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Quantitative Study of Slug Flow Development in a Horizontal Pipe

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Abstract

The development of slug flow along the horizontal pipe was studied experimentally by using Particle Image Velocimetry (PIV) method. An 11.5m-long pipe with an inner diameter of 51mm was built for this study.
The liquid phase velocity of two-phase flow (gas and liquid) in the upstream, midstream and downstream was measured respectively. The experiments were performed under the condition of 0.41m/s gas and 0.5m/s liquid superficial velocity. The ensemble average velocity of slug nose, body, tail and bubble in every test location was calculated to study the development of the slug flow. The results show the quantitative variation of the slug flow along the pipe line and it helps to understand the development process of slug flow and validate the numerical study.

1 Introduction

The two-phase flow especially the gas-liquid pipe flow is commonly encountered in many industrial and engineering fields such as nuclear power plant, oil-gas transportation, cooling system, etc. Due to its complex distribution and transition of phases, it aroused much attention from the researchers. The flow regime maps of two-phase flow in the horizontal pipe according to the velocity or the pipe diameter were published by Taitel & Dukler (1976) and Weisman et al. (1979). Among the flow regime maps, the slug flow is of much importance because of its highly fluctuant pressure and momentum. A hydrodynamic model was developed to predict the slug flow by Dukler & Hubbard (1975). Lin & Hanratty (1986) detected the slug by measuring the pressure in 2 locations. Slug characteristics and its initiation were studied by Nydal et al. (1992) and Ujang et al. (2006).

Particle Image Velocimetry (PIV) is a popular method to measure the flow speed, which has the merit to capture the instantaneous velocity of a certain area without disturbing the flow. Siddiqui et al. (2016) measured the two phase velocity simultaneously in slug flow by applying PIV-LIF method. The slug characteristic was studied through PIV combined with high speed camera and other instruments by Cely et al. (2018), Cerqueira et al. (2019). The high viscous slug flow in a horizontal pipe was studied by Kim et al. (2018).
In this research, we captured instantaneous particle images of the slug flow in different locations and calculated the ensemble average velocity, from which, we can study the development process of the slug flow. In addition, we think our research is of a help to understand the mechanism of the slug development and a reference for the numerical simulation.

2 Experiment Set-up

The research was conducted in a horizontal transparent pipe with a total length (x) of 11.5m, an inner diameter (D) of 51mm. The water with seeding particles was circulated by a pump and the gas comes from the air compressor. Before mixing, both of the flow rates were monitored by the flowmeter and the mass flow controller. Three locations of pipe from upstream (66D) to midstream (126D) and downstream (206D) were used as the PIV measurement test sections, illustrated in Figure 1 and 2.

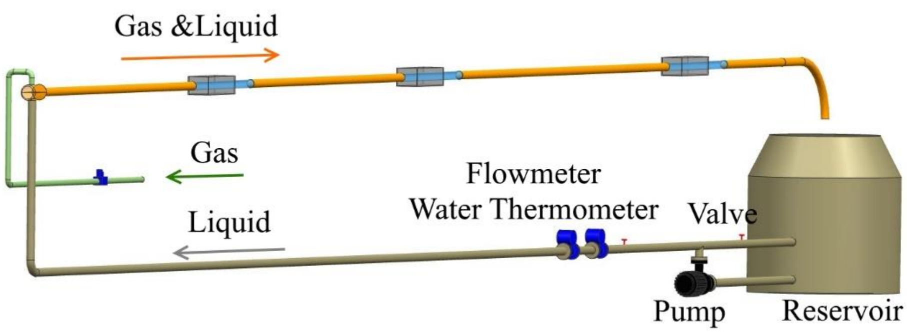
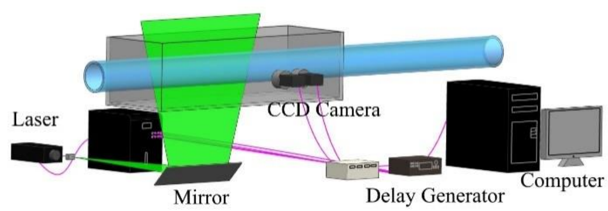


