

Visual Observation of Flow Regime Transition in Downward Vertical Gas-Liquid Flow Using Simple Mixer

Farhad Raeiszadeh^{1,a}, Ebrahim Hajidavalloo^{1,a}, Morteza Behbahaninejad^{1,b}, Pedram Hanafizadeh²

¹, School of Mechanical Engineering, College of Engineering, Shahid Chamran University of Ahvaz, Ahvaz, Iran.

², School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran.

^a, Drilling Research Center, College of Engineering, Shahid Chamran University of Ahvaz, Ahvaz, Iran.

^b, Research Center of Gas Distribution Network, College of Engineering, Shahid Chamran University of Ahvaz, Ahvaz, Iran.

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Abstract

Different flow patterns of downward gas-liquid two-phase flow using simple mixer are studied in an experimental manner. An experimental setup is designed and fabricated to allow the visual observation of downward two-phase flow patterns and their transitions. The flow patterns are recorded by a 1200 frames per second high speed video camera. The quality of downward two-phase flow patterns photos are improved through image processing. The setup includes a transparent vertical pipe of 50 mm diameter and the (L/d) aspect ratio of 80. Flow patterns are obtained through 374 test cases during which air and water superficial velocities changed. In order to assess the performance of the mixer, all expected flow patterns are obtained. The four observed flow regimes are: of falling film, bubbly, slug and froth. The flow map is plotted and transitions among different flow patterns are compared with previous finding in specified conditions indicating a good agreement was observed.

Keywords

Two-Phase Flow Patterns, Simple Mixer, Visual Observation

1. Introduction

Correct calculation of important parameters in two-phase flow like pressure drop, mass transfer and heat depends on correct prediction of phase distribution or flow pattern. In many engineering applications in this case the oil and gas industries, biomechanics and environment pollution analysis of a two-phase contribute highly to good process design (Siddiqui et al., 2016). For this reason, the two-phase flow in industrial applications has been and is the

focus in many studies. Most of the two-phase flow studies focus on the analysis of horizontal and upward vertical flow, while the focus on downward vertical flow is rare.

There exist various methods for determining the two-phase flow patterns like direct observation and high speed photography, ultrasonic, neural networks etc. In high-speed photography and similar emerging techniques, the flow patterns can be observed directly. The present method is less expensive than complicated methods with

* Corresponding Author.

Authors' Email Address:

¹ Farhad Raeiszadeh (farhadreisadeh@yahoo.com), ² Ebrahim Hajidavalloo (hajidae@scu.ac.ir)

³ Morteza Behbahaninejad (bnmorteza@scu.ac.ir), ⁴ Pedram Hanafizadeh (hanafizadeh@ut.ac.ir)

easy implementation. Arosio and Guilizzoni introduced some of the practical methods for a two-phase flow structure visualization (Arosio & Guilizzoni, 2006).

Kendoush and Al-Khatib detected flow regimes in downward two-phase flow through the isothermal air-water system and identified the three distinct flow regimes, of bubbly, slug, and annular. They found that flow pattern transitions are not sharp, but fairly gradual (Kendoush & Al-Khatib, 1994). Ishii et al. identified flow regimes for vertical co-current downward air-water two-phase flow through impedance void meter together with a self-organized neural network. The experimental test sections consist of round pipes with internal diameters of 25.4 and 50.8 mm (Ishii, Paranjape, Kim, & Sun, 2004).

Bhagwat assessed the flow patterns and void fractions in vertical downward two-phase flow in an experimental manner and applied flow visualization to study the flow pattern. The flow visualization confirmed the existence of four major flow patterns in downward two-phase flow: the bubbly, slug, and falling film or froth and annular (Bhagwat & Ghajar, 2012). Jha et al. presented an ultrasonic method for flow pattern classification. They stated that their new method can be adopted in a variety of industrial applications (Jha, Ray, Mukherjee, & Chakraborty, 2013). Almabrok studied the upward and downward gas-liquid flow in vertical pipes using high speed photography in an experimental manner. He assessed the effect of 180° bends exert on the flow in the straight part of the pipe and liquid film behavior close to the bends on the characteristics and development of downward and upward gas-liquid two-phase flow in large diameter pipes (Almabrok, 2013). The different flow patterns of downward two-phase in pipe are shown in Fig. 1 (Bratland, 2010).

