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Natural Circulation Capability Assessment for Small-Medium Reactor

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1. Introduction

Small-medium reactors have been highly evaluated to have more safe characteristics than those of large reactors. In addition, it could be used for a variety of purposes, such as small-scale power production in mountainous or island area, seawater desalination, regional heating system, or large ships promotion power source[3].

Various countries recently have substantiated the small-medium reactors – AST-500 (Russia), NHR-5 and NHR-200 (China), GHR (Germany), SMART (Korea). Since SMART (System-integrated Modular Advanced ReacTor) is integral type contrarily to the original reactors, it contains primary systems including a core, main coolant pumps, steam generators and a pressurizer within a reactor pressure vessel[4]. Accordingly, it can exclude LBLOCA(Large Break Loss Of Coolant Accident) which is primary DBA(Design Basis Accident) of separated reactors.

For a higher safety, we are designing a small sized reactor, REX-10(Regional Energy Reactor - 10 MW_{th}), which uses a natural circulation system. In This study, to evaluate thermal-hydraulics of REX-10, we built experiment facility using the scaling law by Ishii.

2. Scaling law

2.1. Kinds of scaling law

Scaling laws have three kinds of methods such as linear scaling law, volume scaling law, and the scaling law by Ishii. The linear scaling law is the way that aspect ratio is reduced in the ratio of 1:1 developed by Nahavandi(1979), Carbiener and Cudnik(1969) [5]. This way has a defect that velocity is maintained instead of reducing a time.

Once length of experimental equipment and prototype is set equally by using the volume scaling law, comparing the equipment with the prototype is possible at real time. However the area of the equipment is reduced automatically but the length.

The scaling law by Ishii is capable of describing physical phenomenon of the prototype reactor at reduced height[1]. Thus, in this study, the scaling law by Ishii is employed.

2.2. Scaling law by Ishii

Experimental equipments using the natural circulation are expressed with the continuity, integral momentum, fluid energy, solid energy, and fluid-solid boundary equation.

Continuity equation:

$$u_i = \frac{a_o}{a_i} u_r \tag{1}$$

Integral momentum equation:

$$\rho \frac{du_r}{dt} \sum_i \frac{a_o}{a_i} l_i = \beta \rho g \Delta T l_h \frac{\rho u_r^2}{2} \sum_i \left(\frac{fl}{d} + K \right)_i \frac{a_o^2}{a_i^2} \tag{2}$$

Fluid energy equation:

$$\rho C_p \left(\frac{\partial T}{\partial t} + u \frac{\partial T}{\partial z} \right) = \frac{4h}{d} \left(T_s - T \right) \tag{3}$$

Solid energy equation:

$$\rho_s C_{ps} \frac{\partial T_s}{\partial t} + k_s \nabla^2 T_s - \dot{q}_s = 0 \tag{4}$$

Fluid-solid boundary equation:

$$-k_s \frac{\partial T_s}{\partial y} = h \left(T_s - T \right) \tag{5}$$

Equations are non-dimensionalized, and must be satisfied similarity considering a ratio between model and prototype. Then, Ishii's scaling law can make a summary as follows:

$$\rho_{sR} = C_{psR} = k_{sR} = \alpha_{sR} = 1 \tag{6}$$

$$\delta_R = \sqrt{l_R / u_R} \tag{7}$$

$$d_R = \sqrt{l_R / u_R} \tag{8}$$

$$u_R = \left(q_{oR} l_{oR}^2 \right)^{1/3} \tag{9}$$

$$\left[\sum_i \left(\frac{fl}{d} + K \right) \left(\frac{a_o}{a_i} \right)^2 \right]_R = 1 \tag{10}$$

$$\left(l_i / l_o \right)_R = 1, \ \left(a_i / a_o \right)_R = 1 \tag{11}$$

This study is scheduled not only one-phase natural circulation experiment, but also about two-phase including in accidents. Thus, scaling law about two-phase must be considered

3. Results

Based on the scaling law results, we obtained a table below about ratios between model and prototype. Some ratios for diverse parameters between the experimental facility and the prototype are indicated as shown in Table I.

Table I. Scaling ratio between model and prototype

Parameter	Ratio	Parameter	Ratio
Length	1:1	Time	1:1
Diameter	1:7.07	Flow Rate	1:50
Area	1:50	No. of rod	1:50
Volume	1:50	k-factor	1:1
Core Power	1:50	Core ΔT	1:1

Also, the natural circulation capabilities for small-medium reactor were verified, and the flow rates are shown in Fig. 1.

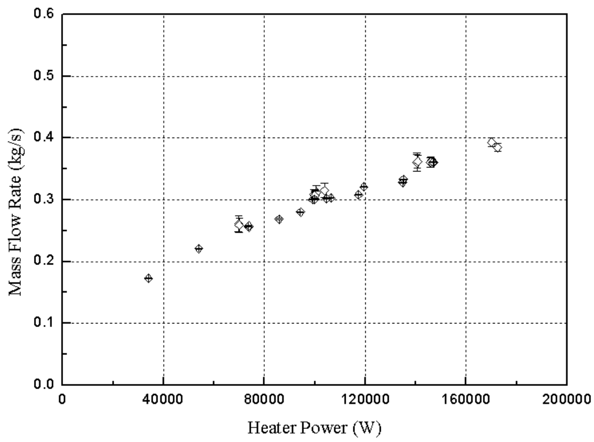

Fig. 1 Flow rates at various heater power

Table 2. Comparing estimated values and experimental values

	Prototype	**Estimated values**	**Experimental values**
Power(KW_{th})	10,000	200	170
Pressure(MPa)	2.0	2.0	2.0
Coolant flow rate(kg/s)	64.9	1.298	0.4~0.5

Compared with estimated values from the scaling law, experimental values presented approximately 0.8 kg/s less (Table II). It can be seen that the under-estimate of the values is because the flowmeters within the very small pipes and the coefficient of the friction interrupt fluid flow.

4. Conclusion

In this study, the way of using the natural circulation except for the pumps was used and analyzed for safety. The expected flow rates, however, were not gained. In order to utilize the reactors using the natural circulation, it is most important to obtain the expected flow rate.

The flow rates can be expected to be more precisely acquired if the experiments for the flowmeters and the coefficient of the friction are performed. Thus, the experiments about efficiency and safety of the natural circulation are now underway.

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