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Pressure Drop of Chamfer on Spacer Grid Strap

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1. Introduction

The roles of spacer grid in assemblies are to support fuel rods and to maintain the structural integrity under the nuclear reactor operating conditions. A swirl flow and cross flow are generated by the spacer grid with mixing vane that enhances the thermal performance and critical heat flux (CHF) [1-3]; however, the mixing vane also causes additional pressure drop. The additional pressure drop makes it difficult to meet acceptance criteria for overall pressure drop in fuel assembly depending upon the pump capacity. The chamfer on the end of spacer grid strap is one solution to reduce additional pressure drop without any adverse effect on flow fields [4].

In this research, the pressure drop tests for spacer grid with and without chamfer were carried out at the hydraulic test facility. The result can be applied to develop high performance nuclear fuel assemblies for Pressurized Water Reactor (PWR) plants.

2. Test facility and section

2.1 Test facility

The pressure drop test was performed at the INFINIT test facility in the KEPCO Nuclear Fuel Co [5]. The INFINIT test facility is certified by the Korea Laboratory Accreditation Scheme (KOLAS) [6]. The pressure drop test procedure was also conducted in accordance with KOLAS certification.

The INFINIT test facility was comprised of heating and cooling systems, circulation pump, flow straightener, flow meter, pressure transducer, and thermo-couples. The figure 1 shows the schematic diagram of the INFINIT test facility. The single phase water was used as the working fluid that enters the flow straightener from the lower part of test section and was pumped through the entire INFINIT facility. The heating and cooling systems were installed to control the water temperature that was maintained at 25 ± 1˚C. The flow rate was controlled by the circulation pump and was measured by a flow rate indicator at upstream flow. The pressure was measured by the pressure transducer connected to the pressure tap that was drilled perpendicularly to the test section. In order to obtain reliable data, pressure shall be measured until the desired steady-state flow rate is reached. The measurement data such as temperature, pressure, and flow rate were collected on the data acquisition system (DAS). The pressure drop test conditions are given in the table I.

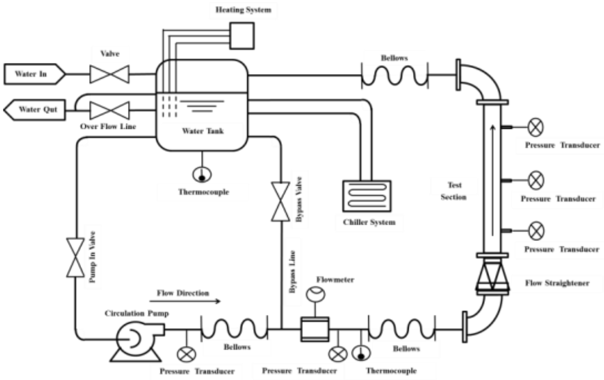

Fig. 1. Schematic diagram of INFINIT test facility [5]

Table I: Pressure drop test conditions

Inlet velocity, m/s	1.524 ~ 6.096
Outlet pressure, kPa	101.325
Inlet temperature, ˚C	25 ± 1

2.2 Test section

The test section was made of acryl plates reinforced by steel bars. The test section was designed to provide the appropriate cross-section for the spacer grid strap and to endure the high pressure and high flow rate. The characteristics of test sections are given in the table Ⅱ.

The spacer grid models were based on commercial nuclear fuel assemblies in PWR plants. The spacer grid models were categorized as the existence of chamfer on the end of spacer grid strap as given in the figure 2. The figure 3 illustrates the chamfer shape of 5x5 and 6x6 spacer grids. The chamfer was manufactured by the coining process. The angle of chamfer on 5x5 and 6x6 spacer grids was the same while the height/depth of chamfer on 5x5 spacer grid was lower than that of 6x6 spacer grid.

The figure 4 presents the pressure measurement position. Four 5x5 and five 6x6 spacer grids were set up in parallel with test sections. The axial gaps among each grid were the same height that was considered to be fully developed. The axial gaps among 5x5 spacer grids were larger than those of 6x6 spacer grids. The pressure drop of the third spacer grid was analyzed.

(a) With chamfer (b) Without chamfer
Fig. 2. Spacer grid strap with and without chamfer

(a) 5x5 (b) 6x6

Fig. 3. Chamfer shape of 5x5 and 6x6 spacer grids.

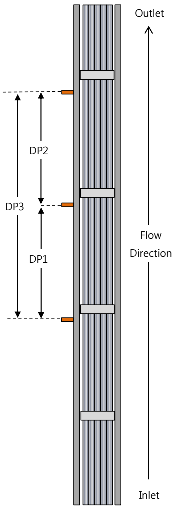

Fig. 4. Pressure measurement position

Table Ⅱ: The characteristics of test sections

Spacer Grid Type	5x5	6x6
Total number of rods	25	36
Rod outer diameter, mm	9.50	9.50
Rod length, mm	2300	2300
Rod pitch , mm	12.60	12.85
Test section type	65 type	80 type

2.3 Pressure loss coefficient

The pressure drop is the sum of spacer grid pressure drop ΔP_{SG}, represented by the spacer grid pressure loss coefficient $K_{SG,}$ and bare rod pressure drop ΔP_{BR}, represented by the bared rod loss coefficient K_{BR}. The bared rod friction factor is expressed in terms of Reynolds number, roughness, and hydraulic diameter by Colebrook equation (1) [7]. The pressure drop of bare rod is calculated by using equation (2). The pressure drop of spacer grid is expressed as equation (3).

