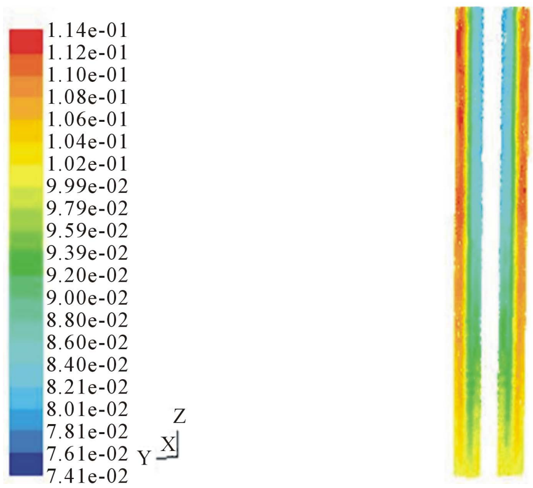


Figure 4. Contour of fluid flow of nanofluid Al_2O_3-Water (3%) with heat flux of 1000 W/m^2.

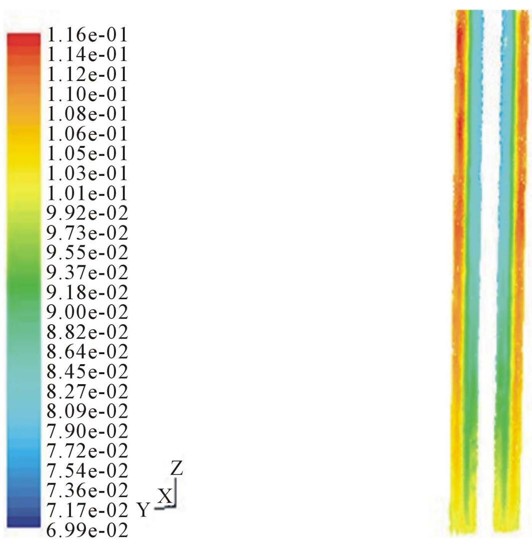


Figure 5. Contour of fluid flow of fluid flow of H_2O with heat flux of 1000 W/m^2.

The picture shows the pattern on the flow velocity in the direction of the z-axis (from bottom to top) shows a decrease in the velocity of the movement began in the early flow of 0.1 m/s decline at the end of the sub channel amounted to 0.083 m/s. This proves that what happened is the natural convection, *i.e.* the heat transfer due to the influence of the buoyant force of the fluid without being influenced by the velocity. And, also shows that the flow velocity profile of each nanofluid and also an increase in water fluid flow velocity at the beginning is marked in yellow as the initial velocity is given, then decreased with the simulation results are marked in light blue.

3.2. Cylinder Wall Temperature Distribution at the Sub Channel on Nuclear Reactor Core of Small Modular Reactor

Furthermore, after knowing the flow patterns that occur on the patio nuclear reactor types Small Modular Reactor (SMR) with the arrangement of sub channel hexagon, can be analyzed temperature distribution on the cylinder walls of fuel when given the fluid coolant is nanofluid of Al_2O_3-Water and fluid water H_2O, can be seen in **Figures 6-8** the following:

Figures 6-8, the contours of the temperature distribution of each of the cooling fluid, *i.e.* nanofluid of Al_2O_3-Water and fluid H_2O water under conditions of heat flux of 1000 W/m^2 to 7 fuel elements in the composition of the sub channel hexagon in a nuclear reactor core Small Modular Reactor (SMR). From Figure above shows that the distribution pattern of temperature in each cooling fluid have similar temperature distribution in the cylinder element of the fuel, which is the spread of the temperature on the cylinder early in the direction of the z-axis (at 0 m to 0.5 m) will increase significantly and approach the linear pattern. Therefore, when made a Curve of the temperature distribution of the cylinder wall to the position (m) for each of the cooling fluid with the condition of the heat flux of 100 W/m^2 and 1000 W/m^2, can be seen in **Figure 9** and **Figure 10**.

