Single- and two-phase flow pressure drop through orifice

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Abstract

Measurements of upward single and two-phase gas-liquid flow pressure drop through an orifice placed in a vertical pipe are reported. These were achieved using differential pressure transmitters. Six orifices of different diameters and thicknesses have been employed. The superficial velocities of the gas was varied from 0 to 4 m/s and for the liquid from 0.3 to 0.91 m/s. For single-phase flow it was found that the models of Idel'chik [1] and that proposed by Akhter et al. [2] correlate fairly good the orifice single-phase pressure drop coefficient for low open area ratio orifices. Moreover present data have been used to assess the most referenced correlations devoted for predicting two-phase flow pressure drop through orifice. It appeared that those of Morris and Simpson are the most reliable with an error of 7 to 20 %.

Keywords: Orifice, single-phase, two□phase, pressure drop, multiplier coefficient

Nomenclature

B	Chisholm constant (Equation (5))		*Greek symbols*	
C_c	contraction coefficient		ρ	density (kg/m3)
D	pipe diameter (m)		β	area ratio ($\beta = d/D^2$)
d	orifice diameter (m)		Φ_{lo}^2	two-phase multiplier
k	the single phase pressure drop coefficient		ΔP	differential pressure (Pa)
S	slip ratio(-)		*Subscripts*	
t	orifice thickness (m)		g	gas
V	lquid velocity (m/s)		l	liquid
x	Mass flow quality (-)		TP	Two-phase
Z	distance from the orifice (m)			

1- Introduction

Gas□liquid two□phase flows through orifices are encountered in a variety of industrial plants. Some examples are: flow characteristics of rupture discs in engineering relief system of chemical reactors; leaks from ruptured vessels and pipes in power generation units; refrigeration systems, control of two phase flow using choke valves on oil production platforms; desalination process by multistage flash (MSF), and the metering of two□phase flows more particularly in wet gas. The evaluation of the pressure drop associated with the orifice and the knowledge of its influence on the flow behaviour are necessary for a safe and optimal design of the equipment where orifices might occur. There has been significant effort in modelling single□phase flow through

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orifices and the corresponding pressure dropes. Details of flow behaviour and models of pressure dropes can be found in fluid mechanics textbooks such as Idel'chik [1].

In two⬜phase flow, the flow mechanics are more complex due to the nature of the flow.These can exhibit a wide range of phase configurations as a consequence of the deformable interface.The majority of published work has been directed to the pressure drop as well as the pressure drop prediction models Simpson et al [3], Chisholm [4], Morris [5], Watson et al. [6], Collins and Gacesa [7], and James [8].

From a literature review it appears that, only the works of Collins and Gacesa [7] and that of Smith [9] have been focusing on pressure drop generated by orifice placed in vertical pipe; despite that the flow pattern may affect dramatically the associated pressure drop. One other hand, another question may arise regarding the reliability of the two-phase pressure drop prediction models if one should apply them for the vertical plane case. The aim of the present work is to fill this gap.

2- Experimental setup and the methodology

A schematic diagram of the experimental apparatus employed for single and two⬜phase flow pressure drop measurements through orifice is shown in Figure 1. It is the same test facility as that used recently by Zeghloul et al. [10]; on which the pressure drop measurement devices and the associated pipes and fittings have been added.

The vertical test section was made of transparent acrylic resin (PMMA), which permits visual observation of the flow pattern, is about 6m long with an inner diameter, D_t, of 34 mm. Tap water is drawn by pump from a storage tank, which also acts as a phase separator, and injected in to the mixer where it is combined with the air supplied from the compressor. Downstream the mixer, the air⬜water mixture flows through the vertical pipe, a bend, a horizontal pipe and finally to the storage tank, where the air and the water are separated.

The water is recirculated and the air is released to the atmosphere. Inflow of air and water are controlled by valve and metered using banks of calibrated rotameters mounted in parallel before the mixing unit. The maximum uncertainties in the liquid and gas flow rate measurements are 2%. The static pressure of the air flow is measured prior entering the mixing section.

A series of six orifices have been used in the present study. *Table 1* summarizes the dimensions of these orifices.

