Effect of Entry/Exit Length on Flow Distribution in the Test Bundle

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1. Introduction

Since the departure from nucleate boiling (DNB) should not occur under the condition I and II events, it is important to predict the critical heat flux (CHF) properly in the core of the pressurized water reactor (PWR). The CHF correlation includes the local fluid conditions, which are produced by using the subchannel analysis code. Therefore, the assumptions applied to the subchannel analysis code have to be valid in order to predict the CHF accurately.

In data analysis, the geometric information within the heated section of the rod bundle is important because the CHF occurs in the heated section. To ensure a constant geometry and to prevent adverse flow effects, it is required to extend the same geometry beyond the heated section of rod bundle geometry.

Regarding to evaluate the validity of inlet boundary condition of subchannel analysis code, the effect of the entry and exit length on the flow distribution is evaluated under the various inlet flow conditions which could be produced without flow distributor or strainer.

2. Methods and Results

The geometry and radial power distribution of the CHF test section considered in this paper are shown in Fig. 1. The test section consists of 36 heated rods and 49 subchannels. Heat generated by type I rods (16 rods located in the center of the test section) is relatively larger than heat generated by type II rods (20 rods outside the test section). The axial power shape is assumed to be uniform. In the bottom and top of the test section, the copper extensions are located to connect the heated rods to the power supply.

After the coolant flows through the entry section, it is entered into the heated section. The coolant is heated while it flows in the heated section. At the certain heat flux, the DNB occurs in the heated section and this heat flux is so called CHF. Afterwards, the coolant moves in the exit section and then flows out of the test section. In this study, the effect of the length of the entry and exit section on the flow distribution in the test bundle is evaluated, which is conducted using the subchannel analysis code, THALES (Thermal Hydraulic AnaLyzer for Enhanced Simulation of core) [1-3]. THALES is developed for the thermal-hydraulic design in the PWR core in KEPCO Nuclear Fuel.

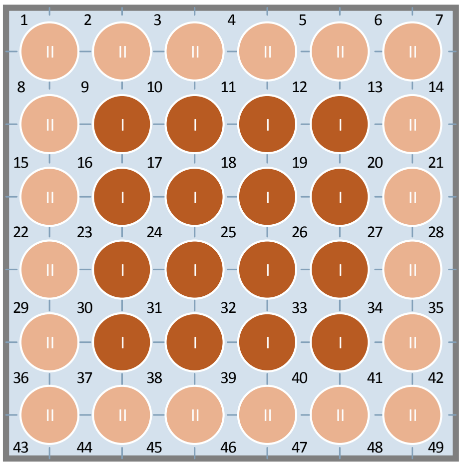


Fig. 1. Schematic diagram of the CHF test section

2.1 Effect of the entry length

In the internal flow, the flow is characterized by the Reynolds number in Eq. (1).

$$Re_D = \rho u d/\mu \tag{1}$$

where, u and d are the average fluid velocity and the hydraulic diameter, respectively. ρ and μ are the density and viscosity of the fluid. To be fully developed flow in the inlet of the test bundle, the entry length (z_{in}) is required. That is, the entry length is defined as the length wich show the same flow distribution regardless of the inlet flow distribution.

For laminar flow, the entry length is expressed in terms of Reynolds number in Eq. (2). [4]

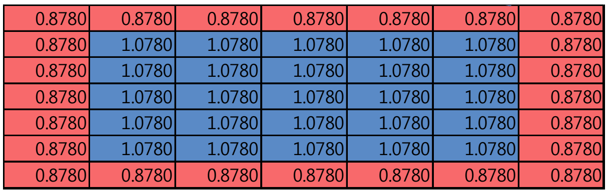
$$z_{in} \approx d \times 0.05 Re_D \tag{2}$$

