Preliminary Validation of Pressure Drop Prediction in SFA Flow Channels of a Research Reactor Using a Fluid Network Analysis Method

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***Keywords :** fluid network analysis, research reactor, multi-channel pressure drop

1. Introduction

In thermal hydraulic safety analysis of research reactors, accurate prediction of coolant flow distribution and pressure drop in complex flow channels is essential. These quantities govern both the total circulation flow rate, which is determined by the pressure loss balance between the pump and the system, and the channel-wise coolant distribution. They are also indispensable for reliable evaluation of local overheating risk and margin to critical heat flux.

Conventional methodologies for such evaluations often require repeated model construction and revision, which limits productivity and scalability. A fluid network analysis code was developed to address these limitations [1]. The program was designed around modularity and reusability to improve modeling efficiency, maintainability, and readability in large scale fluid network problems. Its computational core, including matrix-intensive numerical solution procedures, was implemented in C++ for performance. User-facing components, including the GUI/CLI workflow and plugin framework, were implemented in Python to maximize flexibility and development productivity.

In this study, fluid network analysis method was used to simulate fluid pressure drop in the Standard Fuel Assembly(SFA), a selected part of the research reactor system. The predictions obtained from the developed model were benchmarked against results from an established reference code. This comparison was performed to assess agreement with the reference solution and to establish an initial basis for extending the analysis to a complete reactor core.

2. Methods and Results

2.1 SFA modeling using fluid network analysis

Geometric input data for SFA flow path simulation were obtained from a 3D CAD model. The primary geometric parameters were flow area, wetted perimeter, and segment length. The SFA was divided into three regions: Inner channel, Outer channel, and Gap. The corresponding hydraulic resistance network is shown in Fig. 1. Segments (1) - (2) represent the upper assembly region, segment (3) the fuel region, and segments (4) - (7) the lower assembly region. Segment (8) corresponds to the grid plate region. For the single SFA validation case, segment (8) was excluded because inflow interactions from adjacent channels in that region could not be neglected. The flow paths and nodes of the SFA modeled using the present network model are shown in Fig. 2 and the input variables used for the SFA analysis are summarized in Table 1.

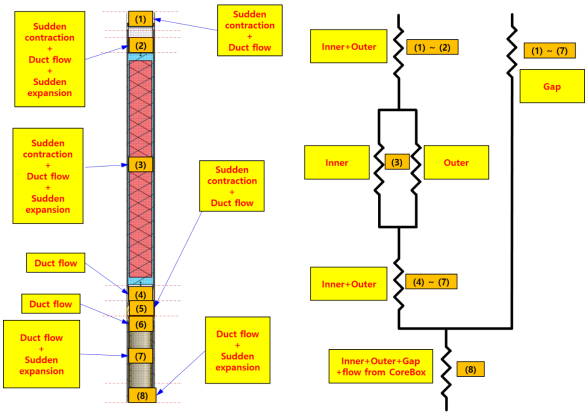

Fig. 1. Schematic of the SFA and hydraulic resistance

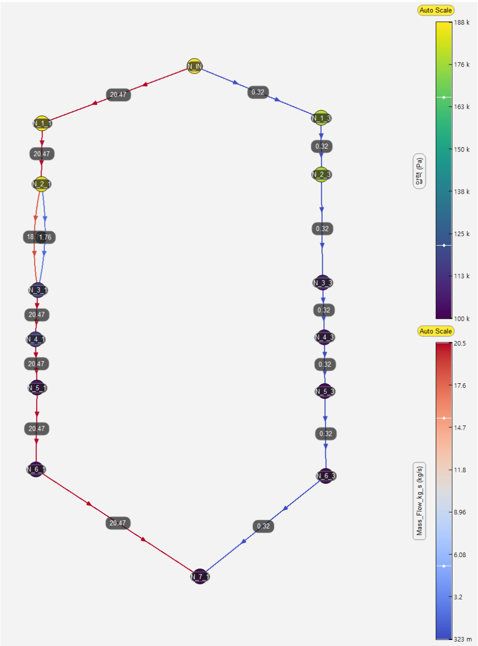

Fig. 2. Flow path and node simulation in SFA using a fluid network analysis method

Table 1: Fluid network analysis input description

	Parameters	Remarks
Setting	Fluid density [kg/m^3]	
	Fluid dynamic viscosity [Ns/m^2]	
	Max iterations	
	Tolerance	
	Relaxation factor	
Node	Node ID	
	Node type	- Fixed pressure - intermediate
	Pressure [N/m^2]	
	losses	- Type - Value -Condition
Pipe	Pipe ID	
	Start node	
	End node	
	Length [m]	
	Flow area [m^2]	
	Perimeter [m]	
	Roughness [m]	
	Friction method	- Blasius - Colebrook - User define

2.2 Fluid network analysis results

Pressure drop predictions from the developed model were compared with reference values using the relative error defined in Eq. (1):

$$\text{Relative Error (\%)} = \frac{|\Delta P_{FNA} - \Delta P_{reference}|}{\Delta P_{reference}} \times 100 \quad (1)$$

Reference values were obtained by an independent hand calculation based on same governing equations and boundary conditions. As listed in Table 2, the maximum relative error between the present model and reference results was 0.124%. Among 15 evaluated segments, 13 segments showed relative errors less than or equal to 0.1%, indicating high reproducibility against the reference solution. In branch-merging sections, no significant discrepancy in trend was observed, supporting the reliability of the proposed modeling approach for pressure drop prediction in complex channel networks.

Table 2: Relative Error of fluid network analysis - Reference by Position

Pipes	Fluid network analysis- Reference Relative error (%)	Position
1-1	0.024	Upper (inner channel)
2-1	0.001	Upper (inner channel)
3-1	0.002	Fuel (inner channel)
4-1	0.124	Bottom (inner channel)
5-1	0.0003	Bottom (inner channel)
6-1	0.124	Bottom (inner channel)
7-1	0.006	Bottom (inner channel)
3-2	0.002	Fuel (outer channel)
1-3	0.005	Upper (gap)
2-3	0.006	Upper (gap)
3-3	0.006	Fuel (gap)
4-3	0.061	Bottom (gap)
5-3	0.036	Bottom (gap)
6-3	0.006	Bottom (gap)
7-3	0.063	Bottom (gap)

3. Conclusions

This study performed fluid network analysis based pressure drop analysis for SFA flow channels in research reactor and validated the results against a reference calculation. Quantitative comparison showed a relative error range of 0.0003% - 0.124%, demonstrating strong agreement of fluid network analysis in SFA pressure drop prediction. Although the present scope is limited to partial validation of SFA, the results provide a practical foundation for full reactor analysis by confirming both modeling consistency and numerical reliability in complex flow paths. Future work will extend the present framework to a full reactor fluid network model and apply the developed fluid network analysis code as a design tool for future research reactor systems.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Ministry of Science and ICT (MSIT), Republic of Korea (No. RS-2025-02313658).

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