Thermal-Hydraulic Effect of Pattern of Wire-wrap Spacer in 19-pin Rod Bundle for SFR Fuel Assembly

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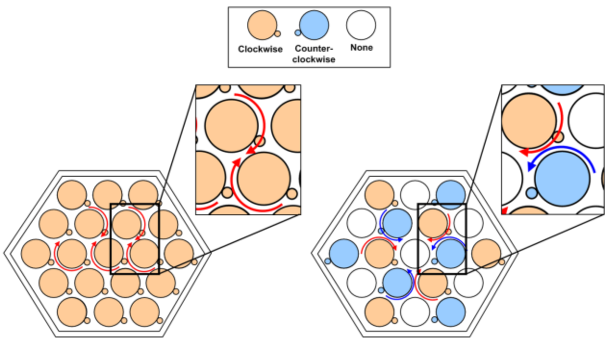
1. Introduction

As sodium-cooled fast reactor (SFR) has been considered the most promising reactor type for future and prototype gen-IV SFR has been developed actively in Korea, thermal-hydraulic aspects of the SFR fuel assembly have the important role for the reactor safety analysis. In PGSFR fuel assembly, 271 pins of fuel rods are tightly packed in triangular array inside hexagonal duct, and wire is wound helically per each fuel rod with regular pattern to assure the gap between rods and prevent the collision, which is called wire-wrapped spacer.

Due to helical shape of the wire-wrapped spacer, flow inside duct can have stronger turbulent characteristics and thermal mixing effect. However, many studies showed the possible wake from swirl flow inside subchannel, which cause local hot spot [1-3]. To prevent the wake flow and improve thermal mixing, new pattern of wire wrap spacer was suggested [4]. By arranging adjacent rods with different turn direction of wire-wrapped spacer adequately, cross flow can be promoted between rods gap, and finally it can enhance local heat transfer between rods and coolant. Figure 1 shows the configuration of the new pattern of wire wrap spacer.

In this paper, the thermal-hydraulic effect of wire-wrapped spacer pattern was evaluated in 19-pin rod bundle by CFD analysis to get detailed temperature and flow field in subchannel.



(a) Conventional (b) New (U-pattern)

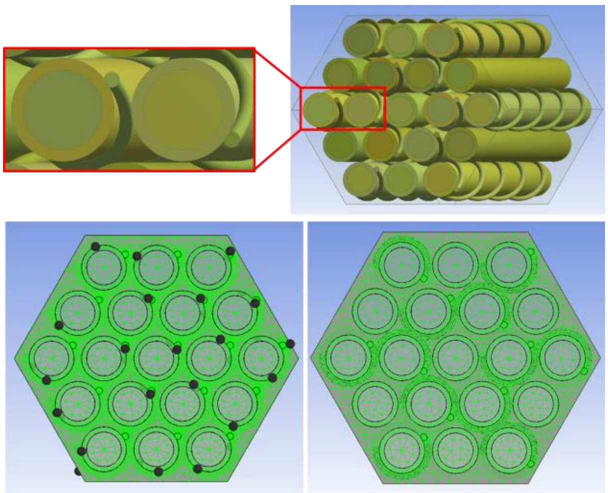
Fig. 1 Configuration of conventional and new U-pattern wire wrap spacer and predicted flow pattern

2. CFD Modeling

The number of rod in duct was selected to be 19, because it is considered the smallest bundles that provides the reasonable representation having the extendibility for 217 or 271 rod bundles [5]. For obtaining the detailed temperature and velocity field in subchannel, CFD analysis was performed using commercial CFD code, ANSYS-CFX.

Computational domains consist of hexagonal duct and 19 wire wrapped rods. From the difficulties of the wire-rod line contact region, shape of wire was slightly changed to have surface contact with rod for improvement of mesh quality and reducing the number of computational cells, as shown in Fig. 2. This modification can have acceptable for modeling the wire wrap spacer [6].

Fluid domain was set to sodium, of which boundary conditions are inlet of constant mass flow rate, pressure outlet, and wall outside duct. For the fuel rod, solid domain with cosine shape of heat flux profile was adjusted. Standard k-epsilon model with scalable wall functions was set. Total number of elements were approximately 8 M of all tetrahedral cells with several layers of prism mesh near wall and interface region between fuel rod and subchannel.



(a) Conventional (b) New (U-pattern)

Fig. 2 Computational domain of 19-pin rod bundle for conventional and new pattern of wire wrap spacer

Table.1 Specification of 19-pin rod bundle simulation

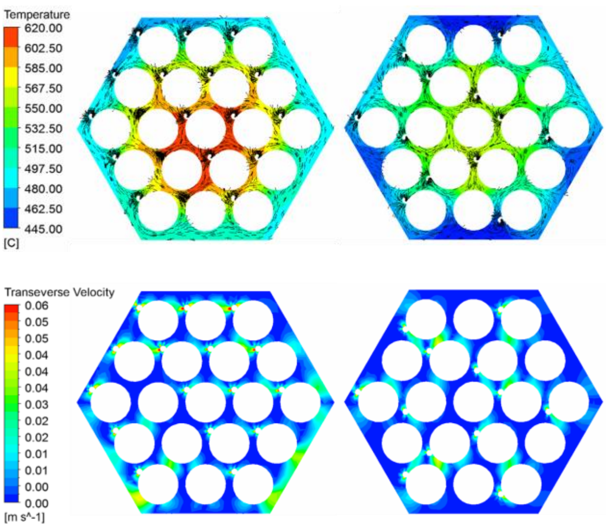
Parameter	*Value*
Fluid	Liquid sodium
Inlet temperature	390 [°C]
Mass flow rate	0.6 m/s - 3.6 m/s (Re=8,300 - 36,000)
Heat	20.0 kW / 1 rod (cosine profile)

cf. Re at 100 % mass flow rate for PGSFR=33,705 [7]

