GAS SOLUBILITY EFFECTS ON SLUG FLOW

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Summary The present work investigates the effects of gas solubility in the fluid dynamic properties of a horizontal water slug flow. The solubility of gas in liquid promotes a change in flow pattern that has a direct impact on the pressure drop. The experimental results are compared with the mechanistic model of Hubbard and Dukler (1975). Measurements of the size distributions of the liquid slug and of the long bubbles are provided, as well as local measurements of the liquid velocity in the slug, the velocity in the liquid film, the velocity of propagation of the nose of the long bubbles and the pressure drop.

INTRODUCTION

In the petroleum industry, certain operations induce an influx of a soluble gas into the wellbore. As a result, changes in the flow pattern and on the pressure drop can occur. The purpose of the present work is to investigate experimentally the changes in slug flow properties provoked by gas solubility. The working fluids are water and carbon dioxide. Local measurements are provided by two optical techniques: Shadow Sizing (SS) and Particle Image Velocimetry (PIV). Results show the size distributions of the liquid slug and of the long bubbles, the liquid velocity in the slug, the velocity in the liquid film, the velocity of propagation of the nose of the long bubbles and the pressure drop. For reference, the experimental results are compared with predictions given by the slug flow model of Hubbard and Dukler (1975). The effects of solubility are shown to exert a significant influence on the flow properties. The pressure drop, in particular, is noted to be reduced by 10%.

FLOW FEATURES AND MEASUREMENT TECHNIQUES

The experiments were conducted in an 8-meter long acrylic pipe with 19-mm internal diameter. The water was driven by a centrifugal pump to a mixer where the gas phase was received from a pressure vessel. The PIV measurements were performed with a two-dimensional Dantec system. To further inspect the two-phase flow characteristics, a Shadow Sizer (Dantec Dynamics) measurement system was used.

RESULTS AND DISCUSSION

Before the effects of gas solubility on slug flow were accounted for, a sensitivity analysis of the proposed geometry for the experiment was made. Measurements in the bubbly flow regime showed an appreciable decrease in bubble size distribution between Stations 1 and 2 (Fig. 1a), which were set 4-m apart. In the two tests that were performed, 4000 images at 100 Hz were recorded. At each station, 239 bubbles were received. Figure 1a shows that between Stations 1 and 2, a decrease of 35% in average bubble volume occurred.

The notation here is that of Dukler and Hubbard (1975). The probability density functions of slug lengths (L_s) resulting from air-water and CO_2-water flows at Stations 1 and 2 are shown in Fig. 1b-c. For the air-water flow, the average value of L_s remains about the same. The effects of the solubility, however, provoke a shift to the right on the density function of L_s, implying that for the CO_2-water flow average value of Ls increases about 33% between sections. It is important to highlight that transient effects are very high in Station 1, so the data obtained at Station 2, where the flow is less affected by these effects, are more representative.

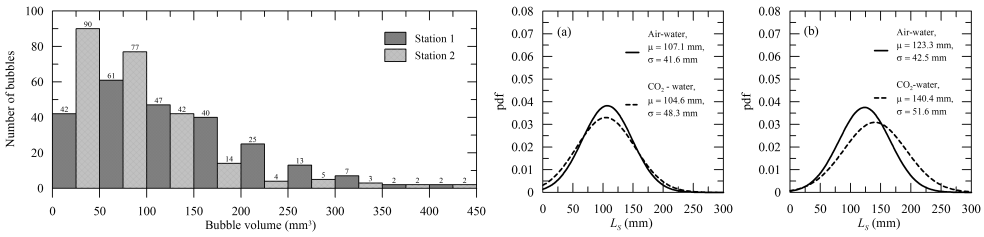

Figure 1. Bubble size distribution for a CO_2-water flow at Stations 1 and 2 (a). Probability density functions of slug lengths (L_s) for air-water and CO_2-water flows: (b) Station 1, (c) Station 2.

The PIV statistics were obtained from 300 pairs of pictures, with a time interval between laser pulses of 150 μs. The local velocity profiles of the mean velocity of fluid in the slug (V_s) and of the mean velocity of fluid in the film in front of the

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slug (V_{fe}) are shown in Figs. 2a-d. The density functions of the mean velocity profiles averaged over a cross section are also shown.

