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Analytical Study of Forced Convection in Fluid Cooling Use Nanofluid Al_2O_3 – Water on Nuclear Reactor Core Based Fuel Cylinder with Hexagonal Sub Channel

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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) as similarly of Hexagonal Sub Channel. One is CAREM-25 developed by Argentina with a power of 25 MW. In this research, analytic study 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%) by forced convection.

Keywords Nanofluid, Nano-Particles, Forced convection, Thermal-Hydraulic, Sub channel of hexagonal

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 neutronic 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 has conducted research related to nanofluid, it has been proven that the value of Critical Heat Flux (CHF) nanofluid greater than fluid water [4, 5].

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

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type CAREM SMR-25 with forced convection.

2. Research Method

Modeling of Core Nuclear Reactor of Small Modular Reactor (SMR) with Hexagonal of Sub Channel

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 hexagonal Sub Channel is similar to the SMR reactor core 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:

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.

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.

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. Properties of nanofluid Al_2O_3-Water [6]

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}

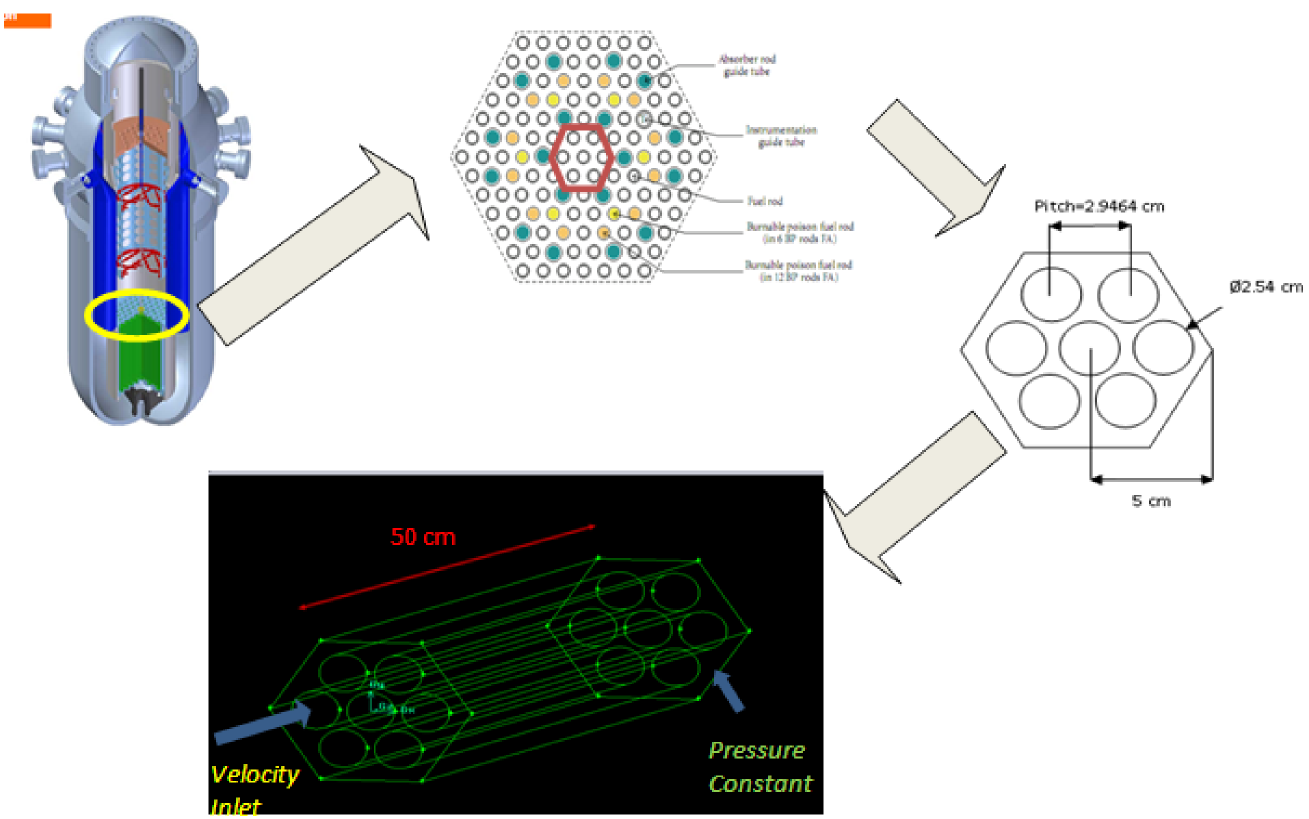

Figure 1. Modeling of sub channel hexagonal

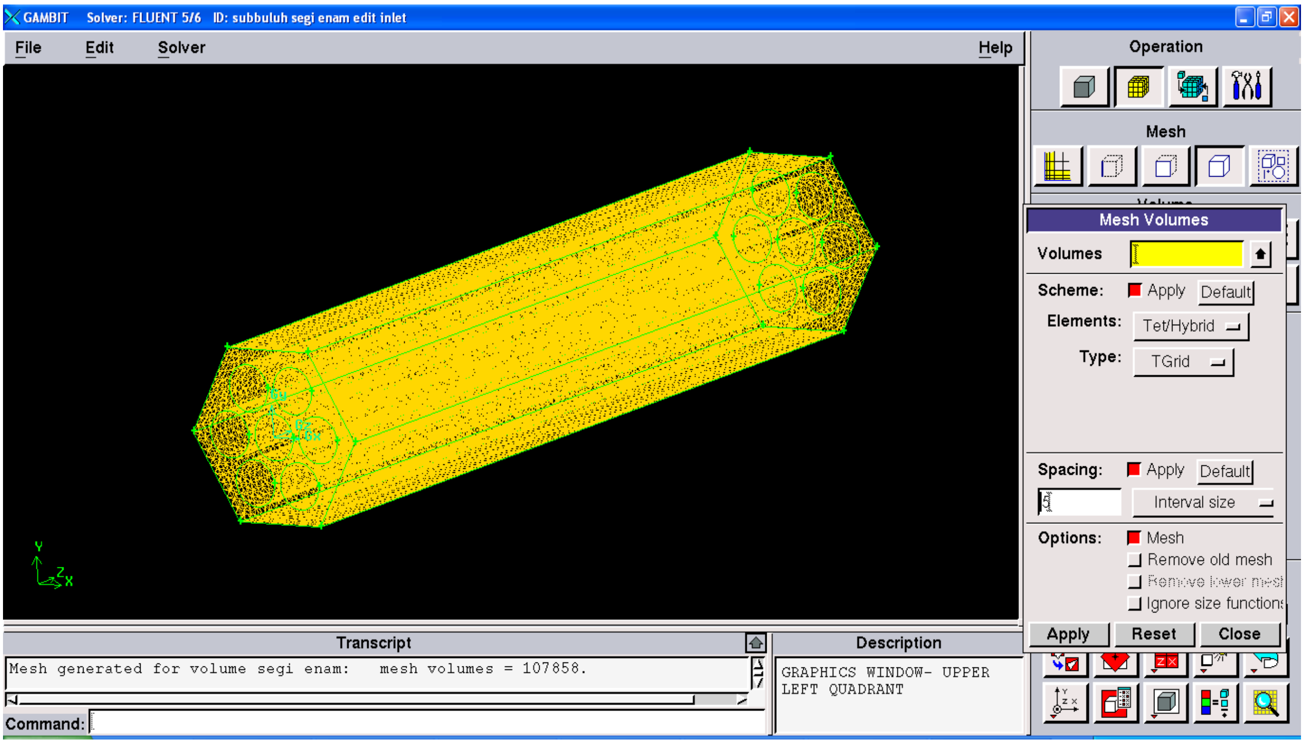

Figure 2. Results meshing in CAD

Table 2. Input parameters values boundary conditions

Type of Boundary	Parameter	Value
Inlet	Velocity inlet	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