Figure 1: Schematic diagram of experimental apparatus



(a) Test section (b) Experimental set-up for PIV

Figure 2: Test section of PIV measurement

To minimize the influence of refraction, we installed a rectangular box with full of water in the test section. An Nd: YAG laser was utilized as the light source and the instantaneous images were taken by two CCD cameras. Total 400 pairs of instantaneous images of each kind were shot under the condition of 0.5m/s liquid and 0.41m/s gas superficial velocity. For example, Figure 3 shows on instantaneous slug nose image.

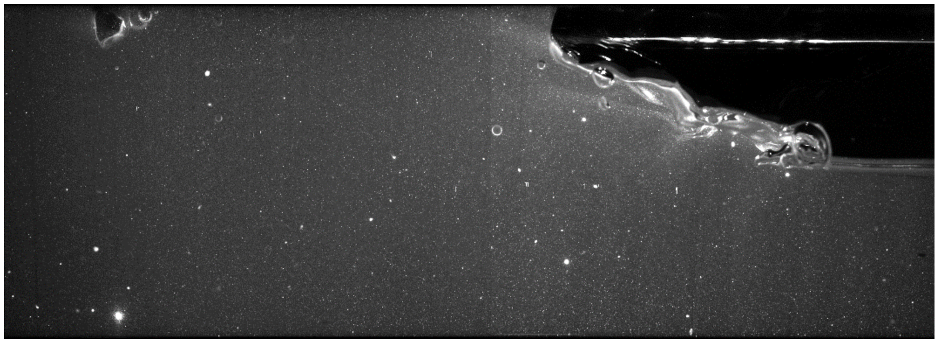


Figure 3. Instantaneous particle image of slug nose

3 Results

3.1 Ensemble average velocity in slug nose

Figure 4 shows the ensemble averaged streamwise velocity at the slug nose. It can be seen that the streamwise velocity in the nose is largest and it drops with the r/D decreases. Moreover, the hydraulic jump always appears in front of the slug nose.

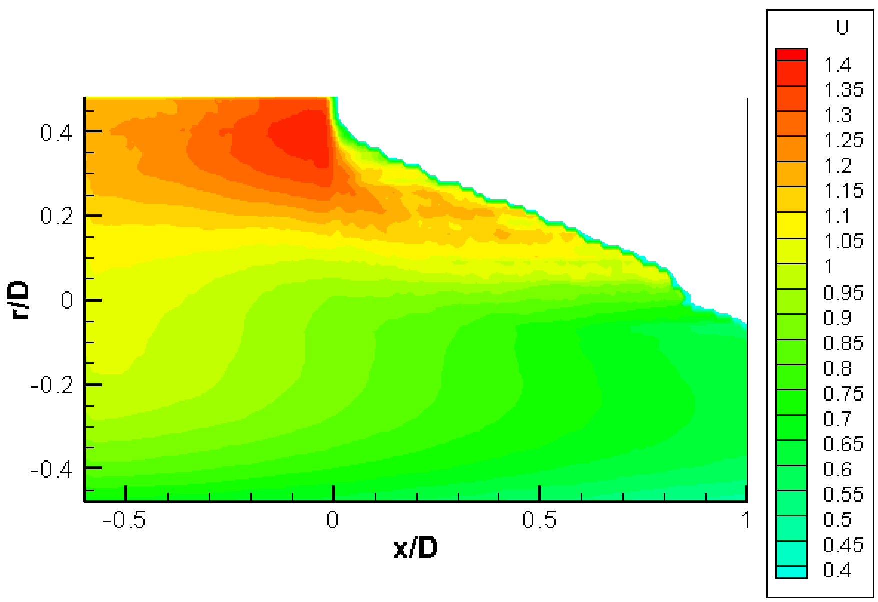


Figure 4. Ensemble average streamwise velocity contour in slug nose (Upstream 66D)

3.2 Ensemble average velocity in slug body

The Figure 5 shows the ensemble averaged streamwise velocity in the upstream slug body. The velocity contour reveals a typical pipe flow contour: the velocity near the pipe wall is small due to the boundary layer and it increases to the largest near the pipe centerline.

