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Preliminary Numerical Analysis of 7 pins Wire-Wrapped Bundle

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1. Introduction

Numerical approach for thermal-hydraulic behavior in a wire-wrapped fuel bundle is applied to understand physical phenomena in the bundle. Especially, a flow blockage in the fuel bundle is a final target in this work. Several numerical and experimental approaches for a wire-wrapped bundle have reported in the open literature [1]. However, it is rare to investigate numerically for flow blockage in the wire-wrapped fuel bundle due to a geometrical complexity and large number of a fuel pin. In this work, preliminary calculations are conducted to check feasibility and applicability of numerical approach in the wire-wrapped bundle with commercial CFD code, CFX. A seven pins wire-wrapped bundle was selected as test bundle size. Seven different flow rates were applied as test cases with different turbulent models, which is ranged both transient and turbulent regimes. Finally, pressure drop results were compared with two pressure drop correlations, which are mostly referred in the previous works.

2. Numerical Analysis

2.1 Computation conditions

Fig. 1 shows modeling of computational domain. A seven pins triangular array wire-wrapped bundle is selected as test geometry. The wire is a key component in a modeling of wire-wrapped owing to higher length scale difference and point contact to a rod bundle. It is assumed that area contact between wire and rod with intrusion length, S_w. The wire is modeled with intruded distance of 0.1 mm to rod side. In addition, this treatment is helpful to avoid the singular point. A detail dimensions are summarized in Table 1 and geometrical

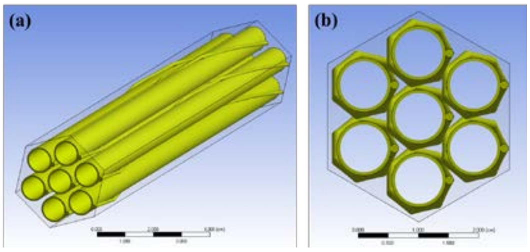

Fig. 1 Computational domain for the wire-wrapped bundle: (a) full view, (b) cross-section.

Table 1 Geometrical parameters

Parameters	Description	Values
D_r [mm]	Rod diameter	9
D_w [mm]	Wire diameter	1.5
P [mm]	Rod pitch	10.5
H [mm]	Wire pitch	204.9
x	P/D_r	1.167
y	H/D_r	22.767
g [mm]	Gap of duct	0.2
D_h [mm]	Hydraulic diameter	4.11
S_w [mm]	Wire contact distance	0.1
L [mm]	Length of duct	204.9

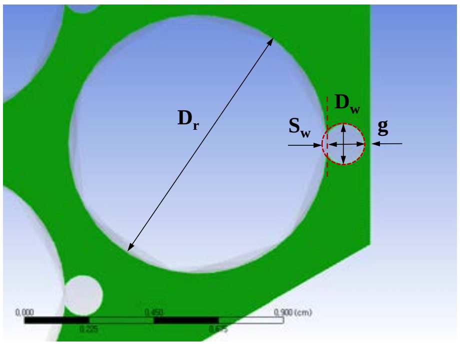

Fig. 2 Dimensional parameters in the modeling

parameters are described in Fig. 2. A uniform inlet velocity, pressure outlet, and no slip wall conditions were applied. A working fluid is sodium which properties are assumed constants. Seven inlet velocities are selected as test cases, which cover Reynolds numbers of 7×10^3 ~ 5×10^5. To investigate turbulent model effect, various turbulent models were used in this analysis. The optimal grid size was found by grid test.

2.2 Entrance effect

Inlet flow is uniform and thus the flow will be developed, which is called entrance region. A pressure drop in the entrance region is higher than that in a developed region due to a higher shear force. Fig. 3 shows pressure gradient for different inlet conditions for SST model. Obviously, the entrance length is increased as a higher velocity. In this paper, pressure drop in the entrance region is not analyzed. However, to evaluate a friction factor extracting the entrance effect, the pressure gradient is obtained at the center of the bundle.

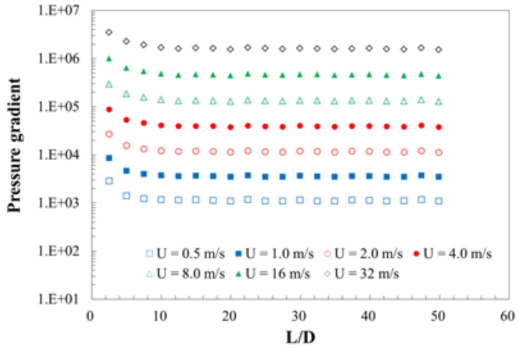

Fig. 3 Pressure gradient for different velocity for SST model

2.3 Turbulent model effect

Eight turbulent models embedded in CFX code were tested in the buddle analysis. Fig. 4 shows friction factor corresponding to Reynolds number for different turbulent models. In addition, two promising pressure drop correlations, Cheng and Todreas's correlation [2] and Rehme correlation [3] were compared with results. It is assumed that Cheng and Todreas's correlation is reference correlation, because this correlation has been widely referred in the open literature. The Shear Stress Transport (SST) and K-omega (K-O) model are best estimation models. And Reynolds stress models (RSM) are underestimated but all model's results includes in between two correlations. Furthermore, considering heat transfer analysis, the omega based model is necessary, because the only omega based model can resolve low Reynolds number calculation in the near wall region including sub-layer [4].

