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Comparison of Three-Dimensional Thermal-Hydraulic Characteristics between 7-pin and 19-pin Wire-Wrapped Fuel Assemblies

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1. Introduction

This work presents a numerical investigation on thermal-hydraulics of a 19-pin wire-wrapped fuel assembly and compares the results for flow field and convective heat transfer characteristics with a 7-pin wire-wrapped fuel assembly based on three-dimensional RANS analysis. In spite of several experimental and numerical works carried out to analyze thermal-hydraulics of the assemblies with different numbers of fuel pins, there has been no specific comparison of the flow field and heat transfer in fuel assemblies with different numbers of fuel pins. Fontana [1] obtained the measurements of temperature distribution on the duct wall and at the exit of a 19-pin wire spacer fuel assembly. Choi *et al.* [2] carried out experimental work to measure the pressure drop in a 271-pin fuel assembly and compared the available data with existing correlations for friction factor. Fernandez and Carajilescov [3] performed an experimental investigation to obtain static pressure and wall shear stress distributions in a 7-pin wire-wrapped assembly. Recently, Ahmad and Kim [4] analyzed precisely the three-dimensional turbulent flow and heat transfer in a 7-pin wire-wrapped assembly based on RANS analysis. Raza and Kim [5] performed the numerical optimization of 7-pin wire-wrapped assembly based on three-dimensional RANS analysis. Comparison has been carried out in terms of axial velocity variation in different subchannels (interior, edge and corner), radial temperature gradients and peak temperature on the central and edge fuel rods.

2. Numerical Analysis

A commercial CFD code, ANSYS CFX 5.7 [6], which employs unstructured grid, has been used for numerical analysis. The numerical analysis has been performed for one period of the wire spacer using periodic boundary condition at inlet and outlet of the calculation domain. Shear Stress Transport (SST) model with automatic wall treatment is used as a turbulence closure Constant heat flux condition is used at the surfaces of fuel rod while adiabatic condition is used at the hexagonal duct wall. Liquid sodium (Na) is used as coolant.

Figure 1 shows the configuration of a 7-pin (shown by dotted line) and 19-pin wire-wrapped fuel assemblies. The analysis is performed for a single period of the wire-spacer. The wire-wrap is mounted on the fuel rods in counter-clockwise direction starting from 12-o'clock position. This figure also shows the definition of geometric parameters of the test assembly and different types of subchannels. The specifications of the test assemblies and operating conditions are shown in Table 1.

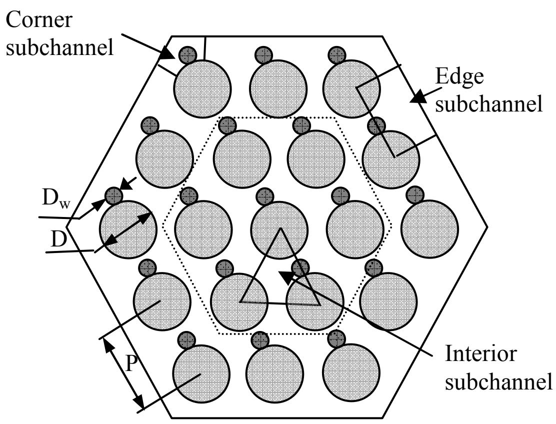

Fig. 1 Configuration of wire-wrapped fuel assembly

Table 1. Specifications of the test assemblies and operating conditions

Assembly	7-pin	19-pin
Lead to diameter ratio, H/D	25.0	25.0
Pitch to diameter ratio, P/D	1.262	1.262
Wire Diameter, D_w (mm)	2	2
Reynolds Number	60,000	60,000
Heat Input (KW/rod)	6.4	6.4
Inlet Temperature (K)	570.52	570.52
Coolant used	Liquid Sodium	Liquid Sodium

