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3-D Visualization of the SLTHEN Code for the Core Thermal-Hydraulic Design in a Sodium-Cooled Fast Reactor

Sun Rock Choi[a*], Huee-Youl Ye[a], Jonggan Hong[a], Gun-Hong Kim[b]
[a]*Korea Atomic Energy Research Institute, 111, Daedeok-daero 989Beon-gil, Yuseong-gu, Daejeon, Korea*
[b]*OpenCAE, Seongnam, Kyungki-do, Korea*
[*]*Corresponding author: choisr@kaeri.re.kr*

1. Introduction

The core thermal-hydraulic design is employed to ensure an appropriate margin for fuel safety limits. In a sodium-cooled fast reactor (SFR), nuclear fuel damage commonly results from creep-induced failure. The creep limit is assessed based on the maximum cladding temperature, considering the uncertainties of the design parameters. An accurate temperature calculation in each subassembly is crucial to ensure the safe and reliable operation of reactor systems.

The core thermal-hydraulic design at KAERI is carried out using the SLTHEN (Steady-State LMR Thermal-Hydraulic Analysis Code Based on ENERGY Model) code, which calculates the temperature distribution based on the ENERGY model[1]. While the SLTHEN code is computationally efficient, its output is provided in the form of a text file, making it challenging to interpret its physical meaning. In this study, we developed a 3-D visualization technique for the SLTHEN calculation results for the core thermal-hydraulic design in an SFR.

2. SLTHEN code

The subchannel analysis is commonly utilized for core thermal-hydraulic design. Figure 1 illustrates the geometry of a typical SFR subassembly with 37 fuel pins. The simplicity of subchannel analysis enhances efficiency in both computer storage and run time but requires predefined parameters that accurately characterize the thermal-hydraulic conditions averaged by each subchannel.

The SLTHEN code employs subchannel coolant flow characteristics determined through empirical correlations instead of solving the mass and momentum transport equations. As a result, it is efficient enough to be applied for routine temperature calculations for SFR cores comprising a large number of subassemblies. At KAERI, the SLTHEN code based on the ENERGY model has been used for core thermal-hydraulic designs because it is computationally much more efficient than other subchannel codes for SFR applications, while its solution accuracy is comparable to others. However, to maximize computational efficiency, the SLTHEN code does not use the mesh's location information but focuses on the connectedness of neighboring nodes. Additionally, it outputs the computational results as a text file.

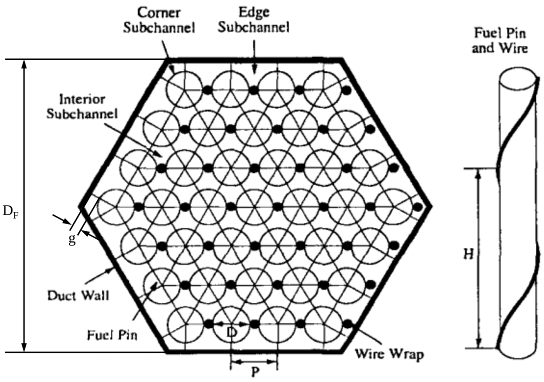
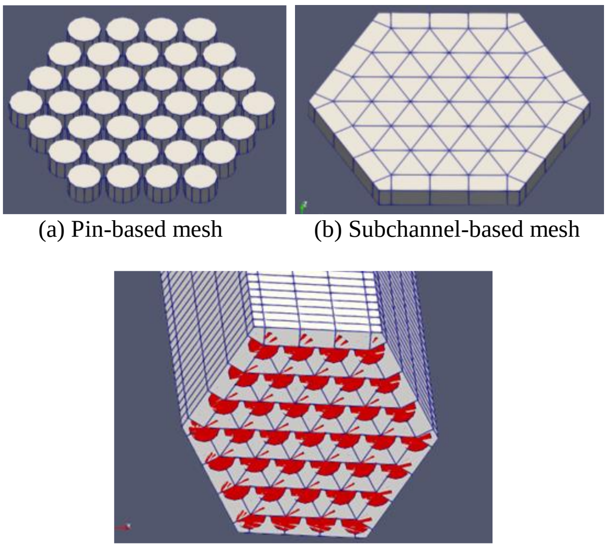


Fig. 1. Geometrical configuration of typical SFR subassembly and subchannel

3. Visualization Methods

To visualize the calculation results from the SLTHEN code, a fundamental monolayer mesh is constructed, as illustrated in Fig. 2. SALOME CAD software is employed for creating these basic meshes[2]. Python scripts automatically generate the basic meshes, considering geometrical parameters such as pin number, pin diameter, pitch-to-diameter ratio, etc. The OpenFOAM software's extrudeMesh utility is then utilized to extrude the basic mesh, extending it to the entire core height as shown in Fig. 2-(c)[3].



