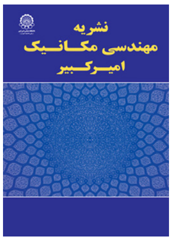

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Numerical and Experimental Study of Two-phase Flow in Downward vertical Pipe

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ABSTRACT: In this study the flow patterns in downward air-water two-phase flow was studied experimentally and numerically. An experimental setup was designed and fabricated to allow visual observation and camera recording. The setup includes a transparent vertical pipe with a diameter of 50 mm and height of 4 m. Water and air were used in the experiments and flow map was prepared by data obtained from a total of 391 test cases by changing in air and water superficial velocities. Using flow pattern map, obtained from experimental results, simulation of two-phase flow in downward pipe has been performed. Multi-fluid model with Eulerian-Eulerian approach was used in Ansys-Fluent software for numerical simulation. Comparison of numerical with experimental results shows acceptable agreement for all expected regimes from flow map and it can be concluded that for downward two-phase flow patterns prediction numerical methods can be used. At the end, the numerical flow pattern map was plotted and compared with experimental results which also show good agreement. Experimental and numerical values of superficial velocities in transition boundaries were also compared.

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1- Introduction

Gas-liquid two-phase flows have many applications in oil and gas, petrochemical, nuclear technology and others [1]. Since many important design and engineering parameters such as pressure, mass transfer, heat transfer are closely related to the distribution phase, thus determining the distribution or rather the determination of two-phase flow patterns is one of the important issues is the two-phase flow analysis [2].

Because of the complex nature of the two-phase flow and problems utilizing numerical methods for modeling these flows, experimental methods have been used for analysis. One of the major weaknesses of experimental methods is that flow maps obtained by this method are usually valid for a certain range of flow parameters and generalizing them to other situations is not always reliable and raises the possibility of error in results [3].

In this research, numerical simulation of downward vertical two-phase flow patterns flow in the pipe was studied. To the best of the authors' knowledge, this is the first time that Computational Fluid Dynamics (CFD) is employed to study downward two-phase flow patterns in pipe.

2- Experimental Study

2- 1- Experimental set up

To study the behavior of two-phase flow, an experimental set up was designed and fabricated. Set up consists of a Plexiglas vertical pipe with 50 mm ID and 4 m length. Equipment such as pump, compressor, mixer, flow meters and valves were installed. Air and purified water were utilized as the working fluid for gas and liquid phases respectively in all experiments.

For better comparison with the most researchers, superficial velocities were chosen as the coordinate axes [1-5]. The superficial air and water velocities are 0.008-2.5 m/s and 0.08-2.5 m/s, respectively. For flow map plotting, 23 cases for air velocity and 17 cases for water velocity which gives a total of 391 points were selected. Flow patterns in all 391 cases were determined by using high speed photography and image processing method [6].

2- 2- Experimental results

Fig. 1 shows processed images due to flow patterns in this study. No change occurred by different superficial air velocity as water superficial velocity is lower than a constant value, and liquid phase moves in the form of layer on the wall falls down. It is worth noting that this constant value varies depending on different researchers: the amount by Al-mabrook [7] and Barnea et al. [3] 0.6 m/s, Kendoush and Al-khatab [8] 0.5 m/s, Raeiszadeh at al. [9] 0.4 m/s, Bhagwat [4] 0.2 m/s and for present study, 0.44 m/s have been reported. When liquid velocity is greater than this constant value, liquid phase occupies the whole of the pipe and gas phase appears in bubbles form. Photos of bubbly flow are presented in Fig. 1 (b). If air velocity is more increased from a specific value, air bubbles accumulates and larger bubbles in scale of pipe diameter. This flow pattern is called slug. Photos of this pattern are shown in Fig. 1 (c). At the end, by increasing air velocity, Taylor bubbles are collapsed and forms the very turbulent mixture of two phase. This pattern is called froth flow. In Fig. 1 (d) photo of froth pattern is presented.

