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# Numerical Investigation of Heat Transfer Characteristics in Wire-Wrapped 19-pin Fuel Assembly

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## 1. Introduction

SFR (Sodium-cooled Fast Reactor) is one of a next-generation nuclear power reactor that can effectively process spent nuclear fuel. Since the SFR uses liquid sodium as a coolant and sodium has a high boiling temperature, high operating pressure is not required, and hence, the design pressure for components inside the reactor is nearly atmospheric. In addition, since sodium has high thermal conductivity, the SFR can effectively remove the heat generated in the reactor.

The fuel assembly of the SFR generally consists of several fuel pins and a hexagonal duct. The fuel pins are arranged in a triangular pitch and wound with helical wire spacers. Because these wire spacers improve the mixing of the coolant, they have a great influence on the flow and heat transfer characteristics. It is important to predict and analyze the flow and temperature distributions for fuel safety.

Various fuel assembly analysis codes have been developed to predict the flow and temperature distribution in the subchannels [1-2] and many experimental studies on fuel assemblies have been conducted for the core thermal-hydraulic design of the SFR [3-4]. Recently, Many CFD (Computational Fluid Dynamics) studies have been performed due to the development of computational resources [5-6]. Since detailed flow phenomena that are difficult to investigate in experiments can be examined, numerical studies using CFD are being conducted more and more.

In this study, numerical investigations of pressure drop and temperature distribution in wire-wrapped 19-pin fuel assembly are presented. Numerical methods and validation results are addressed.

## 2. Experiment descriptions

The experimental benchmark is the ORNL 19-pin SFR fuel assembly [7]. The experiment was performed with a 19-pin test assembly in the sodium loop in which fuel pins were simulated by electrical heaters. Temperatures were measured within the pin bundle, at the exit, and along the duct walls of the pin assembly. The objectives of the experimental program were to measure the temperature distribution, interpret the data with respect to LMFBR (Liquid Metal Fast Breeder Reactor) design, and develop temperature predictive models.

The ORNL test section is shown in Fig. 1. The diameter of the pin is 0.23 inch and the diameter of the wire is 0.056 inch. The wire is wrapped around the fuel pin on a 12 inch pitch. The total length of the fuel assembly is 36 inch, and the heated length is 21 inch. The detailed geometry parameters are listed in Table 1.

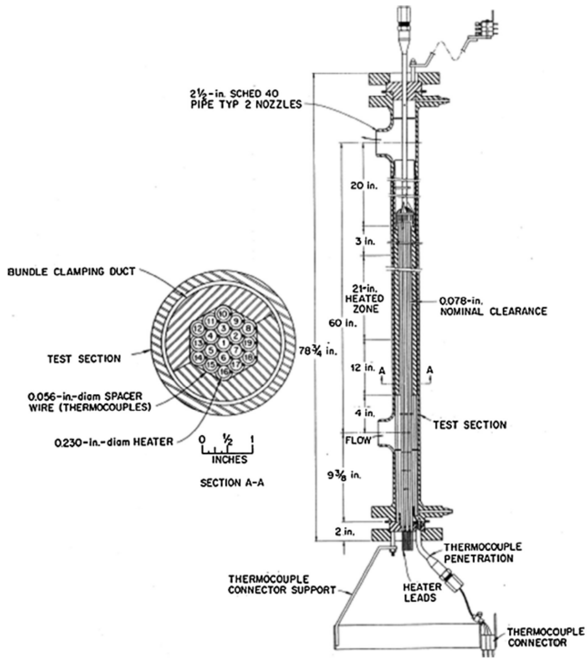


Fig. 1 Test section geometry for the ORNL 19-pin bundle

Table 1. Design parameters of the ORNL 19-pin fuel assembly

| Parameters | Value (inch) |
|---|---|
| Rod number | 19 |
| Rod diameter | 0.23 |
| Rod pitch | 0.286 |
| Wire diameter | 0.056 |
| Wire lead length | 12 |
| Duct flat to flat distance | 1.342 |
| Total length | 36 |
| Heated length | 21 |

## 3. Numerical methods

The CFD simulations were performed using OpenFOAM code [8]. The geometry of the ORNL 19-pin fuel assembly for CFD simulations was modeled using SALOME [9] as shown in Fig. 2. The geometry can be generated automatically through input in python code. Meshes were generated according to the programmable mesh generation strategy for wire-pin bundles [10]. In the programmable mesh generation strategy, directional hybrid mesh is adopted. Unstructured mesh is used in spanwise or radial direction of the bundle, while structured mesh is used in axial or streamwise direction by extruding the spanwise mesh. The computational meshes were created using OpenFOAM mesh generator snappyHexMesh. As shown in Fig. 3, meshes were densely created around wires that were relatively small in size compared to duct and pins, and the total number of computational mesh cells was about 6,000,000.