(a) Pin-based mesh (b) Subchannel-based mesh

(c) Extruded Mesh

Fig. 2. Mesh generation for a single subassembly (37 pins)

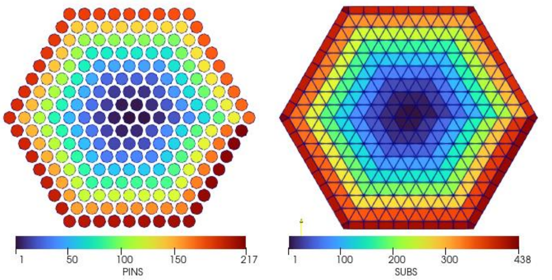


Fig. 3. Typical pin and subchannel numbering of an SFR subassembly in the SLTHEN code (217 pins)

The numbering method employed to identify each pin and subchannel in a single subassembly is consistent with the SLTHEN code. Figure 3 illustrates the number of pins and subchannels in a single subassembly, using 217 pins as an example. Starting from the center of the subassembly, the numbers advance counterclockwise as each radial ring moves outward. The information at the single subassembly level is interconnected with the entire core. Figure 4 depicts the numbering arrangement for the PGSFR, which comprises 451 subassemblies covering the entire core[4].

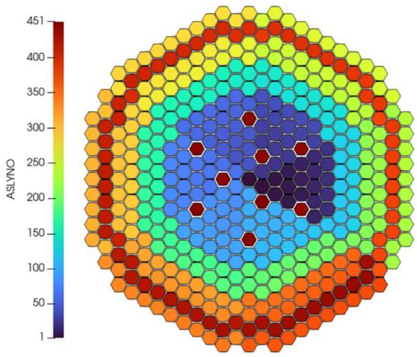


Fig. 4. Subassembly numbering of the PGSFR core for the SLTHEN code (451 subassemblies)

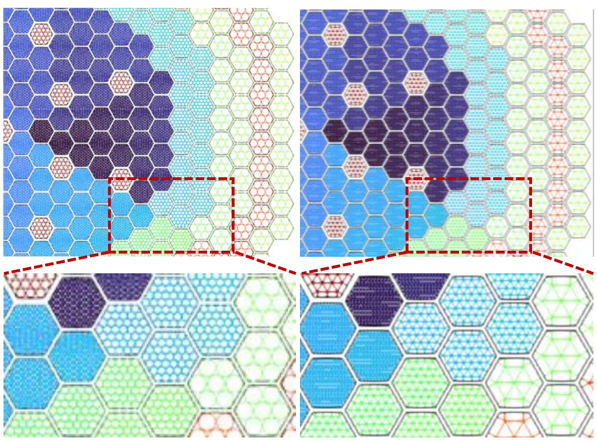


Fig. 5. Radial mesh generation for the whole pin and subchannel in the PGSFR core

Figure 5 displays the pin and subchannel mesh used to visualize the SLTHEN calculation results for the entire PGSFR core. The core is composed of subassemblies with 217, 37, 19, and 7 pins, varying based on their positions in the core. The SLTHEN code includes no information about the shape or position of each node and solely focuses on the connections between neighboring nodes for energy exchange analysis. Approximately 20 million meshes were utilized to assess the coolant temperature across the entire core.

The computation result of the SLTHEN code output is allocated to each generated node on a node-by-node basis using pre-calculated spatial data.

4. Visualization Results

Figure 6 depicts a three-dimensional visualization of the linear power at each fuel pin as well as the coolant temperature distribution in the Westinghouse Advanced Reactors Division (WARD) 61-pin test with a 2.8/1 radial power peaking[5]. The pin power changes linearly with respect to the radial direction of the thermocouple. The power peaking distorts the radial temperature distribution and increase the maximum temperature within a subassembly.

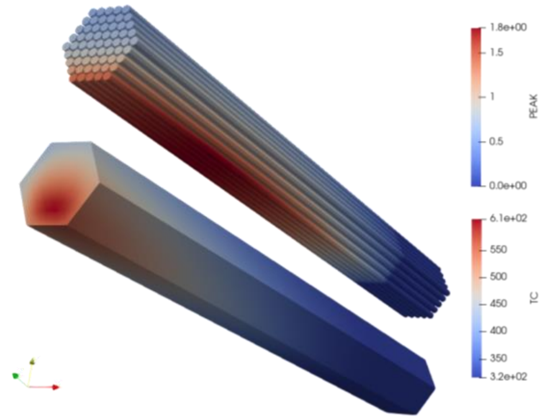


Fig. 6. Linear heating rate and temperature distribution for the WARD-61 test with the radial pin peaking of 2.8/1

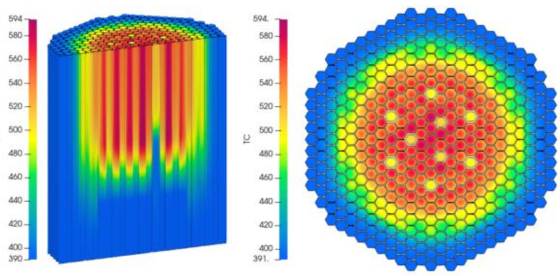


Fig. 7. Entire coolant temperature distribution in the PGSFR core

Figure 7 depicts the coolant temperature distribution over the entire PGSFR core. Depending on the type of subassembly and flow distribution, a vertical temperature increase and radial temperature distribution occur. This provides a more intuitive understanding of the heat transport characteristics.

5. Conclusions

In this work, we developed a three-dimensional visualization technique to visualize SLTHEN code calculation results. Despite the SLTHEN code's computing efficiency, its output is provided in a text file, which complicates physical interpretation. The numbering scheme utilized to identify pins and subchannels inside a single subassembly, as well as mesh architecture, are consistent with the SLTHEN code. This technique improves understanding of heat transport characteristics, resulting in a more intuitive visualization of the core thermal-hydraulic design in a SFR.

ACKNOWLEDGEMENT

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