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The Research of Effect of 2-phase Loss Multiplier on Density Wave Instability Phenomena in Natural Circulation Loop

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1. Introduction

The secondary fluid is circulated by natural circulation in a PWR type steam generator. In this case, a driving force of natural circulation is buoyancy caused by phase change, and the fact that, for density wave instability, natural circulation circuit is more unstable than forced circulation circuit, was widely known [1], [2]. The instability may cause self-sustained or even divergent, flow oscillations in operating nuclear power plant's steam generator. Such flows could induce a boiling crisis, disturb the control system, or may cause mechanical damage due to excitation of flow induced vibrations [3].

Bae et al. developed density wave instability model for PWR type steam generator, using Takeuchi drift flux model, Beattie's local loss multiplier, Thom's friction loss multiplier, and linear perturbation method. [4]

Thus, the objective of this paper is to modify the Bae et al.[4] using Anderson et al.'s [5] experimental data. (ANL experimental data)

2. Mathematical Model Description

2.1 Governing Equation

Following equations are the governing equations for the Bae et al. [4].

Continuity equation

$$\frac{\partial \bar{\rho}}{\partial t}+\frac{1}{A}\frac{\partial W}{\partial z}=0$$

Energy equation

$$\frac{\partial}{\partial}\left(\bar{\rho}\bar{i}\right)+\frac{1}{A}\frac{\partial}{\partial z}\left(Wi\right)=\frac{q''P}{A}+\frac{\partial p_{SYS}}{\partial t}$$

Momentum equation

$$\frac{1}{A}\frac{\partial W}{\partial t}+\frac{1}{A}\frac{\partial}{\partial z}\left(\frac{W^2}{A\bar{\rho}}\right)$$

$$=-\frac{\partial p}{\partial z}-\frac{1}{A}\frac{\partial}{\partial z}\left(A\frac{\rho_L-\bar{\rho}}{\bar{\rho}-\rho_G}\frac{\rho_L\rho_G}{\bar{\rho}}{u'_{Gj}}^2\right)-\frac{2fW^2}{A^2\rho_L D}\phi_{LO}^2$$

$$-\bar{\rho}g\sin\theta-\sum_k K_k\frac{W^2}{2A_{k,OUT}^2\rho_L}\Phi_{LO}^2\delta'\left(z-z_{k,OUT}\right)$$

$$-\sum_k\frac{W^2}{2A_{k,IN}^2}\left(\frac{1}{\rho''_{k,IN}}-\frac{1}{\eta^2\rho''_{k-1,OUT}}\right)\delta'\left(z-z_{k,IN}\right)$$

For single-phase region

$$\bar{\rho}=\rho_L$$

$$\rho''=\rho_L$$

$$\Phi_{LO}^2=\phi_{LO}^2=1$$

For two-phase region

$$\bar{\rho}=\rho_L(1-\alpha)+\rho_G\alpha$$

$$\bar{\rho}\bar{i}=\rho_L i_L(1-\alpha)+\rho_G i_G\alpha$$

$$\rho''=\left[\frac{(1-x)^3}{\rho_L^2(1-\alpha)^2}+\frac{x^3}{\rho_G^2\alpha^2}\right]^{-1}\left(\frac{x}{\rho_G}+\frac{1-x}{\rho_L}\right)$$

$$\Phi_{LO}^2=\left[1+x\left(\frac{\rho_L}{\rho_G}-1\right)\right]^{0.8}\left[1+x\left(3.5\frac{\rho_L}{\rho_G}-1\right)\right]^{0.2}$$ (by Beattie[6])

$$u'_{Gj}=u_{Gj}+\left(C_0-1\right)j$$

C_o, u_{Gj} = Drift flux model coefficients, calculated by Takeuchi's model

2.2 Linear Perturbation method

Bae et al. considered the perturbation of most of parameters (inlet/outlet enthalpy for each node, inlet/outlet mass flow rate for each node, system pressure, boiling start point, other parameter's perturbations are derived to these perturbations) using linear perturbation method, but didn't consider for several parameters. (ρ'', ϕ_{LO}^2, Φ_{LO}^2, C_o and u_{Gj})

2.3 Sudden expansion/contraction

When there is sudden expansion or contraction, pressure drop is calculated by sum of spatial acceleration (which is calculated by separated flow model's energy balance) and local loss (which is calculated by Beattie loss multiplier).

$$\Delta P_{sudden\ area\ change}=K_{k\text{-}1,OUT}\frac{W^2}{2A_{k,in}^2\rho_L}\Phi_{LO}^2$$

$$+\frac{W^2}{2A_{k,IN}^2}\left(\frac{1}{\rho''_{k,IN}}-\frac{1}{\eta^2\rho''_{k-1,OUT}}\right)$$

But this equation has limit for severe sudden expansion (e.g. between separator and steam drum). Fig. 1 indicates predicted pressures by several models for between separator and steam drum.

As shown in Fig. 1, pressure loss model, used in Bae et al.[4], has different estimation value, whereas other correlations have similar estimation value. Thus, these pressure drop equations are replaced to homogeneous model, and the perturbations of these two terms are derived.