Figure 9 and **Figure 10** shows for each cooling fluid that nanofluid Al_2O_3-Water and fluid water H_2O with each condition of the heat flux in the cylinder fuel elements show patterns upward trend in line with the position of the cylinder, starting at position 0 m to the position 0.5 m (end cylindrical fuel elements). And, showed also that nanofluids have a wall temperature is smaller than the fluid water (H_2O). This proves that the given velocity of 0.1 m/s did not significantly affect the temperature of the wall of the cylinder fuel elements. Due also the factor of the thermal properties of nanofluid of Al_2O_3-Water higher than the fluid water. This proves that the results obtained by Pandey, *et al.*, as shown in **Figure 11**.

By comparing the Curves obtained between **Figures 9-11** showed the same pattern, namely the fluid light water has a value of wall temperature greater than the temperature of the wall for nanofluid of Al_2O_3-Water, it is influenced by the movement of the flow velocity in the sub channel so it looks boosts the pattern of the distribution of temperature in the cylinder wall. Furthermore, it can be seen the results of numerical simulation on natural convection heat transfer coefficient by using CFD is as follows:

Figure 12 explains that for nanofluid of Al_2O_3-Water (1%) and (3%) had the same pattern of the static pressure, which decreased pressure based on the effect on the point position of cylinder fuel elements in the model.

Figure 13 shows that nanofluid of Al_2O_3-Water (1%) and (3%) have a static relationship between the temperature of the fuel element cylinder position on raising test model suffered linearly on each of the fuel elements.

Figure 14 shows that nanofluid of Al_2O_3-Water (1%) and (3%) had the relationship between calorific heat transfer coefficient against the position of the cylinder fuel elements in the test model has decreased in each of the fuel elements.

4. Conclusions

From these results provide the following conclusions:

1) The pattern of the spread of the flow rate in each cooling fluid (H_2O) and nanofluid of Al_2O_3-Water (1% and 3%) had a similar pattern, which is beginning to experience a great velocity, along with the altitude is naturally decreasing velocity tip flow cylinder. So what happens is proving convection natural convection.

2) Distribution of temperature on the wall on the analysis of heat transfer occurs in sub channel hexagon on Small Modular Reactor (SMR) shows a tendency to rise significantly and approached the rise linearly in the direction of the z-axis position, and proves also that water has a value of fluid temperature distribution wall larger than nanofluid of Al_2O_3-Water (1% and 3%).

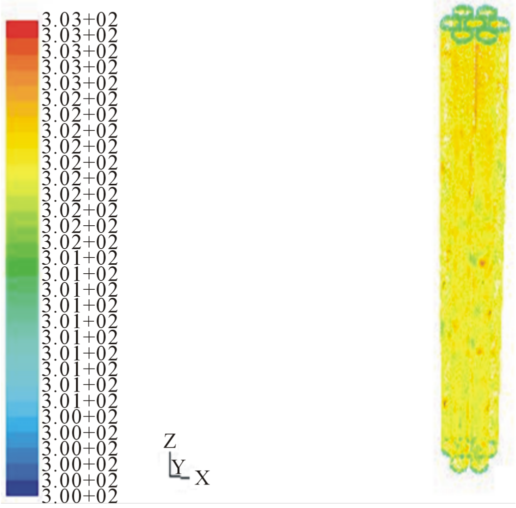


Figure 6. Contour of temperature distribution of nanofluid Al_2O_3-Water (1%) with heat flux of 1000 W/m^2.

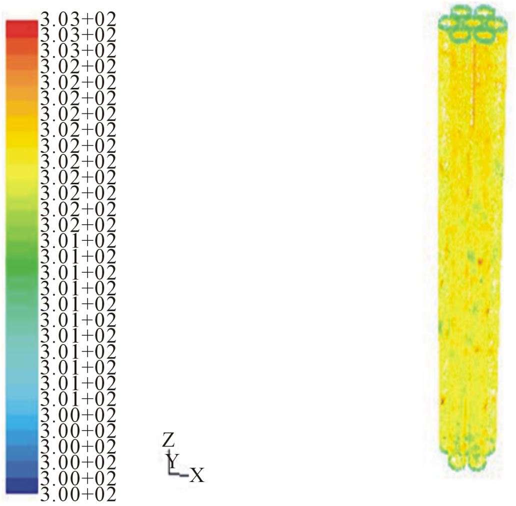


Figure 7. Contour of temperature distribution of nanofluid Al_2O_3-Water (3%) with heat flux of 1000 W/m^2.

