

Image Identification of Large Bubble Breakup in Slug Flows

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ABSTRACT

The work resorts to high-speed filming to discuss the effects of large bubble breakup on the properties of gas-liquid slug flow subjected to geometric constraints and high turbulence. Under this condition, image analysis introduces several challenges, including image blurring from violent movement, low contrast in the liquid slug and in the film region, and difficulty in isolating phases (superposed views, bubble coalescence and breakup, and turbulent interfaces). The work discusses the effects of strong local disturbances on the fine and gross properties of the flow. The sizes of large bubbles, their passage frequency and velocity, the size and velocity distribution of small bubbles, and the lengths of the liquid slugs are assessed and discussed with a view on understanding how changes in these parameters have an effect on the pressure drop. The effects of change in the rheology of the liquid phase are also discussed. Newtonian (water) and non-Newtonian (CMC solutions) fluids are tested. The main benefit of high-speed filming is that it allows for the collection of quantitative and qualitative data under circumstances that would otherwise need the use of several measurement methods.

1. Introduction

Slug flows are a prevalent flow pattern in the oil and gas industry, and for this reason their study has attracted much attention over the last 50 years. Of course, from the engineering point of view, the highest concern is the prediction of pressure drop and some of the gross features of the flows, including Taylor bubble sizes and velocities. Many theoretical models are available in the literature for slug property prediction, including the unit cell model of Dukler et al. (1975) and Orell (2005), the slug tracking model of Cook & Behnia (2000), the slug capturing model of Evje & Flåtten (2003), and the statistical moments transport model (SMT) of Fagundes Netto et al. (2019). Clearly, every model formulation differs greatly in constitutive hypotheses and implementation details and is capable of offering the prediction of different flow properties. However, it is undeniable that the unit cell models are the most popular and widely used.

Unit cell models approximate the transient, chaotic pattern of slug flows through a steady periodic structure that is repeated downstream. The formulation of Dukler et al. (1975) exhibits a very consistent physical model that consists of a long bubble traveling over a liquid film that is followed by a liquid plug with a strong mixing region at the front. Pressure losses then result from two physical effects: the acceleration of the slow-moving liquid film to slug (mixture) velocity and the pressure loss required to overcome the wall shear stress in the main part of the slug. As such, the model of Dukler et al. (1975) depends critically on two input parameters, the frequency passage of bubbles (ν_t) and the degree of aeration of the liquid slug (R_s).

These parameters are normally given closure relations through experimental techniques that rely strongly on flow visualization and other auxiliary methods. However, as it happens, these working relations are proposed for canonical slug flow conditions produced in a controlled environment. In real industrial applications slug flows are subjected to all sorts of perturbations, including passages through bends, enlargements, contractions, valves, and different equipment. The result is that proposed relations may offer predictions that are far removed from the “real” observed values.

The present work uses high-speed filming to study the properties of slug flow that are subject to significant perturbations, strong enough to promote the breakup of the large bubbles. The purpose is to assess the slug properties in the immediate inlet and outlet regions of the pipe fittings that are used to promote bubble breakup and correlate that with the properties of developed slugs. The great advantage of high-speed filming is that a large amount of quantitative and qualitative data can be obtained in conditions that otherwise would have to resort to multiple measurement techniques. In the complex geometries considered here where intense turbulence is present, the analysis of high-speed filming data presents multiple challenges, including image blurring from violent movement, low contrast in the liquid slug and in the film region, and difficulty in isolating phases (superposed views, bubble coalescence and breakup, turbulent interfaces). The emphasis is on an analysis of ν_t and R_s , but many other flow properties are discussed. The sizes of large bubbles, their frequency of passage and velocity, the size and velocity distributions of small bubbles, and the lengths of liquid slugs are obtained.

The work resorts to 240 different flow conditions with the liquid flow rate (Q_L), ranging between 0 and 12 m³h⁻¹, the gas flow rate ranging between 0 and 5 m³h⁻¹, four CMC solutions, and two turbulence generators, to obtain comprehensive data statistics. The work shows that the increase in turbulence levels increase the size of the large bubbles, and substantially reduces ν_t and R_s . Downstream of a violent perturbation, the sizes of the large bubbles rapidly increase and the liquid slugs get highly aerated implying in largely reduced values of ν_t (by as much as 20%) and R_s (by 16%).