$$f = \left[1.74 - 2\log\left(\frac{2\varepsilon}{D_h} + \frac{18.7}{Re\sqrt{f}}\right)\right]^{-2} \quad (1)$$

where,

$$Re = \frac{\rho V D_h}{\mu}$$

$$D_h = \frac{4 \times \text{Flow Area}}{\text{Wetted Perimeter}}$$

$$\Delta P_{BR} = 0.5 \times K_{BR} \times \rho \times V^2 \quad (2)$$

where,

$$K_{BR} = f \times \frac{L}{D_h}$$

$$K_{SG} = \frac{\Delta P_{TOTAL} - \Delta P_{BR}}{0.5 \times \rho \times V^2} \quad (3)$$

3. Results

The sweep test for the spacer grid without a mixing vane was performed in order to check the effect of flow rate sweep-up and sweep-down. The sweep test result showed that there was 0.7 % pressure drop difference between sweep-up and sweep-down test.

The figure 5 compares the pressure loss coefficient for 5x5 spacer grids. On average, the pressure loss coefficient for 5x5 spacer grid with chamfer was 11.5 % lower than that for 5x5 spacer grid without chamfer.

The figure 6 shows the pressure loss coefficient for 6x6 spacer grids. On average, the pressure loss coefficient for 6x6 spacer grid with chamfer was 13.8 % lower than that for 6x6 spacer grid without chamfer.

The ratio of the pressure loss coefficient for 6x6 spacer grid with chamfer to that for 6x6 spacer grid without chamfer was larger than that of 5x5 spacer grid due to the chamfer shape. The end of chamfer on 6x6 spacer grid strap was sharper than that of 5x5 spacer grid. The sharp edge of chamfer made large inlet area and decreased in ratio of inlet area to outlet area that reduced the pressure drop.

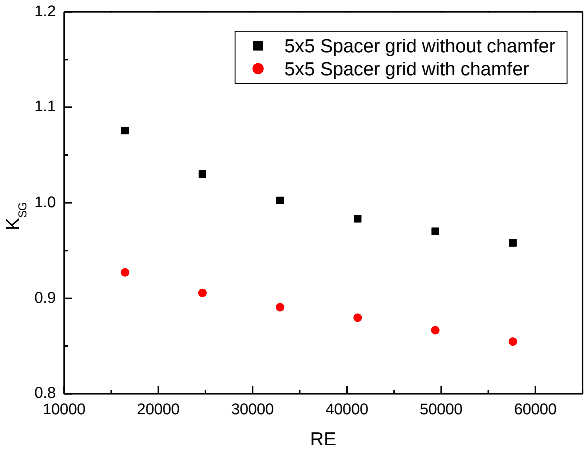

Fig. 5. Pressure loss coefficient for 5x5 spacer grids

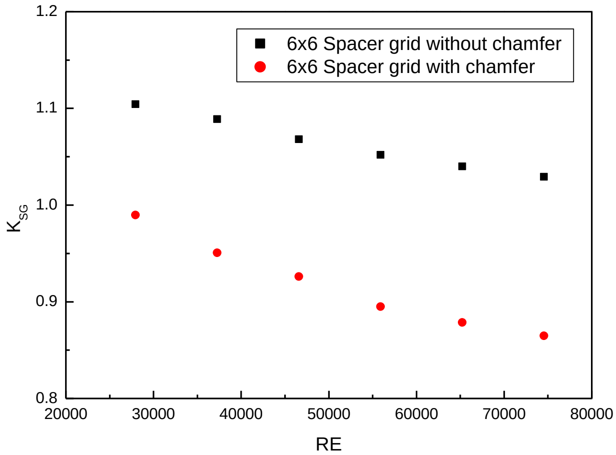

Fig. 6. Pressure loss coefficient for 6x6 spacer grids

4. Conclusions

The pressure drop tests for 5x5 spacer grid with and without chamfer as well as 6x6 spacer grid with and without chamfer were carried out at the INFINIT test facility. The Reynolds number ranged about from 16000 to 75000.

The sweep-up and sweep-down test showed that the direction of sweep did not affect the pressure drop.

The chamfer on spacer grid strap reduced the pressure drop due to the decreased in ratio of inlet area to outlet area. The pressure loss coefficient for spacer grid with chamfer was by up to 13.8 % lower than that for spacer grid without chamfer. Hence, the chamfer on spacer grid strap was one of effective ways to reduce the pressure drop.

In the research, the pressure drop difference between 6x6 spacer grid with and without chamfer was 8 % throughout one span length; however, in the result of computational fluid dynamics, CFD, calculation, pressure drop difference between 6x6 spacer grid strap with and without chamfer was 6 % throughout one span length [4]. Considering repeatability and reproducibility for tests, manufacturing tolerance, and cell type difference, this difference between test and CFD was satisfactory.

NOMENCLATURE

D_h	Hydraulic diameter	(m)
f	Friction factor	
K	Pressure loss coefficient	
L	Length	(m)
Re	Reynolds number	
V	Velocity	(m/s)
ε	Roughness height	(m)
μ	Dynamic viscosity	(Pa-s)
ρ	Density	(kg/m^3)
ΔP	Pressure drop	(Pa)

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