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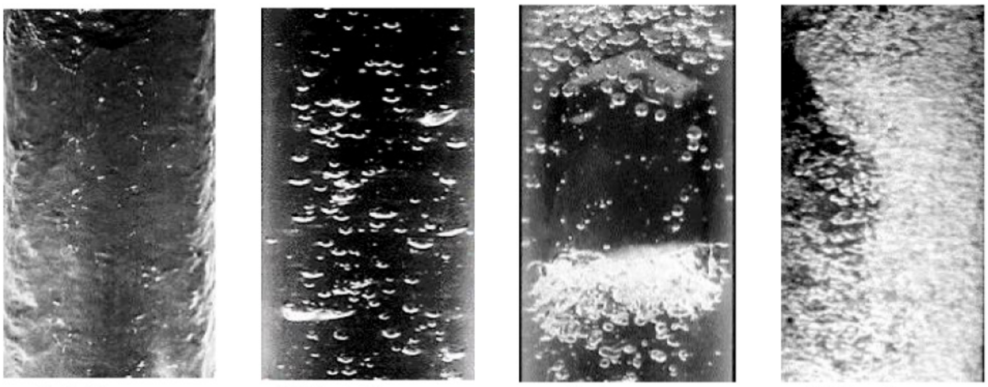

a) f. film (V_{SG}=0.016 m/s, V_{SL}=0.008 m/s) b) bubbly (V_{SG}=0.008 m/s, V_{SL}=0.56 m/s) c) slug (V_{SG}=0.6 m/s, V_{SL}=0.56 m/s) d) Froth (V_{SG}=2.5 m/s, V_{SL}=0.56 m/s)

Fig. 1. Processed photos of different flow patterns

3- Numerical Solution

There are various models in Eulerian-Eulerian viewpoint for numerical simulation of multi-phase flows. The most important multi-phase models are: multi-fluid or Eulerian, mixture and volume of fluid.

Numerical experiences gained from this study shows that multifluid model is the best choice to predict the distribution of phases in downward two-phase flow. This model is used to simulate many multiphase flows [10].

3- 1- Governing equation

In this model for two-fluid model, the equations of continuity and momentum for the phase *i* are respectively as follows [11]:

$$\frac{\partial}{\partial t}\left(\alpha_i \rho_i\right)+\nabla.\left(\alpha_i \rho_i \vec{v}_i\right)=0 \qquad (1)$$

$$\frac{\partial}{\partial t}\left(\alpha_i \rho_i \vec{v}_i\right)+\nabla.\left(\alpha_i \rho_i \vec{v}_i \vec{v}_i\right)=-\alpha_i \nabla P+\nabla.\bar{\bar{\tau}}_i +\alpha_i \rho_i \vec{g}+\vec{F}_i+\vec{F}_{lift,i}+\vec{F}_{vm,i}+\vec{F}_{wl,i}+\vec{F}_{td,i}+\vec{R}_{ji} \qquad (2)$$

In equation Eq. (4) $\bar{\bar{\tau}}_l$ is stress-strain tensor of phase *i*, and five terms: $\overrightarrow{F_i}$, $\overrightarrow{F_{lift,i}}$, $\overrightarrow{F_{vm,i}}$, $\overrightarrow{F_{wl,i}}$ and $\overrightarrow{F_{td,i}}$ are external volume force, lift force, virtual mass force, wall force and turbulence dispersion between two phases respectively, $\overrightarrow{R_{ji}}$ is the interaction force between phases and *P* is the pressure shared in all phases.

3- 2- Numerical simulation approach

For better comparison, three dimensional flow simulations was made using the same experimental geometry (50 mm diameter and 4 m length). According to the analysis of transient two-phase flow, time step was set at 0.001 s. The effect of gravity force was considered. Moreover, it was assumed that there was no mass transfer between two phases. For pressure-velocity coupling, phase coupled algorithms were used and for turbulence modeling, *k-ε* model was used. For discrete momentum equation and two turbulence equations, first order upwind method was used and for discrete volume fraction equation, second-order upwind was used [12].

3- 3- Numerical results

For better comparison of numerical results with experimental results, a part of the pipe is selected as used in experimental study. Numerical simulation results for falling film, bubbly, slug and froth patterns are shown in Fig. 2. The best agreement was about falling film regime (Fig. 2 (a)). In Figs. 2 (b) and 2 (c) of bubbly and slug regimes, fair accommodation was observed. Least accommodation was observed in Fig. 2 (d) for froth regime due to high turbulency and perturbation of flow.