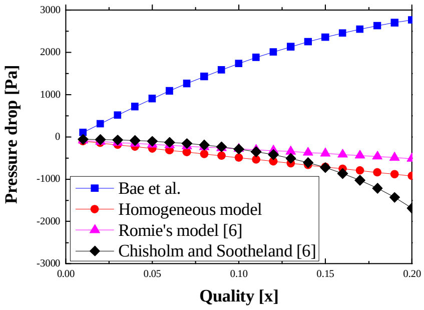

Fig. 1 predicted pressure losses by several models for separator and steam drum (21.7 bara, 0.458 kg/s)

$$\Delta P_{sudden\ area\ change} = K_k \frac{W^2}{2A^2}\left(\frac{1-x}{\rho_L}+\frac{x}{\rho_G}\right)$$

$$+\frac{W^2}{2A^2}\left(1-\frac{1}{\eta^2}\right)\left(\frac{1-x}{\rho_L}+\frac{x}{\rho_G}\right)$$

$$A = \min\left(A_{k-1,OUT}, A_{k,IN}\right)$$

$$\eta = \frac{\min(A_{k-1,OUT}, A_{k,IN})}{\max(A_{k-1,OUT}, A_{k,IN})}$$

2.4 Friction loss multiplier

Bae et al. used Thom's friction multiplier, but Martinelli-Nelson(M-N) friction loss multiplier provides more accurate pressure drop estimates in the low mass velocity range (G<1360 kg/m^{2}s, [6]), and velocity for most experimental cases is lower than 1360 kg/m^{2}s. Thus friction loss multiplier was replaced to M-N model, and the perturbations were derived.

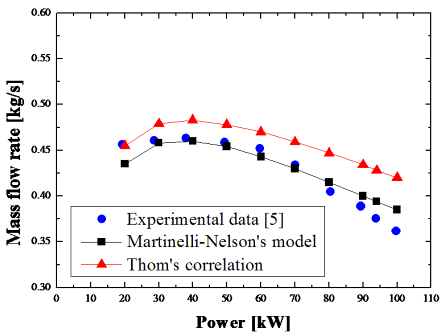

Fig. 2 Mass flow rate comparison between Thom's correlation and Martinelli-Nelson's model at 400 psig

Fig. 2 indicates calculated mass flow rate differenced by each friction loss multiplier. As shown in figure, when mass flow rate is calculated by Thom's correlation, the mass flow rate is over-predicted. The cause is estimated by above reason.

2.5 Analysis results and discussion

Based on Bae et al.[4], computer code was developed using visual basic. Fig. 3 indicates Bae et al. [4], modified Bae et al. and ANL experimental results. In the figure, error bar means 20 % error for experimental data.

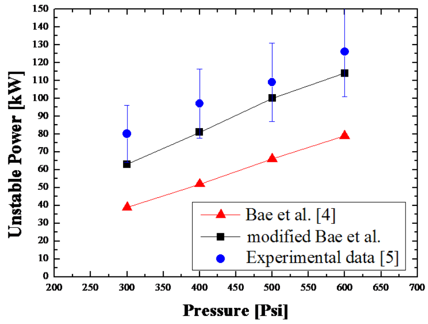

Fig. 3 Comparison between Bae et al., modified Bae et al. and ANL experimental results

3. Conclusion

Based on Bae et al. [4], computer code was developed using visual basic. Previous equations for sudden expansion and contraction equations are replaced to homogeneous model due to mis-estimation at downstream of separator, and friction loss multiplier is replaced from Thom's correlation to Martinelli-Nelson model due to accurate mass flow rate prediction. As a result, through change of 2 phase multipliers and their perturbation derivation improved prediction was obtained.

REFERENCES

[1] Nayak, A. K., and Vijayan, P. K., "Flow Instabilities in Boiling Two-Phase Natural Circulation Systems: A Review," *Science and Technology of Nuclear Installations*, Vol. 2008, 2008.

[2] Vijayan, P. K., Nayak, A. K., Saha, D., and Gartia, M. R., "Effect of Loop Diameter on the Steady State and Stability Behaviour of Single-Phase and Two-Phase Natural Circulation Loops," *Science and Technology of Nuclear Installations*, Vol. 2008, 2008.

[3] G-C Park, M. Z. Podowski, M. Becker, R. T. Lahey, Jr. and S. J. Peng, "The development of a closed-form analytical model for the stability analysis of nuclear-coupled density-wave oscillations in boiling water nuclear reactors," *Nuclear Engineering and Design*, Vol. 92, pp. 253-281, 1986.

[4] J.H. Bae, S. Kim, Y.J. Choi and S.Y. Lee, "Effect of operating variables on the density wave instability phenomena of PWR steam generator", KSME 2011 fall conference, pp. 1434-1439, 2011.

[5] R. P. Anderson, L.T. Bryant, J. C. Carter and J. F. Marchaterre, "Transient Analysis of Two-Phase Natural-Circulation Systems," *Argonne National Laboratory*, ANL-6653, 1962.

[6] J. G. Collier, "Convective boiling and condensation", *McGraw-hill international book company*, 1981