Numerical Analysis of Vortical Flow Structure for 61-pin Wire-Wrapped Fuel Assembly

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1. Introduction

Managing the spent fuel arising from nuclear power plants until its disposal is an important step of the nuclear fuel cycle and constitutes the so-called back end[1]. Sodium-cooled Fast Reactor (SFR) can address the stockpile of the spent nuclear fuel produced during nuclear power generation [2]. Therefore, SFR is one of the ways to managing the spent fuel that studies are conducted by many researchers. Generally, the fuel assembly of the SFR system consists of long and thin wire-wrapped fuel bundles and a hexagonal duct, in which wire-wrapped fuel bundles in the hexagonal tube has triangular loose array [3]. The main purpose of a wire spacer is to avoid collisions between adjacent rods. Furthermore, a wire spacer can enhance convective heat transfer due to the secondary flow by helical type wire spacers. The wire makes the flow inside the fuel bundles complicated by creating a vortex structure by flow separation over the wire [4]. To understand the characteristics of flow and heat transfer, analyzing the vortex structure is necessary. In this study, numerical analysis is conducted, and vortex visualization method is developed to determine the characteristics of vortical flow generated in 61-pin wire-wrapped fuel assembly that is down scaled experimental facility for thermal hydraulic experiment of PGSFR.

2. Numerical methodology

2.1 Analysis Model

Analysis model for this study is experimental 61-pin wire-wrapped fuel bundle in KAERI [5]. Table I shows geometrical parameters of the analysis model. The simulation results were validated with experimental results that is pressure drop and Nusselt number.

Table I: Geometry Parameters of Analysis Model

Parameters	Value [Unit]
Rod diameter (D)	8 [mm]
Total rod length (L)	1,500 [mm]
Wire diameter (D_w)	1 [mm]
Wire lead length (H)	238.9 [mm]
Rod pitch (P/D)	1.14 [-]
H/D	29.86 [-]
L/H	6.28 [-]
Wall gap	1.12 [mm]

2.2 Computational Grids and Boundary Conditions

Fig. 1 shows computational grid system of analysis model. Blue circle and yellow circle represent rod and wire, respectively. Red circle represents fluid domain contains rod and wire. Computational grid system is constructed so that rods and wires are in line contact. ANSYS CFX is used for analysis and SST turbulence model is adopted for this simulation. Table II shows boundary conditions of this simulation.

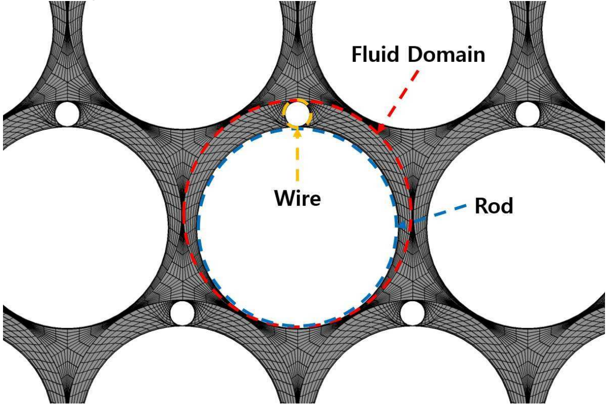

Fig. 1. Computational grid system of analysis model

Table II: Boundary Conditions

Parameters	Value [Unit]
Inlet temperature	335.15 [K]
Inlet mass flow rate	15.4 [kg/s]
Working fluid	Water
Turbulence model	SST

2.2 Vortex Visualization Method

Using the vortex identification method developed by Sawada in 1995, the vortex structure inside the impeller was visualized using the singularity theory, the probabilistic definition of vortex structure and the results of computational fluid analysis [6]. In addition, the visualized vortex core was colored with normalized helicity to visualize the rotation direction of the vortex. Normalized helicity is defined by (1). H_n is Normalized helicity and ζ is an absolute vorticity vector, ω is a relative velocity vector. This value has the following physical meaning.

$$H_n=\vec{\zeta}\cdot\vec{\omega}/(|\zeta|\cdot\ |\omega|) \qquad \textbf{(1)}$$

$H_n > 0$: Rotate and move axially according to the law of the right hand.
$H_n = 0$: Stagnation and rotation.