For turbulent flow, the entry length is obtained in Eq. (3) which is irrelevant to Reynolds number. [4]

$$z_{in}/d \geq 10 \tag{3}$$

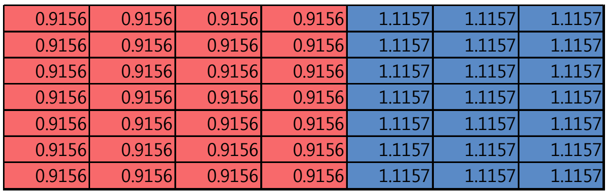
In general, Eq. (3) is mostly applied since the flow in the test section is turbulent. For the evaluation of the non-uniform inlet flow, various non-uniform flow conditions are assumed. Difference between the high and low inlet flow factors is designated 20 % arbitrarily for conservative evaluation. In this paper, three inlet flow distributions are used.

- Center_high_flow and side_low_flow (Fig. 2)
- Side_skewed (Fig. 3)
- Diagonal (Fig. 4)



0.8780	0.8780	0.8780	0.8780	0.8780	0.8780	0.8780
0.8780	1.0780	1.0780	1.0780	1.0780	1.0780	0.8780
0.8780	1.0780	1.0780	1.0780	1.0780	1.0780	0.8780
0.8780	1.0780	1.0780	1.0780	1.0780	1.0780	0.8780
0.8780	1.0780	1.0780	1.0780	1.0780	1.0780	0.8780
0.8780	1.0780	1.0780	1.0780	1.0780	1.0780	0.8780
0.8780	0.8780	0.8780	0.8780	0.8780	0.8780	0.8780

Fig. 2. Inlet flow distribution for center_high_flow and side_low_flow condition case



0.9156	0.9156	0.9156	0.9156	1.1157	1.1157	1.1157
0.9156	0.9156	0.9156	0.9156	1.1157	1.1157	1.1157
0.9156	0.9156	0.9156	0.9156	1.1157	1.1157	1.1157
0.9156	0.9156	0.9156	0.9156	1.1157	1.1157	1.1157
0.9156	0.9156	0.9156	0.9156	1.1157	1.1157	1.1157
0.9156	0.9156	0.9156	0.9156	1.1157	1.1157	1.1157
0.9156	0.9156	0.9156	0.9156	1.1157	1.1157	1.1157

Fig. 3. Inlet flow distribution for side_skewed flow condition case

1.1146	1.1146	1.1146	1.1146	1.1146	1.1146	0.9145
1.1146	1.1146	1.1146	1.1146	1.1146	0.9145	0.9145
1.1146	1.1146	1.1146	1.1146	0.9145	0.9145	0.9145
1.1146	1.1146	1.1146	0.9145	0.9145	0.9145	0.9145
1.1146	1.1146	0.9145	0.9145	0.9145	0.9145	0.9145
1.1146	0.9145	0.9145	0.9145	0.9145	0.9145	0.9145
0.9145	0.9145	0.9145	0.9145	0.9145	0.9145	0.9145

Fig. 4. Inlet flow distribution for diagonal flow condition case

To evaluate the effect of the entry length, three inlet mass fluxes (0.5, 2.0, 3.5 Mlbm/ft^2·hr) are assumed. The schematic diagram of the entry section for the code calculation is assumed as shown in Fig. 5. Gap between the simple supports is 10 inches.

