Assessment of the RELAP5/MOD3.3 Critical Flow Model using the Experimental Data with Non-condensable gas

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1. Introduction

The default critical flow model in RELAP5/MOD3.3 is the Henry-Fauske choked flow model[1]. To assess the model, two Moby Dick experiments, which were conducted to get the steady state, two-phase, two component critical flow in a vertical test section, was chosen and benchmark calculations using RELAP5/MOD3.3 were performed.

2. Experiment Descriptions

The objective of the series of Moby Dick experiments was to get the critical flow of low quality water and nitrogen mixture through a 7-degree divergent nozzle[2]. Flow is directed vertically upward in the test section. The outlet of the vertical test section is located inside the condenser. Table 1 shows the dimensions of the test section. Nitrogen is injected into the pipe at 0.985 meters upstream of the expansion. Void fraction was measured at the entrance of the test section and various locations before and within the nozzle.

Table 1. Geometry for the Moby Dick Experiments

Straight Inlet Section	
Length	2.668 m
Internal Diameter	0.014 m
Nitrogen Injection location	0.985 m
Conical Convergent Nozzle	
Length	0.2534 m
Divergent Angle	7°
Straight Outlet Section	
Length	0.420 m
Internal Diameter	0.045 m

3. Test Descriptions

Table 2. Measured Test Conditions of Moby Dick Experiment

Test	3052	3151
Upstream Liquid Temp(℃)	35.8	38.5
Upstream Pressure(kPa)	625.8	566.0
Condenser Pressure(kPa)	134.36	102.186
Liquid Flowrate(kg/sec)	1.929	1.094
Nitrogen Entrance Temp(℃)	25	19
Void Fraction at Test Section	0.229	0.612
N_2 Flowrate(kg/sec)	0.001632	0.006252

Two tests (Test 3052, 3151) were chosen for the model assessment. The biggest difference between the tests is the nitrogen injection rate. The nitrogen injection rate of test 3151 is about 4 times higher than that of test 3052. Table 2 lists the measured test conditions

4. Analytical Modeling for the experiments

Figure 1 shows the test section and the corresponding nodalization. The test facility of interest is modeled using 45 sub-volumes of 4 different components (pipe, sngljun, tmdpvol, tmdpjun).

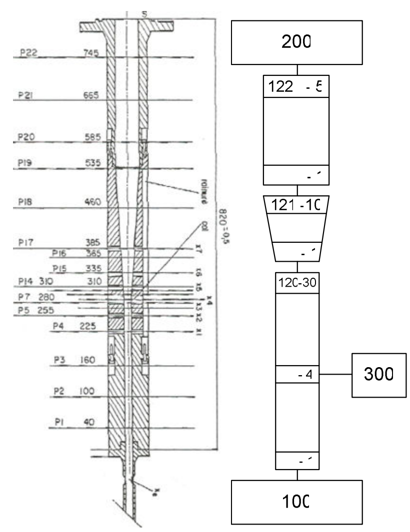

Figure 1. Moby Dick test section & noding diagram

The length of one control volume for the diverging section is determined to model appropriately the gradual volume changes. Irreversible pressure drop loss coefficients(≈ 0.1) for the divergent nozzle were obtained from the correlations presented in Reference 5. The upstream and downstream pressure were modeled using the TDV (Time Dependent Volume) component. The nitrogen flow rate into the test piping is specified using the combination of a TDV and a TDJ (Time Dependent Junction). The main test section is modeled using a Pipe component and nitrogen is injected into a volume connected to the Pipe component. The choking option is applied to the junction connected to the diverging section.

5. Results and Conclusion

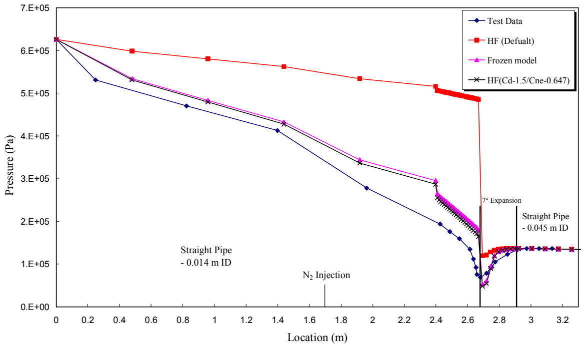

Figure 2. Comparison between pressure measurements and predictions for Moby Dick Test 3052

Figure 2 compares the predicted pressure to the measured data of test 3052. The pressure predicted using the default Henry-Fauske model(C_d=1.0, C_{ne}=0.14) differs significantly from the measured one. On the contrary, the pressure predicted using the Frozen model is relatively close to the measured data.