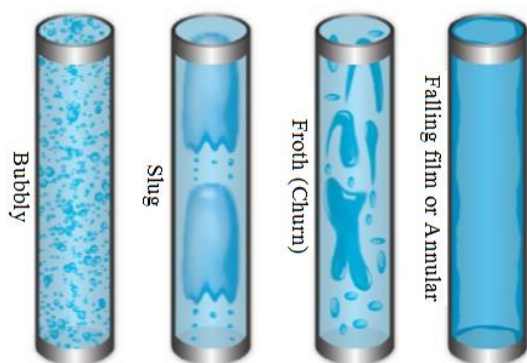


Figure 1. Different Downward Two-Phase Flow Patterns (Bratland, 2010)

In addition to the importance of flow patterns determination method, another significant issue here is how to produce different flow patterns. In the previous studies air and water are blended in a device named mixer. There exist different mixers with complex studies through which the two-phase flow patterns are generated, Fig. 2.

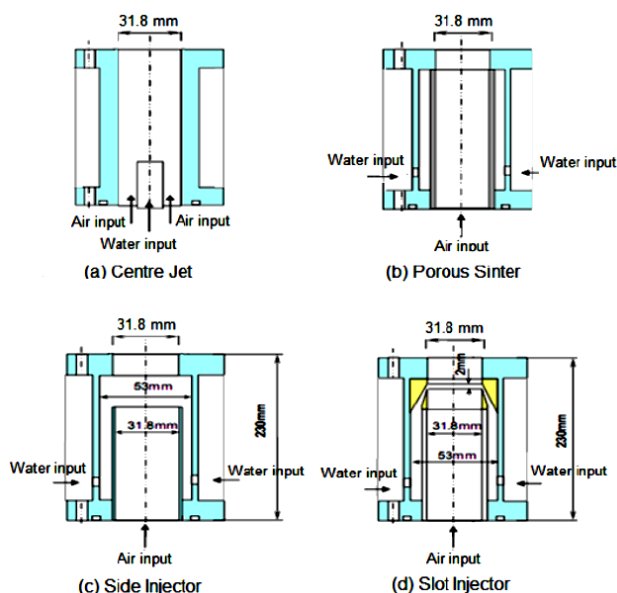


Figure 2. Mixer Structure

The structure of mixer and how it mixes two fluids, has a direct effect on the two-phase flow parameters (Almabrok, 2013). The objective of flow patterns study is to develop flow map plot(s), Fig. 3 (Shoham, 2006).

A simple mixer is applied in features of: generating downward two-phase flow regimes in an easy manner and no significant effect on pressure drop is studied here. Direct observation and high speed photography method are applied here to obtain gas liquid downward two-phase flow patterns in (374 points) different points, which are then compared with previous experimental data.

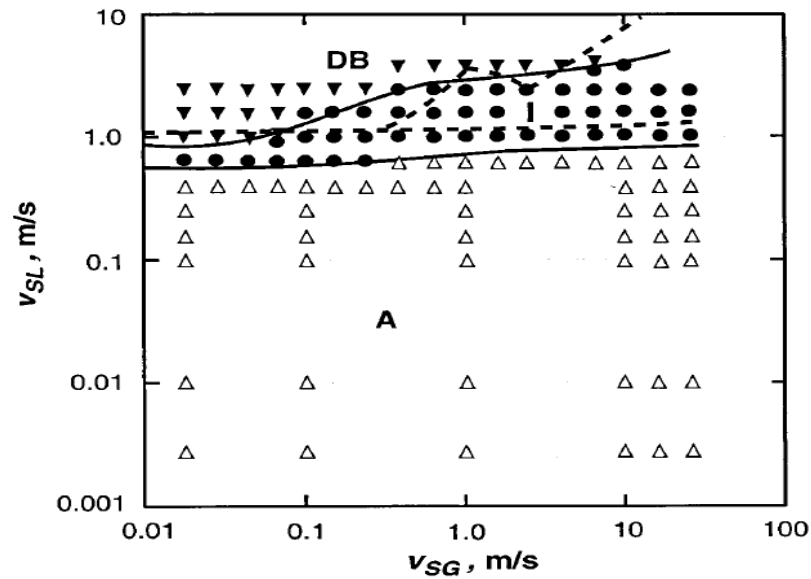


Figure 3. Downward Two-Phase Flow Map in Pipe of 51mm Diameter (Shoham, 2006)

2. Experimental Setup

Different tests are run on two-phase flow in the experimental loop, Fig. 4. Air and water are used as the gas and liquid phases in all

experiments. The main vertical pipe of 50 mm internal diameter at 4 m height is made of transparent plexiglas to allow visual observation.