The orifice is installed at a distance of 4110 mm, 121 pipe diameters downstream the mixer. The conductance probe technique has been used to measure the average void fraction .

The pressure drop generated by the orifice is measured by using two differential pressure transmitters. The ranges of these transmitters are (0-7.2 kPa) and (0-36 kPa) respectively, with a precision of ±0.2 %. According to norme ISO 5167-1 [11] for measurement of pressure drop through orifice, the pressure transmitter are connected to pressure taps placed at 1D and 0.5D, respectively upstream and downstream the orifice plate.
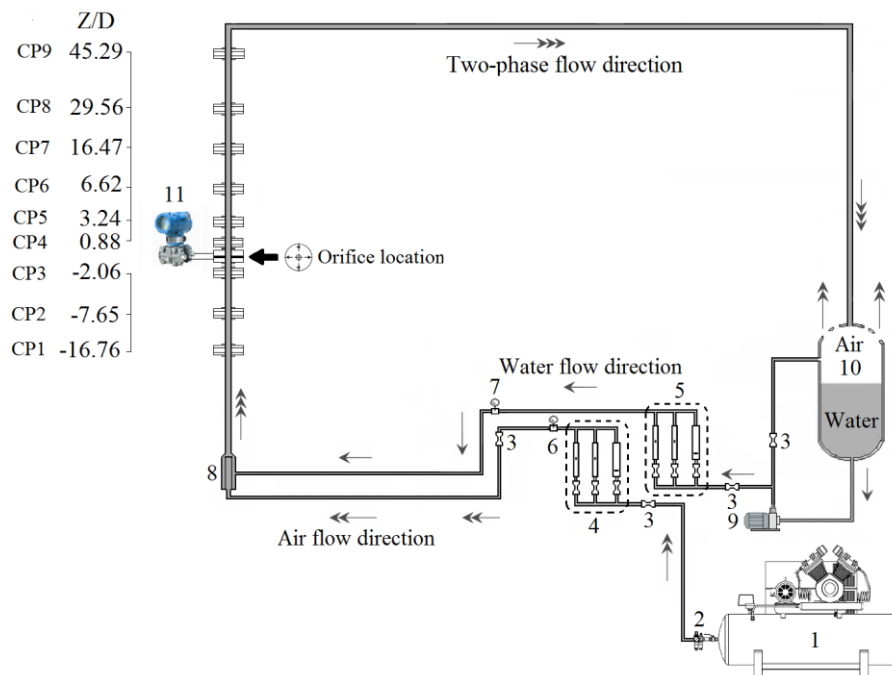
1: Compressor, 2: Pressure regulator, 3: Valve, 4: Air flowmeters, 5: Water flowmeters, 6: Manometer, 7: Thermometer, 8: Mixer, 9: Pump, 10: Tank/Separator, 11: Dp/Cell

Figure 1: Schematic diagram of the experimental facility

Table 1: Dimensions of the orifices

Orifice	Diameter, d [mm]	Thickness, t [mm]	Diameter ratio σ=d/D	Thickness ratio t/d
1	25	2.5	0.73	0.1
2	25	5	0.73	0.2
3	25	14.7	0.73	0.59
4	18.5	1.9	0.54	0.1
5	18.5	3.7	0.54	0.2
6	18.5	10.8	0.54	0.59

3. Results and discussion
3.1. Single-phase flow pressure drop through orifice
The single-phase pressure drop through orifice is generally expressed by:

$$\Delta p = k \rho V^2 / 2 \tag{1}$$

k is the single phase pressure drop coefficient, or resistance coefficient of the orifice given in different fluid mechanics text books or obtained from momentum equation of flow through orifice. From momentum equations, other forms of the pressure drop through orifice can be determinated.