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 Discussion

Velocity flow characteristics on Sub Channel Hexagonal

Characteristic patterns of movement flow of nanofluid as coolant fluid by convection forced occurring in a nuclear reactor core types Small Modular Reactor (SMR) with sub channel hexagonal, can be seen in Figure 3 and Figure 5 below:

Figure 3 shows the treatment conditions nanofluids Al_2O_3-Water for the conditions given heat flux of 100 and 1000 W/m^2 with a fraction of its volume by 1%, and for Figure 4 is nanofluids Al_2O_3-Water with a volume fraction of 3%, and for Figure 5 shows a comparison cooling fluid that normally used in the nuclear reactor of Sub Channel Hexagonal with coolant fluid is water H_2O.

Figure 3 to 5 as velocity vector of Al_2O_3-Water nanofluids and fluid H_2O at the center position of the sub channel on the hexagonal in the nuclear reactor core type of Small Modular Reactor (SMR). In the Figure shows the pattern of flow velocity in the direction of the z-axis (from bottom to top) shows a decline in the velocity of the movement began in the early flow of 1 m/s decline at the end of the sub reed amounted to 0.95 m/s. This proves that what happened is forced convection, i.e the fluid movement caused by differences in fluid density and also due to the fluid temperature gradient.

And, also shows that velocity vector of each nanofluids and water fluid flow velocity at the beginning of an increase marked in yellow as the initial velocity is given, then decreased with the simulation results are indicated in light blue.

Cylinder Wall Temperature Distribution at the Sub channel Hexagonal

Furthermore, after knowing the flow patterns that occur on the patio nuclear reactor types Small Modular Reactor (SMR) with sub channel hexagonal, 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 H_2O, can be seen in Figures 6 - 8 the following:

Figure 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 below:

Figure 9 and Figure 10 shows for each of the cooling fluid that nanofluids Al_2O_3-Water and fluid water H_2O to the respective conditions of the heat flux in the cylinder fuel element patterns show upward trend in line with the position of the cylinder, starting at position 0 m to the position 0.5 m.

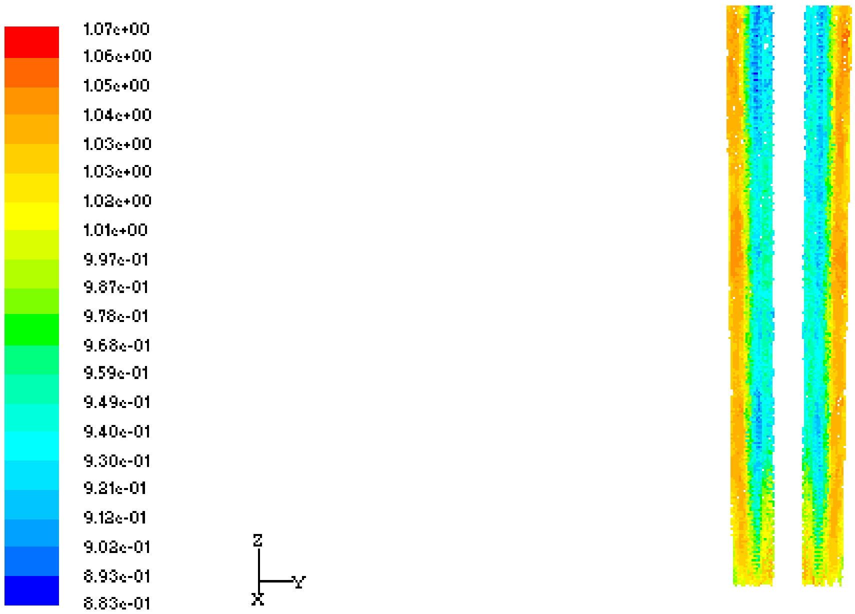

Figure 3. Velocity vector of nanofluid Al_2O_3 – Water (1%) with heat flux of 1000 W/m^2

