Measurement of Pressure Loss in Tight Lattice Rod Bundle with Spacer Grid

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1. Introduction

KAERI (Korea Atomic Energy Research Institute) has been developing a dual-cooled annular fuel to increase a significant amount of the reactor power in OPR1000, an optimized PWR (Pressurized Water Reactor) in Korea. The dual-cooled annular fuel is simultaneously cooled by the water flow through the inner and the outer channels. To introduce the dual-cooled fuel to OPR1000 is aimed at increasing the power of reactor by 20% as well as at reducing the fuel temperature by 30%, as compared to the conventional solid fuel without the change of reactor components. However, the pitch-to-diameter ratio of dual-cooled annular fuel assembly, one of the important geometrical parameters to determine the pressure drop [1], should be decreased in order to become the same array size and guide tube location as the solid fuel assembly. In such a case, the trend of pressure loss in the dual-cooled annular fuel assembly may be definitely different from that in the conventional solid fuel assembly due to the different pitch-to-diameter ratio. In this study, the 4x4 rod bundle having the pitch-to-diameter ratio of 1.08, which simulates the dual-cooled annular fuel assembly, is prepared with the plain and the split-vane spacer grids. Then, the friction factor in rod bundle and the pressure loss coefficients of spacer grids are preliminarily tested and reported.

2. Experimental Details

The schematic diagram of experimental set-up called OFEL (Omni Flow Experimental Loop) is depicted in Fig. 1, which consists of a water tank, a centrifugal pump, a flow meter, a test section, valves and piping. As the working fluid, the pure water is used, and all experiments are performed in the single-phase flow. By the centrifugal pump, the water flows from the reservoir to the plenum, the lower part of vertical test section. The lower plenum contains the honeycomb flow rectifier to suppress the large scale vortices generated by the pump and the pipe bends. The test section is connected to the upper plenum, which maintains a free surface at the atmospheric pressure condition. The water flow rate is measured by the flow meter downstream of pump. The bypass and the rupture loops are installed to control the flow rate of test section and to keep the loop pressure lower than the design pressure.

The test section is composed of 16 smooth rods in a 4x4 square array installed in a square channel. The square channel is made of acrylic plate with 30 mm in

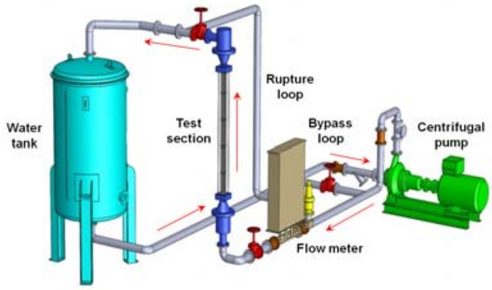

Fig. 1. Schematic diagram of experimental set-up.

thickness to visualize the flow. The characteristic geometric parameters of test section are summarized in Table I. In this study, two different kinds of spacer grids with 40 mm in height are tested; the plain and the split-vane spacer grids. Rod bundle is held by 4 spacer grids placed at 400 mm intervals. In order to estimate the friction factor in rod bundle and the pressure loss coefficients of spacer grids, the pressure holes are prepared, as shown in Fig. 2, and then the pressure drop of spacer grids in the middle of test section, which is independent of entrance and exit effects, are measured at various flow rate conditions.

Table I. Characteristic geometric parameters of test section.

Rod bundle array	4×4
Square channel (mm)	72.54×72.54
Rod diameter (D, mm)	15.9
Rod Length (L, mm)	2000
Hydraulic diameter of test section (d_h, mm)	7.656
Pith to diameter ratio (P/D)	1.08
Wall distance to diameter ratio (W/D)	1.17

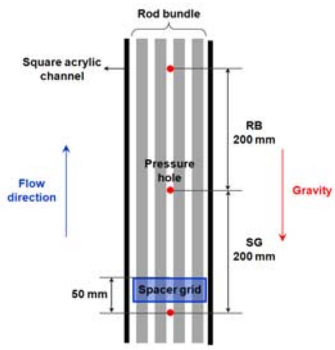

Fig. 2. Preparation of pressure holes (Side-view).