In figure 2 is given the evolutions of the single-phase flow pressure drop through the six orifices as function of the liquid superficial velocity. The effect of the diameter ratio is obvious. The pressure drop increases with the decrease of this ratio. The pressure drop for small diameter ratio can reach seven times that of the high diameter ratio at the highest liquid superficial velocity. Moreover the thickness of the orifice has a clear influence on the pressure drop. Independently of

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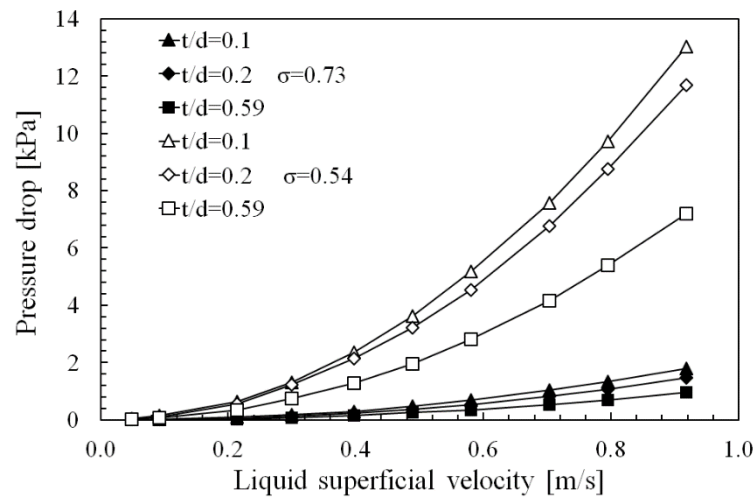the diameter ratio, the pressure drop increases with orifice thickness decreasing.

Figure 2: Single-phase flow pressure drop through the orifice versus the liquid superficial velocity

3-2 Two-phase flow

During two-phase flow experiments, A a series of visual observations through the transparent vertical acrylic test section allowed to observe bubbly, slug and churn flow pattern similar to the recent study of Zeghloul et al [10]. These latter plotted the experimental gas and liquid superficial velocities on the flow pattern map of Shoham [12], (Figure 3), for the pipe upstream the orifice. On this figure the flow pattern was identified using a combination of direct observation and inspection of the Probability Density Function of the void fraction time series as suggested by Costigan and Whalley [13]. Similar to the present study, most of the experiments lies in the slug flow region.
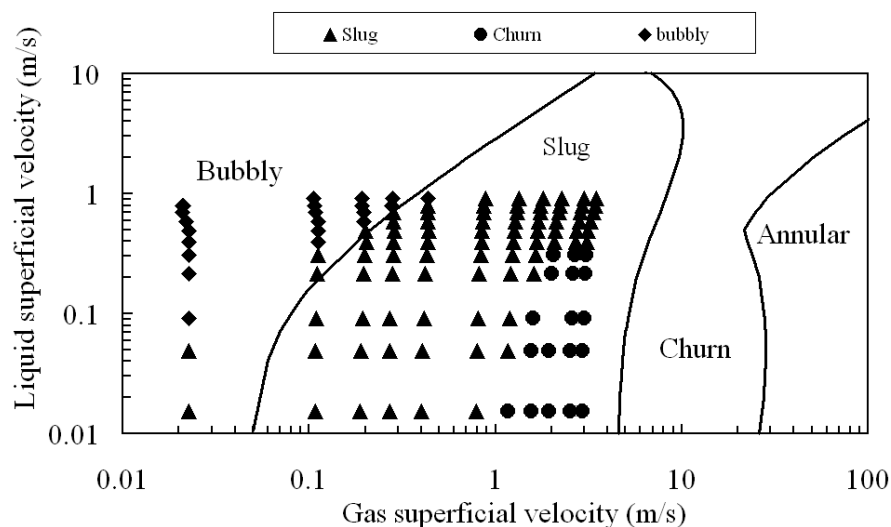

Figure 3: Flow pattern map in the vertical pipe before the orifice, Zeghloul et al. [10]

The two-phase multiplier has been obtained by comparison with single phase measured pressure drops. They are expressed as:

$$\Phi_{LO}^2 = \Delta p_{TP}/\Delta p_{LO} \tag{2}$$

The Table 2 sumarised the diffrent multiplier correlations for orifice from the literature.

