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EFFECT OF VISCOSITY ON VOID FRACTION OF A GAS-LIQUID FLOW IN VERTICAL PIPE

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1. ABSTRACT

The determination of various multiphase flow parameters, such as heat transfer coefficient and pressure gradient, is significantly influenced by void fraction. A comprehensive understanding of void fraction behaviour, coupled with precise prediction, is crucial for designing efficient equipment that can lead to increased production rates in the petroleum industry. Given the prevalence of higher viscous liquids in the petroleum sector, this study focuses on investigating void fraction in vertical pipes using gas-liquid mixtures with a viscosity range of 4.8-234 mPa·s. The research explores the impact of superficial gas velocity and liquid viscosity. The results showed a good agreement between the predicted and experimental data.

2. INTRODUCTION

Practical applications of liquid-gas–liquid flow, of two different components or a single substance, are commonly encountered in the petroleum, nuclear, and process industries. The two gas and liquid phases may exist in the flow of different components (e.g., air and water) and/or in the event of phase change due to the evaporation and condensation of a single fluid. Void fraction (α) is one of the most important parameters in characterizing two-phase flow. Void fraction is the key physical parameter for determining other two-phase parameters, namely, two-phase density, and gas and liquid velocities. It plays an important role in the modelling of two-phase pressure drop, flow pattern transition, and heat transfer. For example, in modelling and correlating convective heat transfer coefficient in gas–liquid flow without phase change, the void fraction is one of the indispensable parameters, but Current two-phase flow models and their closure relationships are based on experimental data with low viscosity liquids (μ_L < 20 mPa s). However, recent studies [1] show that the two-phase flow behaviour of high-viscosity liquids is significantly different than that of low-viscosity liquids. To develop more robust correlations, several flow parameters such as physical properties and pipe geometry, should be considered for a wide range of flow conditions. Therefore, the knowledge of two-phase flow development in risers for viscous oil is crucial from the perception of research as well as industrial applications.

3. METHODOLOGY

The two-phase air-silicone oil flow experiments were conducted in the flow rig illustrated in Figure 3.1. The flow facility consists mainly of a liquid tank, a liquid centrifugal pump, a mixing section, a vertical riser, two horizontal sections, two 90° bends, air and liquid flowmeters, temperature sensors and pressure transmitters.

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The main pipe section has an average internal diameter of 68mm, while the air and the liquid inlets to the mixing section are 28 mm and 42 mm in diameter, respectively. The silicone oil was pumped from the storage tank using the centrifugal pump into the mixing section. A bypass line with an appropriate valve arrangement was installed for better liquid flow control and to boost flow stability. The air was supplied from a central compressed air line. The temperature and pressure of both the liquid and the gas streams were measured before the mixing section by temperature sensors and pressure transmitters, respectively. The silicone oil and air were well mixed within the mixing section and then the mixture flows along a vertical riser of 4.5 m before it reaches the bend. This offers a 66-pipe diameter length which should be enough for the flow development [2], [3]. The flow was returned, through a return PVC pipe that passes beneath the main test section, to the holding tank where the phases separate. The air was vented into the atmosphere while the silicone oil was returned to the bottom of the storage tank before its reuse.

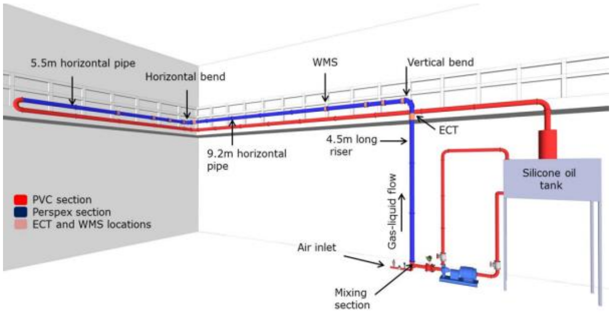

Figure 3.1 Experimental flow facility [4]

An Electrical Capacitance tomography probe (ECT) was installed upstream of the bend respectively as illustrated in Figure 3.1. During the flow measurements around the vertical bends, the ECT was placed 5D immediately upstream. The density of the air and silicone oil are 1.18 and 915 kg/m3, respectively. The velocity range for the air and the silicone oil are (0.07- 2.4) and (0.15 – 0.53) m/s, respectively. The facility runs at ambient temperature and atmospheric pressure.