$H_n < 0$: Rotate according to the law of the right hand and move in the opposite direction of the axial direction.

3. Analysis of vortical flow structure in fuel assembly

Fig. 2 shows vortical flow structures of fuel assembly sub-channel. Vortex core is visualized by using vortex visualization technique and the surface streamline on the cross-sectional plane of 750mm, 775mm, 800mm, 825mm is plotted in Fig. 2. As shown in Fig. 2, the multi-scale vortical flow structures are developed in fuel assembly sub-channel. The red line indicates corner vortex structure and blue line indicates edge vortex structures. Corner vortex and edge vortex structures are closely related with relative position between the duct wall and the wire spacer.

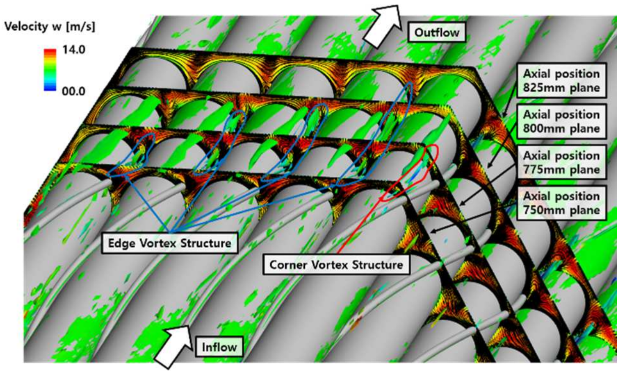

Fig. 2. Vortex core distribution and surface streamline

Fig. 3 and Fig. 4 shows tangential and axial velocity distribution in fuel assembly, respectively. As shown in Fig. 3 and 4, edge and corner sub-channel have a high axial velocity and tangential velocity than interior sub-channel. The reason of higher velocity increase at edge and corner sub-channel is friction between fluid and rods and wires around interior sub-channel. Therefore, axial and tangential velocity increase higher at edge and corner sub-channel than interior sub-channel. This means that vortex structures induced from corner and edge sub-channel are bigger than vortex structures induced from interior sub-channel and improve heat transfer performance.

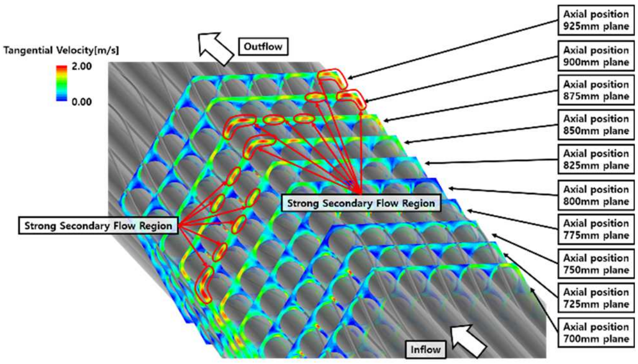

Fig. 3. Tangential velocity distribution in fuel assembly

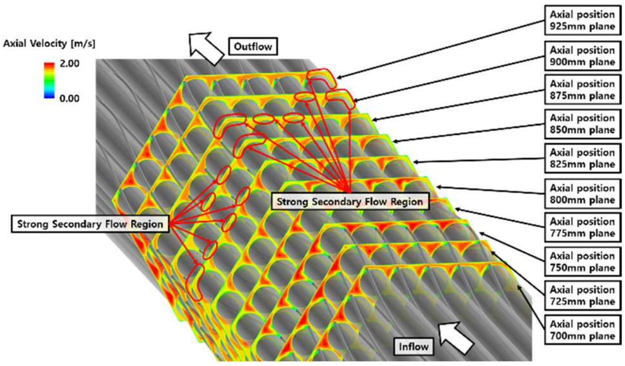

Fig. 4. Axial velocity distribution in fuel assembly

4. Conclusion

In this study, vertical flow structures are visualized by using vortex visualization technique and vertical flow structures in 61-pin fuel assembly. In edge and corner sub-channel, vortex induced by developing of secondary flow after wire spacer. As a result, it is observed edge and corner vortex structures is closely related with relative position between the duct wall and the wire spacer. Therefore, edge and corner vortex structures are induced regularly by axial position is changing and improve heat transfer performance of fuel assembly.

Acknowledgement

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