Table 2: Two-phase flow multiplier correlations for orifice

Author	Correlation	
Homogeneous	$\Phi_{LO}^2 = 1 + x\left[\dfrac{\rho_l}{\rho_g} - 1\right]$	(3)
Simpson et al. [3]	$\Phi_{LO}^2 = [1 + x(S-1)][1 + x(S^2-1)]; \qquad S = \left(\dfrac{\rho_l}{\rho_g}\right)^{1/6}$	(4)
Chisholm [4]	$\Phi_{LO}^2 = 1 + \left(\dfrac{\rho_l}{\rho_g} - 1\right)\left[Bx(1-x) + x^2 \right]$ Thin Orifice $\qquad\qquad$ Thick Orifice $B = \dfrac{\left[\frac{1}{(C_c\beta)^2} - 1\right]\frac{1}{S} - \frac{2}{C_c\beta S} + \frac{2}{S^{0.25}}}{\frac{1}{(C_c\beta)^2} - 1 - \frac{2}{C_c\beta} + 2}; \qquad B = \dfrac{\left[\frac{1}{(C_c\beta)^2} - 1\right]\frac{1}{S} - \frac{2}{C_c\beta^2 S} + \frac{2}{\beta^2 S^{0.25}} - \left[\frac{1}{\beta} - 1\right]\frac{2}{S^{0.25}}}{\frac{1}{(C_c\beta)^2} - 1 - \frac{2}{C_c\beta^2} + \frac{2}{\beta^2} - \frac{2}{\beta} + 2}$ $C_c = \dfrac{1}{[0.639(1-\beta)^{0.5} + 1]}$ $S = \begin{cases} \left(1 + x\left(\frac{\rho_l}{\rho_g} - 1\right)\right)^{0.5} & \text{si } X > 1 \\ \left(\frac{\rho_l}{\rho_g}\right)^{\frac{1}{3}} & \text{si } X \leq 1 \end{cases}; \qquad X = \dfrac{(1-x)}{x}\left(\dfrac{\rho_l}{\rho_g}\right)^{0.25}$	(5)
Morris [5]	$\Phi_{LO}^2 = \left[x\dfrac{\rho_l}{\rho_g} + S(1-x)\right]\left[x + \left(\dfrac{1-x}{S}\right)\left(1 + \dfrac{(S-1)^2}{(\rho_l/\rho_g)^{0.5} - 1}\right)\right]$	(6)
Watson et al. [6]	$\Phi_{LO}^2 = (1-x)^2[1 + 4.25Y + Y^2]; \qquad Y = \left(\dfrac{x}{1-x}\right)\left(\dfrac{\rho_l}{\rho_g}\right)^{0.5}$	(7)
Collins and Gacesa [7]	$\Phi_{LO}^2 = (1-x)^2\left[0.928 + 0.375\sqrt{Y} + 0.913Y\right]^2; \qquad Y = \left(\dfrac{x}{1+x}\right)\left(\dfrac{\rho_l}{\rho_g}\right)^{0.5}$	(8)
James [8]	$\Phi_{LO}^2 = \left[\left(\dfrac{\rho_l}{\rho_g}\right) - 1\right]x^{1.5} + 1$	(9)

