Int. J. Multiphase Flow Vol. 8, No. 6, pp. 683–693, 1982
Printed in Great Britain.

0301-9322/82/060683-11$03.00/0
Pergamon/Elsevier

TWO-PHASE FLOW MEASUREMENTS WITH SHARP-EDGED ORIFICES

Z. H. LIN

Xian Jiao-Tong University, Xian, The People's Republic of China

(*Received* 21 *January* 1981; *in revised form* 15 *April* 1982)

Abstract—This paper contains the results of a set of two-phase flow measurements of 4 different ratios of vapor to liquid density (up to 0.328) across a sharp-edged circular orifice. Test fluid was R-113. Tests were carried out upon 3 orifices whose diameter ratios were 0.312, 0.439 and 0.625. The test quality ranged from 0–100%, while the mass velocity from 917–1477 kg/m^2.s. On the basis of a modified separated flow model, a relationship is developed for the flow rate and quality and is compared with experimental data and 5 proposed correlations. Comparison shows this method can be used to calculate the flow rate or the quality of vapor liquid (or steam water) mixture in the range 0.00455 to 0.328 of the density ratio, and in pipe size ranging from 8 to 75 mm ($\beta = 0.25$–0.75).

The RMS error of this method is about 12% when the quality, x, ranges from 2% to 100%.

1. INTRODUCTION

Measurements of flow rate and quality of vapor liquid mixture are of interest in many fields of engineering such as power cycles, chemical, geothermal, petroleum and control. An orifice is a convenient and reliable device and has sufficient accuracy for these measurements, it has been receiving increasing attention in the recent two decades, and a considerable number of papers on this topic have been published. For instance, the use of orifices for quality and flow rate metering is described by Hoopes (1957), Ragolin (1958), Murdock (1962), James (1965), Bizon (1965), Chisholm (1967, 1974), Heckle (1970), Collins & Gacesa (1971), Smith & Leang (1975), Lorenzi & Muzzio (1976) and Smith & Murdock (1977).

However, in previous studies, all experiments were conducted with a low ratio of gas (or steam) density ρ_G to liquid density ρ_L, ρ_G/ρ_L. The highest tested ratio was $\rho_G/\rho_L = 0.107$ and the largest tested ratio of the operating pressure to the critical pressure was $P/P_c = 0.535$ (table 1). Apparently, these cannot satisfy the requirements of various practical engineering problems. In addition, the effective ranges of these proposed correlations are in narrow limit, and there is a lack of generality in them.

This paper contains the results of a set of two-phase flow measurements of high ρ_G/ρ_L (up to 0.328) and high P/P_c (up to 0.8319) across a sharp edged circular orifice. On the basis of a modified separated flow model, a simple and rational relationship is developed for the flow rate and quality by the introduction of a corrective coefficient θ, to be determined empirically. θ is a function of ρ_G/ρ_L and is derived from the experimental data of high ρ_G/ρ_L presented in this paper as well as that of lower ρ_G/ρ_L ratio obtained by other authors.

Our experimental work was accomplished in collaboration with engineers† of the Shanghai Boiler Institute of China and the author. The test fluid was R-113 vapor liquid mixture.

The relationship is compared with other experimental data and 5 proposed correlations.

2. THEORETICAL CONSIDERATIONS

Reported correlations for two-phase flowmeters were mainly derived from two flow models: The homogeneous flow model and the separated flow model. However, in reality, experiments showed that the flow at the throat of a two-phase flowmeter was not homogeneous. Even the flow pattern upstream of the throat was bubbly flow which is usually considered as a homogeneous flow. Three-dimensional suction effects gave rise to an appreciable transverse

†Wang Monghao, Han Buping, etc.

Table 1. Summary of experimental data for orifice

Author	Fluid	Pressure (bar)	Pressure ratio $\frac{P}{P_c}$	Pipe dia (mm)	Diameter ratio β	Orifice dia (mm)	Density ratio $\frac{\rho_G}{\rho_L}$	Quality X
James (1965)	Steam water	7.72 - 16.82	0.035- 0.076	200.7	0.707	142	0.00455- 0.00980	0.062- 0.669
Murdock (1962)	Steam water	39.61- 40.31	0.1794- 0.1823	63.4	0.500	31.7	0.0251 (average)	0.78 0.95
Collins (1971)	Steam water	67.567	0.306	58.9- 73.6	0.620- 0.753	41.3- 53.3	0.0472	0.05- 0.95
Bizon (1965)	Steam water	82.738	0.374	25.4	0.45 0.70	11.4 17.8	0.062	0.05- 0.50
Ragolin (1958)	Steam water	27.3- 120.6	0.1211- 0.5354	19	0.83	15.8	0.0161- 0.1047	0-1.00
Harbin Boiler Institute (1979)	Steam water	169.66- 188.29	0.7672- 0.8514	60.0	0.598	35.9	0.2079 0.2813	0.27- 0.93
Lin Wang and Han	R113 vapor liquid	19.61- 28.635	0.5698- 0.8319	32	0.312- 0.624	10.0- 20.0	0.1425- 0.3280	0-1.00

pressure gradient at the throat section. This gradient caused a localized increase in void fraction near the wall (Chang & Davis 1979). It was not a wholly separated flow either. Therefore this paper uses a modified separated flow model to derive the correlation.

