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# Investigation on the frictional pressure drop of gas liquid two-phase flows in vertical downward tubes☆

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ABSTRACT

Experimental studies on the frictional pressure drop of air-water two-phase flows in vertical downward tubes are conducted in this paper. Experiments are performed at room temperature with the outlet pressure of experimental tube ranging from 0.17 MPa to 0.28 MPa, and four tubes are used with the tube inner diameter being 15 mm, 25 mm, 40 mm and 65 mm respectively. Based on the 978 data obtained in the experiments, prediction performances of 19 existing correlations, which have been developed for predicting the frictional pressure drop of gas-liquid two-phase flow in different tubes, are evaluated to assess the possibility and rationality of using these correlations to predict the frictional pressure drop of gas-liquid two-phase flow in vertical downward tubes as studied in the present paper. The results show that the prediction accuracy of the existing correlations for the frictional pressure drop of air-water two-phase flow in vertical downward tubes decreases remarkably with the increase in tube diameters, and the prediction values are far less than the experiment results under conditions with slug flow and churn flow patterns. It is also found that the buoyancy of bubbles can lead to the increase in the frictional pressure drop of the gas-liquid two-phase flow in vertical downward tubes, especially when big bubbles exist in the two-phase flow. A new model is then established in this paper by introducing a new parameter *B* into the separated flow model to consider the effect of buoyancy. It is found that in comparison with the existing correlations, the new model can well predict the frictional pressure drop of gas-liquid two-phase flows in vertical downward tubes with higher accuracy.

## 1. Introduction

Gas-liquid two-phase flow in vertical downward tubes has found wide applications in various industrial processes pertaining to nuclear engineering, chemical engineering, refrigeration engineering, petroleum industries, etc. For example, during the operation of the microbial enhanced oil recovery technology (MEOR) [1] in the oil industry, air and water are forced to flow downwards together along a long-distance pipeline so as to supply oxygen to microbes in the deep underground reservoir, forming the typical vertical downward gas-liquid two-phase flow.

It is well known that the pressure drop of the gas-liquid two-phase flow is a very important parameter for the design and operation of related application systems. Generally, the total pressure drop of gas-liquid two-phase flows essentially consists of four components, namely, hydrostatic, frictional, accelerational and local pressure drop. Among these four components, calculation of the frictional pressure drop is the most complex one, and has received extensive attentions and researches (see [2,3] for a comprehensive review). Many researchers have attempted to predict the two-phase frictional pressure drop over whole range of flow patterns with one model. The models they developed can be generally classified into two categories, i.e. the homogeneous flow model (HFM) [4–13] and the separated flow model (SFM) [13–23]. The HFM assumes the two phases in the flow are well mixed with each other and move with identical velocities without any interfacial slip, while the SFM considers the two phases to move separately with different velocities in the flow but share common interfaces between them, and the movement of the gas phase and the liquid phase follows its own analytical solutions, respectively. By contrast, some researchers have developed pressure prediction models dependent on flow regimes (see [2] for a comprehensive review).

As one of the important factors affecting the frictional pressure drop of gas-liquid two-phase flow, tube orientation affects not only the phase distribution in the flow, but also the force conditions exerted on the gas phase and the liquid phase, leading to changes in the characteristics of gas-liquid two-phase frictional pressure drop. However, the majority of existing studies related to the two-phase flow frictional pressure drop focus on the frictional pressure drop of two-phase flow in horizontal

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**Nomenclature**

| | |
|---|---|
| $C$ | Chisholm parameter (−) |
| $D$ | hydraulic diameter (m) |
| $f$ | frictional factor (−) |
| $Fr$ | Froude number (−), $\mathrm{Fr} = G^2/gD\rho$ |
| $g$ | gravity ($\mathrm{m \cdot s^{-2}}$) |
| $G$ | mass flux ($\mathrm{kg \cdot m^{-2} \cdot s^{-1}}$) |
| $J$ | superficial velocity ($\mathrm{m \cdot s^{-1}}$) |
| $La$ | Laplace number (−), $\mathrm{La} = [\sqrt{\sigma/g(\rho_l - \rho_g)}]/D$ |
| Q | volume flowrate ($\mathrm{m^3/s}$) |
| $Re$ | Reynolds number (−), $\mathrm{Re} = GD/\mu$ |
| $We$ | Weber number (−), $\mathrm{We} = G^2D/\rho\sigma$ |
| $x$ | vapor quality (−) |
| $X$ | Lockhart-Martinelli parameter (−) |
| $dP/dL$ | pressure drop gradient ($\mathrm{Pa \cdot m^{-1}}$) |

*Greek letters*

| | |
|---|---|
| $\alpha$ | void fraction (−) |
| $\beta$ | gas-liquid volumetric flowrate ratio (−) |
| $\mu$ | dynamic viscosity (Pa·s) |
| $\rho$ | density ($\mathrm{kg \cdot m^{-3}}$) |
| $\phi^2$ | two-phase friction multiplier (−) |
| $\sigma$ | surface tension coefficient ($\mathrm{N \cdot m^{-1}}$) |

