Onset Condition of the Off take from the Stratified Region to the Branch with Arbitrary Direction

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1. INTRODUCTION

Two phase discharge from a stratified region through single or multiple branches has been studied considerably in the past two decades. The flow distribution in the header-feeder system of CANDU(Canada Deuterium and Uranium) reactors during accident scenario is one of good examples of these applications. Recently, the passive safety feature for PWR(Pressurized Water Reactor) introduce the concept of DVI(Direct Vessel Injection) for the emergency core make up. The expected water sweep out phenomena needs careful models including the curvature effect of down comer shell and the multi branches.

It has been generally accepted that the onset condition of the off take follows the 2.5 power law [1,2], but recently, Lee et al. [3] discussed that the experimental data produced large scattering to the 2.5 power law. Also, the effect of branch angle on the onset point of off take remains still as an unsolved problem. Hwang et al [4] produced the CANDU specific branch angles of 0, +-90, +-36, +-72. The experimental results showed severe deviation from the 2.5 power law and needs mechanistic understanding on these phenomena.

In the present paper, we try to develop a general model of onset point including the branch orientation.

2. METHODS AND RESULTS

2.1 Physics

There are many physical understandings on the onset condition but it can be classified into two categories: force equilibrium and the instability. But both methods need flow field calculation based on the potential flow theory. In the present work, we try to develop the onset condition model based on the force balance theory. Let us setup the Bernoulli energy balance between the points A and B in the figure 1:

$$p_A + \frac{1}{2}\rho_1 v_A^2 + \rho_1 g H = p_B + \frac{1}{2}\rho_1 v_B^2 + \rho_1 g h \qquad (1)$$

Since the suction velocity is faster than the surface velocity at point A($v_A << v_b$), the velocity at the point B can be estimated as :

$$v_B^2 = 2g\frac{\Delta\rho}{\rho_1}\left[H - h\right]$$

Also, the liquid velocity on the superficial flow surface, a hemisphere with the radius of rho measured form the center of the branch inlet is determine dform the potential flow model:

$$v_\rho = \frac{\partial \Phi}{\partial \rho} = \frac{Q}{S}$$

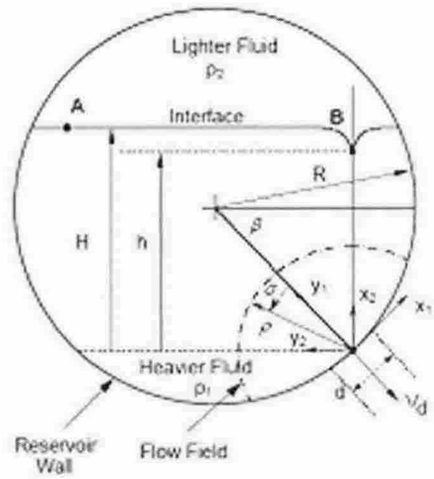


Figure 1. Conceptual Diagram of the onset mechanism to define the Bernoulli energy balance, fluid potential, and the superficial flow surface for the local velocity.

The force balance is made at the point B in which the fluid acceleration and gravitational acceleration of the vapor cone , i.e. buoyancy acceleration :

$$a_B = g$$
$$a_B = -\left.\frac{\partial \Phi}{\partial x_2}\right|_B \left.\frac{\partial^2 \Phi}{\partial x_2}\right|_B \qquad (2)$$

2.2 Ahmed et al.

Recently Ahmed et al.[5] developed a model for the onset of offtake based on their geometrical interpretation as follows:

$$\frac{H_{OGE}}{d} = \frac{R}{d}h^* + \left(\sqrt{gd\frac{\Delta\rho}{\rho}}\right)^{-1}\frac{g\sin\beta R h^{*3} I_1(h^*)}{4\left(h^{*2} I_1(h^*) - I_2(h^*)\right)} \qquad (3)$$

However, the above equation has singular and imaginary values so the application range is limited.