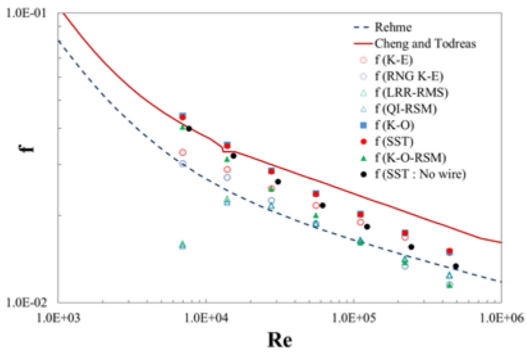

Fig. 4 Friction factor and Reynolds number for different turbulent model.

2.4 Wire effect

A wire configuration is most important parameter in the thermal-hydraulic characteristics in a wire wrapped buddle. And thus, it is reason that all pressure drop correlations have developed with D_w and H. Therefore, a bundle without wire is calculated as reference to obtain fundamental understanding of phenomena in the wire-wrapped bundle. As shown in Fig. 4, the friction factor in the bundle without wire is lower than the wire-wrapped bundle due to higher frictional surface area and additional loss related to a swirling flow. Fig. 5 indicates x and y velocity components in the cases with and without wire (z-axis is flow direction). And main

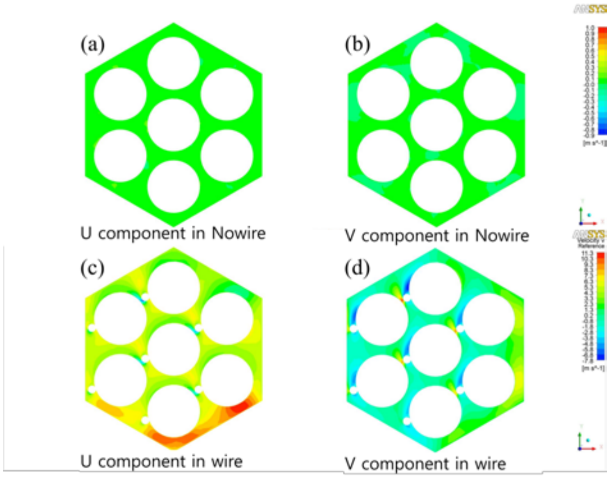

Fig. 5 Perpendicular velocity components at mid-plane for no-wire (a and b) and wire (c and d) bundles.

flow direction is z-direction. The x and y-directional flow component in the no-wire are negligible. Otherwise, in- and out-flows are calculated in the wire-wrapped bundle.

3. Conclusions and Further Works

A preliminary numerical analysis of a 7 pin wire-wrapped bundle using CFX is conducted to check feasibility and applicability of commercial code, CFX. A major objective of this work aims at flow blockage analysis in the wire-wrapped bundle. Turbulent model effect was evaluated with seven flow rate conditions. A K-omega based models including a SST model shows best estimation comparing with Cheng and Todreas's correlation.

Design parameters related wire is the most influential in thermal-hydraulic phenomena in the wire-wrapped bundle since the wrapping wire increases the pressure drop and heat transfer with swirling effect. However, it is not avoidable to make perfect wire-modeling in order to satisfy a higher mesh quality. Therefore, wire configuration effect will be investigated to evaluate uncertainty of fixed wire configuration. In addition, Numerical approach for flow blockage phenomena will be validated with experimental data.

REFERENCES

[1] E. Bubelis, and M. Schikorr, Review and Proposal for best fit of wire-wrapped fuel bundle friction factor and pressure drop predictions using various existing correlations, Nuclear Engineering and Design, Vol.238, p.3299, 2008.

[2] S. K. Cheng, and N. E. Todreas, Hydrodynamic models and correlations for bare and wire-wrapped hexagonal rod bundles-bundle friction factors, sub-channel friction factors and mixing parameters, Nuclear Engineering and Design, Vol.92, p.227, 1986.

[3] K. Rehme, Pressure drop correlations for fuel element spacers, Nuclear Technology, Vol.17, p.15, 1973.

[4] ANSYS CFX-Solver Modeling Guide, Chapter 4, 2010.