2. Experiments

The experiments were conducted in a pipe with a 2-inch internal diameter and a length of 60 m (two 30 m sections). Under this condition, the flows were observed to be fully developed. Turbulence levels were imposed by baffles installed 30 m from the injection point. The shear-thinning fluid solutions were prepared with CMC concentrations of 0.05, 0.1, and 0.2%. The quoted Reynolds number is the generalized Reynolds number for non-Newtonian flow. Details of the instrumentation, including comparison with resistive sensor measurements will be reported.

3. Results and Discussion

Typical flow pattern results are shown in Figs. 1 to 3. These figures illustrate the effects of flow turbulence on bubble breakup. The increase in turbulence produces a significant increase in the number of small bubbles in diameters that are close to 1 mm and therefore are bubbles that remain dispersed in the flow. It is of interest to notice the very different dispersed flow patterns in Fig. 3 as a result of bubble breakup. The small bubbles present in Fig. 3 originate from turbulent and shear instabilities in the fittings (the chicanes).

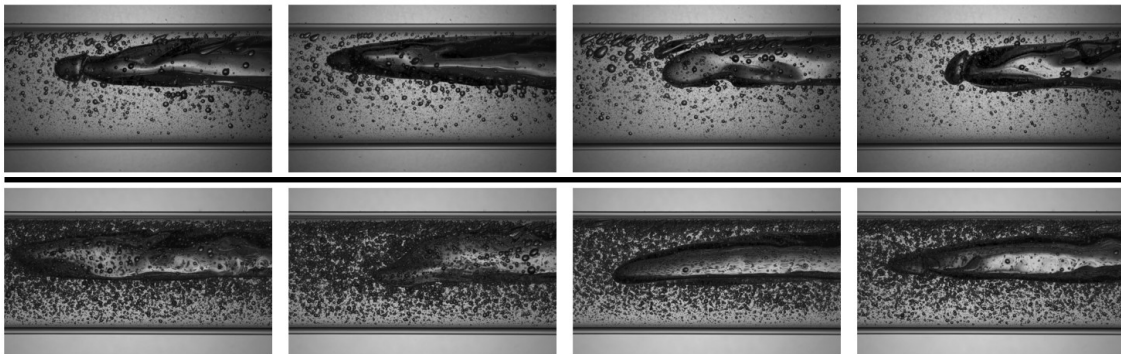


Figure 1. Flow patterns near the bubble nose upstream and downstream the disturbances provoked by the chicane.
 $Q_L = 10 \text{ m}^3\text{s}^{-1}$, $Q_L = 3 \text{ m}^3\text{s}^{-1}$. Air and water flow.

The graphs in Figs. 4 and 5 illustrate the changes in bubble passage frequency (ν_t) and the degree of aeration of the liquid piston (R_s) due to disturbances caused by different baffles. It is very clear that higher turbulence increases ν_t and decreases R_s , respectively the bubble passage frequency and the liquid fraction in the liquid piston. These effects are very noticeable in the pressure drop along the pipeline, as shown in Fig. 6. Figures 4 and 5 quantify the effects of the phase flow rates, the rheology of the liquid phase, and the type of disturbing chicane. These data are compared to existing theoretical closing relations and other experiments. Depending on the flow conditions, the large bubbles are observed to plunge and travel underneath a layer of small bubbles that remain in the top region of the pipe.