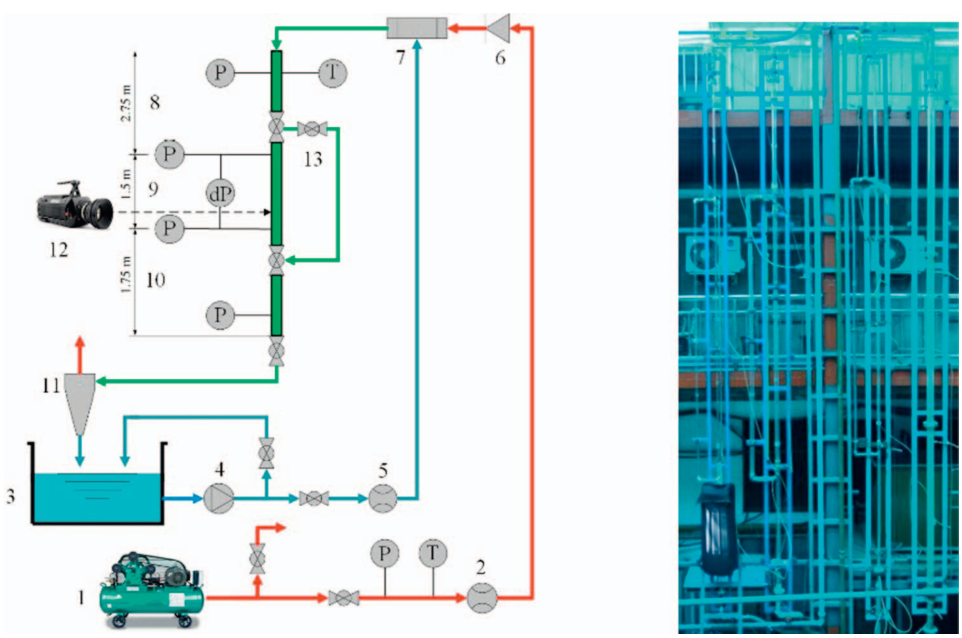
*Subscripts*

| | |
|---|---|
| f | friction |
| g | single phase gas flowing at a mass flow rate of $G_{tp}x$ |
| go | single phase gas whose mass flow rate is assumed to be equivalent to the entire two phase mixture flow rate $G_{tp}$ |
| l | single phase liquid flowing at a mass flow rate of $G_{tp}(1-x)$ |
| lo | single phase liquid whose mass flow rate is assumed to be equivalent to the entire two phase mixture flow rate $G_{tp}$ |
| tp | two-phase |

and vertical upward tubes, while little has been reported on that in vertical downward tubes. Among the literature collected by this study, only Friedel [17] proposed a SFM-based correlation for the frictional pressure drop of two-phase flow in vertical downward tubes based on an experimental data bank of about 25,000 data points of air-water and refrigerants.

Ghajar et al. (2014) (seen in Chapters 4.7 & 4.8 of [24]) compared 35 existing correlations for different tube orientations against an experimental database of air-water two-phase flow frictional pressure drops, which consists of 688 data points for vertical downward tubes (D = 12.5–45.5 mm), 991 data points for vertical upward tubes (D = 9.5–50 mm) and 1468 data points for horizontal tubes (D = 12.5–152 mm). It was found that, the existing correlations have a lower accuracy in the prediction of two-phase frictional pressure drop in vertical downward tubes than that in horizontal and vertical upward tubes. And the Cavallini et al. [20] was found to be the top performing correlation for vertical downward tube. They suggested that the large inaccuracies for the vertical downward tubes with diameter in the range of 20 mm < $D$ < 45.5 mm are probably due to the fact that most of the data for these tube diameters belong to the annular flow regime in which existing correlations perform not well. However, precise explanation of the poor adaptability of existing correlations on vertical downward two-phase flow has not been given by Ghajar et al. (2014) [24], which remains to be further studied.

Therefore, it is of great necessity to systematically and thoroughly study the frictional pressure drop of gas liquid two-phase flow in vertical downward tubes, and develop an appropriate prediction correlation. Under the above-mentioned background experimental studies on the characteristics of frictional pressure drop of air-water two-phase flows in vertical downward tubes are systematically conducted in the present paper. 978 experimental data are gained and then used to evaluate 19 existing correlations [4–23] which have been proposed for two-phase flows with different tube orientations, tube inner diameters and working fluids. Based on the analysis of the experimental results in




(a) Schematic diagram (b) Photo of 4 experimental tubes*

**Fig. 1.** Experimental system.
*The bypass of the 65 mm experiment tube for QVC method had been uninstalled when the photo was taken.
1 - Air compressor; 2 - 3 Gas flow rate meters with different measurement ranges; 3 - Water tank; 4 - Centrifugal water pump; 5 - Water flow rate meter; 6 - Check valve; 7 - Gas-liquid mixer; 8 - Upstream stabilization section; 9 - Test section; 10 - Downstream stabilization section; 11 - Gas-liquid separator; 12 - High speed camera; 13 - Ball valve.