It is well-known that the equation for the single phase mass flow rate in an orifice is:

$$W_{sp} = \frac{\psi C_d A}{\sqrt{(1-\beta^4)}} \sqrt{(2\Delta P_{sp}\rho_{sp})} \qquad [1]$$

where W_{sp} is the mass flow rate of single phase fluid, Ψ is the orifice thermal expansion factor, C_d is the orifice discharge coefficient, A is the orifice flow area, β is the diameter ratio, $\beta = d/D$, ΔP_{sp} is the pressure drop across orifice for single phase fluid flow, ρ_{sp} is the single phase density.

In the case of two-phase flow, we assume the following: the vapor and liquid phases flow separately through an orifice; the vapor phase is incompressible; the discharge coefficient C_d is the same for both phases; the pressure drop for each phase is the same as the pressure drop for the two-phase flow in the device; there is no evaporation during the flow. Then, the mass flow rate of the vapor phase, if flowing alone through an orifice, would be:

$$W_G = \frac{\psi C_d A}{\sqrt{(1+\beta^4)}} \sqrt{(2\Delta P_G\rho_G)} \qquad [2]$$

where W_G is the mass flow rate of gas or vapor phase, ΔP_G is the pressure drop across orifice for gas or vapor phase flow alone.

The mass flow rate of the liquid phase, if flowing alone through an orifice, would be:

$$W_L = \frac{\psi C_d A}{\sqrt{(1-\beta^4)}} \sqrt{(2\Delta P_L\rho_L)} \qquad [3]$$

where W_L is the mass flow rate of liquid phase, ΔP_L is the pressure drop across orifice for liquid phase flow alone.

The mass flow rate of the vapor phase when two phases flow together is:

$$W_G = \frac{\psi C_d A_G}{\sqrt{(1-\beta^4)}}\sqrt{(2\Delta P_{TP}\rho_G)} \quad [4]$$

where A_G is the flow area occupied by gas or vapor phase at orifice, ΔP_{TP} is the pressure drop across orifice for two phase flow.

The mass flow rate of the liquid phase at that condition is:

$$W_L = \frac{\psi C_d A_L}{\sqrt{(1-\beta^4)}}\sqrt{(2\Delta P_{TP}\rho_L)} \quad [5]$$

where A_L is the flow area occupied by liquid phase at the orifice. The orifice flow area is:

$$A = A_G + A_L. \quad [6]$$

By using [2]–[6], one can get

$$\sqrt{\left(\frac{\Delta P_{TP}}{\Delta P_G}\right)} = \sqrt{\left(\frac{\Delta P_L}{\Delta P_G}\right)} + 1. \quad [7]$$

Equation [7] is the separated flow model correlation obtained under the above assumptions. It does not wholly correspond to the real case and should be modified by a corrective coefficient θ.

$$\sqrt{\left(\frac{\Delta P_{TP}}{\Delta P_G}\right)} = \theta\sqrt{\left(\frac{\Delta P_L}{\Delta P_G}\right)} + 1. \quad [8]$$

The corrective coefficient, θ, is to be determined by experimental data. The corrective coefficient θ has certain physical meanings. Substituting [2], [3] and [4] into [8] and using the relationships $W_L = W_{TP}(1-x)$, $W_G = W_{TP}x$, and $\alpha = A_G/A$ gives

$$\alpha = \frac{1}{1+\theta\sqrt{(\rho_L/\rho_G)}\left[\frac{\rho_G}{\rho_L}\left(\frac{1-x}{x}\right)\right]} \quad [9]$$

where α is the void fraction, x is the vapor quality. From two-phase flow theory, void fraction α can be expressed as follows:

$$\alpha = \frac{1}{1+S\left[\frac{\rho_G}{\rho_L}\left(\frac{1-x}{x}\right)\right]} \quad [10]$$

where S is the velocity ratio between the phases. Comparing [9] to [10] one may find that the corrective coefficient θ is a function of velocity ratio S and density ratio ρ_G/ρ_L. Therefore, θ reflects the influence of velocity ratio S and working pressure or density ratio (ρ_G/ρ_L).

As the velocity ratio S is also a function of ρ_G/ρ_L (Thom 1964), on the whole, θ should be a function of ρ_G/ρ_L.

Under given ρ_G/ρ_L, θ is a constant.

Equation [9] can be rewritten as follows:

$$\left(\frac{1-\alpha}{\alpha}\right) = \theta\sqrt{(\rho_g/\rho_L)}\left(\frac{1-x}{x}\right). \quad [11]$$

Equation [11] is a relationship of similarity criteria (Kutateladze 1961, 1966). It expresses that under certain geometry and flow conditions, the main similarity parameters of low viscosity two-phase flow, such as R–113 vapor liquid mixture, passing through an orifice are $(1 - x/x)$ and ρ_G/ρ_L. This means that with the exception of ρ_G/ρ_L the influence of other physical properties of low viscosity fluid on similarity is negligible.

As θ is also a function of ρ_G/ρ_L, under given ρ_G/ρ_L, θ is a constant.