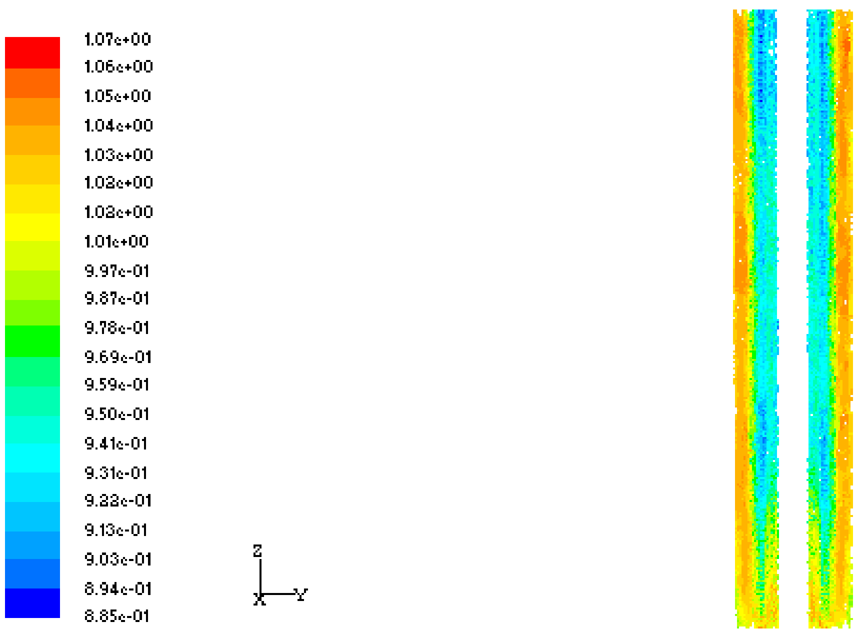

Figure 4. Velocity vector of nanofluid Al_2O_3 – Water (3%) with heat flux of 1000 W/m^2

