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Technical Note

A PROPOSED CORRELATION FOR CRITICAL FLOW RATE OF WATER FLOW

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ABSTRACT

A new correlation predicting the idealized critical mass-flow rates of water for subcooled and saturated liquid water including two-phase water flow was developed for a wide range of upstream stagnation pressures (e.g., 0.5–20.0 MPa). A choking correction factor dependent on the upstream stagnation pressure and subcooled temperature was introduced into a new correlation, and its values were suggested to satisfy the idealized nozzle data within 10% error ranges. The suggested correlation will be instructive and helpful for related studies and/or engineering works.

1. Introduction

In the safety analysis of loss-of-coolant-accident (LOCA) and steam generator tube rupture scenarios of light water reactors, a modeling of a break is very important to predict the result of the accident. For example, the design of a break simulator to simulate an LOCA in light water reactors requires accurate knowledge of the leakage flow through the break, whose shape can be assumed as an orifice or a nozzle according to the characteristics of the break shape. In the case of a small-break LOCA scenario, the critical flow mostly occurs by subcooled and saturated liquid water including a two-phase water flow at relatively high-pressure conditions.

Among previous critical flow maps, Moody's [1] maps are well-known for their critical flow rate and pressure of a single-component and two-phase mixture with respect to the upstream enthalpy and pressure. In Moody's [1] model, a slip ratio defined by maximizing the critical flow rate with respect to the slip ratio was introduced, and thus its predictions tended to be too conservative. Later, Moody [2] suggested other maps based on a homogeneous equilibrium model, and they were useful to predict a choked condition for a given upstream condition. However, their predictions of the critical flow rate seemed to show an underestimation compared with various test data.

Kim [3] suggested more practicable critical flow maps for a critical mass flux and pressure of a steam-water flow with respect to the upstream stagnation conditions using an extended Henry–Fauske model [4]. A comparison with the selected test data, for example, Fauske [5], Sozzi and

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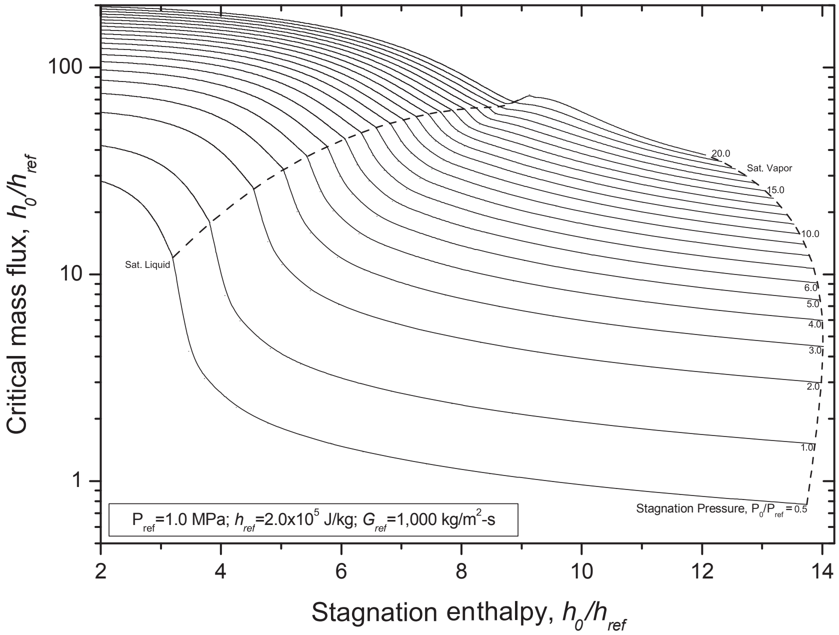

Fig. 1 – Critical mass flux map with respect to upstream conditions for steam-water flow [3].

Sutherland [6], Marviken [7], and Park [8], suggested that critical flow maps showed conservative predictions within reasonable ranges. As a result of the study by Kim [3], a new critical mass flux map based on upstream stagnation conditions [e.g., stagnation pressure (P_0) and enthalpy (h_0)] for steam-water flow was suggested, as shown in Fig. 1. In addition, another map of the corresponding critical pressure at the choking point was also presented in that study by Kim [3].

In another study by Kim [9], a new correlation predicting the idealized critical mass flux of subcooled and saturated water was suggested, which can be applicable for a wide range of stagnation pressures (e.g., 0.5–20.0 MPa). Here, the idealized critical mass flux of subcooled and saturated water corresponds to the left-hand side of the dotted saturated liquid line in Fig. 1. In that study, Kim introduced a new parameter called "choking correction factor" (C_f), which depends on the stagnation pressure and subcooled temperature.

In this report, the application of the correlation proposed previously [9] was extended to the entire range of steam-water flows (e.g., subcooled, saturated water, and two-phase steam-water flows), which simulates the whole regions of the suggested critical mass flux map [3] within a reasonable range of error.

2. An extended correlation for critical flow rate of water flow

Most correlations for the critical flow rate were suggested using an incompressible flow equation for the orifice [10] as follows:

$$g_c = K\sqrt{2\left(P_0 - P_b\right)\rho_{f0}} \tag{1}$$

where g_c is the critical mass flux; K is a discharge coefficient, which is typically 0.61; P_0 is the stagnation pressure; P_b is the backpressure; and ρ_{f0} is the fluid density based on the stagnation condition. Despite its usefulness, the predictions of Equation 1 had some limitations for all ranges of water flow. The orifice-type correlation, like Equation 1, for example, was found to predict a rather underestimated value for large subcooling and an overestimated value for small subcooling and two-phase mixture conditions with respect to the ideal data. The main reason for these discrepancies seems to be due to the use of the total hydraulic pressure difference (e.g., P_0–P_b) as a driving force for the critical flow.

To overcome the limitations of the orifice-type correlation, a practicable correlation predicting the critical flow rate for any kind of water condition using a Bernoulli-type relation was adopted from a previous study [9] as follows:

Table 1 – Values of the choking correction factor for water flow.

Upstream state	Condition	P_0 (MPa)	C_f	Remark
Subcooled and saturated water	$0.0 \le \Delta T^*_{sub} < 0.15$	0.5	0.87	10% error
		1.0	0.85	
		2.0, 3.0	0.83	
		4.0–6.0	0.82	
		7.0–20.0	0.81	
	$0.15 \le \Delta T^*_{sub} \le 1.0$	0.5–20.0	1.0	5% error
Two-phase mixture	$0.0 < x \le 1.0$	0.5	0.81	10% error
		1.0	0.80	
		2.0–11.0	0.79	
		12.0, 13.0	0.78	
		14.0–17.0	0.77	
		18.0	0.76	
		19.0, 20.0	0.75	