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Calibration Tests of Fuel Assembly Simulators of APR+ Reactor

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1. Introduction

A Reactor flow distribution is regarded to be major importance in improving the design margin of a flow distribution. The prediction of APR+ core fluid flow phenomena has been in demand, since 257 fuel assemblies are adapted in the APR+, unlike in the APR1400. The APR+ reactor flow test facility, the ACOP (APR+ Core Flow & Pressure Test Facility), was constructed to analyze the hydraulic characteristics [1]. For the ACOP facility, the core simulator was designed with a scale analysis to simulate the real HIPER fuel assembly of an APR+.

In this study, for all 257 core simulators, several calibration tests were conducted to verify their design performance before applying them to the ACOP facility. The inlet flow rate and the total pressure drop of the simulators were measured by varying flow rates to evaluate its compatibility. The discharge coefficients were also calculated from the experimental data to produce a statistical database for a further ACOP facility test.

2. Experimental facility

2.1 Core simulator of APR+

The core simulator was designed to measure the core inlet flow and pressure fields at the inlet and exit of the core, respectively. The simulator was developed to be a high representative test in comparison to a realistic HIPER fuel assembly of an APR+. The 1/5 linear scale was adopted by conserving the geometric similarity. The Euler number was simultaneously preserved to simulate the effect of pressure drop of the fluid flow under a sufficient turbulent flow condition. A summary of the main scaled parameters is shown in Table 1.

A schematic of the core simulator is shown in Fig. 1. The venturi tube at the inlet was designed to simulate the pressure drop between the LEF (Lower End Fitting) and first grid spacer of the HIPER fuel assembly. Four perforate plates and four holes on each side of the quadrant were used for a similarity of the axial hydraulic resistance of the HIPER fuel assembly and the cross flow between the adjacent fuel assemblies, respectively.

2.2 Calibration test facility

The calibration tests were carried out for each of the 257 core simulator using the CALIP (Calibration Loop for Internal Pressure drop) test facility. CALIP consists of a main test section, a flow supply system with piping structures, a water reservoir with two heaters, and a data acquisition system. DP transmitters and Coriolis flow meters with high accuracy were used to obtain more reasonable results. A more detailed description of CALIP was given [2].

Table 1 Main scaled value of core simulator

	APR+ (HIPER)	Core Simulator
Core inlet/outlet average temperature, ℃	309.6	60
Pressure drop, kPa	150.75	52.50
Exit pressure, MPa	15.51	0.2
Mass flow rate, kg/s	81.78	2.28
Length, mm	4527.5	905.5
Hydraulic dia', mm	12.656	34.612
Flow Area, m^2	2.352E-02	9.409E-04
Reynolds number	4.96E+05	1.79E+05

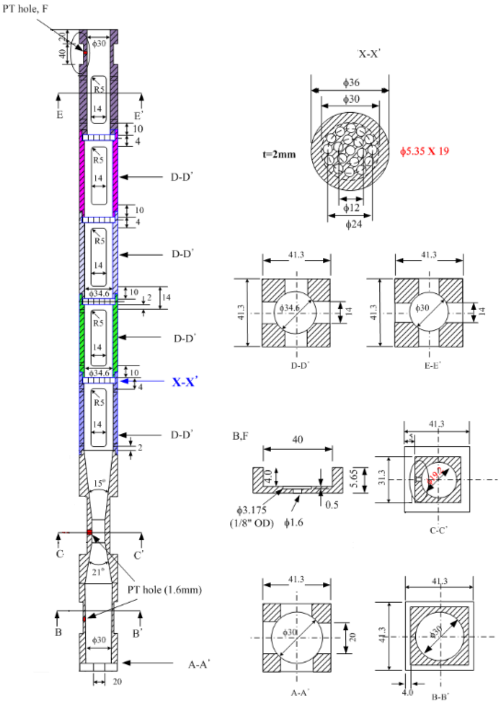

Fig. 1 Schematic diagram of core simulator of APR+

The calibration tests were divided into three types: (1) a screening test for the discharge coefficient of the venturi tube, (2) a calibration test for the total axial pressure drop, and (3) a calibration test for discharge coefficient of venturi tube by varying the flow rate from 40% to 130% of the nominal flow rate (2.28kg/s, see Table 1).