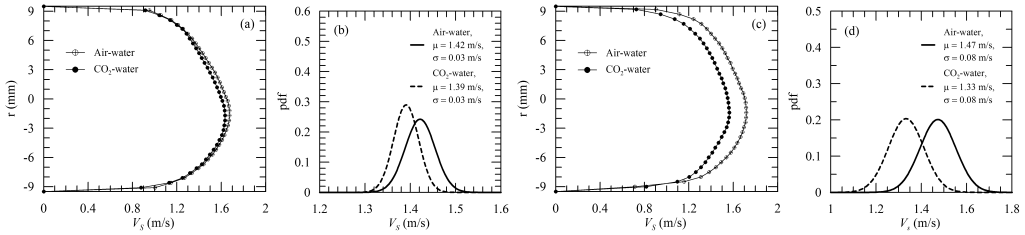

Figure 2. Local velocity profiles of the fluid in the slug (V_s) at (a) Station 1 and (c) Station 2 and probability density functions at (b) Station 1 and (d) Station 2 for the air-water and CO_2-water flows.

The average value of V_s for the air-water and CO_2-water flows at Station 1 were 1.42 and 1.39 ms^{-1} respectively. At the same station, V_{fe} changed from 1.15 to 1.13 ms^{-1} respectively. These slight differences were due to the short distance between the point where CO_2 was injected into the flow and the measurements were made. At Station 2, however, changes were significant. The average value of V_s for the air-water and CO_2-water flows changed from 1.47 to 1.33 ms^{-1}; V_{fe} changed from 1.14 to 1.11 ms^{-1}.

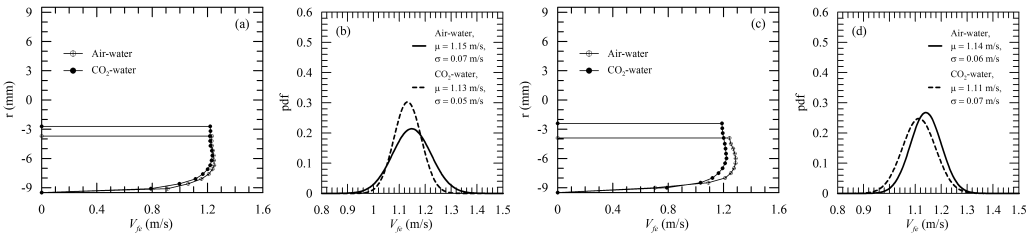

Figure 3. Local velocity profiles of the mean velocity of the film in front of the slug (V_fe) at (a) Station 1 and (c) Station 2 and probability density functions at (b) Station 1 and (d) Station 2 for the air-water and CO_2-water flows.

A comparison between the present measurements and theoretical predictions furnished by the mechanistic model of Dukler and Hubbard (1975) is shown in Table 1.

Table 1. Comparison between the present measurements and predictions given by the model of Dukler and Hubbard (1975).

	Predictions Dukler and Hubbard (1975)	Air, Station 2	CO2, Station 2
s [Hz]	—	7.87	7.23
L_s [mm]	139.9	123.4	140.4
L_f [mm]	62.6	94.5	76.9
R_s	—	0.991	0.996
R_{fe}	—	0.255	0.340
V_t [ms^{-1}]	1.595	1.714	1.565
V_s [ms^{-1}]	1.292	1.471	1.334
V_{fe} [ms^{-1}]	0.812	1.142	1.113
$\Delta p/\Delta x$ [psi m^{-1}]	0.207	0.174	0.154

The solubility of CO_2 in water resulted in a volume reduction of 30% of the gas phase. This, in turn, provoked reductions of about 10% in V_s, V_t and $\Delta P/\Delta x$. When compared with predictions given by the model of Dukler and Hubbard (1975), the experimental pressure drop for the CO_2-water flow is 25% below the theoretical value. This is strong evidence that any model advanced to simulate two-phase flows with a soluble phase cannot safely ignore this feature.

References

[1] DUKLER, A., HUBBARD, M., 1975, "A model for gas-liquid slug flow in horizontal and near horizontal tubes", Industrial and Engineering Chemistry Fundamentals, 14, 4, 337-347.