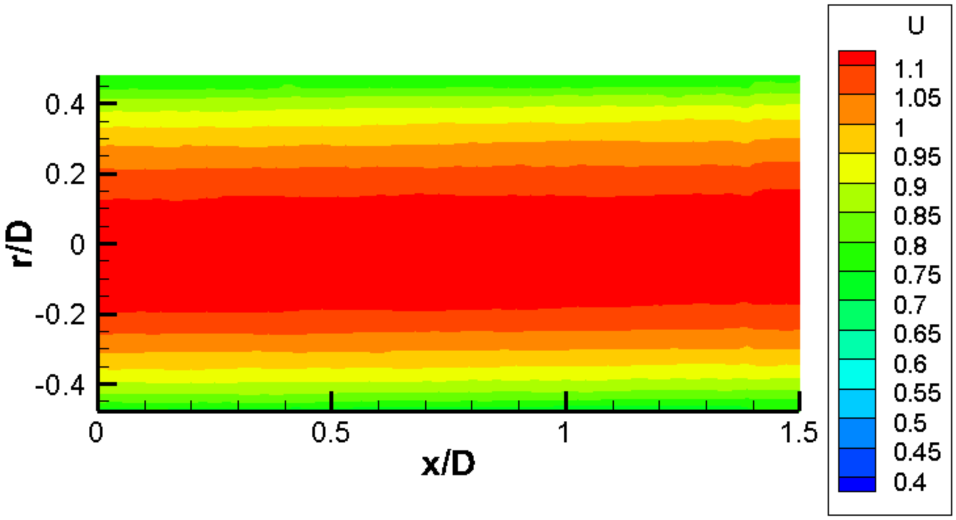


Figure 5. Ensemble average axial velocity contour in slug body (Upstream, 66D)

3.3 Ensemble average velocity in slug tail

The ensemble averaged streamwise velocity in upstream slug tail is depicted in Figure 6. The largest velocity appears below the pipe centerline (r/D=-0.2~0) and the slug tail has the concave shape.

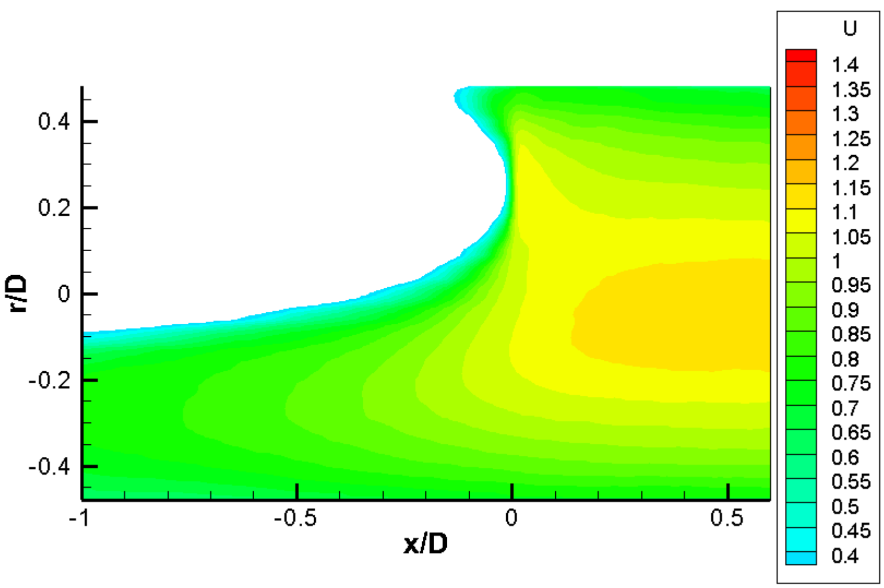


Figure 6. Ensemble average streamwise velocity contour in slug tail (Upstream, 66D)