4. RESULTS

The experimental results of void fraction in vertical flow were measured from the test section for flow visualization and void fraction illustrated in Figure 3.1. The variation of void fraction with gas superficial velocities for vertical pipe flow is shown in Figure 4.1. The void fraction is a function of the flow patterns and varies with respect to the individual superficial velocities and hence the flow patterns [5]. The corresponding flow patterns were visually identified, as well as, using the probability density function (PDF) of the averaged void fraction time series. For the major flow patterns appearing in the vertical two-phase flow, it is observed that the void fraction is least for bubbly flow while it attains a maximum value as the flow regime transits to the churn flow pattern. The variation of the void fraction was plotted against varying superficial gas velocity and at constant superficial liquid velocity as shown in Figure 4.1. The void fraction initially increases rapidly with the introduction of the gas phase. This observation is consistent with the conclusions of [6]. The tendency of accelerated growth in the void fraction against increasing superficial gas velocity is typically associated with the bubbly, spherical cap bubble and churn flow regimes. This phenomenon can be attributed to the fact that in the bubbly flow regime the small increase in the superficial gas velocity results in the laterally elongated and increased number of gas bubbles which try to coalesce and occupy almost the entire pipe cross-section. This translates to the existence of a higher void fraction even for a small increment in the superficial gas velocity. However, for 234 cp oil the bubble flow pattern was not observed at low gas and liquid superficial velocity as expected to occur, instead, cap bubbles were identified which suggests that cohesive forces tend to pull the bubbles together, forming a cluster of bubbles which eventually merge to form a cap bubbles. reason for the existence of cap bubbles instead of bubbly flow for the viscous fluid mixture at low liquid and gas velocities. Slug flow was seen to extend and dominate the entire flow regime which is in line with previous findings [6].

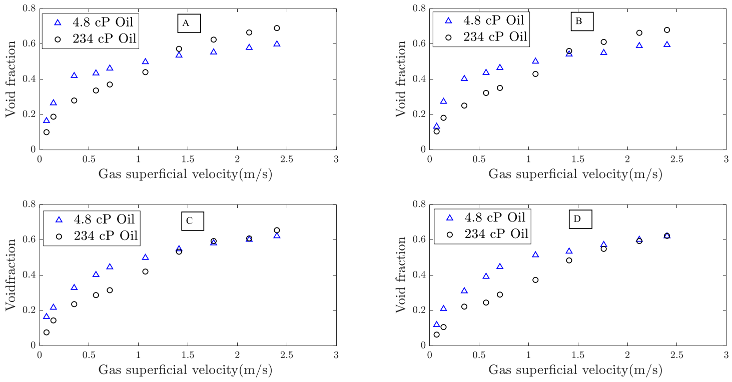

Figure 4.1 Effect of viscosity and gas superficial velocity on void fraction data for different Liquid velocities; (A) Usl = 0.15m/s, (B) Usl = 0.23m/s, (C) Usl = 0.38m/s and (D) Usl = 0.46m/s

5. CONCLUSIONS

In this paper, experimental data from a 68mm ID vertical pipe section, in which an air-silicon oil of viscosities 4.8cp and 234cp mixture flow is presented. An Electrical Capacitance Tomography (ECT) was used to provide a cross-sectional averaged void fraction at 5D before the vertical pipe section. The results showed that viscosity affects void fraction in gas-liquid flow in vertical pipes by influencing the flow regime transition and bubble coalescence or breakup. Higher viscosity tends to promote bubble coalescence, leading to larger bubbles and consequently lower void fraction. Conversely, a lower viscosity allows for easier bubble breakup and promotes smaller bubbles, resulting in higher void fraction. Additionally, viscosity influences the overall flow pattern and dynamics, impacting the distribution and behaviour of gas and liquid phases within the pipe.

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REFERENCES

[1] M. Abdulkadir, O. T. Kajero, D. Zhao, A. Al–Sarkhi, and A. Hunt, "Experimental investigation of liquid viscosity's effect on the flow behaviour and void fraction in a small diameter bubble column: How much do we know?," *J. Pet. Sci. Eng.*, vol. 207, no. June, p. 109182, 2021, doi 10.1016/j.petrol.2021.109182.

[2] S. Benbella, M. Al-Shannag, and Z. A. Al-Anber, "Gas-liquid pressure drop in vertical internally wavy 90° bend," *Exp. Therm. Fluid Sci.*, vol. 33, no. 2, pp. 340–347, 2009, doi: 10.1016/j.expthermflusci.2008.10.004.

[3] M. Abdulkadir, D. Zhao, A. Azzi, I. S. Lowndes, and B. J. Azzopardi, "Two-phase air-water flow through a large diameter vertical 180 º return bend," *Chem. Eng. Sci.*, vol. 79, pp. 138–152, 2012, doi: 10.1016/j.ces.2012.05.029.

[4] D. Zhao *et al.*, "The control and maintenance of desired flow patterns in bends of different orientations," *Flow Meas. Instrum.*, vol. 53, pp. 230–242, 2017, doi: 10.1016/j.flowmeasinst.2016.09.003.

[5] G. Costigan and P. B. Whalley, "Slug flow regime identification from dynamic void fraction measurements in vertical air-water flows," *Int. J. Multiph. Flow*, vol. 23, no. 2, pp. 263–282, 1997, doi: 10.1016/s0301-9322(96)00050-x.

[6] R. Omar, "Transitional two-phase flow around 90 degrees bends of different orientations," *PhD thesis*, vol. 116, no. 1, p. 1, 2017, doi: 10.1080/17436753.2016.1267942.