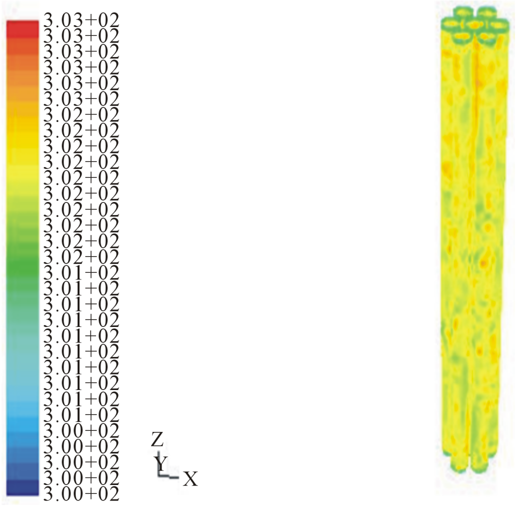


Figure 8. Contour of temperature distribution of H_2O with heat flux of 1000 W/m^2.

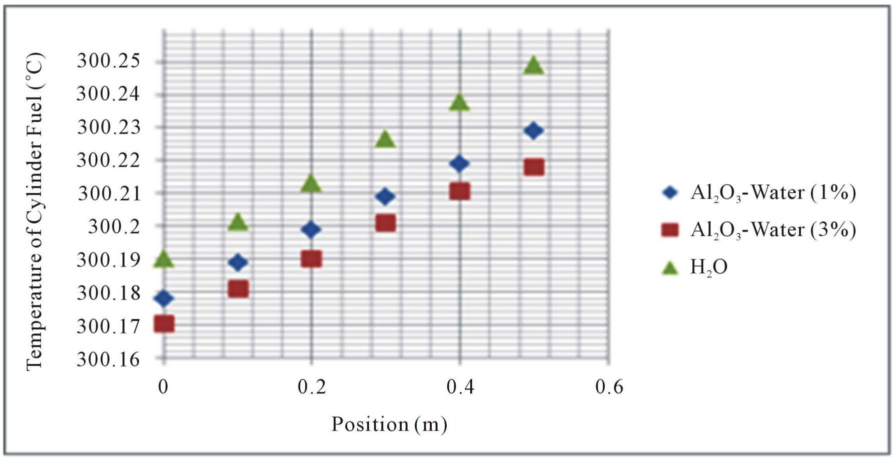


Figure 9. Relationship massive cylinder wall temperature distribution of the position (m) in the sub channel hexagon in nuclear reactor core SMR for nanofluid of Al_2O_3-Water and Water H_2O with a heat flux of 100 W/m^2.

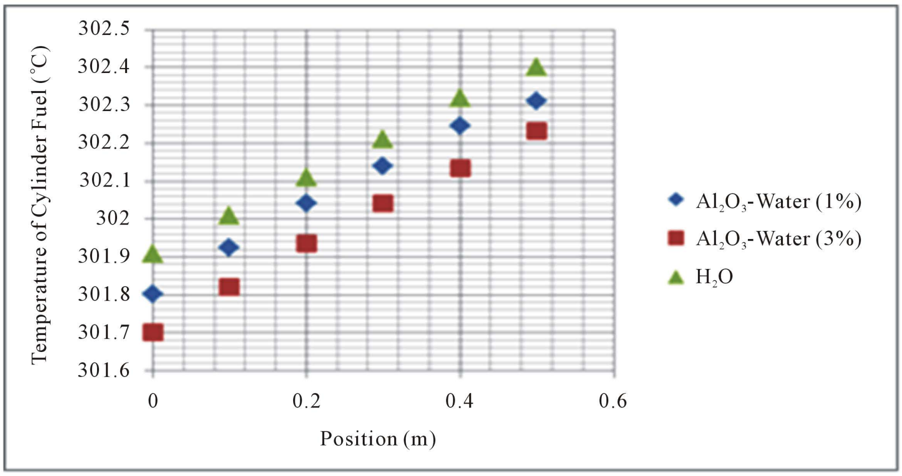


Figure 10. The relationship on the distribution of the temperature of the cylinder wall to the position (m) in the sub channel hexagon in nuclear reactor core SMR for nanofluid of Al_2O_3-Water and H_2O with a heat flux of 1000 W/m^2.