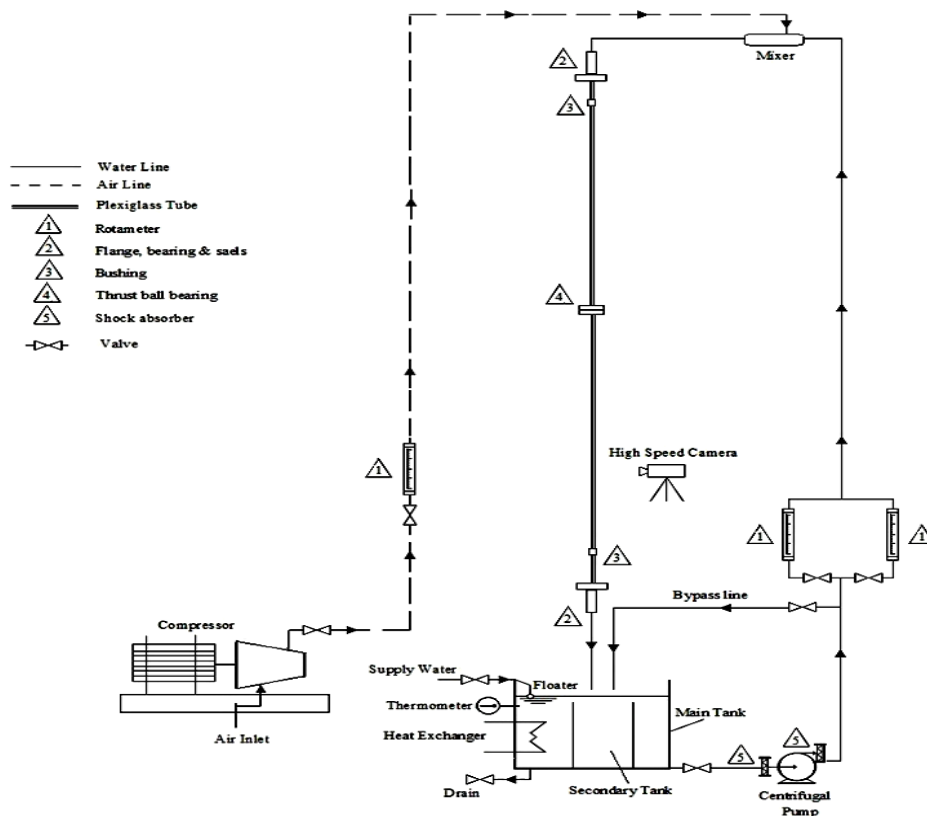


Figure 4. Schematic of the Experimental Setup

The test section is located around 3.5 m downstream of the mixer and 3 m downstream of the final bend, allowing the flow to have enough distance to reach the fully developed regime, Fig. 4. Based on the turbulent flow correlation, the entrance length is about 0.5 m which is much less than the available length in the experiment. The visual observation, confirms that the entrance effect is important only in the initial 0.5 meter of the pipe after which the flow is fully developed and stable.

To prevent vibrations, six shock absorbers are installed at the inlet, outlet and under the pump. The water flow rates are regulated by four valves and measured using two calibrated rotameters with accuracy of 2%. The air and water rotameter are within 0-350 lit/min and 0-400 lit/min range, respectively. The water is pumped from the main tank through a centrifugal pump with 4 kW power.

Up to 8 bars of compressed air pressure is fed to the device by a compressor. The air flow rate is measured by four calibrated rotameters with accuracies of 2%. Air and water are mixed in a simple mixer located at the top of the main pipe. To build a simple mixer, the most convenient manner for air injection, air stone which is used mostly in home aquariums, is considered, Fig. 5.

The air stone of a hard material is appropriate for various operations in CNC machines. Inside of the air stone inlet should be drilled

to allow air hose. This stone is placed in a metal frame welded inside the pipe wall. At the outlet of the pipe, the air and water mixture is drained to the main tank where they have enough room to separate. The air is discharged into the atmosphere and the water remains in the main tank.

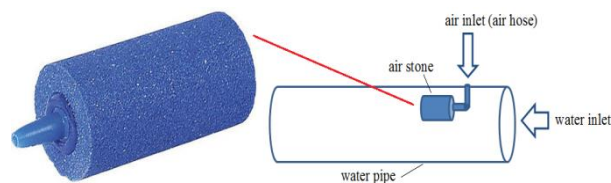


Figure 5. Schematic of the Mixer

3. Results and Discussion

3.1. Study of Mixer Performance

To begin with, first, it should be checked that if the mixer has the ability to produce downward two-phase flow patterns. To record the mixer performance a high speed digital camcorder (CASIO EX-F1) with 1200 fps (frame per second) shutter speed equipped with visualization, flow regime identification and flow recording apparatus is installed. An image processing computer code is considered in order to improve quality of the images of two-phase flow (Hanafizadeh, Ghanbarzadeh, & Saidi, 2011). For bubbly flow, results of these processes are shown in Fig. 6.