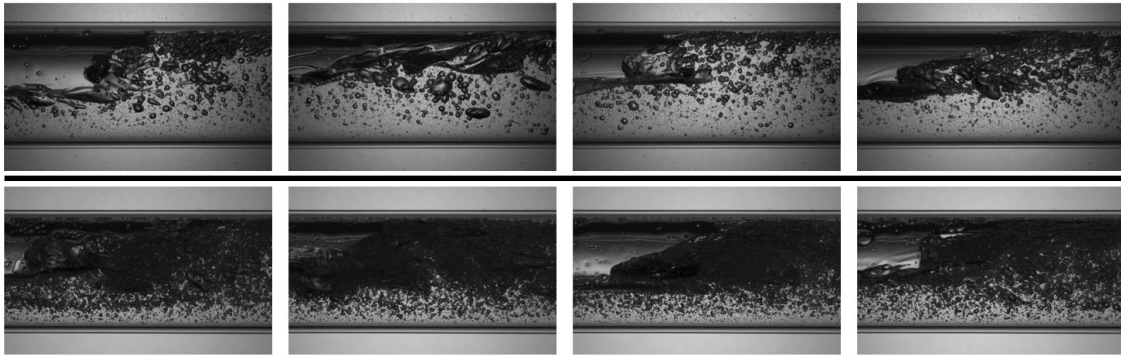


Figure 2. Flow patterns near the bubble tail upstream and downstream the disturbances provoked by the chicane. $Q_L = 10 \text{ m}^3 \text{ s}^{-1}$, $Q_L = 3 \text{ m}^3 \text{ s}^{-1}$. Air and water flow.

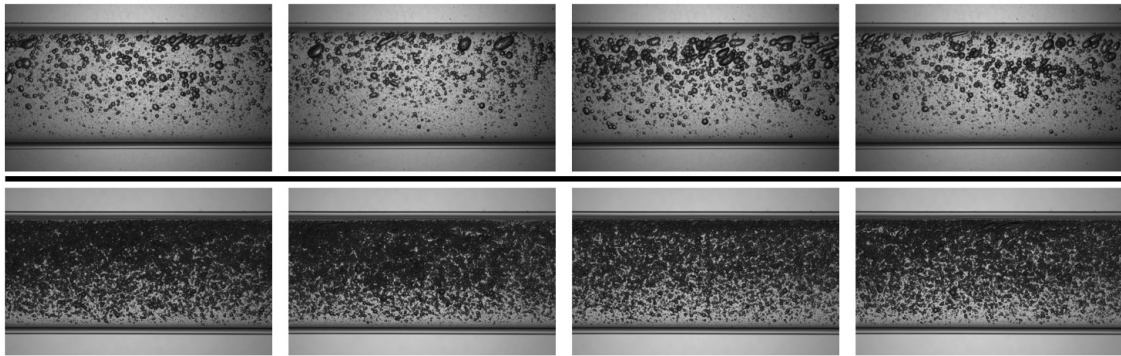


Figure 3. Flow patterns in the liquid slug upstream and downstream the disturbances provoked by the chicane. $Q_L = 10 \text{ m}^3 \text{ s}^{-1}$, $Q_L = 3 \text{ m}^3 \text{ s}^{-1}$. Air and water flow.

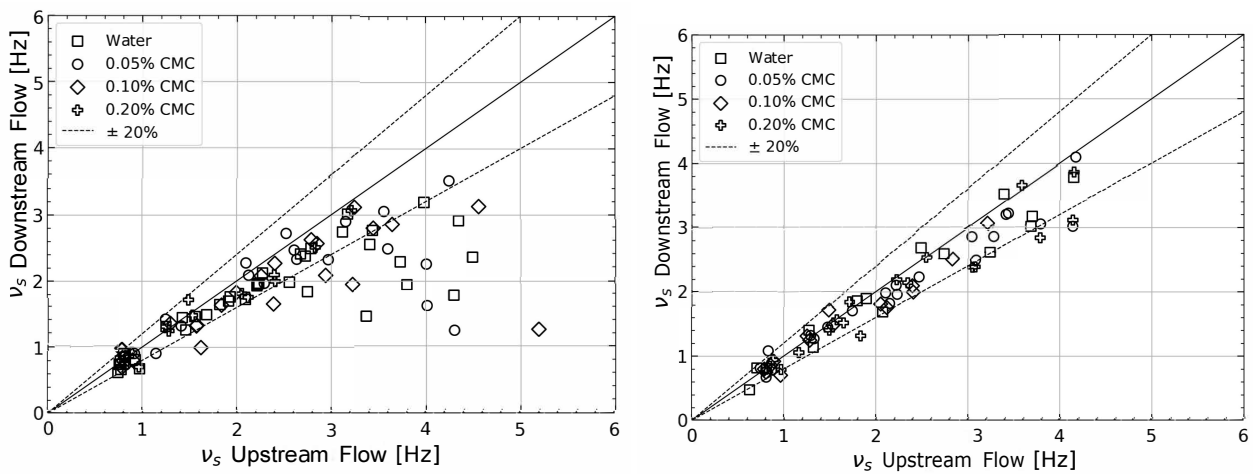


Figure 4. Variation in ν_t for slug flows as a result of large bubble breakup in the different baffles.