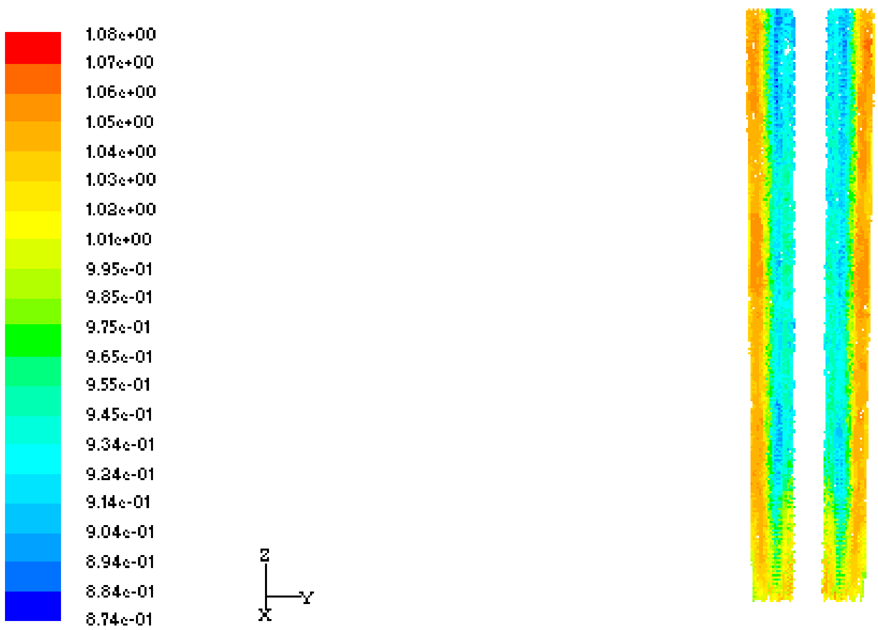

Figure 5. Velocity vector of H_2O with heat flux of 1000 W/m^2

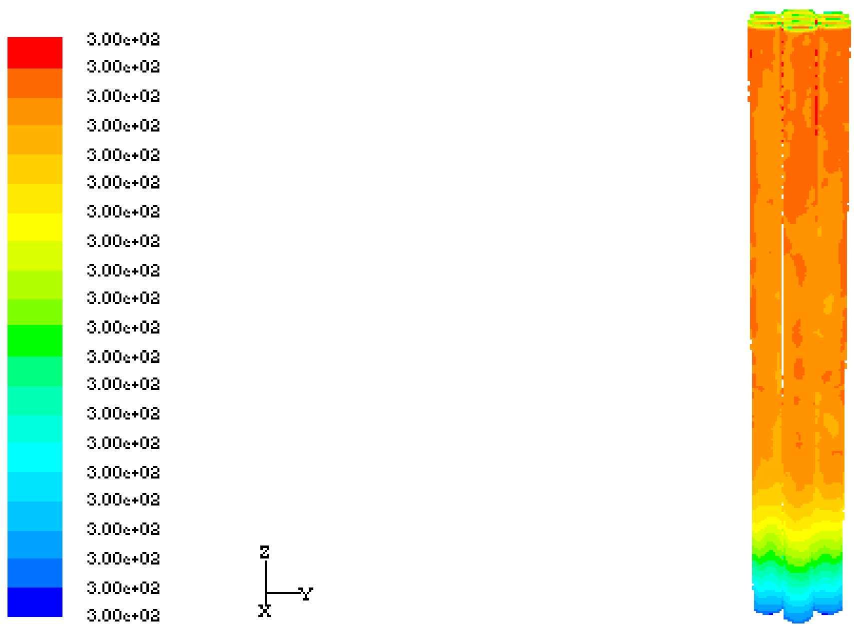

Figure 6. Contour of temperature distribution of nanofluid Al_2O_3 – Water (1%) with heat flux of 1000 W/m^2

This is due to factors properties of the fluid (fluid density, viscosity and thermal conductivity and heat capacity) of the volume fraction of alumina is used as a cooling fluid. And for the value of the magnitude of the temperature of a huge wall to the fluid is because the value of thermal conductivity smaller than the thermal conductivity of nanofluids is owned by 1%, 2% and 3%. Where the value of thermal conductivity is inversely proportional to the temperature of the cylinder wall of the fuel element. And, also showed that nanofluids have a wall temperature is smaller than the fluid water (H_2O). This proves that given the velocity of 1 m/s should not unduly influence the cylinder wall temperature of the fuel element. This proves that the results obtained by Pandey, et al, as shown in Figure 11 below:

By comparing the graphs obtained between Figures 9 and 10 to Figure 11 showed the same pattern, namely the fluid light water has a value of wall temperature greater than the temperature of the wall for nanofluids Al_2O_3, it is influenced by the movement of the flow velocity in the sub channel of hexagonal so it looks boosts the pattern of the distribution of temperature on the cylinder wall.

