Pressure Drop Prediction of Rectangular Channel Thermal Hydraulic Test Loop

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1. Introduction

KAERI has been designing an experimental loop mainly focused on testing thermal hydraulic characteristics of rectangular channel under single and two-phase conditions. In this study, two-phase pressure drop characteristics of the test loop has been analyzed for pump selection. First, single-phase pressure drop of the loop has been evaluated using in-house code CORAL. Second, pressure drop multiplier has been evaluated from CHF test data of similar experiment facility. Lastly, aforementioned single phase data and multiplier are combined to predict the loop pressure drop under CHF condition.

2. Methods and Results

In this chapter, pressure drop evaluation methods and results are discussed.

2.1 Single-phase Pressure Drop Characteristics

Figure 1 illustrates schematics of the primary circuit of the test loop along with code nodalization. The loop is composed of rectangular channel test section, preheater, heat exchanger, steam-water separator, and pump. The loop is being designed to simulate single and two-phase flow conditions (up to critical heat flux, CHF) which correspond to steady state and abnormal states of fuel cooling channels of open pool type research reactors fueled by plate-type fuels[1]. The primary pump should be selected to overcome two-phase pressure drop of the system, which is much higher than the single-phase case.

First, single-phase pressure drop of the loop is evaluated utilizing in-house code CORAL[2]. As depicted in Fig.1, the analysis region spans from pump outlet to inlet to obtain system pressure drop. For steam-water separator, only form losses are considered due to lack of information. Table I summarizes analysis conditions. Figure 2 shows stream-wise pressure distribution of the system for 2 selected conditions (6, 10 m/s). The analyses shows that most of the pressure drop occurs in the rectangular channel region, and its portion is increased with velocity.

Table I: Analysis condition for single-phase flow

Item	Value
Test section geometry	width: 66.6 mm, thickness: 2.35 mm
Flow rate	0.2~2.0 kg/s
Coolant temperature	35 ^{o}C
Pump inlet pressure	120 kPa
Pipe surface roughness	0.002 mm (stainless, new) [3]
Friction factor correlation	Colebrook (1939) [4]

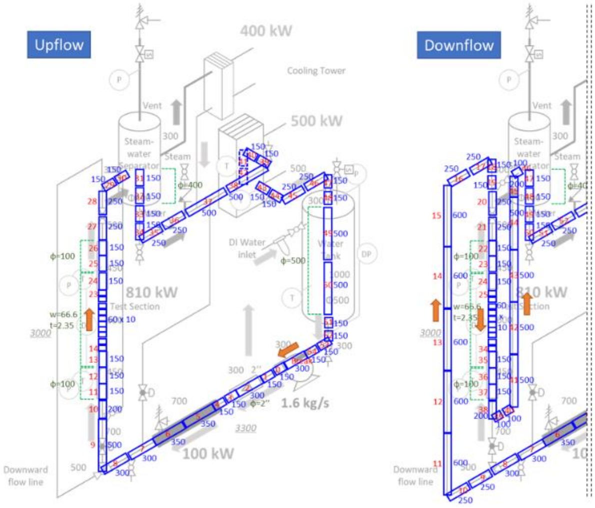
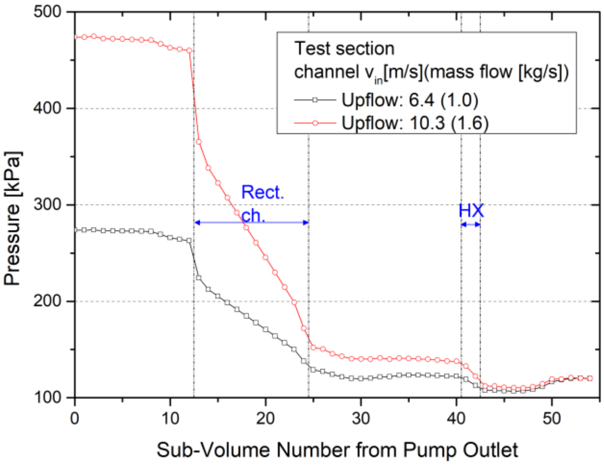


Fig. 1. Schematic diagram and code nodalization of primary circuit (left: upward flow, right: downward flow)



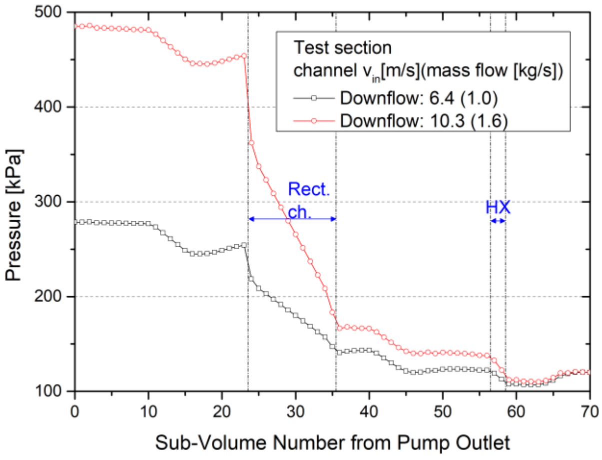


Fig. 2. Pressure distribution for single-phase flow (upper: upflow, lower: downflow).