Table 3. Comparison between mass flow rate measurements and predictions

Test	3052	3151
$\dot{M}_{calc} - \dot{M}_{data} / \dot{M}_{data}$		
HF(Default)	-0.514	-0.663
HF(Adjusted)	-0.064	0.073
Frozen model	-0.077	0.038

The measured critical flows in both tests are compared to the predictions in Table 3. It can be seen from the table that the Henry-Fauske model underpredicts the critical flow rate in both tests. Similar results have been observed in other studies[3][4]. This underprediction is attributed to several defects in the Henry-Fauske model, which can be summarized as follows:

1) The critical value of the mass flux(G_c) is calculated in equation (1). The v_v in equation (1) is calculated at equilibrium conditions for the vapor pressure experiencing the flashing at the throat. The specific volume for the vapor/gas mixture at the throat is defined by equation (2). Thus, the non-condensable gas effects were not taken into account in the calculation of v_v.

$$G_c^2 = \left\{ \frac{x_0 v_v}{\eta P} + \left(v_v - v_{l,0}\right)\left[\frac{(1-x_0)N}{\left(s_{v,eq}-s_{l,eq}\right)}\frac{ds_{l,eq}}{dP} - \frac{x_0 C_{p,v}(1/\eta - 1/\gamma)}{P_t\left(s_{v,0}-s_{l,0}\right)}\right]\right\}_t^{-1} \quad (1)$$

$$\left(v_{v,eq}\right)_t = v_{v,sat}\left(P_v\right)_t \quad (2)$$

2) Within the throat pressure iteration loop of the Henry-Fauske choked flow model, the necessary fluid properties related to two phase as well as the vapor/gas mixture is evaluated. By the way, when the non-condensable gas quality is less than the stagnant quality, the non-condensable gas term is neglected.

$$\frac{dG_c}{dP_t} = f\left(\frac{ds_{l,eq}}{dP}, \frac{dv_{v,eq}}{dP}, \frac{dN}{dP}\right) \quad (3)$$

In the Frozen model, the dN/dP term in equation (3) and the non equilibrium factor are assumed to be zero and one, respectively. When the Frozen model is used, the choked flow is predicted better, but it does not mean that the Frozen model is better than the Henry-Fauske model in the consideration of non-condensable gas effects.

To get a better prediction using the Henry-Fauske model calculations using increased discharged coefficient(C_d) and thermal non-equilibrium constant(C_{ne}) were conducted because the mass flow rate was underpredicted. The best predictions were obtained when C_d of 1.5 and C_{ne} of 0.647 were used. The results in this case are presented also in Table 3.

From the results described above, the following findings and conclusions were made about the RELAP5/MOD3.3 critical flow model.

1. The model needs improvements to take into account the non-condensable gas effects more appropriately because it does have a proper property model for vapor/gas mixture.

2. If the model is used to predict the critical flow with non-condensable gas, C_d of 1.5 and C_{ne} of 0.647 are recommended based on this assessment.

REFERENCES

[1] Information Systems Laboratories, Inc. for the U.S. Nuclear Regulatory Commission, NUREG/CR-5535. Rev. P3, RELAP5/MOD 3.3 Code Manual, March 2003.
[2] Jeandey, C et al., CEA-Centre d'Etudes Nucleaires de Grenoble, Etude Experimentale d'Ecoulements Eau-Air a Grande Vitesse, January 1979.
[3] William J. Krotiuk, Office of Nuclear Regulatory Research, TRAC-M Critical Flow Calculation Assessment, January 2003.
[4] B.D.Chung, Korea Atomic Energy Research Institute, Comparison of Two Critical Flow Models in Relap5/Mod3.3 Patch2(version 3.3ef), Fall 2006 CAMP Meeting October 26-28. 2006.
[5] Idel'chik, I.E., U.S. Department of Commerce, AEC-TR-6630, Handbook of Hydraulic Resistance, 1966.