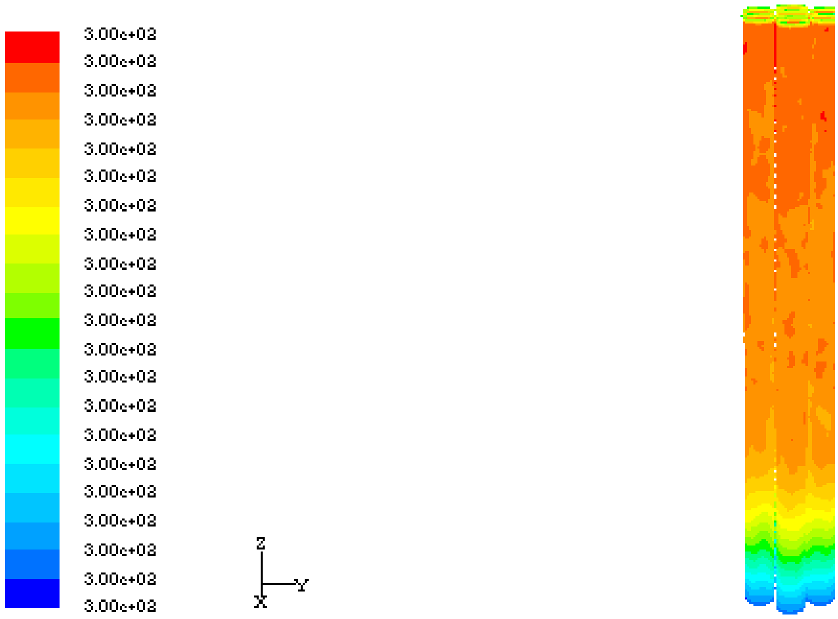

Figure 7. Contour of temperature distribution of nanofluid Al_2O_3 – Water (3%) with heat flux of 1000 W/m^2

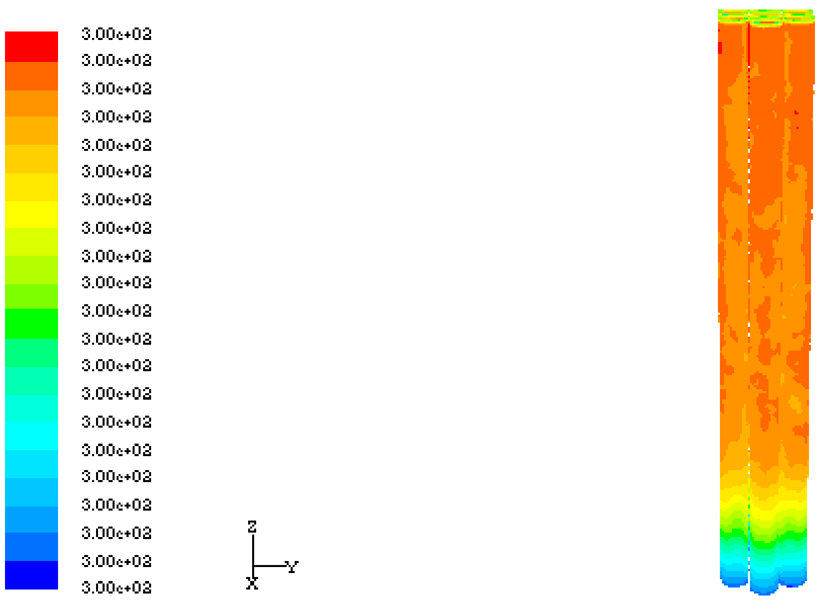

Figure 8. Contour of temperature distribution of H_2O with heat flux of 1000 W/m^2

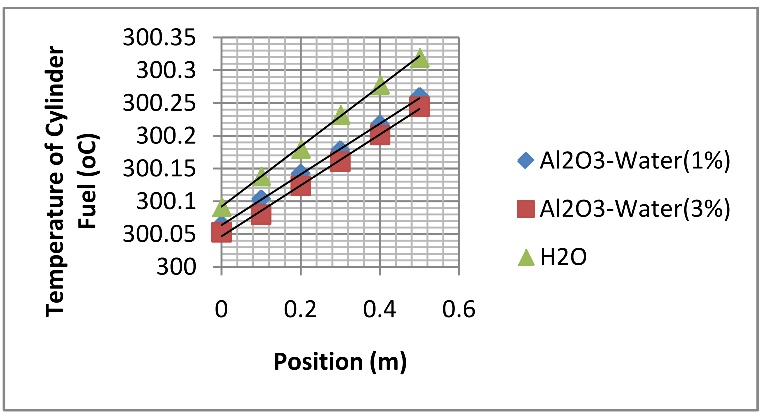

Figure 9. Relationship massive cylinder wall temperature distribution of the position (m) in the sub channel hexagonal in nuclear reactor core SMR for nanofluid of Al_2O_3-Water and Water H_2O with a heat flux of 100 W/m^2