Therefore, [8] and the corrective coefficient θ obtained from R–113 data can be applied to other low viscosity fluid, such as steam water mixture, R–11, R–22 etc., if their respective ρ_G/ρ_L are equal.

3. EXPERIMENTAL APPARATUS AND DATA TREATMENT

Our experiments were carried out in the high ρ_G/ρ_L two-phase flow experimental loop in the Shanghai Boiler Institute. It was a multipurpose loop and used R–113 as its working fluid. Its schematic diagram is shown in figure 1. The critical pressure of R–113 is 34.42 bar.

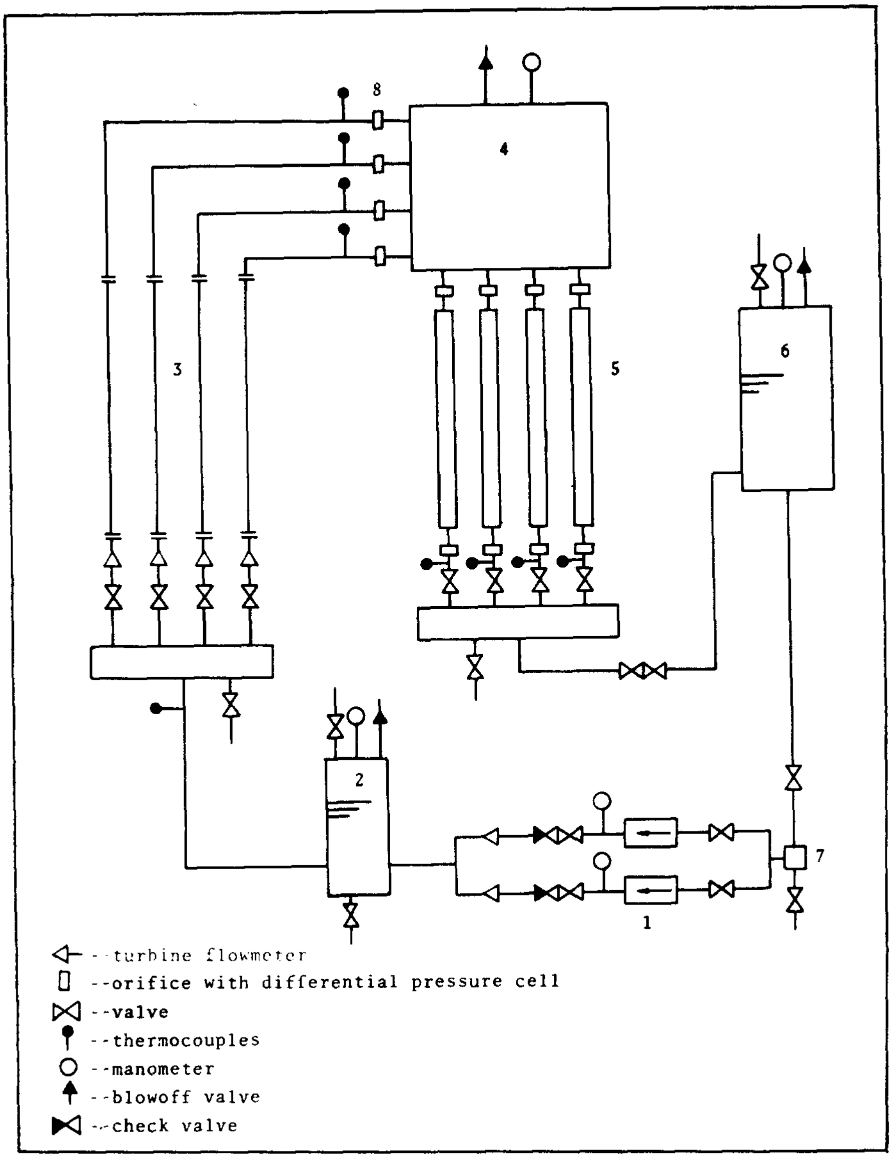

Figure 1. Schematic diagram of the experiment loop: 1, pump; 2, pressurizer; 3, electrically heated pipe; 4, other test model; 5, cooler; 6, liquid container; 7, filter; 8, tested orifice with differential pressure cell.

The orifices used for the tests were mounted at the outlet of an electrically heated horizontal pipe with an inside diamter of 32 mm. The diameters of tested orifices were 10.00, 14.05, and 20.00 mm, and the diameter ratios were 0.312, 0.439, and 0.624 respectively. Pressure taps of every tested orifice were standard corner taps with carrier rings. The internal diameters of the rings were the same as the pipe diameter. There was a narrow annular slot between the inner lip of the rings and the orifices plate, so that the mean pressures could be effectively communicated to the liquid in the annular chambers and through the positive and negative connections to the differential pressure cell. The tested orifices were carefully calibrated with liquid R-113 before tests. The discharge coefficients or orifices for liquid R-113 are shown in figure 2. During the runs, the total single phase liquid flow rate entering the tube was measured by a turbine flowmeter with an error of about $\pm 1\%$, while the pressure drop across the orifice was measured by a bellows type differential pressure cell. Temperatures were measured by thermocouples with an error of about $\pm 1\%$. The vapor quality was evaluated from input power with appropriate correction for heat losses. The tested pressure ratios p/p_c were 0.5698, 0.7108, 0.7401 and 0.8319, and the respective density ratios ρ_G/ρ_L were 0.1425, 0.2150, 0.2450 and 0.3280. The tested quality ranged from 0 to 100%, while the mass velocity passing through the orifice ranged from 917.16 to 1477.42 $\mathrm{kg/m^2 \cdot s}$.