4. Conclusion

The present work has used image techniques to assess the flow properties in air-water CMC solutions of slug flows subject to severe turbulent perturbations. The work discusses the effects of the

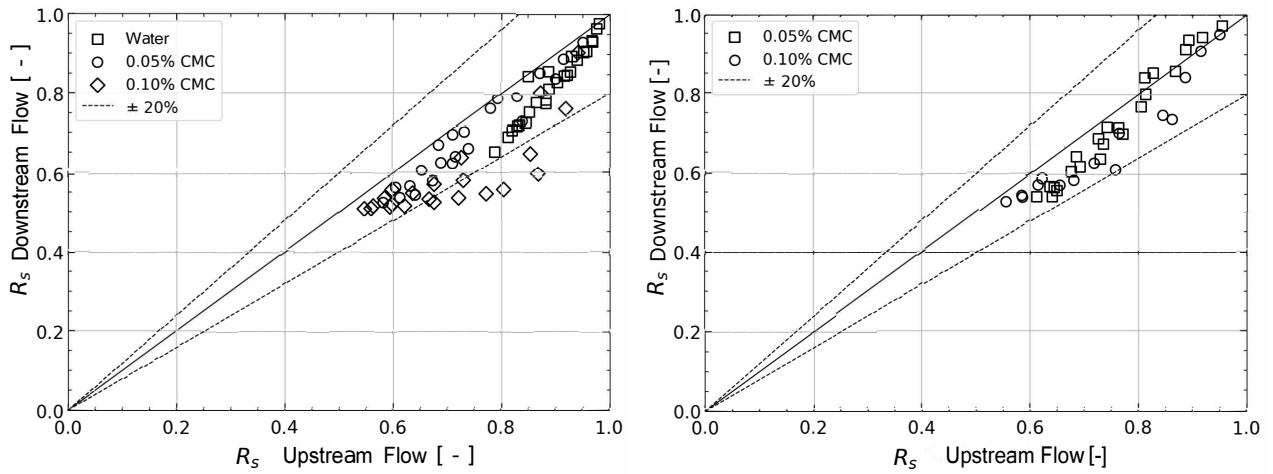


Figure 5. Variation in R_s for slug flows as a result of large bubble breakup in the different baffles.

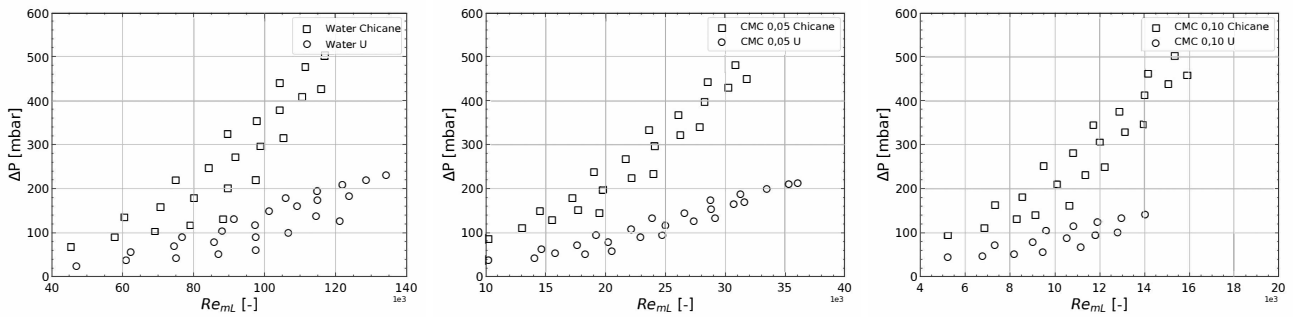


Figure 6. Pressure drops (ΔP) for slug flows as a result of large bubble breakup in the different baffles. The circles represent the flows upstream of the disturbances. The squares represent flows downstream of the disturbances.

liquid rheology and mixture velocity on the flow pattern, with emphasis on assessing how ν_t , R_s and ΔP are modified by these parameters. The work shows how high-speed filming can be used to obtain the properties of highly aerated flows with success.

The generated data are currently being used together with machine learning techniques for the automatic identification of flow rheology (of the liquid phase) and corrections on existing formulations for the prediction of pressure drop.

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