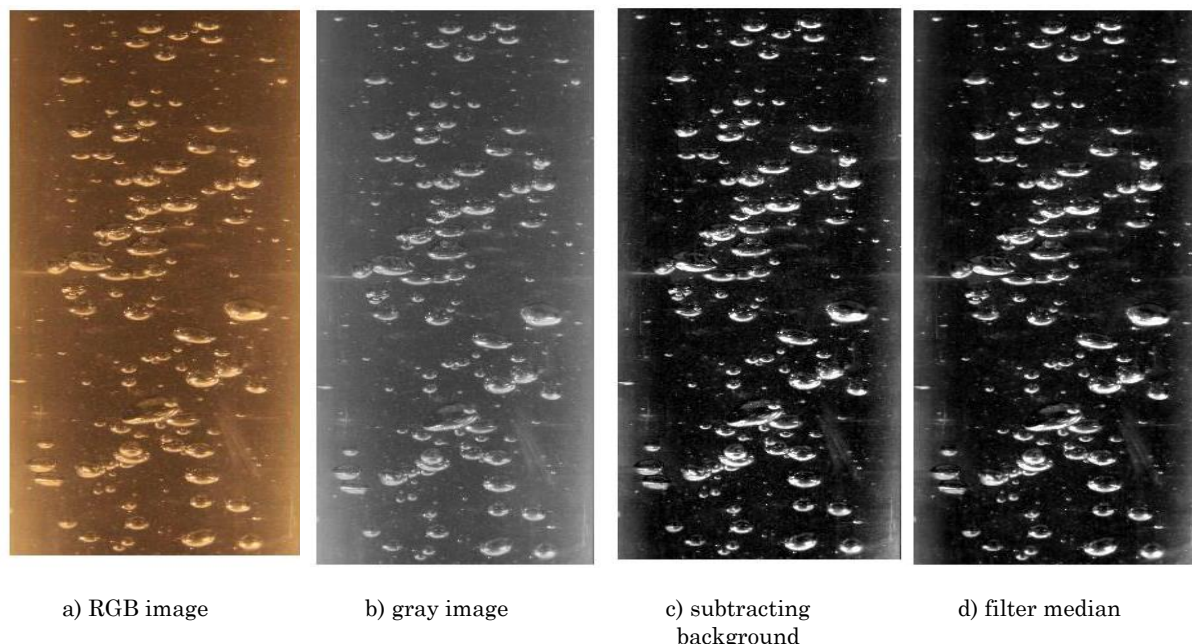


Figure 6. Image Processing Steps for Improving Image Quality (for Example: Bubbly Flow)

Since most researchers apply the superficial phase velocities of water (V_{SL}) and air (V_{SG}), these parameters are involved as the coordinates of flow map, defined as follows:

$$V_{SL} = \frac{Q_L}{A_p} \quad (1)$$

$$V_{SG} = \frac{Q_G}{A_p} \quad (2)$$

In these equations A_p is the pipe diameter, Q_L and Q_G are the volumetric flow rates of liquid

and gas, respectively. The flow patterns in downward vertical gas-liquid two-phase flow, after image processing run on four flow regimes are shown in Figs. (7-9).

As observed in Figs. (7-9) all expected flow patterns are obtained; therefore, it can be deduced that the new simple mixer has the ability to produce two-phase flow patterns in a proper manner. Falling film images are presented in Figs. (7a-9a).

