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Preliminary Study on the Effect of Pressure Drop due to Spacer Grid in SMRs

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1. Introduction

The role of the spacer grids in the fuel assembly is important for the fuel thermal hydraulic design such as supporting the fuel rods and mixing coolant to enhance heat transfer. A number of research works have been done to characterize the effects of spacer grid with or without mixing vane and to optimize its design. The related studies for PWRs have been generally conducted but little attention was given to the Small Modular Reactors (SMRs) operating conditions. Since, the technology development of SMRs is actively in progress, the optimum design of the spacer grid with mixing vane appropriate for SMRs is necessary. Moreover, some of SMRs are designed to adopt the natural circulation during the full power operation. Thus, optimizing design of mixing vane becomes more important because the pressure drop is one of the important factors determining the natural circulation flow.

In this paper, as a preliminary study, the effect of pressure drop due to the spacer grid is evaluated with three different pressure loss correlations under the normal operating condition for various flow rate (without natural circulation), first.

2. Pressure Drop Calculation

2.1 Information of Reference Reactor

As a reference reactor of this study, System Integrated Modular Advanced ReacTor (SMART) was selected and the basic design information of SMART [1] is listed in Table I and II. In the fuel assembly of SMART, there are five spacer grids (three with mixing vane and the others without mixing vane).

Table I: Design Information of SMART Core and Fuel Rod

Core (mm)		Fuel rod	
Pellet diameter	8.05	Total height (mm)	2400
Gap thickness	0.17	Fuel rod #	264 per assembly
Rod diameter	9.5	Fuel assembly	17 by 17
Fuel pitch	12.6	Fuel assembly #	57
Fuel active length	2000	Core barrel Diameter (mm)	2182

Table II: Thermal Hydraulic Information of SMART Core

Parameter	Value
Total power (MWth)	330
Pressure (MPa)	15
Core inlet temperature (°C)	270
Core outlet temperature (°C)	310

2.2 Pressure Drop due to Spacer Grids

To predict the pressure drop due to the spacer grids, three different pressure loss correlations published by1) De Stordeur [2], 2) Rehme [3], and 3) In et al [4, 5] were used and shown as Eqs. (1) ~ (10). The drag coefficients in De Stordeur's and Rehme's correlation were obtained from the plotted figures of the relationship between the drag coefficients and the Reynolds number. Only In's correlation consider pressure loss due to the mixing vane. In Eq. (3), each term (i.e. term A ~ D) denotes grid form loss, grid friction loss, rod friction loss within the spacer region, and mixing vane form loss, respectively. The last term, D, is not considered in the case of the spacer grid without mixing vane. Each loss coefficient is put in Eq. (11) then pressure drop is calculated.

$$K_{grid}^{deStordeur} = \left(C_{grid} \frac{A_{grid,frontal}}{A_{flow}} \right) \left(\frac{A_{flow}}{A_{flow} - A_{grid,frontal}} \right)^2 \quad (1)$$

$$K_{grid}^{Rehme} = C_{grid,modified} \left(\frac{A_{grid,frontal}}{A_{flow}} \right)^2 \quad (2)$$

$$\begin{aligned} K_{grid}^{In} = & \underbrace{\left[C_{grid}^{form} \frac{\varepsilon}{(1-\varepsilon)^2} \right]}_{Term\ A} + \underbrace{\left[C_{grid}^{fric} \frac{A_{grid,wetted}}{A_{flow}} \frac{1}{(1-\varepsilon)^2} \right]}_{Term\ B} \\ & + \underbrace{\left[C_{rod}^{fric} \frac{A_{rods,wetted@grid}}{A_{flow}} \frac{1}{(1-\varepsilon)^2} \right]}_{Term\ C} \\ & + \underbrace{\left[C_{mv} \frac{\varepsilon_{mv}}{(1-\varepsilon_{mv})^2} \right]}_{Term\ D} \end{aligned} \quad (3)$$

where:

$$C_{grid}^{form} = 2.75 - 0.27 \log_{10}(\text{Re})_{\text{away from grid}} \quad (4)$$

$$C_{grid}^{fric} = C_{grid,lam}^{fric} \frac{3\times10^4 \mu_{avg}}{G_{@grid} H} + C_{grid,turb}^{fric} \frac{\left(H - (3\times10^4 \mu_{avg} / G_{@grid})\right)}{H} \quad \text{for } H \geq \frac{3\times10^4 \mu_{avg}}{G_{@grid}}$$
$$= C_{grid,lam}^{fric} \frac{3\times10^4 \mu_{avg}}{G_{@grid} H} \quad \text{for } H < \frac{3\times10^4 \mu_{avg}}{G_{@grid}} \qquad (5)$$

$$C_{grid,lam}^{fric} = 1.328 \left\{ G_{@grid} \frac{\left(H - (3\times10^4 \mu_{avg} / G_{@grid})\right)}{\mu_{avg}} \right\}^{-0.5} \qquad (6)$$

$$C_{grid,turb}^{fric} = 0.523 \left\{ \ln\left[0.06 \times G_{@grid} \times \frac{\left(H - (3\times10^4 \mu_{avg} / G_{@grid})\right)}{\mu_{avg}} \right] \right\}^{-2} \qquad (7)$$

$$C_{rod}^{fric} = 0.184 \mathrm{Re}_{@grid}^{-0.2} / 4 \qquad (8)$$

$$C_{mv} = 0.72 \qquad (9)$$

$$\varepsilon = \frac{A_{grid,frontal}}{A_{flow}}, \quad \varepsilon_{mv} = \frac{A_{mv}}{A_{flow}} \qquad (10)$$

$$\Delta P_{grid} = K_{grid} \frac{\rho_{avg} V_b^2}{2} \qquad (11)$$

Since there was no detail information for the spacer grid design, some design values from In's study, which are reasonable and applicable for the spacer grid of SMART, were used. The values are summarized in Table III.

