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BRIEF COMMUNICATION

A SIMPLIFIED METHOD OF DETERMINING FLOW PATTERN TRANSITION OF TWO-PHASE FLOW IN A HORIZONTAL PIPE

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Taitel & Dukler (1976a) showed that the gas velocity for waves to grow on a liquid at the gas–liquid interface is

$$\bar{U}_G > \left(1-\frac{\delta_L}{D}\right)\left[\frac{(\rho_L-\rho_G)g\delta_G}{\rho_G}\right]^{1/2} \quad [1]$$

where $\bar{U}$ is the true velocity, δ the phase depth, D the conduit diameter, ρ the density, g the acceleration due to gravity and the subscripts L and G refer to liquid and gas respectively.

Use of [1] in determining flow pattern transitions in horizontal two-phase flow is facilitated by having a relation between the air gap and phase holdup. It is desirable to have a simple relationship for substitution in the equation in order to give ease of application, particularly in the field situation and in computer coding.

The holdup, $\bar{R}$, for equilibrium stratified flow in a circular conduit may be evaluated by the Taitel & Dukler (1976b) method, or more simply by using stratified flow holdup equations derived by Chen & Spedding (1979) and Spedding & Chen (1979).

A simpler relationship between δ_G and $\bar{R}_G$ than the graphical one used by Taitel & Dukler (1976a) may in fact be conveniently arrived at by a simple geometrical consideration and the approximate solution obtained by a straight line curve-fit method to give;

$$\delta_G/D = 0.80\bar{R}_G^{0.69} \qquad \text{for } \bar{R}_G < 0.5\,, \quad [2]$$

$$\delta_G/D = \bar{R}_G \qquad \text{for } \bar{R}_G \geq 0.5\,. \quad [3]$$

It is possible to employ exact curve fitting methods but this would unnecessarily complicate the whole approach without providing any worthwhile increase in precision. Moreover, since flow pattern predictions always involve a rather large degree of inaccuracy, the errors introduced by using [2] and [3] will not be sufficient to cause an effective offset on any resulting prediction.

For the horizontal slug-annular flow transition, Taitel & Dukler reasoned that if an unstable wave is formed and reaches the top of the channel, the resultant flow pattern will be slug or annular depends on whether the initially assumed equilibrium stratified flow had a liquid level of greater or less than half the height of the flow channel. In the first case there is sufficient liquid to maintain continuity in the liquid phase thus blocking off the entire flow cross-section. This is the reason why the suggested (δ_G/D) vs $\bar{R}_G$ relationship is divided into two ranges with the change over point at $\bar{R}_G = 0.5$.

In the case of a high flow rate reticulation system, such as the one at the geothermal field at Wairakei, New Zealand, the predominant flow patterns are slug and annular flow. For the efficient operation of the steam–water system, it is important that the flow pattern by predicted accurately and conveniently. Since the flow rates are high and therefore the phases are both in the turbulent flow regimes, the equation governing the equilibrium stratified flow may be chosen appropriately from Spedding & Chen (1979). The conditions for slug and annular flow may be more conveniently written as;

for slug flow to occur $\quad \bar{R}_G/\bar{R}_L < 1.0$,

for annular flow to occur $\quad \bar{R}_G/\bar{R}_L \geq 1.0$.

The equation to be used for predicting $\bar{R}_G/\bar{R}_L$ when its value is close to unity is,

$$\frac{\bar{R}_G}{\bar{R}_L} = 1.48\left(\frac{Q_G}{Q_L}\right)^{0.77}\left(\frac{\rho_G}{\rho_L}\right)^{0.34}\left(\frac{\mu_G}{\mu_L}\right)^{0.09}. \qquad [4]$$

Thus, to check whether the flow is annular or slug, it is merely a matter of determining whether [4] is greater or less than unity. Equation [4] may also be expressed in terms of the dryness fraction.

It is to be noted that the diameter has no effect on the slug-annular transition when both phases are in turbulent flow regime in the equilibrium stratified flow situation. The diameter still has no effect if both phases are in the laminar flow regime although this is not a common practical situation. However, if the phases are in dissimilar flow regimes, the slug–annular transition will be affected by the diameter since the equations for ($\bar{R}_G/\bar{R}_L$) contain the diameter term.

The equations obtained together with the appropriate equilibrium stratified flow equations derived by Spedding & Chen (1979) are used to calculate the superficial velocities U_{LS} and U_{GS} at transition for comparison with the flow regime maps of Mandhane *et al.* (1974) and Taitel & Dukler (1976). Figure 1 shows the predicted transition boundaries for air–water flow in a 4.55-cm-diameter pipe plotted vs those given by Mandhane *et al.* Also plotted are the transition lines obtained by Taitel & Dukler for a 5.0-cm-diameter pipe corresponding to the transitions analysed in this work. Data from Chen (1979) are also included. In general there is good agreement between the theoretical prediction and experimental data. It is to be noted that Mandhane's transition boundaries were derived using data obtained mainly from 1.3 to 5.0-cm-diameter pipes. Pipe diameter effect may also be investigated using these equations but since Taitel & Dukler have already carried out that examination, it will not be repeated here. Harrison (1975) has in fact shown that the flow regime map of Mandhane is superior to the Baker chart when applied to the Wairakei geothermal steam–water system. It is, therefore, envisaged that the analysis carried out here should prove useful in the geothermal field for determining the annular–slug transition.