2.3 The present model

The major reason of the complicated integration of the Andalleev et al's approach is the estimation of the effective fluid surface to estimate the suction fluid volume rate(Q). In the present model, we slightly change the surface integration which is very analytical without large error.

$$S = 2\pi\rho^2 - 4\pi\rho^2 \int_{\cos^{-1}\frac{\rho}{2R}}^{\pi/2} \sin\sigma\cos\sigma d\sigma$$
$$= 2\pi\rho^2 - \frac{\pi\rho^2}{2}\left(\frac{\rho}{R}\right)^2$$

(4)

The velocity field is determined from the above surface and the outlet volume rate:

$$\left.\frac{\partial\Phi}{\partial x_2}\right|_B = \left.\frac{\partial\Phi}{\partial\rho}\right|_{\rho=h} = \frac{Q}{2\pi R^2 h^{*2} - 0.5R^2 h^{*4}}$$

(5)

Acceleration of the flow field also determined with the following relation:

$$\frac{\partial}{\partial x_2}\left(\left.\frac{\partial\Phi}{\partial x_2}\right|_B\right) = \frac{\partial\rho}{\partial x_2}\frac{\partial}{\partial\rho}\left(\left.\frac{\partial\Phi}{\partial\rho}\right|_{\rho=h}\right)$$
$$= -\left(\frac{Q}{\sin\beta}\right)\frac{\left(4\pi Rh^* - 2\pi Rh^{*3}\right)}{\left(2\pi R^2h^{*2} - 0.5\pi R^2h^{*4}\right)^2}$$

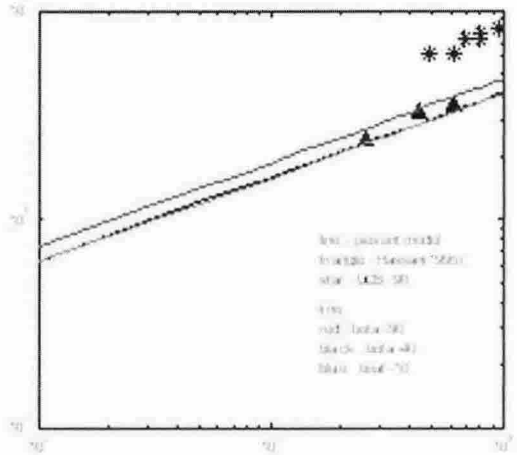
(6)

With some algebraic work, the onset condition of the off take is determined in the following form which is very analytic without any singularity or imaginary value. Furthermore, the results naturally include the orientation of the branch:

$$\frac{H_{OGE}}{d} = \frac{R}{d}h^* + \frac{1}{2}A_d^2 Fr^2\left(2\pi R^2h^{*2} - 0.5\pi R^2h^{*4}\right)^{-2} \quad (7)$$
$$= \frac{1}{2}\left(\frac{D}{d}\right)\left[h^* + h^*\left(\frac{2-0.5h^{*2}}{4-2h^{*2}}\right)\sin\beta\left(\frac{\rho}{\Delta\rho}\right)\right]$$

2.4 Results

The present correlation for the onset condition was tested by the experimental data of Hassan[6]. The data with triangle mark are made by Hassan. For UCB, star marks are used. As shown in Fig.2, the data of UCB show a large deviation from the present model. The orientation of the branch was tested by the angles, -90, -40, and -10 degree. The onset conditions of -90 degree and -40 degree are very close to each other but that of -10 degree branch are far away from the value. From this observation it can be said that the dependency of the onset condition upon the orientation of the branch is very nonlinear so simple average between the vertical result and horizontal result with weighting of the angle should be prohibited in the analysis and need more careful experimental validation is requested .



.Figure 2. The onset condition for the downward branches with angles of -90, -40,-10 with respect to the Froud number

3. CONCLUSION

The onset condition of the off take plays a key role in estimation of the quality and the mass flow rate in the branch when the two-phase discharge occurs between the stratified region through branches. In the present paper, we modify the analytic model based on the force balance at the pichfork bifurcation point on the stratified surface. The potential flow theory was adopted to calculate the local acceleration and velocity at the onset point. The final equation derived has complicated function of Froud number and the orientation of the branch. The functional form has physical soundness but need further effort to improve based on the experimental data by including other accelerations not included in the present model

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