4- Conclusion

For downward two-phase flow four patterns; falling film, bubbly, slug and froth patterns were determined by high speed photography method. By using experimental flow map, occurrence condition of downward two-phase flow patterns was identified. Then in these conditions, with multifluid model in Ansys-Fluent 16, simulation of patterns was performed and flow patterns were extracted in the same experimental condition.

Good agreement simulation results with experimental data, especially in case of flow map, are signs of well capability of computational fluid dynamics in downward two-phase flow patterns prediction.

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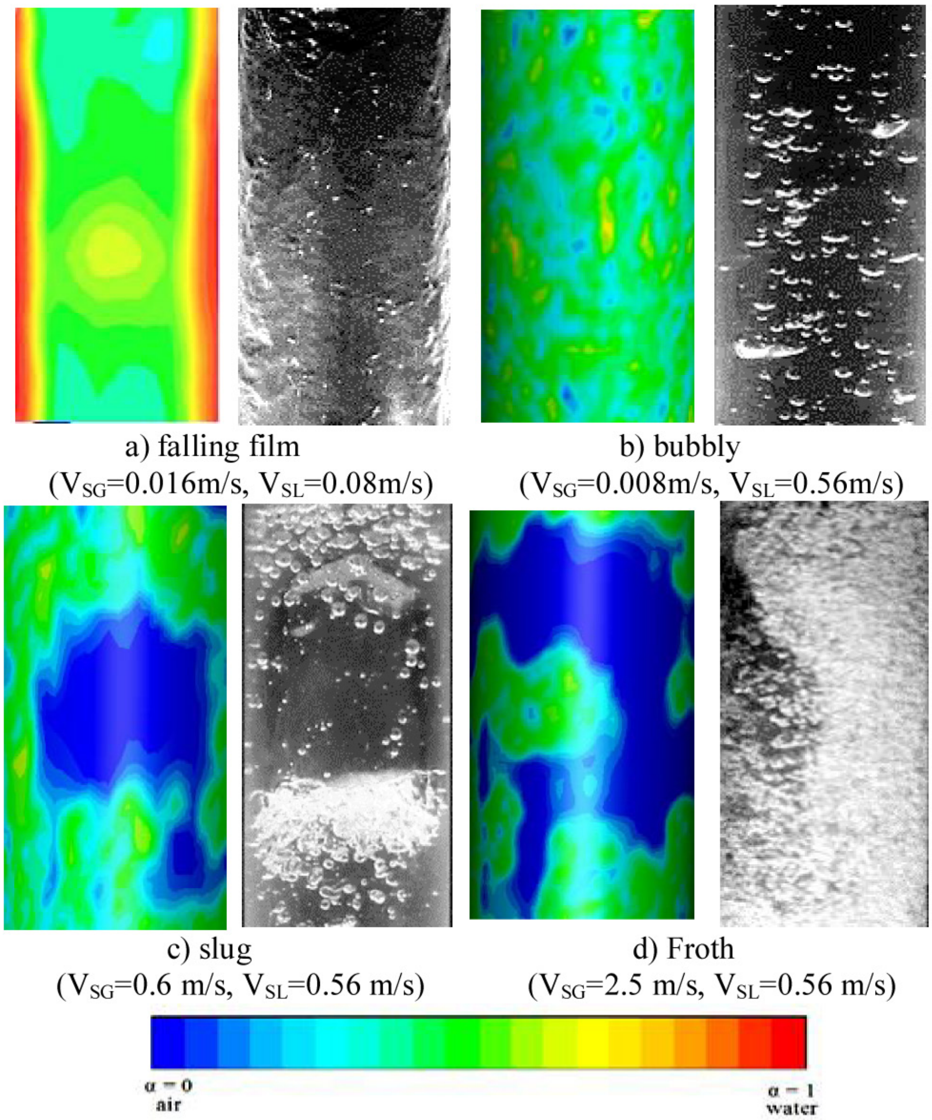

Fig. 2. Contours of phase 2 (air) volume fraction and comparison with experimental results

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