The experimental results were correlated in the form of Martinelli parameters $\sqrt{(\Delta P_{TP}/\Delta P_G)}$ and $\sqrt{(\Delta P_L/\Delta P_G)}$. The parameter $\sqrt{(P_{TP}/\Delta P_G)}$ is plotted against $\sqrt{(\Delta P_L/\Delta P_G)}$ at different density ratios. One of them is shown in figure 3.

Experiments show $\sqrt{(\Delta P_{TP}/\Delta P_G)}$ varies approximately linearly with $\sqrt{(\Delta P_L/\Delta P_G)}$. The corrective coefficient θ varies with ρ_G/ρ_L. According to the test results of tests with four ρ_G/ρ_L, 0.1425, 0.2150, 0.2450 and 0.3280, θ equals to 0.900, 0.935, 0.975 and 0.900 respectively.

The effect of diameter ratio $\beta = d/D$ and mass velocity is not apparent within the test range (figures 5 and 6). Similar results have also been reported by other authors (Chisholm 1967, Lorenzi & Muzzio 1976, Lavagno & Panella 1979).

Figure 3 compares [8] to the R-113 vapor liquid data as well as the steam water data of similar ρ_G/ρ_L (average pressure 179.50 bar) obtained by the Harbin Boiler Institute of China (Chen 1979). Good agreement is obtained. Both have the same values of θ equal to 0.97. The Chisholm correlation for steam water mixture only (Chisholm 1974) and the Murdock (1962) correlation are also shown in the same figure.

Figure 3 proves that [8] and the coefficient θ obtained from R-113 two-phase mixtures can also be applied to steam water mixtures, if they have the same ρ_G/ρ_L or vice versa.

Hence, we may use other steam water mixture experimental data of lower ρ_G/ρ_L to get the $\theta = f(\rho_G/\rho_L)$ curve.

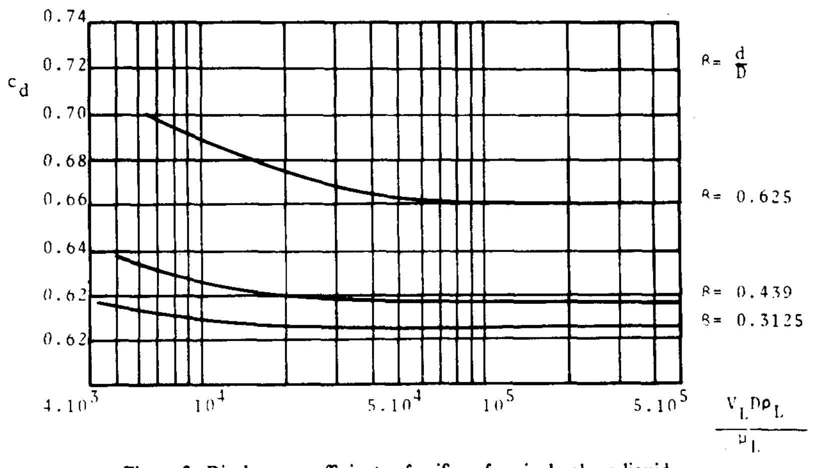

Figure 2. Discharge coefficients of orifices for single phase liquid.

By using the same method to correlate steam water mixture experimental data of lower ρ_G/ρ_L obtained by Murdock (1962), James (1965), Bizon (1965) and Collins (1971), we may get a set of values θ. The coefficient θ is plotted against ρ_G/ρ_L, θ may be found from figure 4 or calculated by the following equation:

$$\theta = 1.48625 - 9.26541(\rho_G/\rho_L) + 44.6954(\rho_G/\rho_L)^2 - 60.6150(\rho_G/\rho_L)^3 - 5.12966(\rho_G/\rho_L)^4 - 26.5743(\rho_G/\rho_L)^5. \quad [12]$$

Equation [8] is not a convenient form of practical use when $x = 0$, i.e., $\Delta P_G = 0$, ΔP_{TP} does not converge to ΔP_L.

Multiplying [8] by $\surd(\Delta P_G/\Delta P_0)$ gives:

$$\surd(\Delta P_{TP}/\Delta P_0) = \theta\surd(\Delta P_L/\Delta P_0) + \surd(\Delta P_G/\Delta P_0). \quad [13]$$

