Application of Network Analysis Method to VHTR core

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1. Introduction

A Very High Temperature Reactor (VHTR) [1] is currently envisioned as a promising future reactor concept because of its high-efficiency and capability of generating hydrogen. Prismatic Modular Reactor (PMR) is one of the main VHTR concepts, which consists of hexagonal prismatic fuel blocks and reflector blocks made of nuclear grade graphite. However their shape could be changed by neutron damage during the reactor operation and the shape change can makes the gaps between the blocks inducing bypass flow. Most of reactor coolant flows through the coolant channel within the fuel block, but some portion of the reactor coolant bypasses to the interstitial gaps. The vertical gap and horizontal gap are called bypass gap and cross gap, respectively. CFD simulation for the full core of VHTR might be possible but it requires vast computational cost and time. Therefore, fast, flexible and reliable code is required to predict the flow distribution corresponding to the various bypass gap distribution. Consequently in this study, the flow network analysis method is applied to analyze the core flow of VHTR. The applied method was validated by comparing with SNU VHTR multi-block experiment. As a result, the calculated results show good agreements with experimental data although computational time and cost of the developed code was very small.

2. Governing Equations

In the VHTR core, main flows are pipe which is usually calculated with Darcy-Weisbach equation. The form of Darcy-Weisbach equation is Eq. (1).

$$h_f = f\frac{L}{D}\frac{V^2}{2g} \qquad (1)$$

Where h is head loss, f is friction factor, L is length of the flow path, D is diameter of path, V is flow velocity, and g is the gravity acceleration.

To analyze network, Eq. (1) can be expressed as relation of head loss and flow rate

$$h_f = KQ^2,\ \ where\, K = \frac{fL}{2gDA^2} \qquad (2)$$

Where A is flow area, Q is the volumetric flow rate, and K is the loss factor that can be thought as flow resistance.

The analysis of looped network consists of the determination of flow rates of the pipes and heads at the nodes. The following laws, called Kirchhoff's circuit laws [2], generate the governing equations.

- The algebraic sum of inflow and outflow discharges at a node is zero.
- The algebraic sum of the head loss around a loop is zero

2.1 Conservation of Mass

Conservation of mass at a node is established based on the law that the amounts of inflow and outflow are same at the junction where the pipes are connected. For a junction node i, conservation of mass can be written as Eq. (3).

$$F_j = \sum_{n=1}^{j_n} Q_{jn} - q_j = 0 \qquad (3)$$

Where, Q_{jn} is the inlet flow from *n-th* pipe at node j, q_j is the outlet flow at the node, and j_n is the total number of pipes at node j.

2.2 Conservation of Momentum

The conservation equation of momentum can be represented with head loss. While traversing along a loop, as one reaches at the starting node, the net head loss is zero. It can be written as Eq. (4).

$$F_k = \sum_{n=1}^{k_n} K_n \left|Q_{kn}\right| Q_{kn} = 0 \qquad (4)$$

Where, K_n is the total number of pipes at the *k-th* loop.

Since one loop has one head loss equation, it can be referred as loop equation.

3. Network Modeling of SNU Multi-Block Experiment

The test facility of SNU multi-block experiment [3] consists of 28 test blocks; 7 columns radially and 4 layers axially. Two types of test blocks are used. One is a standard fuel block and the other is a reflector block. Fig. 1 shows a schematic of the experimental apparatus.