3. Results and Discussions

For the rod bundle with conventional pattern of wire wrap spacer, swirling flow due to helical wire was generated in gap, enhancing heat transfer from fuel rod surface to sodium coolant compared with the bare rod. Velocity in wall and corner subchannel was higher than that of center subchannel, because of higher cross-sectional flow area. From the swirling flow in same rotational direction due to regular pattern of conventional ones, local flow stagnation point was generated near wire. This results coincided with previous studies [1-3, 6], which showed that wake flow was observed due to swirl flow generated in counter-current direction between rods.

With new pattern of wire wrap, called U-pattern, sodium temperature distribution is even across the cross sectional area as shown in Fig. 3. In addition, new pattern wire wrapped rod bundle showed lower temperatures in both coolant that of conventional one. In addition, maximum fuel rod temperature decreased in all cases. For the case of Re=36,000 in channel, which conditions corresponds 100 % of mass flow rate condition for PGSFR [7], maximum fuel rod temperature dropped by 19 K for center rod, compared with conventional wire wrap rod bundle.



(a) Conventional (b) New (U-pattern)

Fig. 3 Comparisons of the conventioanl and new pattern of wire wrap spacer in sodium temperature and cross flow contour

To compare the pressure drop for each pattern of the helical wire structure inside duct, loss coefficients of conventional and new pattern ones were evaluated as eqn. (1), shown in Table. 2. For the new pattern of wire wrap, loss coefficient was smaller than that of conventional ones because the cross sectional flow between rods, which causes significant pressure drop, is evenly distributed. For the smallest case of Re=8,300, pressure loss coefficient is similar with conventional and U-pattern.

$$\Delta P = K\left(\frac{L}{D_e}\right)\left(\frac{\rho V^2}{2}\right) \quad (1)$$

Table.2 Comparisons of loss coefficient for 19-pin rod bundle

Channel Re	Conventional	New (U-pattern)
8,300	0.0400	0.0400
14,000	0.0360	0.0360
22,000	0.0320	0.0318
36,000	0.0281	0.0280

From the simulation results, U-pattern of wire wrap spacer can improve heat transfer without compensating pressure loss effect. Generally, enhanced swirling flow causes larger pressure loss due to cross flow in channel. However, U-pattern arranged rods in different twined way of wire wrap spacer has no wire wrap in center rod for unit, so that pressure loss is not significantly increasing in spite of stronger cross flow between rods.

4. Conclusions and Further Work

To evaluate the effect of wire wrap spacer pattern, CFD analysis was performed for 19-pin rod bundle with comparison of conventional and U-pattern wire wrap spacer. To prevent the wake due to same direction of swirl flow, 7-rod unit pattern of wire spacer, which are arranged to have different rotational direction of wire with adjacent rods and center rod without wire wrap was proposed. From simulation results, swirl flow across gap conflicts its rotation direction causing wake flow from the regular pattern of the conventional one, which generates local hot spot near cladding. With U-pattern of wire wrap spacer, heat transfer in subchannel can be enhanced with evenly distributed cross flow without compensating pressure loss. From the results, the pattern of wire wrap spacer can influence the both heat transfer characteristics and pressure drop, with flow structures generated by wire wrap spacer.

For the further work, experiment will be performed for the same conditions of CFD analysis to validate the simulation results by visualizing the temperature and velocity field by PIV technique. Test facility comprises 19-pin wire-wrapped rod bundle test section and test loop. Test section consisted of the inlet assembly, rod with helical wire wrap, outlet assembly. Rod and wire wrapped spacer was made of FEP tube, which refractive index is same with water to get undistorted image to measure velocity field at axial and horizontal plane by PIV technique. Some of the rods are cartridge heaters to examine the thermal mixing effect according to the wire wrap pattern. Fig. 4 shows the schematics of test facility for 19-pin wire-wrapped rod bundle.

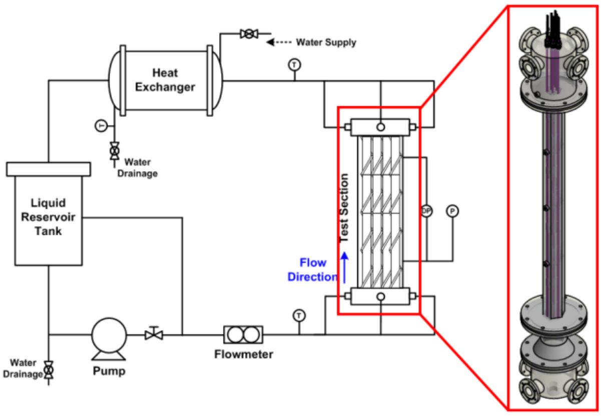


Fig. 4 Schematics of test facility for 19-pin wire wrapped rod bundle

ACKNOWLEDGEMENTS

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