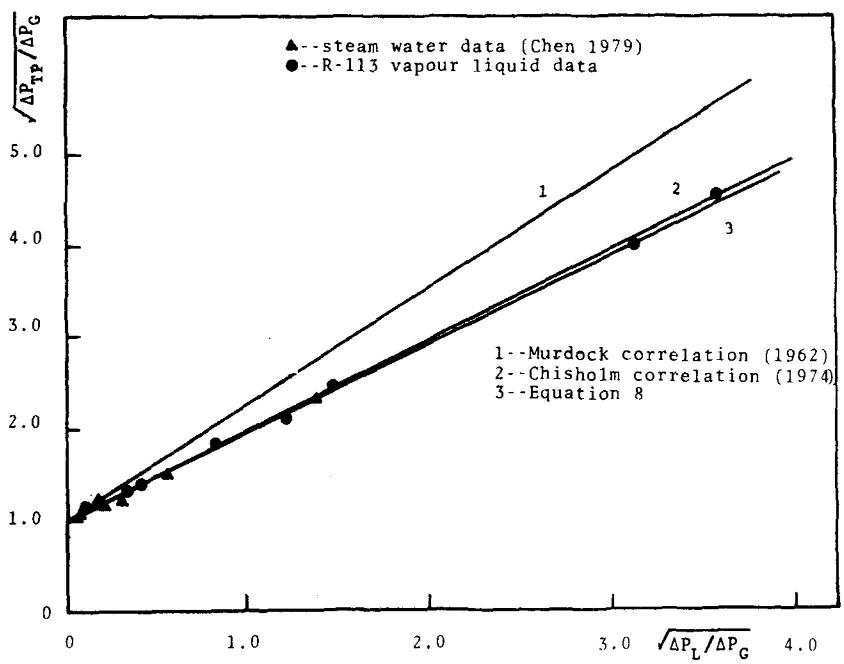

Figure 3. Comparison of experimental data with correlations. $\rho_G/\rho_L = 0.2450$.

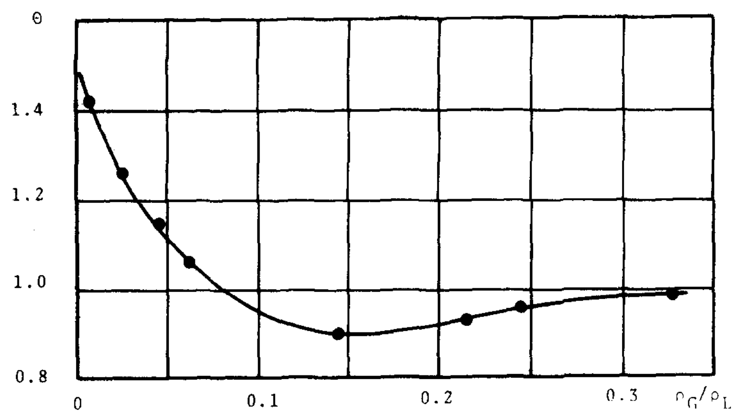

Figure 4. Variation of θ and ρ_G/ρ_L.

Substituting [2], [3] and [15] into [13] and remembering $W_L = W_{TP}(1-x)$, $W_G = W_{TP}x$, produces:

$$\sqrt{(\Delta P_{TP}/\Delta P_0)} = \theta + x(\sqrt{(\rho_L/\rho_G)} - \theta). \quad [14]$$

In [13], ΔP_0 is the pressure drop across orifice assuming total flow to be liquid, and is a function of total two-phase flow rate W_{TP} at the same time. $\sqrt{(\Delta P_0)}$ can be calculated from the following equation:

$$\sqrt{(\Delta P_0)} = \frac{W_{TP}\sqrt{(1-\beta^4)}}{\Psi C_d A \sqrt{(2\rho_L)}}. \quad [15]$$

So knowing ΔP_0, W_{TP} can be calculated at once.

Equation [14] is a more convenient form for application. Using [12] and [14] under measured pressure drop and working pressue, we may predict the value of ΔP_0, i.e. the total two-phase flow rate W_{TP}, for a given quality or vice versa. What is more, in [14] under given pressure, $\sqrt{(\rho_L/\rho_G)}$ and θ being constants, the relationship between x and parameter $\sqrt{\Delta P_{TP}/\Delta P_0)}$ should be a straight line.

Equation [14] fits for $x \geq 0.1$. When $x < 0.1$, $\sqrt{(\Delta P_{TP}/\Delta P_0)}$ can be calculated by using interpolation between the value of $\sqrt{(\Delta P_{TP}/\Delta P_0)}$ at $x = 0.1$ and the value of $\sqrt{(\Delta P_{TP}/\Delta P_0)}$ at $x = 0$, i.e. $\sqrt{(\Delta P_{TP}/\Delta P_0)} = 1.0$. This method of interpolation has been shown to be approximately correct by Chisholm's (1974) experimental data (figure 8) and the current data (figures 5 and 6).

4. RESULTS AND DISCUSSION

Equation [14] has been used to calculate the quality for the 9 steam water data obtained by Murdock (1962), and the 25 steam water data ($\beta = 0.707$) obtained by James (1965). The R.M.S. error is $\pm 7.7\%$. The comparison of 131 data of R-113 presented in this paper with values calculated by [14] shows an R.M.S. error of $\pm 10\%$.

In figures 5 and 6, [14] is plotted at different ρ_G/ρ_L and compared with the correlations of homogeneous flow model, Murdock (1962), James (1965), Chisholm(1974), Smith (1975) as well as with current experimental data.

