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Calibration of Fuel Assembly Mockup of Advanced Research Reactor

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1. Introduction

Construction of an advanced research reactor is planned to supply useful radioisotopes to industrial and medical fields [1]. The reactor is open-pool type and cooled by forced convection downward flow. Two types of fuel assemblies (FA), standard fuel assemblies (SFA) and follower fuel assemblies (FFA), which serve as a control absorber rod (CAR), are used in the reactor. Each FA is comprised of fuel plates to enhance heat transfer. The channel between the fuel plates is characterized by high aspect ratio narrow rectangular channel. Within the parallel channel system, flow can be maldistributed due to transverse pressure distribution at the channel inlet. Therefore, uniformity of the core flow distribution needs to be validated;

This study addresses calibration of FA mockups, as a supplementary step for the core flow measurement. The relationship between pressure drop and flow rate was obtained as a means of flow measurement. Additionally, the axial flow resistance of FAs was measured to validate hydraulic homogeneity within them.

2. Experimental facility

2.1 FA mockups

Since Hetsroni [2] introduced the reactor hydraulic model using PI theorem, core flow of various types of power reactors have been measured by using linearly-scaled mockup, where the Euler number was matched to preserve similarity [3, 4, 5]. However, Reynolds number of the research reactor flow is not sufficiently high, which does not allow scaling. Therefore, mockups of SFAs and FFAs were fabricated in real-scale. For each assembly, two pairs of common manifolds were machined at interval to measure the pressure drop. These common manifolds were comprised of multiple pressure ports to average the pressure within internal channels. Pressure wave in the common manifolds was transmitted through 1/16-inch pressure line and finally to a differential pressure (DP) transmitter.

2.2 Test sections

At the core, SFA is surrounded by neighboring components with a narrow gap, while FFA is surrounded by the guide tube. Peripheral channel, which contacts with a single fuel plate and orthogonal channel, which is perpendicular to the fuel plate, should be preserved in the calibration experiment. In this regard, square guide tubes were designed to implement single FA flow environment (Figure 1). Pressure taps were machined on the guide tubes to measure pressure drop of peripheral and orthogonal channel flows. Grid plate and lower plenum were also simulated by the mockup. Lower plenum has bulk-head unions to take out 1/16-inch pressure lines of FA mockups. Additional pressure taps were machined on the guide tube and lower plenum to measure total axial pressure drop of FAs.

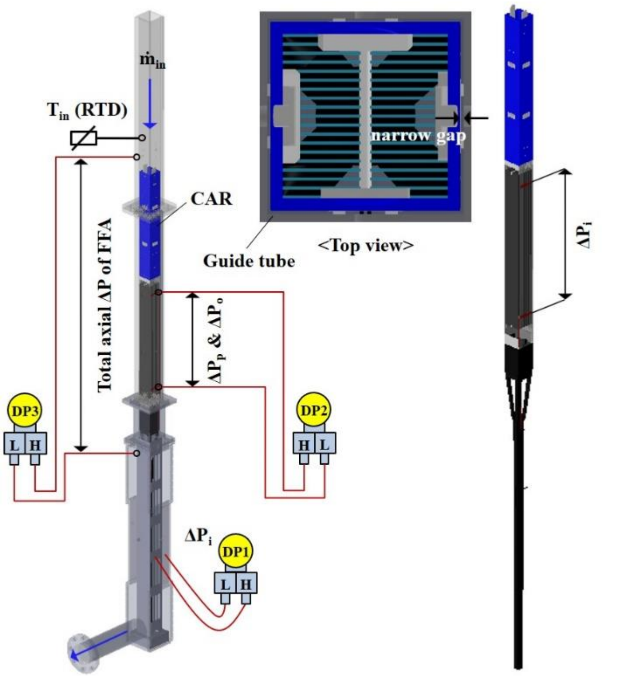
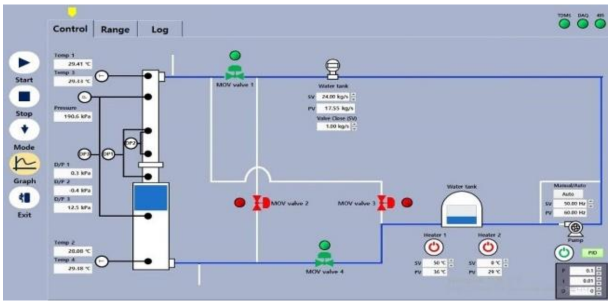


Fig 1 FFA mockup and test section

2.3 Experimental loop

To obtain the relationship between pressure drop and flow rate of internal channels, inlet flow rate condition was set 6~24 kg/s with an interval of 1 kg/s. Calibration was conducted in 35, 40, and 45 °C to evaluate the temperature effect. In the experimental loop, centrifugal pump, immersion heater, and control valves were installed. Several solenoid valves were installed in the loop to vent the air. To measure the inlet flow of the test section, electromagnetic flowmeter was used. Three DP transmitters were utilized in the experiment: (1) ΔP of internal channels, (2) ΔP of peripheral and orthogonal channels, (3) total axial ΔP of FA. Lastly, resistance temperature detector was installed to measure inlet temperature. Experimental procedure was automated by LabVIEW based computer program (Figure 2).