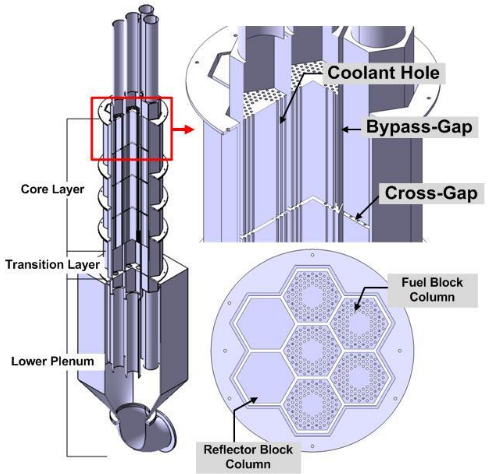

Fig. 1. Configuration of SNU multi-block experimental apparatus

The flow paths of the experiment were grouped and simplified for modeling. Flow paths of the bypass gap are classified into reflector region gap, reflector-fuel interface region gap and fuel region gap. Flow paths of the coolant hole within the fuel block are modeled as single grouped pipe. 30 bypass gap paths in the multi-block experiment are divided into three groups of bypass gap. Since reflector and fuel block combination were tested in the multi-block experiment, there are just five flow path groups for the coolant hole. Fig. 2 shows the grouping of flow paths and the flow network model of multi-block experiment.

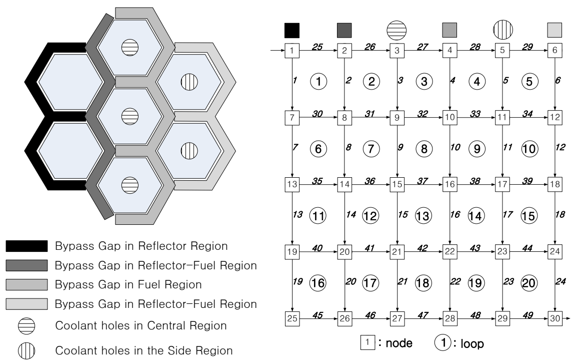

Fig. 2. Grouping of flow paths in multi-block experiment and the flow network model of multi-block expeiment

At node 1, inlet flow is the total flow and outlet flows are flow of pipe 1 and pipe 25. Therefore, equation of mass is represented as Eq. (5).

$$Q_{total} - Q_1 - Q_{25} = 0 \qquad (5)$$

At loop 1, the sum of head losses of all pipes are zero. It can be represented as Eq. (6).

$$K_1|Q_1|Q_1 + K_{30}|Q_{30}|Q_{30} - K_2|Q_2|Q_2 - K_{25}|Q_{25}|Q_{25} = 0 \qquad (6)$$

4. Results and Discussions

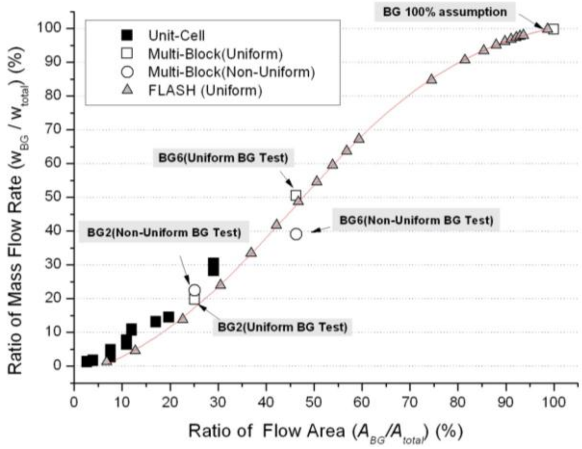

Fig. 3. Bypass flow ratio according to the ratio of bypass gap area to total flow are

As shown in Fig. 3, the bypass flow distribution of uniform gap test shows a good agreement with calculation results of FLASH code. However, the result of non-uniform bypass gap test was not predicted by the uniform correlation. When the crossflow does not occur such as in uniform bypass gap cases, the core flow distribution of the block-type VHTR could be modeled as the parallel pipe system simply.

5. Conclusions

The flow network analysis method is applied to analyze the core flow of VHTR. Complex flow network could be solved simply. For the uniform bypass gap test, the bypass flow ratio calculated by network analysis method was proportional to bypass gap area ratio in common with the experimental data. Since the core design is based on the conservative assumption of the bypass flow, the results of this study can contribute to assure the core thermal margin by the detailed analysis of the core bypass flow.

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