The calibration test was conducted under lower pressure and temperature conditions as shown in Table 1. The first screening test was conducted to confirm the designed venturi tube diameter, which induced a pressure drop due to a sudden variation in shape. If needed, the venturi tube diameter was reproduced. Calibration tests were then performed to verify total pressure drop of the core simulators. The four perforate plates positioned along the simulator's length were developed to simulate an axial hydraulic resistance of the core simulators. The diameter and number of holes on the perforate plate were analytically calculated previously and reconfirmed in this experiment. These previous two confirmation tests were very important, since the discharge coefficient is a function of the pressure gradient, and the pressure gradient may affect the discharge coefficient significantly.

Finally, the calibration test to obtain the discharge coefficient of the venturi tube was carried out by varying the mass flow rates for all of the 257 core simulators. The inlet mass flow rate supplied to the core simulator was controlled by adjusting the Coriolis mass flow meters, and the pressure drop of the venturi throat and whole simulator were measured using ultra-precise grade differential pressure (DP) transmitters. The flow meter and transmitter with two different measurement ranges were used for measurement redundancy to prevent a false signal from damage and/or a malfunction. From the obtained value, the discharge coefficients were calculated for all of the 257 core simulators.

3. Test results

The main results for a 100% nominal flow rate were shown in Fig. 2. The measured pressure drop of the current calibration test was close to the designed value to within a 0.85% relative error. All of the calculated discharge coefficients show minor differences with the average value and small variations, which asserts that the results are reasonable. As another issue, the discharge coefficient depends on the Reynolds number. The average discharge coefficients for varying mass flow rates were shown in Fig. 3. From these data, the curve fits of the calibrated discharge coefficients for the 257 core simulators to be used in the ACOP facility were obtained with good accuracy.

4. Conclusions

Several calibration tests were conducted to evaluate the hydraulic characteristics and performance of the core simulators using the CALIP test facility. The designed venturi flow meter and perforated plates were evaluated and coincided with the target value. The obtained discharge coefficients which cover 25% to 130% of the nominal mass flow rate were expected to be used in estimating the inlet mass flow rate of the fuel channel in the ACOP facility.

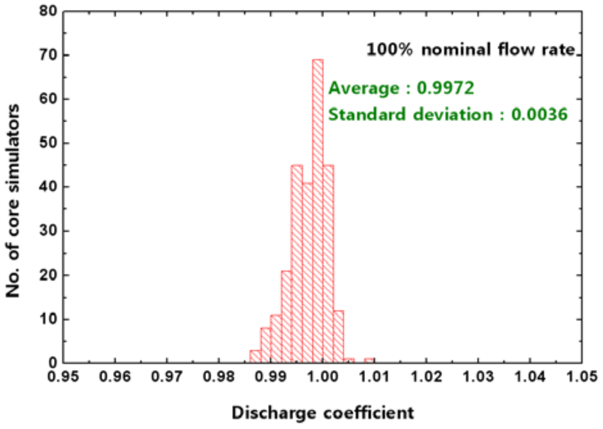

Fig. 2 Discharge coefficient distribution of nominal flow rate (2.28 kg/s) for 257 core simulators

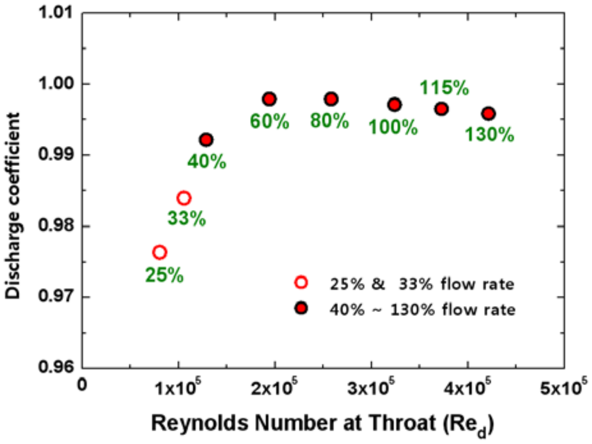

Fig. 3 Discharge coefficient distribution for varying flow rates

Acknowledgement

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