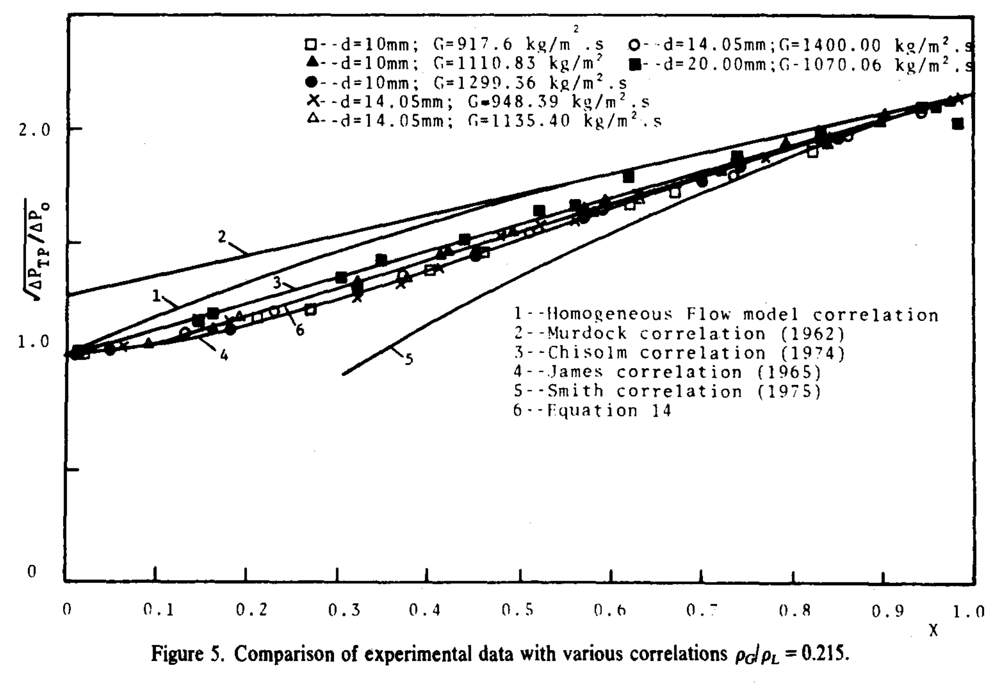

Figure 5. Comparison of experimental data with various correlations $\rho_G/\rho_L = 0.215$.

As can be seen from these figures, the current experiment results fall within the range of the various predictive equations. Of these equations, the proposed predictive equation appears to agree best with the experimental data.

Figure 7 indicates that the present predictive equation agrees very well with Ragolin's (1958) steam water experimental data which have not been applied to derive the corrective coefficient θ curve.

Equation [14] can predict Ragolin's data with R.M.S. errors smaller than 12.5%. Figure 8 expresses that the proposed interpolation method is approximately correct. The calculated results agree well with Chisholm's steam water data (1974).

The corrective coefficient θ curve is derived from data of orifices with different location of pressure taps. For the sake of checking the influence of the location of pressure taps on

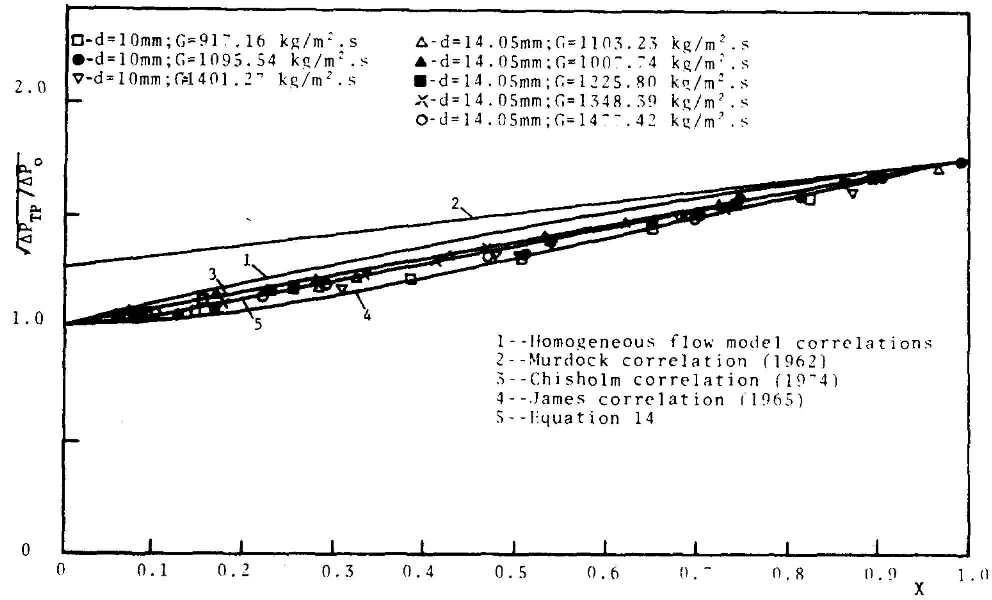

Figure. 6. Comparison of experiment data with various correlations $\rho_G/\rho_L = 0.328$.