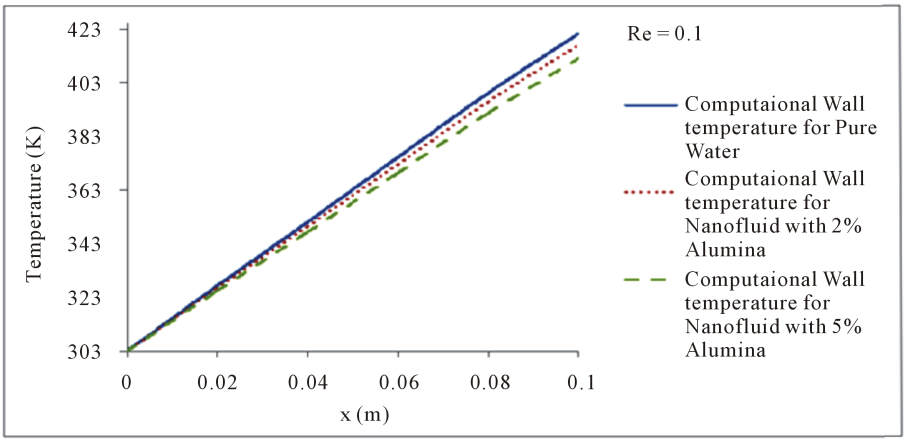
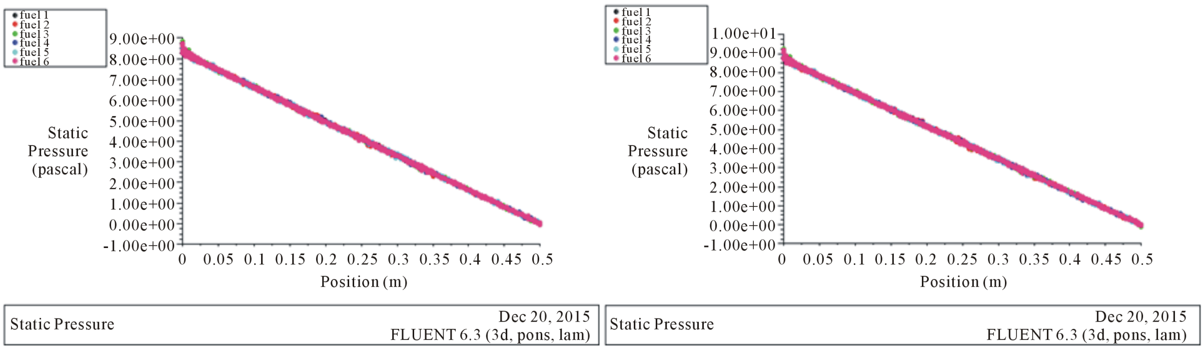
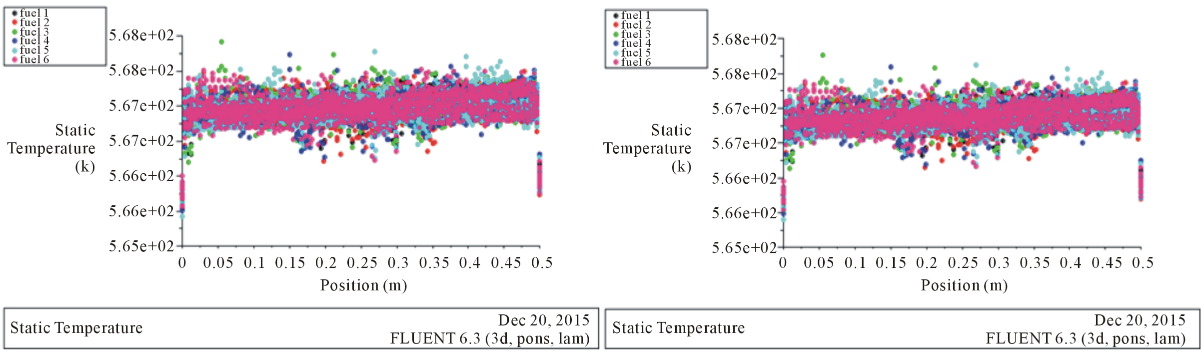


Figure 11. The relationship of the distribution of the wall temperature of the position (m) in the micro channel [6].