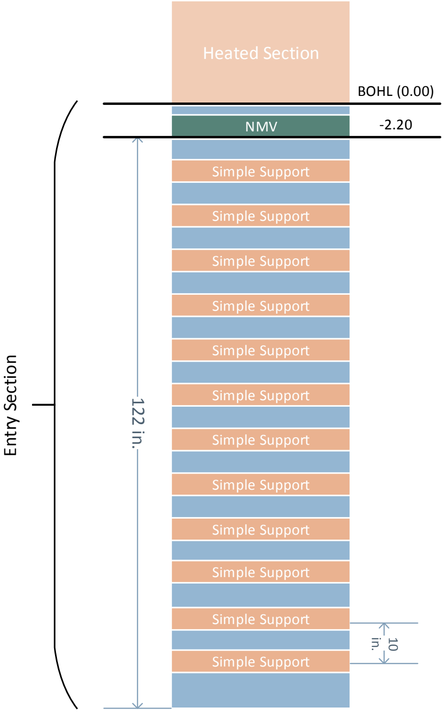


Fig. 5. Schematic diagram to evaluate the effect of the entry length

By combining the inlet flow conditions as mentioned above, various code calculations are conducted and the representative results are shown in Fig. 6 to Fig. 8. These figures present the normalized flow distribution (the ratio of the local mass flux to average mass flux). The mass flux changes due to the rod friction and simple supports and then the flow is to be fully developed gradually. From these figures, it is concluded that at least 40~80 inches of the entry length is required. That is, these results indicate that an assumption related to the inlet boundary condition (fully developed flow or saturated flow distribution) can be applied to the subchannel analysis code if the test bundle has the entry length as mentioned above.

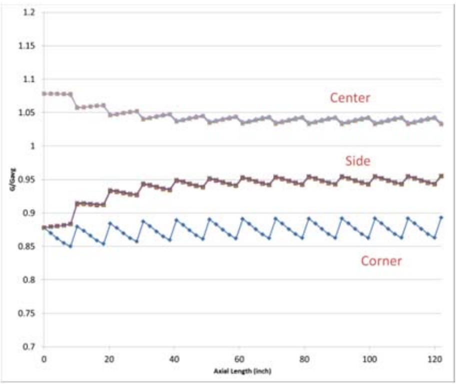


Fig. 6. Flow Distribution under center_high_flow and side_low_flow condition with 2.0 Mlbm/ft^2·hr of mass flux

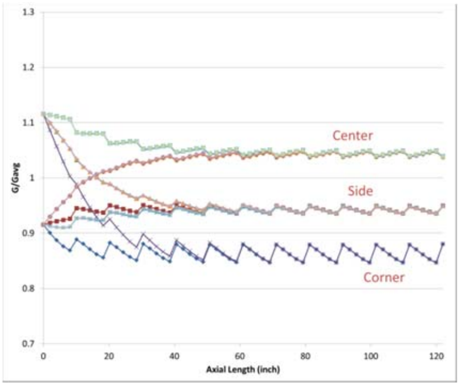


Fig. 7. Flow Distribution under side_skewed flow condition with 0.5 Mlbm/ft^2·hr of mass flux

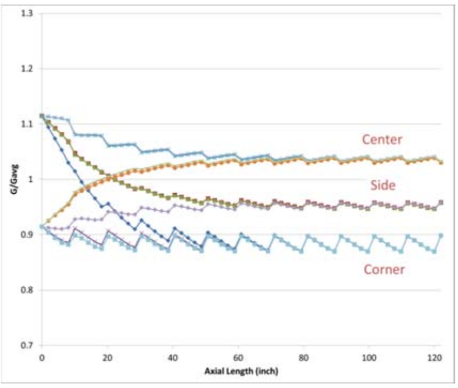


Fig. 8. Flow Distribution under diagonal flow condition with 3.5 Mlbm/ft^2·hr of mass flux

Table I summarizes the entry length according to various differences between the high and low inlet flow factors. The smaller the flow difference is, the shorter the entry length needed is. The entry length is possible to be reduced in order to install the flow distributors or strainer.

Table I: Entry length due to various flow differences

Flow Difference (%)	20	10	0
Inlet Entry Length (in.)	< 60	< 40	< 30

2.2 Effect of the exit length

On the basis of the analysis results presented in previous section, 60 inches of the entry length is assumed to analyze the effect of the exit length. The flow conditions and inlet mass fluxes are identical to those used in previous section. To evaluate the effect of the exit length on the flow distribution, the geometry of the test section is set up as shown in Fig. 9. The test sections are composed of the entry, heated, and exit sections. In this analysis, three exit qualities (0.0, 0.3, 0.5) are added as the test parameter since the quality is one of the important variables.