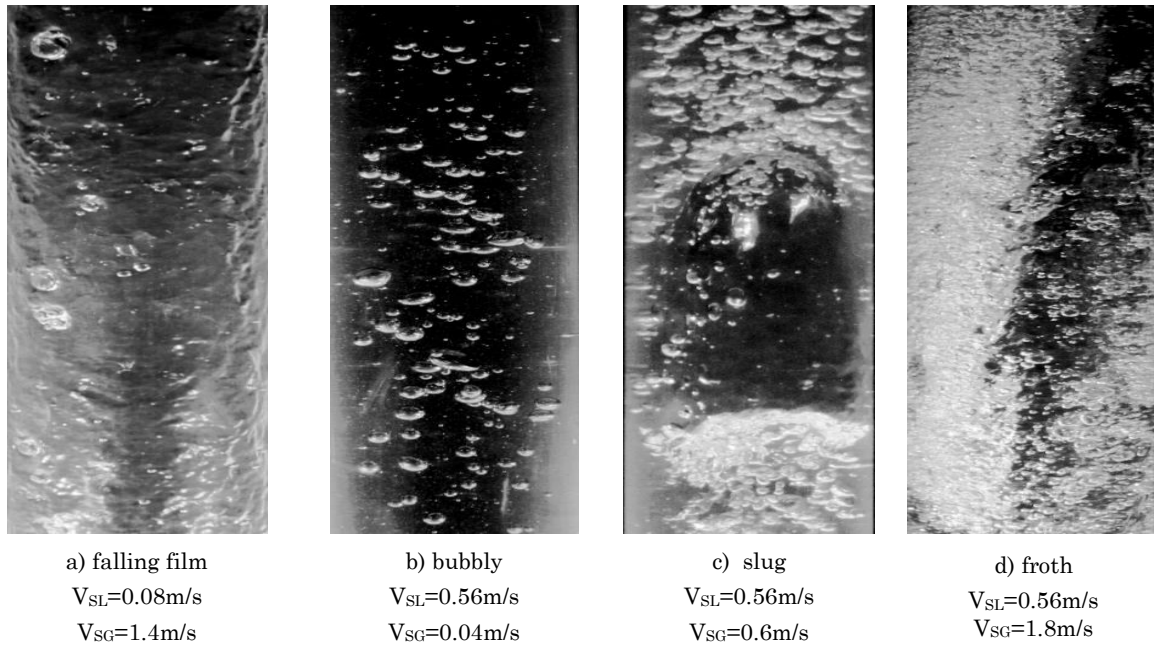


Figure 7. Final Processed Images of the Four Main Flow Patterns in Downward Flow (series 1)

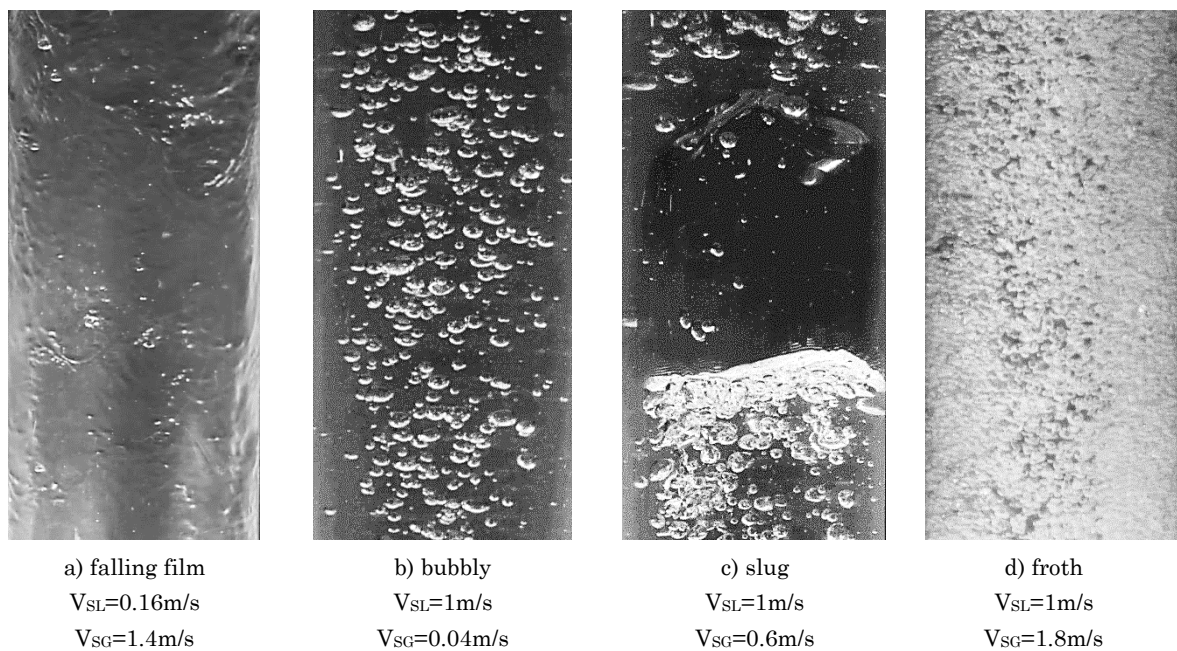


Figure 8. Final Processed Picture of Four Main Flow Patterns in Downward Flow (series 2)

As observed in Fig. 10, no change occurs at different superficial air velocities, since the water superficial velocity is lower than a constant value, where liquid phase moves in the form of layer on the pipe wall and fall down. It should be worth noted that this constant value (V_{SL}) varies on the researchers' choice: Kendoush and Al-khatib 0.5 m/s, Al-mabrook, Barnea et al. 0.6m/s (Barnea, Shoham, & Taitel, 1982), Raeiszadeh et al. 0.4 m/s, Bhagwat 0.2 m/s and in this study, it is 0.42 m/s.