3. Results and Discussion

To find the optimal number of grids for the numerical analysis, grid dependency test for both the 7-pin and 19-pin fuel assemblies have been carried out. The optimum number of grids is found to be 9.46 x10^5 and 2.142x10^6 in 7-pin and 19-pin assemblies, respectively. In both the assemblies, the flow characteristics are found to be greatly influenced by the presence of wire spacers and similar in terms of directional periodicity between the adjacent subchannels in radial gradients induced due to wire spacers. The investigation of streamlines at the planes normal to flow direction reveals that, there is a large recirculation zone exists behind the wire spacers in the interior subchannel in case of 7–pin assembly. There is larger recirculation zone in the interior subchannels closer to the duct wall in case of 19-pin assembly. In the edge subchannels also, there exists a recirculation zone in both the assemblies. In both assemblies, there exists a strong sweeping flow except highly localized back flow in the corner subchannel where the wire is blocking the subchannel. A substantial radial pressure gradient exists in both the assemblies, but in case of 19-pin assembly the overall pressure difference is found to be larger. In case of 7-pin assembly, the dimensionless axial velocity is higher than that of 19-pin assembly in most of the region except behind the wire spacers where lowest axial velocity occurs. In the edge subchannel, there is not much difference between the dimensionless axial velocity (local axial velocity non-dimensionalized by average axial velocity) distributions; initially the axial velocity increases, reaches a maximum value at the location where the wire is leaving the edge subchannel producing a low pressure zone, then reaches a minimum value where the wire enters the edge subchannel producing higher pressure against the duct wall, and finally reaches initial velocity. In the corner subchannel, the local axial velocity is higher than the average axial velocity everywhere except just behind the wire spacers where the velocity decreases rapidly to reach the minimum for both the assemblies.

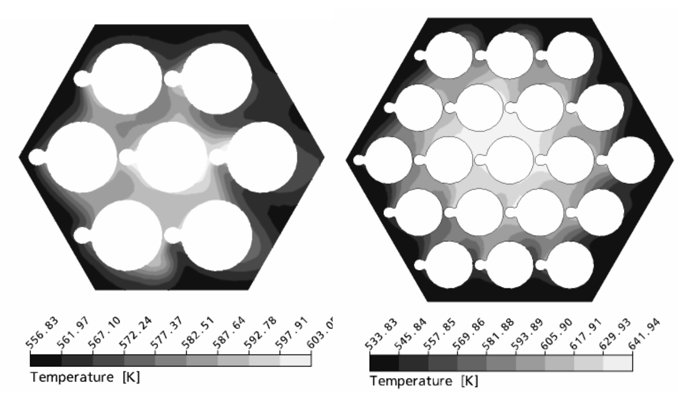

Fig. 2 Temperature contours on a plane normal to flow direction

Maximum temperature of the cladding, fuel elements and core coolant is an important aspect in the liquid metal reactors design. Therefore, it is necessary to analyze precisely the difference in thermal field of the two assemblies. Figure 2 shows the temperature contour on a plane normal to the flow direction at an axial distance of 50mm The temperature in the interior subchannels surrounding the central fuel rod is higher in the 19-pin assembly. On central fuel rod, total six hot spots are observed in both the assemblies, but in case of 19-pin assembly the temperatures of hot spots are generally quite higher than those of 7-pin assembly.

5. Conclusion

The comparative analysis of three-dimensional fluid flow and heat transfer between 7-pin and 19-pin wire-wrapped fuel assemblies has been carried out using RANS analysis for one period of wire spacer. It is found that both the assemblies exhibit the directional periodicity in radial gradients between the adjacent subchannels due to presence of wire spacer. Large recirculation zones exist in the interior subchannel surrounding the central fuel rod of 7-pin assembly unlike the case of 19-pin assembly. The dimensionless axial velocity in the interior subchannel is found to be higher for 7-pin assembly except just behind the wire spacers when the wire is passing through the subchannel. In both the assemblies, the local axial velocity in the edge subchannel is higher than the average axial velocity. The interior subchannel temperature and temperature gradient between the interior subchannels is found to be higher in 19-pin assembly. The maximum temperature on the central fuel rod is higher in 19-pin assembly.

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