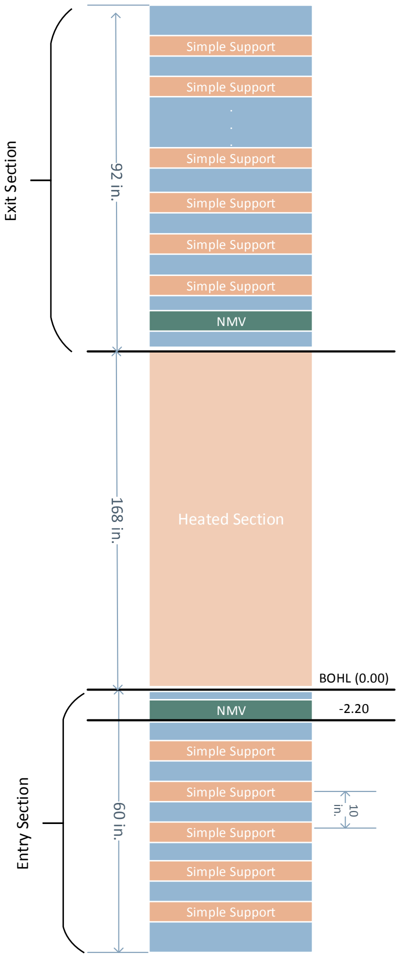


Fig. 9. Schematic diagram for the exit length test

The representative result is shown in Fig. 10 to Fig. 11, which is conducted under the center_high_flow and side_low_flow condition with 2.0 Mlbm/ft^2·hr of mass flux (Fig. 2) and 0.3 of exit quality. From these results, it is concluded that the test bundle has at least 30~40 inches of the exit length to stabilize the exit flow and to minimize the effect of the exit pressure on the thermal hydraulic phenomena of the test section. Under the other calculation conditions, the similar results are produced.

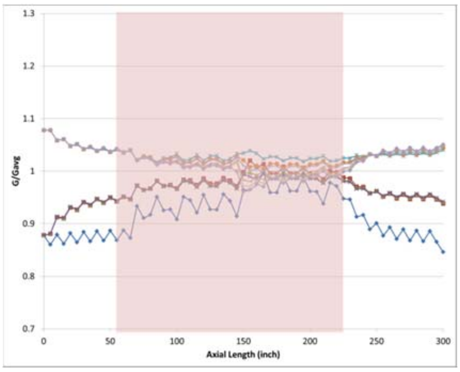


Fig. 10. Results of the exit length test (Flow)

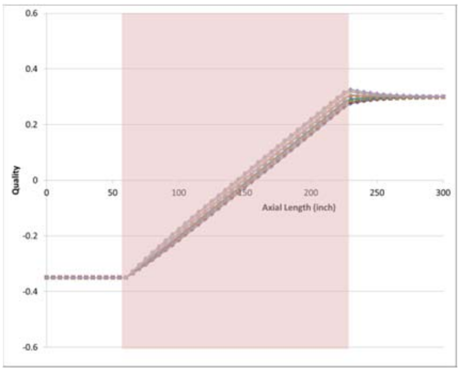


Fig. 11. Results of the exit length test (Quality)

3. Conclusions

To evaluate the validation of the inlet and outlet boundary conditions used in the subchannel analysis code, a study on the effect of the entry and exit length on the flow distribution is conducted. Even though the non-uniform flow is entered inside the test bundle, the flow gets more saturated by the simple supports and frictions. Through the code calculation under various flow conditions, it is concluded that the flow is to be fully developed flow over about 40~80 inches of the entry length. If the exit length is about 30~40 inches, the effect of the exit pressure can be negligible. The entry and exit length in this paper is calculated based on only rod bundles and simple supports. By installing the flow distributors or strainer, these lengths can get shorter and the flow difference between the subchannels become smaller. This study could be very useful in order to confirm the validation of the boundary conditions used in the subchannel analysis code.

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