The experimental data are compared with the predictions models from the Comparison of the experimental two-phase pressure drop data collected by the authors with the two-phase flow pattern model is presented in Figure 4 and Table 2. It can be observed that they are in agreement with the models of Morris and Simpson et al.
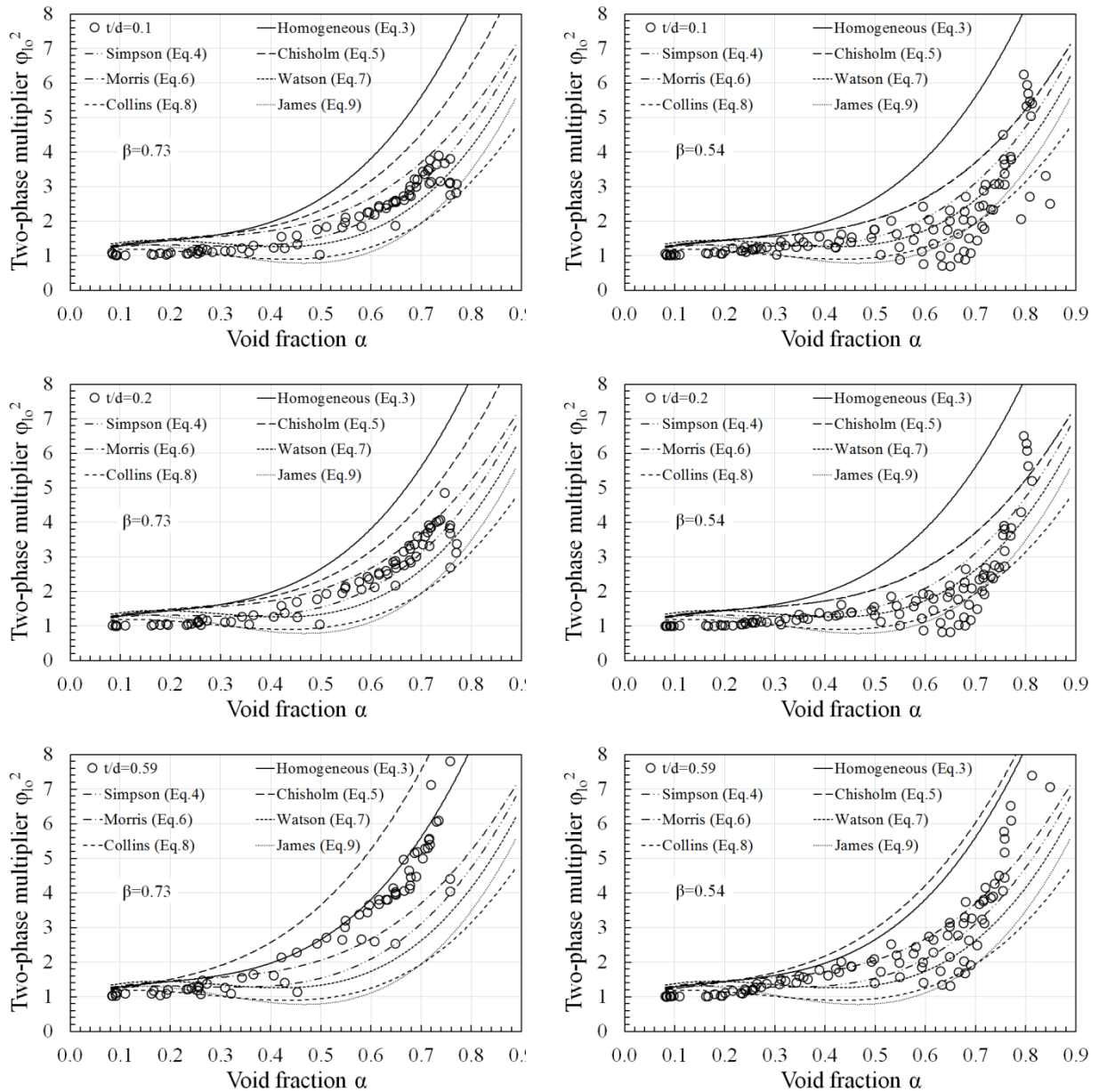
Figure 4: Pressure multiplier versus gas volume fraction for different orifice geomrtries

Govan [14] carried out an assessment of the methods for comparing predictions and experimental data for large data sets. He concluded that rather than use an error, comparison should be made through the logarithm of the ratio of predicted to experimental values as this tends to yield a more Gaussian distribution.

Two statistical parameters, *F* and *S*, are employed to judge the accuracy of the prediction methods. These are defined as: *F*, the correction factor, which is the average factor by which the calculated value must be multiplied to give the experimental value; and *S* which is a transformed standard deviation $=\exp(\sigma)-1$, where P(i) is the predicted two-phase pressure drop and E(i) is the experimental two-phase pressure drop.

$$\mu= \text{meam}=\frac{1}{n}\sum_{i=1}^{n}e(i) \qquad\qquad \text{with:}\quad e(i)=\log\left[\frac{P(i)}{E(i)}\right] \qquad (3)$$

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$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(e(i)-\mu)^2} \qquad (4)$$