When superficial liquid velocity is greater than this constant value, the liquid phase occupies the whole pipe volume and gas phase appears in bubbles, Figs. (7b -9b). If air velocity is increased more from a specific value, air bubbles accumulate and larger bubbles in the scale of pipe diameter appear. This flow pattern is named 'slug', Figs. (7c-9c). It is notable that this determined value varies for different superficial water velocities, for

$V_{SL}=0.48$ m/s, for $V_{SG}=0.048$ m/s, for $V_{SL}=1$ m/s, for $V_{SG}=0.12$ m/s, for $V_{SL}=1.7$ m/s and for $V_{SG}=0.6$ m/s.

Eventually, by an increase in air velocity the Taylor bubbles collapses, thus formation of a very turbulent mixture of two-phase. This pattern is named the 'froth flow', Figs. (7d-9d). Here, it can be deduced that mixer performance is acceptable due to the fact that different patterns of two-phase flow are generated completely. In the next step the mixer accuracy is examined in generating two-phase map. The map preparation is the objective of such studies. Thus comparison of the obtained flow map with the existing ones constitutes the bases of this assessment.

In this flow pattern map the superficial air velocity is 0.008-2.5 m/s and water velocity was 0.01-2.5 m/s. This map is drawn through the results obtained by direct observation of 374 test cases of variation in V_{SL} and V_{SG} , Fig. 10.

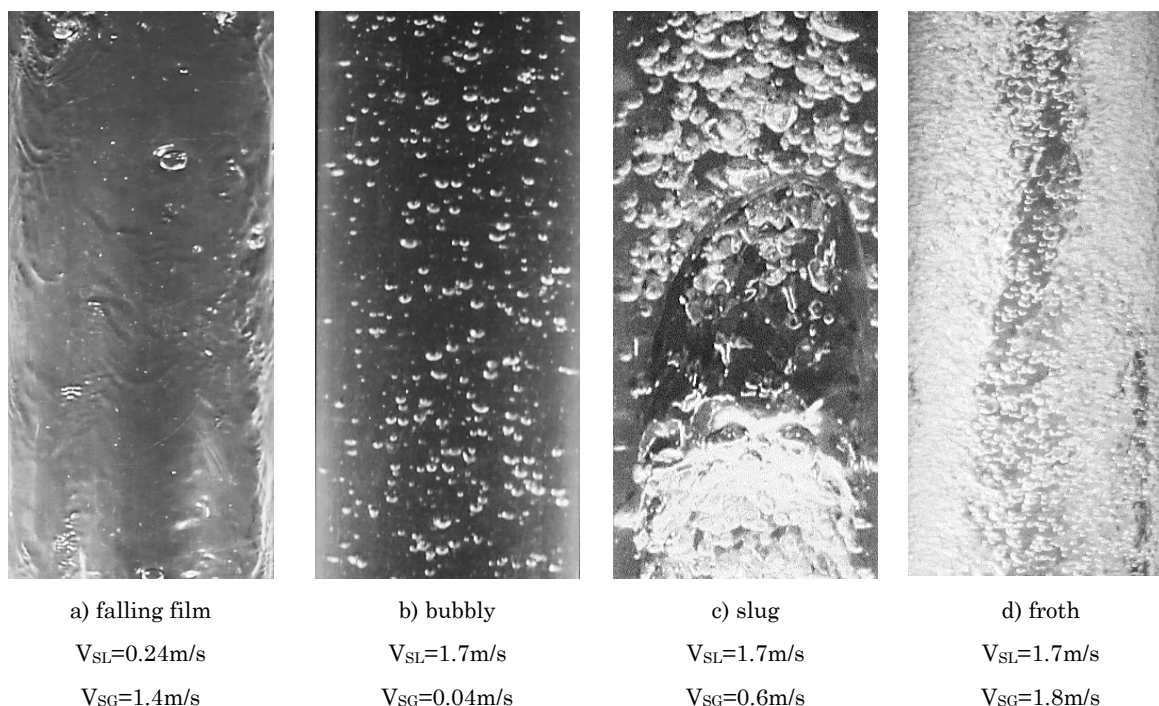


Figure 9. Final Processed Picture of Four Main flow Patterns in Downward Flow (series 3).

Fig. 11 compares the present flow map with other references. Flow map is compound of

several parts. Each part shows transition between two flow patterns as shown in Fig. 12.

