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Coolant Supply through Side Flow Holes in Long Lower End Cap In the Case of Complete Blockage of Inner Channel Entrance of Dual-Cooled Annular Fuel

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1. Introduction

Annular fuel for PWR has dual flow channels around itself, as shown in Fig. 1. The geometry can help to decrease fuel temperature substantially relative to the conventional cylindrical fuel [1, 2]. However, the inner flow channel is isolated unlike the outer flow channel which is opened to other neighbor outer channels for coolant exchange in the reactor core.

If the inner channel is, as a hypothetical event, completely blocked by the debris like wires, metal chips, and flat straps during normal operation, then the inner cladding may experience a rapid temperature increase because of no further coolant supply. Eventually, it could cause the Departure from Nucleate Boiling (DNB) at the inner channel and reach the Critical Heat Flux condition, which means a fuel failure. Therefore, some remedy to avoid such an accident is indispensable for the safety of the annular fuel.

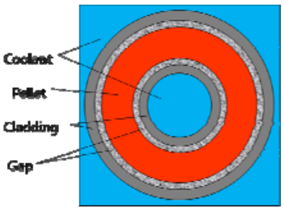

Fig. 1 Cross section of dual cooled annular fuel

A long lower end cap for the annular fuel [3] as shown in Fig. 2 was suggested to provide alternative flow paths in addition to the center entrance of the inner channel. Those are four perforated holes on the side surface of long annular end cap body. It is expected, at least, to allow a minimum coolant supply to prevent the DNB occurrence at the inner channel in the case of partial or even complete blockage of the inner channel entrance. But due to very unusual shape of the lower end cap, it is hard to estimate the flow resistance of the side flow holes using empirical equations available in the open literatures. Thus, it demands an experimental investigation to assure its function.

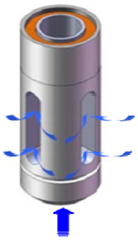

Fig. **2** Long lower end cap with side flow holes

2. Experimental Setup and Test Conditions

Fig.3 shows a test loop to conduct the pressure drop measurement for the long end cap with side holes. The loop is composed of several components like test section, pump, flow-meter, flow control and bypass valves and water storage reservoir. Water is circulated through the test section in upward direction.

The test section is a transparent 800 mm long and 25 mm diametric tube containing an annular metal rod with fins to simulate the spacer grid as well as to maintain the gap between rod and outside tube. The annular rod has inside and outside diameters of 8.4 mm and 15.9 mm, respectively and two sets of three fins are attached at the axial locations of 30 mm and 430 mm from the bottom of the rod. The long lower end cap is also installed at the bottom end of the rod. Each side hole has a dimension of a 3 mmx6 mm rectangular with two 3 mm diameter hemispheres at both ends. A total area of side holes is about 180 % of the center entrance area.

Experiments were conducted at atmospheric pressure and temperature. Flowrate of the loop is measured by a flow meter in the loop. Pressure drop is measured over the region of the annular rod. The maximum flowrate is 20.0 ℓ/min which corresponds to the Reynolds number of about $5.0\text{x}10^4$.

The water entering the test section can be divided into inner and outer channel of the annular rod and merged again after leaving the annular rod. However, in this experiment the outer channel is plugged at just upstream of two fin locations to measure the inner channel flowrate directly. And the pressure drop characteristics for the two ways of flow paths approaching to the inner channel were tested separately: *i*) center entrance of the lower end cap, *ii*) side holes of the lower end cap.

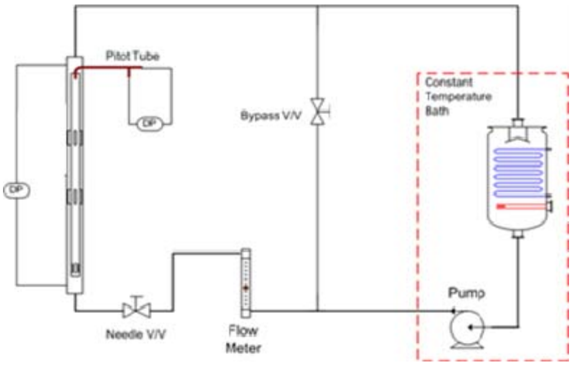

Fig. 3 Schematic diagram of test loop

3. Results

A form loss coefficient of the side holes in the long lower end cap, K_{side} is defined as follows:

$$K_{side} = \Delta P / \tfrac{1}{2} \rho v^2 \qquad (1)$$

For each flow path, a balance of hydrodynamics could be expressed along the streamline:

$$\Delta P_{ent} = (K_{in} + f d/L + K_{exit}) \cdot \tfrac{1}{2} \rho v^2 \quad \text{for center entrance} \quad (2)$$

$$\Delta P_{side} = (K_{out} + K_{side} + f d/L + K_{exit}) \cdot \tfrac{1}{2} \rho v^2 \quad \text{for side holes} \quad (3)$$