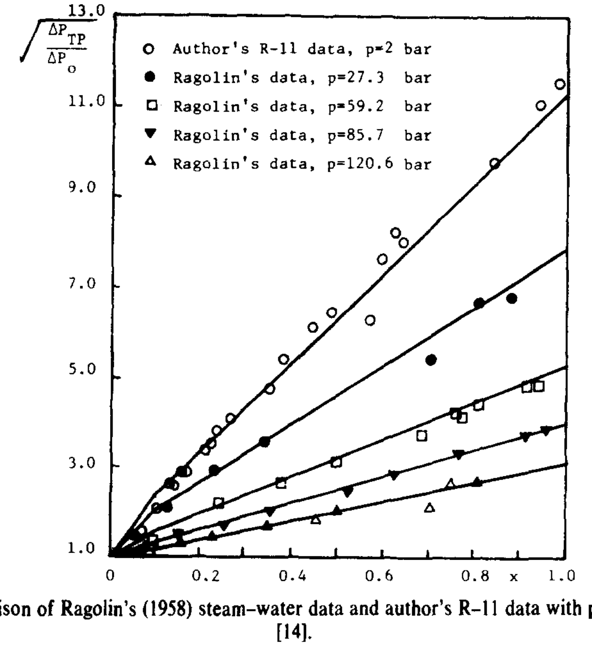

Figure 7. Comparison of Ragolin's (1958) steam-water data and author's R-11 data with proposed equation [14].

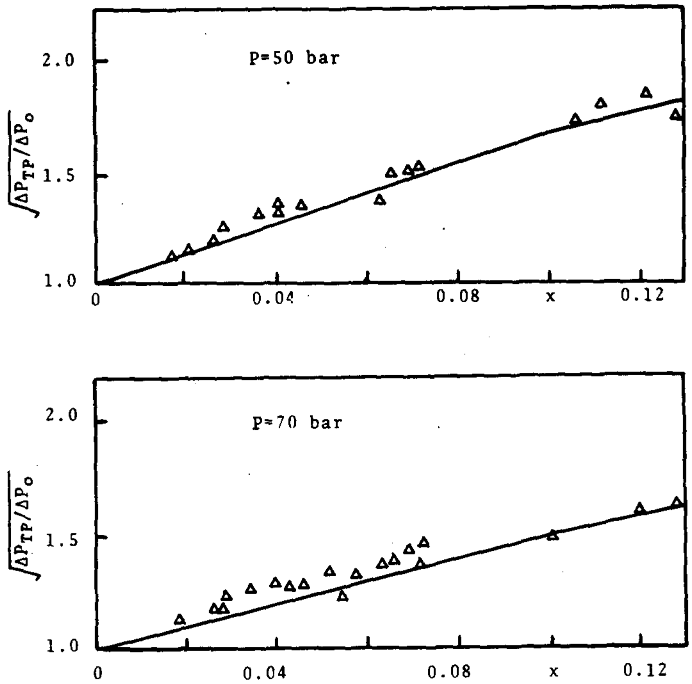

Figure 8. Comparison of Chisholm's (1974) steam–water data ($X = 0$–0.12) with the proposed method.

predicting results of [14], supplementary experiments were conducted by Gurgenci, Mentes and the author at the University of Miami, U.S.A. The diameter of the test tube was 7.49 mm, and the diameter ratio β of the orifice was 0.22. The test pressure was 2 bar. Non-standard pressure taps are located 10 pipe diameter upstream and 0.6 pipe diameter downstream of the orifice plate. Test fluid was R-11. Tested vapor quality ranged from 0–98%.

Test results are also expressed in figure 7. Equation [14] is in good agreement with these experimental data, and can predict these data with R.M.S. errors smaller than 12.2%.

This experiment shows when [14] is expressed by the ratio of pressure drop $\Delta P_{TP}/\Delta P_0$, the influence of pressure taps location is not apparent.

Because test data do not express an apparent influence of d/D and mass velocity on [14] within the experiment range, we may consider approximately that [14] can be used to calculate the flow rate or the quality of vapor liquid (or steam water) mixture in the range 0.00455 to 0.328 of the ρ_G/ρ_L ratio and in pipe size ranging from 8 to 75 mm ($\beta = 0.25$–0.75). The mean square root error of this method is about 12% when the quality, x, ranges from 2% to 100%.

When $\rho_G/\rho_L = 1.0$, i.e. $(P/P_c) \geq 1.0$, then $\sqrt{(\Delta P_{TP}/\Delta P_0)}$ should equal to 1.0. Substituting these values into equation [14], we may get $\theta = 1.0$. The curve shown in figure 4 expresses this tendency.

Substituting [2] and [3] into [8] and remembering $W_G = W_{TP}x$, $W_L = W_{TP}(1-x)$, then gives:

$$W_{TP} = \frac{\psi C_d A \sqrt{(2\Delta P_{TP}\rho_L)}}{\sqrt{(1-\beta^4)}\,[(1-x)\theta + x\sqrt{(\rho_L/\rho_G)}]}. \qquad [16]$$

Equation [16] is a direct equation for calculating W_{TP} from given x or vice versa, and can be used in the range of $x \geq 0.1$. When $X < 0.1$, as it should be calculated by the method of interpolation mentioned above, it is more simplified to use [14].