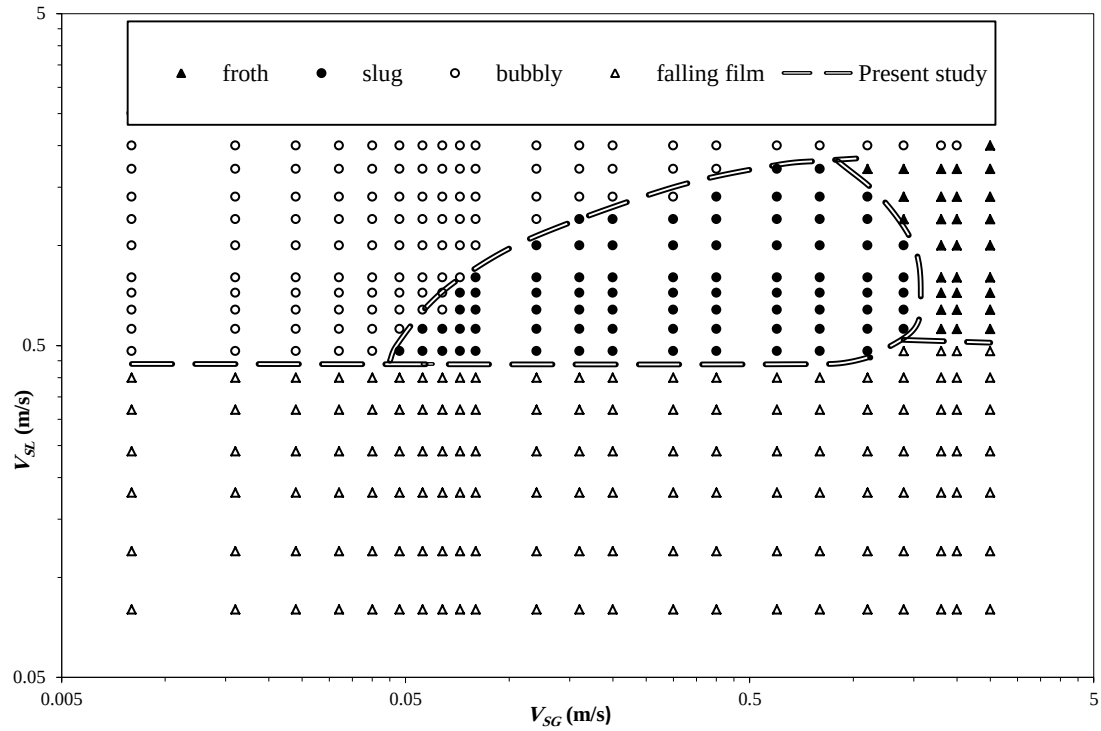


Figure 10. Flow Pattern Map for Vertical Downward Two Phase Flow in 50mm Pipe for Present Study

