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Comparison of the Thermal Hydraulic Behaviors in the Rectangular and Triangular sub-channels of Bare Rod Bundles

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1. Introduction

Thermal-hydraulic characteristics in a sub-channel of triangular lattice fuel rod bundles which are adopted in a liquid metal cooled fast reactor were studied by using the commercial CFD code CFX 5.7 [1]. Also, the appropriateness of the triangular lattice fuel rod bundles was evaluated through a comparison with the results of the thermal-hydraulic characteristic analysis of rectangular lattice fuel rod bundles.

2. Analysis Methods

Table 1 shows the major specifics and boundary conditions with lattice type variations.

Pitch-to-diameter ratio (P/D) of each lattice was regulated to obtain an identical hydraulic-diameter to offer the same flow condition.

Figure 1 shows the computational domain for the CFX calculations. Each lattice fuel rod bundle consists of a 120cm height bare rod without a grid spacer.

Computational domains of the rectangular and triangular lattice rod bundles were taken respectively as 1/8 and 1/12 of that of a whole sub-channel because of the symmetric geometries.

Table 1. Major specifics and boundary conditions with sub-channel type variations

Sub-channel Geometry	Rectangular	Triangular
Fuel Rod Diameter (cm)	0.88	0.88
Cladding Thickness (mm)	0.57	0.57
Core Height (cm)	120	120
Pitch to Diameter Ratio (P/D)	1.31	1.41
Inlet Velocity (m/s)	1.6	1.6
Inlet Temperature (℃)	420	420
Hydraulic Diameter (m)	0.01049	0.01049
Flow Area of Sub-channel (m^2)	7.25E-05	7.25E-05
Power Density of Fuel (W/cc)	464	464
Reynolds No.	7.59E+04	7.59E+04

The material data used in the calculation are listed in Table 2. Although the material properties of the lead, fuel, cladding change with the temperature variation because the thermal-physical properties of materials are a function of the temperature, in this study, temperature-independent material properties are used for the lead, fuel, and cladding material HT-9. Therefore, it leaves some room for a consideration in a detailed calculation.

Two turbulence models are selected to predict the flow characteristic of the sub-channels. They are the standard k-ε model (k-ε) with the standard wall function and Reynolds stress models of Speziale (SSG) [2].

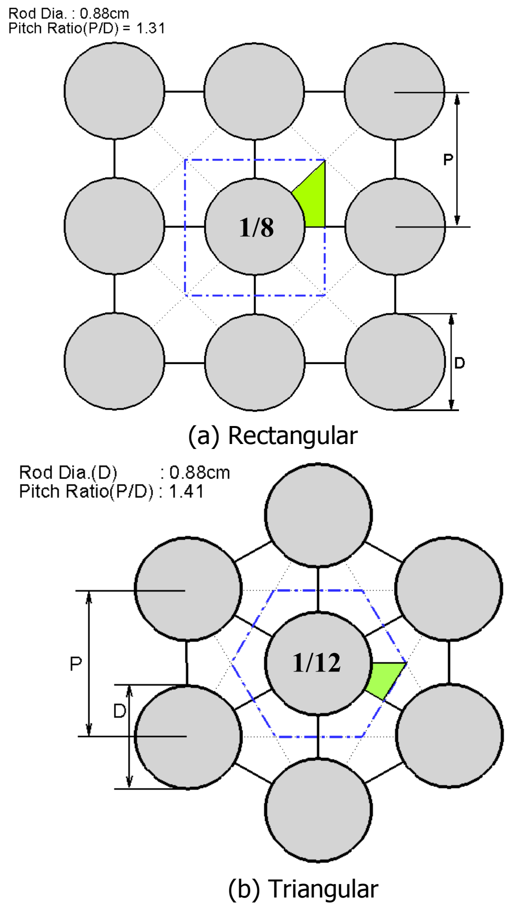


Figure 1.The computational domain

Table 2. The material data

Materials	Lead	Fuel	Cladding
Density (g/cm^3)	10.574	15.9	7.705
Thermal Conductivity (W/m· K)	15.5	20	21.4
Specific Heat (J/kg· K)	146.7	224.6	21.4
Dynamic Viscosity (kg/m· s)	2.34E-03		

3. Calculation Results

Table 3 shows the thermal-hydraulic analyses results of each lattice with the turbulence model variations. There are some differences between the triangular and rectangular lattice in the maximum outlet velocity, pressure drop, maximum or minimum outlet temperature, heat transfer coefficient (HTC), and maximum cladding and fuel temperature, etc. The results show that Pressure drop of the triangular lattice are higher than that of the rectangular lattice in either turbulence model. Especially, because the mean heat transfer coefficient of the triangular lattice is higher than that of the rectangular lattice in either turbulence model, the maximum temperature of the fuel, fuel surface, and the cladding surface of triangular lattice are smaller than that of the rectangular lattice in either turbulence model.