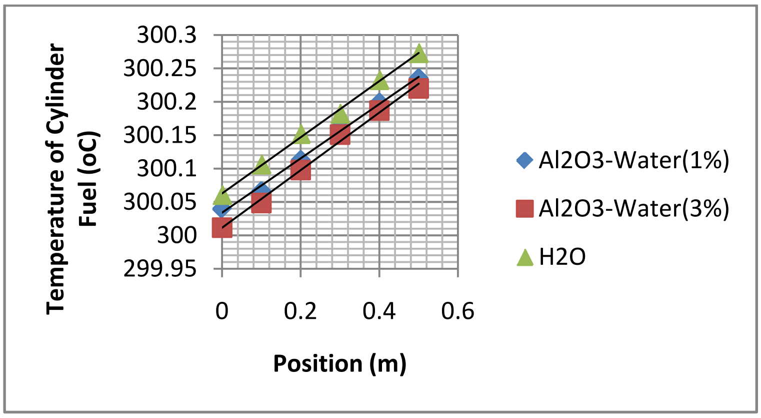

Figure 10. The relationship on the distribution of the temperature of the cylinder wall to the position (m) in the sub channel hexagonal in nuclear reactor core SMR for nanofluid of Al_2O_3-Water and H_2O with a heat flux of 1000 W/m^2

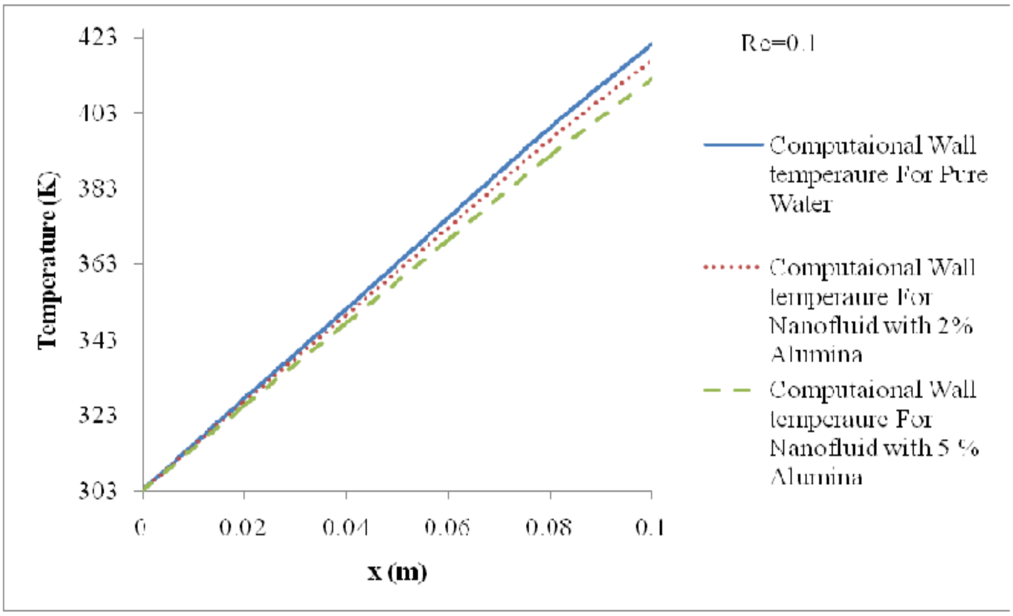

Figure 11. The relationship of the distribution of the wall temperature of the position (m) in the micro channel [7]

4. Conclusions

From these results provide the following conclusions:

1. Distribution patterns of flow rate in each cooling fluid (fluid water (H_2O) and Al_2O_3–Water of nanofluids (1% and 3%) had a similar pattern, which is beginning to experience a great pace, in line with the height of forcibly became a natural where a decline in the flow velocity at the threshold of the cylinder.
2. Distribution of temperature on the wall on the analysis of heat transfer occurs in sub channel of hexagonal showed a significant upward trend and approaching the increase linearly in the direction of the z-axis position, and proves also that the fluid water has a temperature distribution value wall that is larger than Al_2O_3–Water of nanofluids (1% and 3%).

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