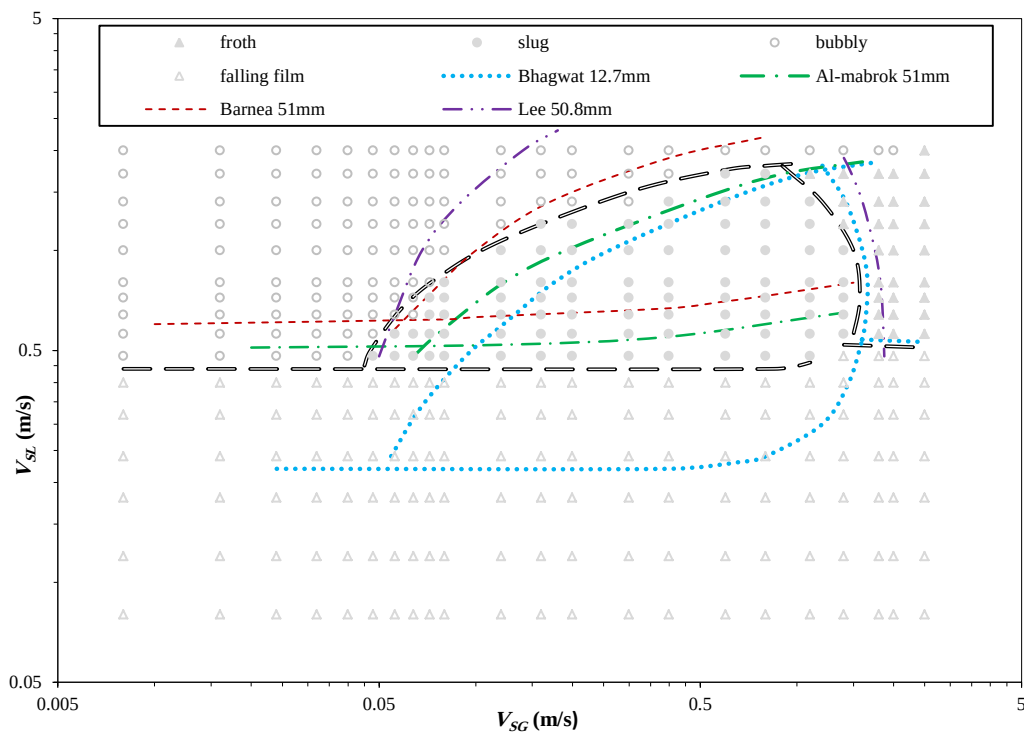


Figure 11. Comparison Present Flow Map with other Researchers

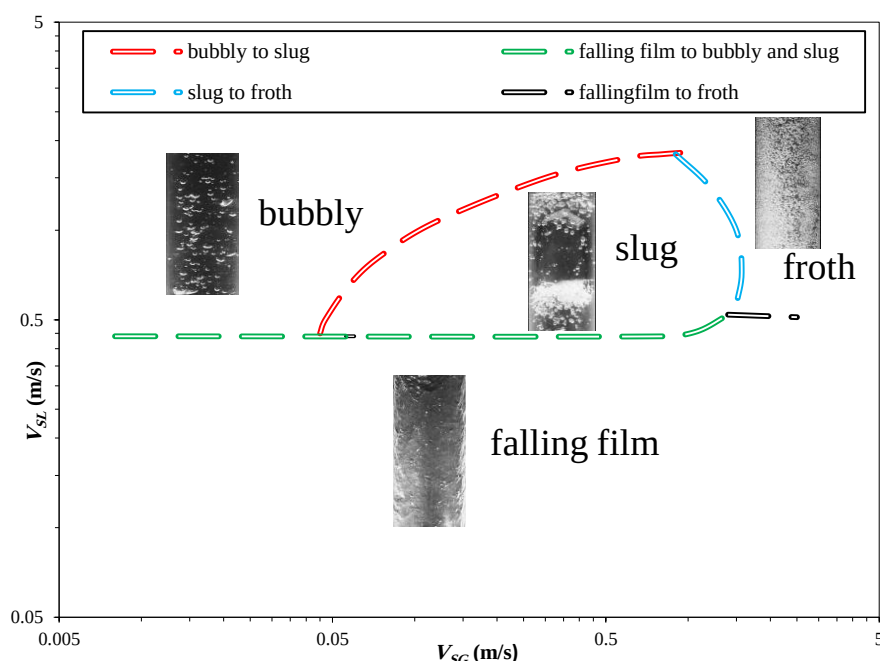


Figure 12. Several Parts of Present Flow Map

The results regarding bubbly to slug transition the findings of Bhagwat, Almabrok, Barnea et al., Lee et al. (Lee, Ishii, & Kim, 2008) are plotted in Fig. 11 where except for the transition proposed by Lee et al., the other transitions are in a good agreement with the findings here.

As to the slug to froth transition, results obtained by Bhagwat and Lee et al. are not illustrated, because the froth regime is not reported separately in a number of sources (Raeiszadeh et al., 2016). Good fairly was observed with two investigations (Bhagwat & Ghajar, 2012) and (Lee et al., 2008).

To the knowledge of the authors here, there exist only one study through which the falling film to froth is compared with and a good agreement is observed.

The falling film flow to bubbly and slug transition is compared with the findings of Bhagwat, Almabrok, Barnea et al., and Lee et al. As previously mentioned, at a constant gas flow rate, the transition from falling film to bubbly and slug occurs at a distinguished values which varies near different researches. In this part more accommodation is by Almabrok and Barnea et al.

According to the above results, this prepared flow map where the simple mixer is applied is in good agreement with its counterparts. It is worth noting that the flow regime transition strongly depends on pipe diameter and this factor can be considered as the major reason for the discrepancy in flow regime transition. Also

measurement error and regime definition can be deviation factors (Raeiszadeh et al., 2016).

4. Conclusion

A simple mixer is applied here to generate downward air-water two-phase flow in a pipe with 50 mm in diameter and 4 m in height. The mixer performance is studied based on: mixer ability confirmed by observation of four main flow regimes of falling film, bubbly, slug, and froth flow in the pipe and mixer accuracy assessed by comparison of this newly prepared flow pattern map with others where a good agreement is observed. The main factors for a discrepancy in the flow pattern maps, that is, between this and the available findings can be the chosen pipe diameters, measurement error, and different definitions of the flow regimes.

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