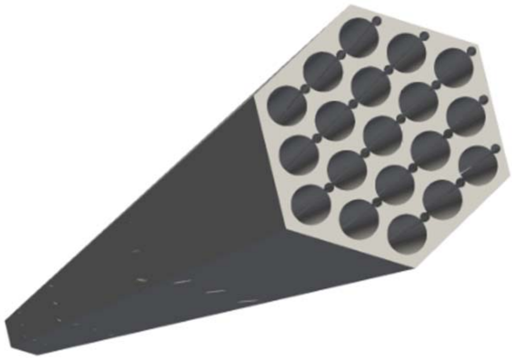

Fig. 2 The computational geometry for the ORNL 19-pin bundle

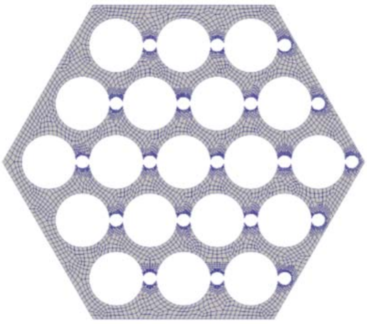

Fig. 3 Meshes for the ORNL 19-pin bundle

The three dimensional, steady state, incompressible RANS (Reynolds Averaged Navier-Stokes) based simulations were performed. The velocity was applied to the inlet and the pressure was given at the outlet, and no-slip condition was applied on the walls. The working fluid is sodium and has a constant density and viscosity. The boundary conditions are shown in Table 2. In this study, the SST (Shear Stress Transport) model was used as a turbulence model. Constant turbulent Prandtl number was used to predict the thermal eddy diffusivity and turbulent Prandtl number can be specified by the user.

Table 2. Boundary conditions of the ORNL 19-pin fuel assembly

| Parameters | Value |
|---|---|
| Temperature (°C) | 315.6 |
| Density (kg/m$^3$) | 878.6 |
| Viscosity (Pa·s) | 0.000329 |
| Inlet velocity (m/s) | 7.3 |
| Outlet pressure (Pa) | 0 |

## 4. Results

### *4.1 Pressure drop*

The pressure drop between the CFD simulation and the friction factor correlation was compared to validate the numerical calculation. The friction factor from the pressure drop was calculated according to Eq. (1).

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

where L is the total length of the fuel assembly, $D_e$ is the hydraulic diameter of the pin bundle, and V is the bundle averaged flow velocity. UCTD (Upgraded Cheng & Todreas Model) correlation was used as the friction factor correlation and it is widely used and is known to accurately predict the pressure drop. Figure 4 shows the friction factor comparison between the CFD simulation and the UTCD correlation. The CFD simulation shows relatively good agreement with the correlation and predicts the friction factor about 3.6% higher than the correlation at the operating point (Reynolds number ~ 65,000).

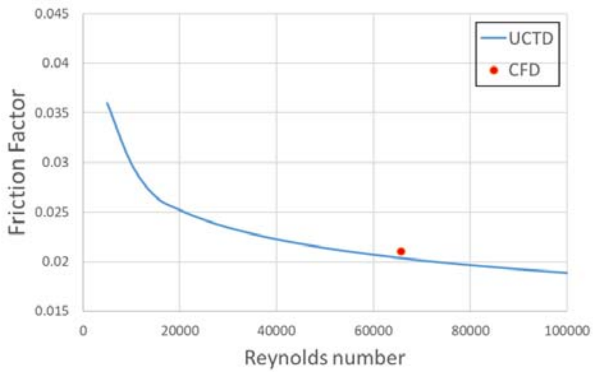


Fig. 4 Comparison of friction factor between CFD and correlation

### *4.2 Temperature distribution*

Heat transfer simulation was performed by giving the same heat flux to all pins and the heat flux value was set the same as in the experiment. In order to investigate the heat transfer characteristics in the subchannels, the temperature distribution at the exit is shown in Fig. 5. As shown in this figure, the temperature is high in the inner subchannels and low in the edge and corner subchannels. For comparison with the experiment, the temperature values in the subchannel numbers shown in Fig. 5 were calculated and shown in Table 3. In the same way as the experimental results, the temperatures at the outlet was normalized to the temperature difference between the outlet and inlet. The temperatures in the inner subchannels show good agreement with the experiment, while there is a slight difference in the edge and corner subchannels.

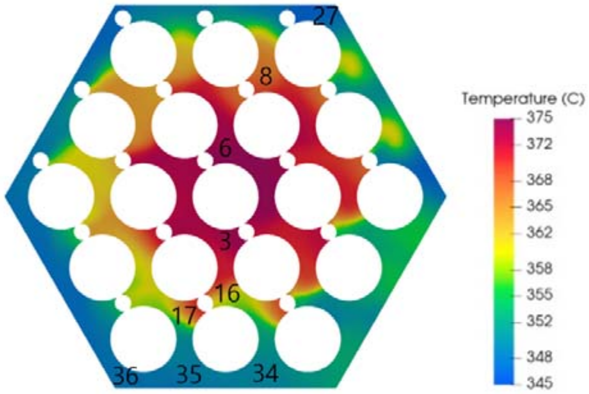


Fig. 5 Temperature distribution at the outlet

Table 3. Comparison of normalized outlet temperatures in the subchannels

| Subchannel number | Experiment | CFD | Error (%) |
|---|---|---|---|
| 34 | 0.859 | 0.791 | -7.9 |
| 35 | 0.888 | 0.766 | -13.8 |
| 36 | 0.917 | 0.749 | -18.3 |
| 17 | 0.955 | 1.120 | 17.3 |
| 16 | 1.198 | 1.176 | -1.8 |
| 3 | 1.301 | 1.336 | 2.7 |
| 6 | 1.299 | 1.368 | 5.3 |
| 8 | 1.101 | 1.190 | 8.1 |
| 27 | 0.848 | 0.726 | -14.4 |

## 5. Conclusions

In this study, numerical investigations of pressure drop and temperature distribution in wire-wrapped 19-pin fuel assembly are presented. The CFD simulations were performed using OpenFOAM code for the ORNL 19-pin SFR fuel assembly. The pressure drop between the CFD simulation and the friction factor correlation was compared to validate the numerical calculation. The temperature distribution at the outlet was investigated to analyze heat transfer characteristics.

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