In this work, three flow pattern transitions, stratified–annular, stratified–slug and annular–slug, were examined in the light of the equilibrium stratified holdup prediction equations derived by Spedding & Chen (1979). The very crude relationships obtained by using piecewise straight line curve fit for δ_G/D and $\bar{R}_G$ appear to be adequate for the purpose of regime boundary prediction and as a result, lead to a greatly simplified set of equations. The advantages that this analysis has over that of Taitel & Dukler are listed as follows:

(1) No complicated dimensionless equations are involved.

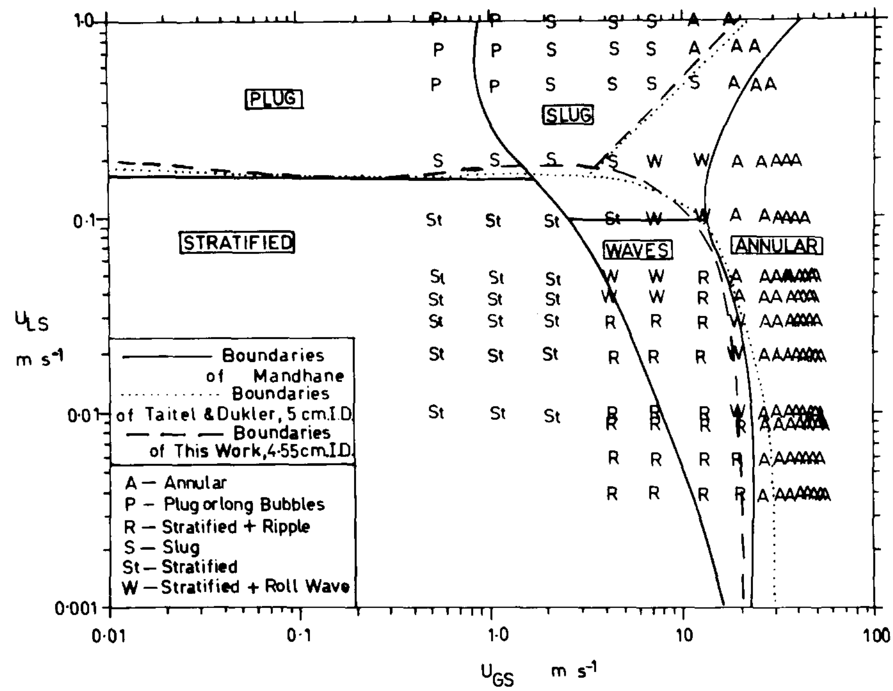

Figure 1. Comparisons of the stratified–annular–slug flow pattern transitions derived in this work with those of Taitel & Dukler (1976a), Mandhane *et al.* (1974) and the observed flow patterns of Chen (1979). The flow patterns observed by Chen (1979) are shown as letters while the general flow pattern region observed by Mandhane *et al.* (1974) and Taitel & Dukler (1976a) are labelled accordingly.

(2) No graphs are essential for the evaluation of the equations since all the solutions are expressed explicitly in equation form. This provides a simple means of putting flow pattern transition relationships into computer codes.

(3) Because all controlling situations are expressed in simple equation form, it is possible for the use of one simple equation to determine the annular–slug transition. This should prove useful in a field situation such as that of a geothermal or an oil field.

(4) The form of equation for unstable wave growth in a circular conduit has been greatly simplified in terms of $\bar{R}_G$.

REFERENCES

CHEN, J. J. J. 1979 Two phase gas–liquid flow—with particular emphasis on holdup measurement and predictions. Ph.D. Thesis, University of Auckland.

CHEN, J. J. J. & SPEDDING, P. L. 1979 Correlation of holdup in two-phase flow. *ANZAAS* **49**, 16.

HARRISON, R. F. 1975 Methods for the analysis of geothermal two-phase flow. M.E. Thesis, University of Auckland.

MANDHANE, J. M., GREGORY, G. A. & AZIZ, K 1974 A flow pattern map for gas–liquid flow in horizontal pipes. *Int. J. Multiphase Flow* **1**, 537–553.

SPEDDING, P. L. & CHEN, J. J. J. 1979 Correlation and measurement of holdup in two-phase flow. *Proc. N.Z. Geothermal Workshop* **1**, 180–199.

TAITEL, Y. & DUKLER, A. E. 1976a A model for predicting flow regime transitions in horizontal and near horizontal gas–liquid flow. *A.I.Ch.E. J.* **22**, 47–56.

TAITEL, Y. & DUKLER, A. E. 1976b A theoretical approach to the Lockhart–Martinelli correlation for stratified flow. *Int. J. Multiphase Flow* **2**, 591–595.