2.2 Pressure Drop Multiplier

CORAL code can solve momentum and energy conservations only for single-phase flows. In this study, pressure drop multiplier of test section at CHF as defined by Eq. (1) has been obtained and utilized on the single-phase calculation data to predict two-phase (CHF) pressure drop. In order to obtain the multiplier, CHF pressure drop measurement data of reference experimental facility at Pusan National University has been analyzed[5, 6]. The test section pressure drop of the facility has been analyzed using CORAL code and compared with test data to obtain multiplier. Figure 3 shows distribution of the multiplier with respect to mass fluxes.

As it is often discussed, the actual two-phase multiplier has complex relationship with flow conditions and coolant properties which makes obtaining correlation rather difficult. In this study, considering the flow conditions of the test section would be similar to ones used in the reference test facility[6], a simple mass flux based regression curve has been obtained and used. Detailed geometric data of the facility test section are not presented here for proprietary reasons. As shown in Eq. (2), an exponential function gave best R^2_{adj} value (≈ 97%) among tested shapes. Using Origin® Pro program, the measured-to-predicted ratio ('M/P') of the multiplier passed general normality tests, and its 95/95 probability and confidence level range has been obtained and used for conservative pressure drop prediction[7].

$$\Phi_{\Delta P@CHF} = \frac{\Delta P_{test@CHF\ condition}}{\Delta P_{code@single\ phase}} \tag{1}$$

$$\Phi_{\Delta P} = e^{0.61+\frac{5058.84}{G+7.89}} \tag{2}$$

where, G is mass flux [kg/m^2/s].

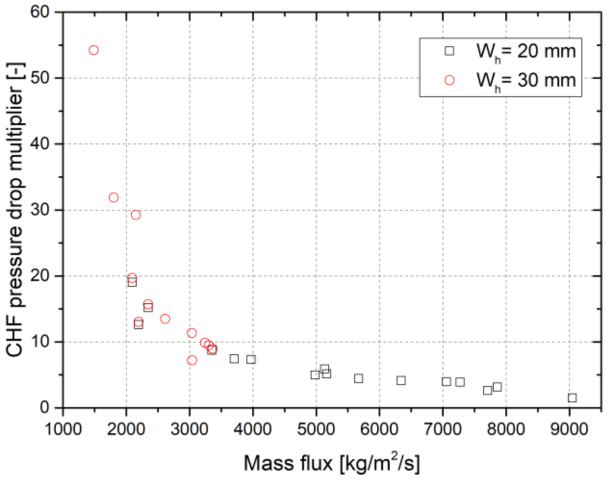
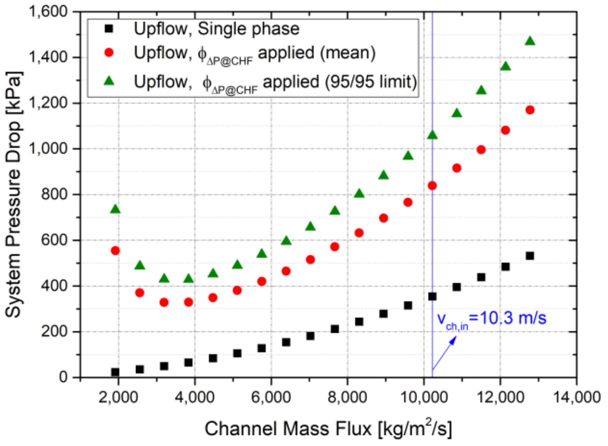


Fig. 3. Distribution of pressure drop multiplier at CHF condition

2.3 CHF Pressure Drop

The previously obtained multiplier has been applied to the test seciton region to predict pressure drop at CHF condition. Figure 4 shows the pressure drop prediction results for upflow and downflow conditions. Considering 95/95 probability and confidence level of the fitting curve, the system pressure drop at CHF condition for target coolant velocity (~10 m/s) was evaluated to be less than 1,100 kPa. In other words, the primary circuit pump should be able to generate at least 115m of water head (assumed 20 °C operation) for successful run of CHF experiment.



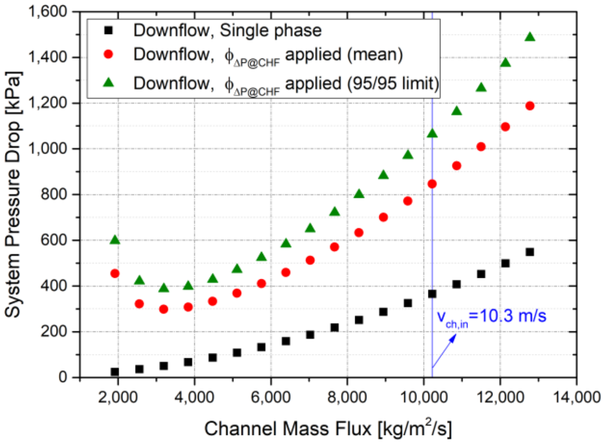


Fig. 4. Predicted system pressure drop at CHF condition (upper: upflow, lower: downflow)

3. Summary

In this study, the pressure drop characteristics of the rectangular channel thermal hydraulic test loop currently under design has been analyzed. The CHF pressure drop measurement data from reference experimental facility with similar thermal hydraulic conditions has been utilized to yield simple form of pressure drop multiplier in terms of the coolant mass flux. Then the multiplier is conservatively applied to the single-phase pressure drop calculation result and the CHF condition value has been predicted. For target operating condition (~10 m/s), the pump should be able to generate more than 115m of water head. This results will be utilized to select appropriate pump for the primary system of the loop. Furthermore, the multiplier presented in this study is only applicable to rectangular channel test section with dimension and flow conditions similar to the reference facility.

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