The friction factor in rod bundle and the pressure loss coefficients of spacer grids are simply calculated as follows.

$$f=\frac{\Delta P_{RB}}{0.5\rho V^2 (L_{RB}/d_h)}, \quad K=\frac{\Delta P_{SG}-\Delta P_{RB}}{0.5\rho V^2} \qquad (1)$$

Here, f and K are the friction factor in rod bundle and the pressure loss coefficient of spacer grid, respectively. ρ, V, L and d_h are the density of water, the velocity of water, the measuring length (i.e., 200 mm) and the hydraulic diameter of test section, respectively. Subscripts, RB and SG, indicate the portions of rod bundle and spacer grid, respectively.

3. Experimental Results

In order to validate the experimental set-up, the measurement of pressure drop in bare rod bundle (i.e, no spacer grids) is performed as shown in Fig. 3. In the same plane, the friction factors predicted by the McAdams and the Blasius correlations are plotted for comparison.

$$f_M = 0.184\,\mathrm{Re}^{-0.2}\text{; McAdams correlation} \qquad (2)$$
$$f_B = 0.316\,\mathrm{Re}^{-0.25}\text{; Blasius correlation} \qquad (3)$$

Both correlations over-predict the friction factors measured in this tight lattice rod bundle, which is consistent with the previous report [1]. It implies that the friction factor of circular tube using the concepts of mean velocity and hydraulic diameter as the characteristic length does not describe the pressure drop of real flows in the tightly assembled non-circular sub-channels.

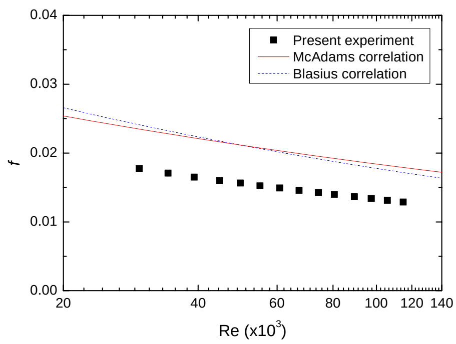

Fig. 3. f in bare rod bundle.

In Fig. 4, the friction factors in rod bundle with the plain and the split-vane spacer grids are shown. Both cases still appear the smaller friction factors than the previous correlations. The friction factors in rod bundle with the split-vane spacer grid are slightly larger than those with the plain spacer grid, which may be due to the flow disturbance induced by the mixing vane.

Fig. 5 displays the pressure loss coefficients of plain and split-vane spacer grids. As expected, the pressure loss coefficients of split-vane spacer grid appear larger than those of plain spacer grid over the whole range of Re number, which may be attributed to the larger relative plugging of flow cross section in the split-vane

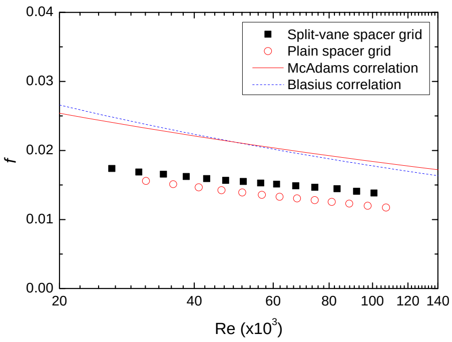

Fig. 4. f in rod bundle with spacer grid.

spacer grid. The relative plugging of flow cross section in the spacer grid is defined as the A_p/A_f. Here, A_p is the projected cross section area of spacer grid, and A_f is the undisturbed flow section. At Re=10^5, the pressure loss coefficients of plain and split-vane spacer grids become 0.55 and 0.70, respectively.

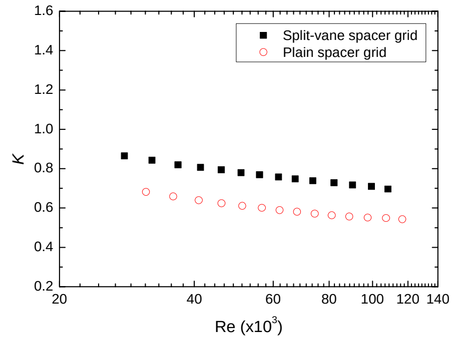

Fig. 5. K of spacer grid.

4. Conclusions

In this study, the friction factor of rod bundle and the pressure loss coefficient of spacer grid in 4x4 rod assembly of P/D=1.08 were preliminarily investigated. Both of the Blasius and the McAdams correlations over-predicted the measured friction factors. Therefore, the correlation to predict the friction factor in the tight lattice rod bundle should be needed. In the pressure loss coefficients, the split-vane spacer grid became larger than the plain spacer grid. At Re=10^5, the pressure loss coefficients of plain and split-vane spacer grids were 0.55 and 0.70, respectively.

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