Table 3: Comparison of the experimental data with the selection of correlations

		Orifice 1	Orifice 2	Orifice 3	Orifice 4	Orifice 5	Orifice 6
Number of points		78	75	71	105	102	101
Homogeneous	F	0.828	0.841	0.969	0.721	0.738	0.835
	S	0.151	0.135	0.079	0.327	0.232	0.173
Chisholm	F	0.902	0.918	0.884	0.858	0.881	0.809
	S	0.085	0.079	0.117	0.177	0.150	0.190
Morris	F	0.951	0.971	1.108	0.847	0.869	0.981
	S	0.069	0.075	0.118	0.200	0.134	0.100
Simpson	F	1.035	1.057	1.207	0.916	0.939	1.061
	S	0.082	0.091	0.139	0.203	0.123	0.104
Watson	F	1.148	1.177	1.336	1.030	1.057	1.193
	S	0.118	0.136	0.210	0.165	0.126	0.142
James	F	1.217	1.250	1.417	1.082	1.111	1.254
	S	0.154	0.174	0.253	0.188	0.128	0.164
Saadawi	F	1.135	1.163	1.313	1.060	1.062	1.197
	S	0.109	0.130	0.206	0.188	0.225	0.220
Collins et al.	F	1.206	1.236	1.401	1.086	1.116	1.259
	S	0.122	0.141	0.217	0.160	0.137	0.154

5- Conclusion

From the work presented above it can be concluded that:

- Experimental data of the single-phase and two-phase upward flow pressure drop in orifices have been presented.

- The single–phase flow was found to increase with superficial velocity, and decreases with the orifice thickness increasing.

- The two-phase multiplier for thin orifices (t/d=0.1 to 0.2) are found to be quite well correlated by Simpson equation. Thicker orifices (t/d=0.59) are characterized by higher pressure multipliers. Finally, the two-phase multipliers pertinent to the orifice having area ratio β=0.73 show values close to unity (or even lower) when the gas volume fraction is less than about 0.5.

References

[1] I. Idel'chik, G. Malyavskayafs, O. Martynenko et E. Fried, «Handbook of Hydraulic Resistances,» 3rd edition, CRC Press, 1994.

[2] M. Akhter, J. McNaught et D. A. McNeil, Pipe3: Single and two-phase pressure drop calculations in pipeline systems, AERE-R 3022, HTFS DR38, 1990.

[3] H. Simpson, D. Rooney et E. Grattan, «Two☐phase flow through gate valves and orifice plates,» Int. Conf. Physical Modelling of Multi☐Phase Flow, Coventry, 1983.

[4] D. Cisholm, Two☐Phase Flow in Pipelines and Heat Exchangers, London: Longman Group Ed., 1983.

[5] S. Morris, «Two☐phase pressure drop across valves and orifice plates,» European Two Phase Flow Group Meeting, Marchwood Engineering Laboratories, Southampton, UK., 1985.

[6] G. Watson, V. Vaughan et M. W. McFarlane, Two-phase pressure drop with a sharp-edged orifice, NEL Report N°290, May, 1967.

[7] D. Collins et M. Gacesa, «Measurement of steam quality in two-phase upflow with venturis ans orifice plates,» J. Bas. Engng, vol. 93, n° %11, pp. 11-21, 1971.

[8] R. James, «Metering of steam–water two-phase flow by sharp-edged orifices,» Proceedings of the Institution of Mechanical Engineers, vol. 180, p. 549–572, 1965.

[9] J. Smith, «Numerical predictions of bubbly two-phase flow through an orifice,» MSc thesis, Lehigh university , Lehigh, USA., 1997.

[10] A. Zeghloul, A. Azzi, F. Saidj, B. Azzopardi et B. Hewakandamby, «Interrogating the effect of an orifice on the upward two☐phase gas☐liquid flow behaviour,» International Journal of Multiphase Flow, vol. 74, pp. 96-105, 2015.

[11] International Organization for Standardization, Measurement of fluid flow by means of pressure differential devices－part1: orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full, ISO 5167-1., Geneva, 1991.

[12] O. Shoham, « Mechanistic modelling of Gas☐liquidtwo☐phase flow in pipes,» Society of Petroleum Engineering, USA., 2006.

[13] G. Costigan et P. Whalley, «Slug flow regime identification from dynamic void fraction measurements in vertical air☐water flows,» International Journal of Multiphase Flow, vol. 23, p. 263☐282, 1997.

[14] A. H. Govan, «UKAEA Report AERE-M3621.,» 1988.