Table 3. The thermal-hydraulic analyses results of each lattice with turbulence model variations.

Turbulence Model	Triangular		Rectangular	
	k-ε	SSG	k-ε	SSG
Outlet Mean Vel. (m/s)	1.6	1.6	1.6	1.6
Maximum Outlet Vel. (m/s)	1.81	1.78	1.92	1.86
Pressure Drop (Pa)	31687	29274	30971	28766
Outlet Mean Temp. (℃)	567.33	567.36	567.34	567.35
ΔT (T_{outlet} - T_{inlet}) (℃)	147.33	147.36	147.34	147.35
Max. Outlet Temp. (℃)	587.84	585.72	595.51	591.30
Min. Outlet Temp. (℃)	558.10	560.08	550.15	553.67
Mean heat transfer coefficient.(W/m^2℃)	470371	442509	462889	437645
Max. Clad. Surf. Temp. (℃)	589.46	587.45	597.09	592.97
Max. Fuel Surf. Temp. (℃)	611.28	609.43	617.21	613.75
Max. Fuel Temp. (℃)	696.25	694.54	699.59	697.09
ΔT (T_{fuel} - T_{bulk})	128.93	127.18	132.25	129.74
ΔT_{fuel} (T_{center} - $T_{surface}$)	84.973	85.11	82.378	83.338
$\Delta T_{clad.}$ ($T_{fuel\text{-}side}$ - $T_{coolant\text{-}side}$)	21.818	21.98	20.122	20.787
$\Delta T_{sub\text{-}channel}$ ($T_{clad.\text{-}side}$ - T_{center})	29.736	25.636	45.36	37.622

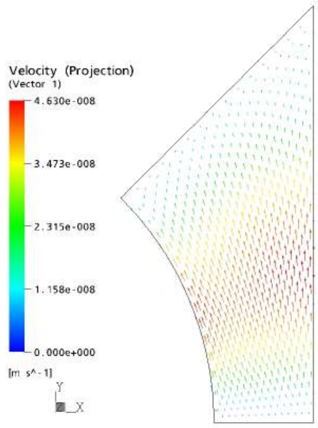
Figure 2 shows the velocity vector of the triangular lattice with the turbulence model variation. In the case of k-ε model, there is no turbulent driven secondary motion. But, in the case of the SSG model, the turbulent driven secondary motion is predicted well at the center of sub-channel.

4. Conclusion

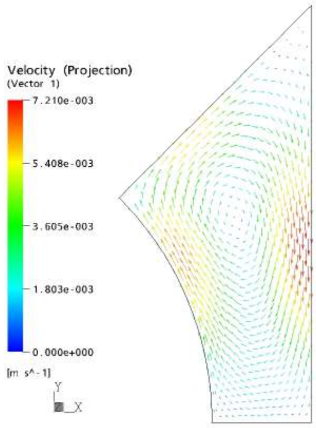
To assess the appropriateness of the turbulence model and sub-channel shape, the thermal-hydraulic behaviors analysis of the rectangular and triangular lattice fuel rod bundles was performed with two turbulence model.

First of all, the k-ε model do not predict the secondary flows. According to existing studies [3-4], a non-circular duct flow like the flow in rod bundle forms a secondary flow that was caused by a anisotropic turbulence. Therefore, the k-ε model is not appropriate for a sub-channel flow analysis in rod bundles.

Also, in terms of the pressure drop, the rectangular lattice is better than the triangular lattice, on the contrary, in terms of the heat transfer from the fuel to coolant, the triangular lattice is better than the rectangular lattice.



(a) k-ε model



(b) SSG model

Figure 2.The velocity vector of triangular lattice with turbulence model variation.

Acknowledgements

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