Comparing [16] with [1], we may find the main difference between them is the two-phase factor $1/[(1-x)\theta + x\sqrt{(\rho_L/\rho_G)}]$. The two-phase factor is a function of θ, x and ρ_L/ρ_G, i.e. a function of quality x and pressure P. When P is equal to P_c, θ and $\sqrt{(\rho_G/\rho_L)}$ should both be equal to 1.0. Thus, this factor is equal to 1.0 too. At that time, [16] is equal to [1]. That is, [16] or [14] turns to the equation for single phase. When $x = 1.0$, the two-phase factor is equal to $\sqrt{(\rho_G/\rho_L)}$, and [16] becomes the equation for vapor flow rate. When $x = 0$, by using the proposed method of interpolation, we may also get from [14], that $\sqrt{(\Delta P_{TP}/\Delta P_0)}$ is equal to 1.0. From this result, by using [15], we may get the equation for liquid mass flow rate.

CONCLUSIONS

(1) The present experiments confirm that quality or flow rate can be predicted with rather good accuracy by pressure drop measurements in orifices in the case of high ρ_G/ρ_L as well as lower ρ_G/ρ_L.

(2) On the basis of theoretical and experimental studies, this paper presents a simple and practical relationship—[14] for calculating two-phase rate or quality whose mean square root error is about 12% when the quality ranges from 2–100%. The comparison with experimental data shows that [14] can be used to calculate the quality or flow rate of low viscosity vapor liquid or steam water mixtures in the effective range 0.00455–0.328 of the ρ_G/ρ_L ratio and in pipe size ranging from 8–75 mm ($\beta = 0.25$–0.75). For steam water mixtures, the corresponding effective range of the pressure is about 8–198 bar.

(3) To further improve the proposed relationship, additional high ρ_G/ρ_L and lower ρ_G/ρ_L steam water mixture data are required. We intend to conduct experimental work in the super-high pressure steam water experimental loop under construction in Xian Jiaotong University of China.

Acknowledgements—The author wishes to express his thanks to Prof. T. N. Veziroglu, Director of Clean Energy Research Institute, University of Miami, and Professor Samuel S. Lee, Assoc. Dean of School of Engineering and Architecture, University of Miami, for their enthusiastic help and valuable suggestions.

REFERENCES

Bizon, E. 1965 Two-phase flow measurements with sharp-edged orifices and venturies. AECL–2273.

Chen, S. T. 1979 The primary report about using orifice to measure the quality of steam water mixture. Report of the Harbin Boiler Institute of China, CB2–092.

Chisholm, D. 1967 Pressure gradients during flow of incompessible Two-phase mixture through pipes, venturies and orifice plates. *Br. Chem. Engr* **12**, 454–457.

Chisholm, D. 1967 Flow of compressible two-phase mixtures through throttling devices. *Chem. Proc. Engng* **12**, 73–78.

Chisholm, D. 1974 Pressure drop during steam/water flows through orifices. *J. Mech. Engr. Sci.* **16**, 353–355.

Collier, J. G. 1972 *Convective Boiling and Condensation.* McGraw-Hill, New York.

Collins, D. B. 1971 Measurement of steam quality in two-phase upflow with venturimeters and orifice plate. *ASME Ser. D.* 11–21.

Dean, C. W. & Kuo, S. C. 1980 Two-phase nozzle theory and parametric analysis. UTRC Report R80–954624–2.

Hoopes, J. W. 1957 Flow of steam–water mixture in a heated annulus and through orifices. *AIchE J.* **3**, 268–275.

James, R. 1965 Metering of steam–water two-phase flow by sharp-edged orifices. *Proc. Inst. Mech. Engrs* **180**, 549–566.

Kutateladze, S. S. 1961 *Problems of Heat Transfer and Hydraulics of Two-Phase Flow.* A symposium published by National Energy Publishing House of U.S.S.R.

Kutateladze, S. S. 1966 *Modeling of Thermal Energy Apparatus.* A book published by Energy Publishing House of U.S.S.R.

Lavagno, E. & Panella, B. 1979 Two-phase flow measuements with venturies: a correlation and a comparison with theoretical models. *Multiphase Transport* (Edited by T. N. Veziroglu) **5**, 2731–2764.

Lorenzi, A. & Muzzio, A. 1976 Two-phase measurement with sharp-edged orifices. Two-phase transport and reactor safety, (Edited by T. N. Veziroglu and S. Kakac) **4**, 1269–1280.

Murdock, J. W. 1962 Two-phase flow measurements with orifices. *J. Basic Engng* **84**, 419–433.

Ragolin, N. V., 1958, Measurements of steam–water flow. *Teploenergetika* **2**, 51–55.

Smith, L. T. & Murdock, J. S. 1977 An evaluation of existing two-phase flow correlations for use with ASME sharp edged metering orifices. *ASME Ser. A.* **99**, 343–347.

Smith, R. V. & Leang, J. T. 1975 Evaluations of correlations for Two-phase flowmeters three current-one new. *ASME Ser. A.* **97**, 589–593.

Thang, N. T. & Davis, M. R. 1979 The structure of bubbly flow through venturies. *Int. J. Multiphase flow* **5**, 17–37.

Wang, M. H. & Han, B. P. 1978 The experimental study of the two-phase distribution of a once through boiler. Report of the Shanghai Boiler Institute of China, BS 78–1.