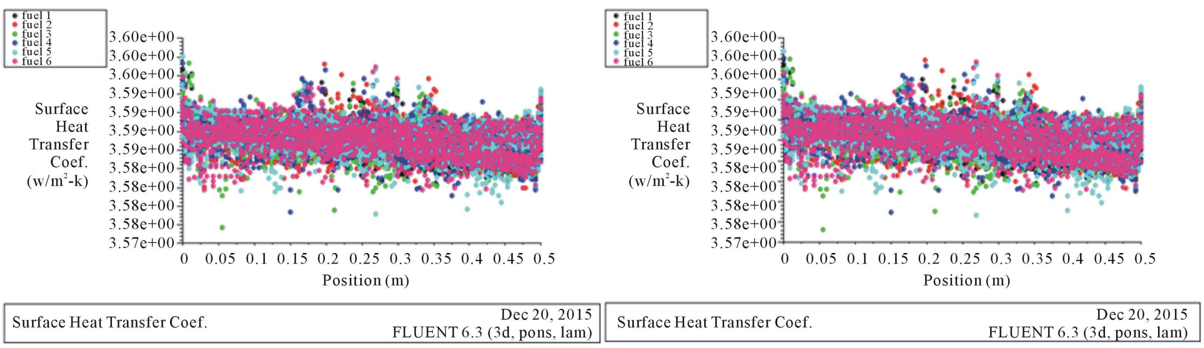
(a) (b)

Figure 12. Curve the relationship between the static pressure of the fuel element positions. (a) Nanofluid Al_2O_3-Water (1%); (b) Nanofluid Al_2O_3-Water (3%).



(a) (b)

Figure 13. Curve the relationship between the static temperature of the fuel element positions. (a) Nanofluid Al_2O_3-Water (1%); (b) Nanofluid Al_2O_3-Water (3%).



(a) (b)

Figure 14. Curve the relationship between the coefficient of heat transfer to the position of fuel elements. (a) Nanofluid Al_2O_3-Water (1%); (b) Nanofluid Al_2O_3-Water (3%).

3) The results of numerical simulation using saw that for the coefficient of heat transfer by natural convection is affected by the value of the volume fraction of the nanoparticles in nanofluid of Al_2O_3-Water, a value of 3% volume fraction has a heat transfer coefficient greater than the volume fraction of 1%.

Acknowledgements

The authors would like to thank PAKARTI (Center of Affiliate for Study and Research Technology) Faculty of Engineering, Universitas Muhammadiyah Jakarta, which has provided a research grant to develop this research

in 2015.

References

[1] Puradwi and Juarsa, M. (2009) Literature Review of Nuclear Reactor Safety Innovation through Technology Use as a Nano Fluid as Cooling Fluid. *Journal of Sigma Epsilon*, **13**, 49-53.

[2] Ramadhan, A.I. and Diniardi, E. (2014) Analytical Study of Velocity Flow and Temperature Distribution of Fuel Elements Cylinder in Nuclear Reactor Core. *National Symposium on Applied Technology* (*SNTT*), Surabaya.

[3] Gimenez., M.O. (2011) CAREM Technical Aspects, Project and Licensing Status. *Interregional Workshop on Advanced Nuclear Reactor Technology*, Vienna.

[4] Buongiorno, *et al*. (2008) Alumina Nanoparticles Enhance the Flow Boiling Critical Heat Flux of Water at Low Pressure. *Jurnal of Heat Transfer*, **130**.

[5] Ramadhan, A.I., Lasman, A.N., Septilarso, A. (2015) Correlation Equations of Heat Transfer in Nanofluid Al_2O_3-Water as Cooling Fluid in a Rectangular Sub Channel Based CFD Code. *International Journal of Science and Engineering*, **8**, 120-124.

[6] Pandey, A.K. (2011) A Computational Fluid Dynamics Study of Fluid Flow and Heat Transfer in a Micro Channel. Thessis Programme Master, National Institute of Technology Rourkela, India.