3.4 Ensemble average velocity in liquid film

The ensemble averaged streamwise velocity contour in upstream is shown in Figure. 7

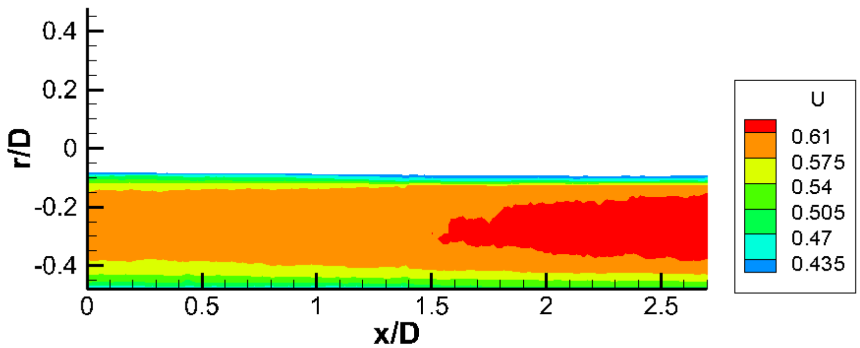


Figure 7. Ensemble average streamwise velocity contour in liquid film (Upstream, 66D)

4 Conclusion

Experimental study was conducted to investigate the slug flow development in a horizontal pipe via particle image velocimetry. In this study we obtained ensemble averaged velocity contour. The analyses are presented above and more researches are underway to obtain the characteristics of the slug flow.

Acknowledgements

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References

Taitel Y and Dukler AE (1976) A model for slug frequency during gas-liquid flow in horizontal and near horizontal pipes. *International Journal of Multiphase Flow* 585:596

Weisman J, Duncan D, Gibson J and Crawford T (1979) Effects of fluid properties and pipe diameter on two-phase flow patterns in horizontal lines. *International Journal of Multiphase Flow* 437:462

Dukler AE, & Hubbard MG (1975) A Model for Gas-Liquid Slug Flow in Horizontal and Near Horizontal Tubes. *Industrial and Engineering Chemistry Fundamentals* 337:347

Lin PY, & Hanratty TJ (1987) Detection of slug flow from pressure measurements. *International Journal of Multiphase Flow* 13:21

Ujang PM, Lawrance CJ, Hale CP and Hewitt GF (2006) Slug initiation and evolution in two-phase horizontal flow. *International Journal of Multiphase Flow* 527:552

Nydal OJ, Pintus S and Andreussi P (1992) Statistical characterization of slug flow in horizontal pipes. *International Journal of Multiphase Flow* 439:453

Siddiqui MI, Munir S, Heikal MR., de Sercey G, Aziz ARA, & Dass SC (2016) Simultaneous velocity measurements and the coupling effect of the liquid and gas phases in slug flow using PIV–LIF technique. *Journal of* 103:114

Hernández Cely MM, Baptistella VEC & Rodriguez OMH (2018) Study and characterization of gas-liquid slug flow in an annular duct, using high speed video camera, wire-mesh sensor and PIV. *Experimental Thermal and Fluid Science* 563:575

de Cerqueira RFL, Paladino EE, Brito RM, Maliska CR, & Meneghini C (2019) Experimental apparatus and flow instrumentation for the investigation of a quasi-real slug flows in vertical ducts. *Experimental Thermal and Fluid Science* 421:451

Kim TW, Aydin TB, Pereyra E & Sarica C (2018) Detailed flow field measurements and analysis in highly viscous slug flow in horizontal pipes. *International Journal of Multiphase Flow* 75:94