Temp 1 29.41 °C
Temp 3 29.33 °C
Pressure 190.6 kPa
D/P 1 0.3 kPa
D/P 2 0.4 kPa
D/P 3 12.5 kPa
Temp 2 20.00 °C
Temp 4 29.48 °C
Water tank SV 24.00 kg/s
PV 17.55 kg/s
Valve Close (SV) 1.00 kg/s
Manual/Auto Auto
SV 50.00 Hz
PV 60.00 Hz
Heater 1 SV 50 °C PV 36 °C
Heater 2 SV 0 °C PV 29 °C
P 0.1
I 0.01
D 0

Fig 2 Loop schematic and LabVIEW program

2.4 Test result

When the inlet flow meets FA in the guide tube, inlet flow splits into internal, peripheral, and orthogonal channels. Therefore, flow rate of internal channels is:

$$\dot{m}_i = \dot{m}_{inlet} - \dot{m}_p - \dot{m}_o \tag{1}$$

Flow rate in peripheral channel is estimated by inversely calculating the frictional pressure drop.

$$\dot{m}_p = \left(0.1582\emptyset_p\right)^{-\frac{4}{7}} \times A_p \Delta P_p^{\frac{4}{7}} D_{h,p}^{\frac{5}{7}} L_p^{-\frac{4}{7}} \rho^{\frac{4}{7}} \mu^{-\frac{1}{7}} \tag{2}$$

Where combination of the Blasius equation and high aspect ratio correction term proposed by Garland et al. [6] was adopted for friction factor in narrow channel. Density and viscosity values were determined based on the inlet temperature. Similarly, flow rate in orthogonal channel can be calculated. Then, the relationship between mass flow rate and pressure drop of internal channels were linearly correlated in logarithmic scale:

$$\dot{m}_i = a\Delta P_i^b \tag{3}$$

Figure 3 illustrates the representative calibration result from among the FA mockups. Flow rate was slightly larger in higher temperature for the same measured pressure drop, due to decrease in viscosity. For all correlations, coefficient of determination was larger than 0.9999, which indicates that the flow was always in turbulent flow regime. The relative uncertainty of internal channel flow rate was less than 1.3 % for all conditions. Therefore, if the FA mockups are installed in the reactor and pressure drops are measured, the flow rate of FAs can be determined with high fidelity.

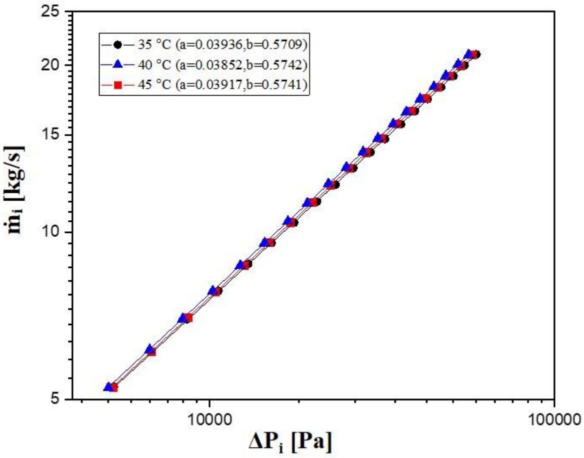


Fig 3 Relationship between ṁᵢ and ΔPᵢ of FFA No.1

Figure 4 depicts total axial flow resistance of SFAs and FFAs for the same flow velocity in internal channel. There were no outliers in quartile plot for the hydraulic characteristics of the mockups within the group. However, higher pressure drop was observed in SFAs compared to FFAs, implying that flow would be more distributed to FFAs in the actual core. When the reactor power is needed to be regulated, vertical position of CAR is changed by fully inserting CAR into the core (FFA_350) [7]. However, change of flow resistance of FFA was meaningless. Therefore, it is anticipated that the effect of CAR position on the core flow distribution is negligible in the actual reactor.

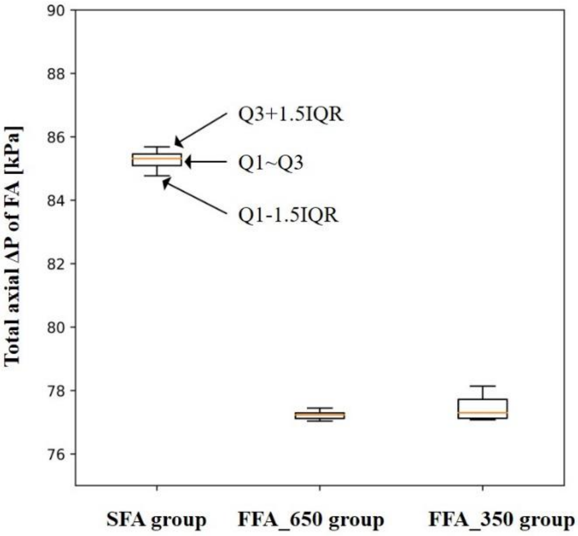


Fig 4 Total axial pressure drop of FA (plotted in quartile)

3. Conclusions

Mockups of SFAs and FFAs were fabricated in real-scale to simulate the reactor and enable the flow measurement. It was confirmed that FA mockups showed hydraulic homogeneity within the group. Obtained correlations will be utilized in real-scale core flow measurement for advanced research reactor.

Nomenclature

ΔP	pressure drop [Pa]
$\dot{m}$	mass flow rate [kg/s]
$\emptyset$	high aspect ratio correction term [-]
A	channel area [m^2]
ρ	density [kg/m^3]
D_h	hydraulic diameter [m]
L	pressure drop interval [m]
μ	dynamic viscosity [N/m^2·s]

Subscript

i	internal channel
inlet	test section inlet
p	peripheral channel
o	orthogonal channel

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