2.3 Pressure Drop through the Core

The total pressure drop through the core was calculated by the sum of friction and form loss due to the spacer grids and nozzles. Pressure loss coefficients for nozzles were used from the design information of SMART as listed in Table III.

For the calculation of friction loss, Darcy friction factor was used. Each Eq. (12) and (13) is for the laminar and turbulent flow, respectively.

$$f = \frac{64}{Re} \quad \text{for } Re < 2300 \qquad (12)$$

$$\frac{1}{\sqrt{f}} = -2.0 \log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}} \right) \quad \text{for } Re \geq 2300 \qquad (13)$$

Table III: Design Features of Spacer Grid

Parameter		Value
Spacer grid #	with mixing vane	3
	without mixing vane	2
Grid strap height (mm)	with mixing vane	53
	without mixing vane	38
Strap thickness (mm)		0.45
Relative plugging of mixing vane, ε_{mv}		0.13
Mixing vane type		Split
Pressure loss coefficient	Bottom nozzle	1.87
	Top nozzle	1.11

The sum of each pressure loss term from the correlation for the spacer grids and friction loss term for the core is calculated. Then, the portion of pressure drop due to the spacer grids with respect to the core pressure drop is evaluated.

3. Results

Fig. 1 shows the result of pressure drop calculation for each pressure loss correlation for various flow rate. For simplicity of calculation, it was assumed that the total thermal power is equal and just the flow rate is changed. Even though, the flow rate is changed, the ratio of pressure drop due to the spacer grid to that though the core does not show a big difference as summarized in Table V.

In In's correlation, the pressure drop due to the mixing vane is considered and pressure drop at each part is also modeled in detail compared to the other correlations. Generally, the portion of pressure drop due to the spacer grid and core pressure drop is larger. The effect of pressure drop at each part in Eq. (3) with respect to the pressure drop due to spacer grid is summarized in Table VI. The effect of pressure drop due to the spacer grid and mixing vane is not negligible.

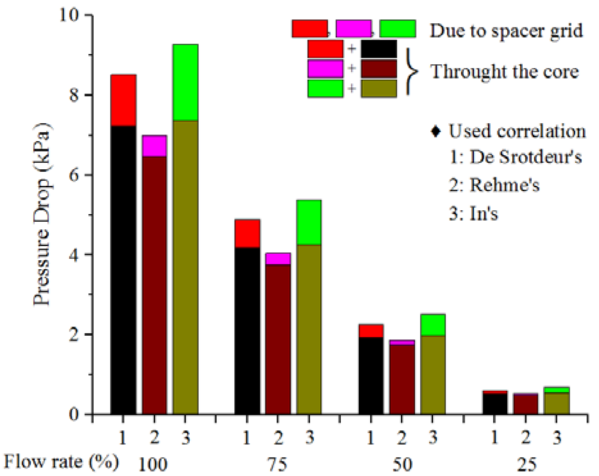

Fig. 1. Effect of pressure drop due to spacer grid calculated by each correlation

Table V: Effect of Pressure Drop due to the Spacer Grid Calculated by Each Correlation

Flow rate (%)	De Stordeur (%)	Rehme (%)	In (%)
100	17.8	8.0	26.0
75	17.3	7.8	26.1
50	16.6	7.5	26.2
25	15.4	6.9	26.4

Table VI: Effect of Pressure Drop at Each Part in Spacer Grid Calculated by In's Correlation

Flow rate (%)	Term A (kPa, %)	Term B (kPa, %)	Term C (kPa, %)	Term D (kPa, %)
100	1.05 (54.9)	0.012 (0.6)	0.50 (26.3)	0.35 (18.2)
75	0.61 (54.5)	0.010 (0.9)	0.30 (27.0)	0.20 (17.6)
50	0.28 (53.8)	0.008 (1.6)	0.14 (27.9)	0.087 (16.7)
25	0.074 (51.4)	0.006 (4.4)	0.042 (29.0)	0.022 (15.2)

4. Summary and Further Works

Under the normal operating condition, the pressure drop due to spacer grid in the core was first calculated with various correlations: De Stordeur, Rehme, and In et al. Depending on the correlation, the results were different. Furthermore, the effect from the analysis, it was also shown that the pressure loss due to the spacer grid form loss and mixing vane are significant although the flow rate is reduced.

As the next step, similar analysis will be performed for the natural circulating condition. The pressure drop due to the spacer grids with mixing vane will be evaluated for various flow rate and flow regimes. After then, to reduce the pressure drop through the core to enhance the natural circulation performance, further studies will be conducted to optimize the shape of spacer grid and mixing vane under natural circulation operating condition.

NOMENCLATURE

ΔP	= pressure drop (kPa)
K	= pressure loss coefficient
C	= form drag or friction coefficient
V_b	= bulk fluid velocity of subchannel (m/s)
D_h	= hydraulic diameter of subchannel (m)
A_{flow}	= flow area of subchannel (m^2)
$A_{grid,frontal}$	= projected spacer grid cross section (m^2)
$A_{grid,wetted}$	= wetted area of the grid strap (m^2)
$A_{rods,wetted@grid}$	= wetted area of the fuel rod at the grid (m^2)
ε	= relative plugging of flow area
H	= grid strap height (m)
μ	= fluid viscosity (Pa·sec)
ρ	= fluid density (kg/m^3)

Subscripts

avg	= average
grid or @gird	= of or at the spacer grid
mv	= mixing vane
lam	= laminar
turb	= turbulent

ACKNOWLEDGEMENT

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