,where ΔP_{ent} is pressure drop over the inner channel through center entrance path, ΔP_{side} pressure drop over the inner channel through side hole path, K_{in} form loss of sudden contraction at inner channel entrance, K_{out} form loss of sudden contraction at outer channel entrance, f friction factor, d diameter, L friction length, K_{exit} form loss of inner channel exit, and v average velocity of inner channel. Here, it has to be noticed that all the form loss coefficients are defined on the velocity head of inner channel.

If the pressure drops for two flow paths are measured at the same flowrate, the sum of two terms ($f \cdot d/L + K_{exit}$) is identical each other. Then the loss coefficient of the side holes, K_{side} could be determined by subtracting eq.(3) by eq.(2) as follows:

$$K_{side} = (\Delta P_{side} - \Delta P_{ent}) / \tfrac{1}{2} \rho v^2 - (K_{out} - K_{in}) \qquad (4)$$

From the test section geometry, the form loss coefficient for sudden contraction at the inner channel entrance K_{in} corresponds to an entry from larger pipe with Borda mouthpiece [4];

$$K_{in} = 0.44 \quad \text{at } Re > 10^4 \qquad (5)$$

The form loss coefficient for sudden contraction at the outer channel entrance K_{out} is taken from simple abrupt change of flow area [4];

$$K_{out} = 0.25 \quad \text{at } Re > 10^4 \qquad (6)$$

Then, using the measurement data, the form loss coefficient of the side holes K_s is plotted in Fig. 4 in terms of Re.

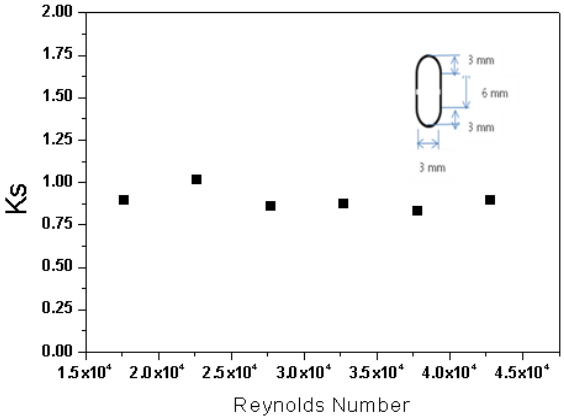

Fig. 4 Loss coefficient of side holes in long end cap

The best fit for K_s was formulated as a constant:

$$K_{side} = 0.90 \qquad (7)$$

Thus it revealed that the K_s is about two times larger than that of K_{in}. According to the previous analysis on the relation of partial blockage of center entrance versus corresponding form loss coefficient [5,6], the form loss coefficient of the side holes K_s is equivalent to a 12 % area reduction in the center entrance.

On the other hand, from the core thermal-hydraulic analysis for OPR-1000 with 120% power [5], a partial flow blockage with 12% at the entrance of inner channel, particularly for hot pin, may cause a decrease of inner channel mass flux by 4% compared to normal flow (no blockage) of lower end cap without side holes. At the condition, the MDNBR of dual-cooled annular fuel core was 3.64, which is much higher than the DNBR limit of 1.3. Therefore, even at the hypothetical event, the fuel does not reach the DNB during the normal operation.

4. Conclusions

A long lower end cap with side holes as the alternative flow path was proposed for the dual cooled annular fuel in order to avoid the occurrence of CHF even in the case of complete blockage at the entrance of the inner channel, as a hypothetical event.

An experiment with single annular fuel within a round tube was performed to measure the form loss coefficient of the side holes in the long lower end cap. It is concluded that the long end cap with side holes can provide the sufficient coolant flow to the inner channel even in the complete blockage of main entrance.

Acknowledgement

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