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Bubbles Size Estimation in Liquid Flow Through a Vertical Pipe

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Abstract: Multiphase flows such as those in the oil and gas industries complicate the production operation in many ways. Abilities to predict the behavior of such flow may reduce high operational cost and increase productivity. While a real crude oil comprises more than three phases of fluid, experimental simulations of a simplified two-phase flow system may help to understand the flow behavior at fundamental level. In this study, bubbles diameters in liquid flow at different vertical displacements and flow rates are studied. The study is carried out experimentally on flows of water at 5, 10 and 15 gpm with air bubbles, of which the diameters are measured by using Phase Doppler Anemometer (PDA). It is found that the air bubbles are larger near the pipe wall as compared to those in the central region of the pipe. The bubbles are also observed to become smaller with increase in the water flow rate.

Key words: Bubbles, size, confined flow, multiphase flow, phase Doppler anemometer

INTRODUCTION

In a production well, crude oil flows from a high-pressure reservoir. As the pressure and temperature reduces, gas evolves from the liquid (Arnold and Stewart, 2008). Further reduction in the pressure causes the volume of gas increases and the gas begins to move to the wellbore (McCain, 1990). Such phenomenon complicates the flow of crude oil, since the pipeline now consists of a multiphase flow and this poses many operational problems (Abdul-Bari and Yunus, 2009).

At some fields, the crude naturally appears in three phases in reservoirs: gas, liquid and solid. Proper metering of multiphase production from oil and gas wells is required for reservoir management, custody transfer, fiscal obligations and leak detection in the flow lines. Multiphase flow metering is more difficult than single-phase flow measurement due to the existence of numerous regimes, such as annular, bubbly, churn, slug, stratified, wavy (Manning and Thompson, 1995), which are dependent on parameters such as pipe geometry, line orientation (vertical, inclined and horizontal), flow direction, fluid properties and flow rates.

Murai *et al.* (2007) reported that by having small bubbles of a few millimeter in dimension, can reduce wall drag but the opposite effect may occur with the presence of bubbles under certain conditions. In a simulation study by Lu and Tryggvason (2007) on downward turbulent flows of bubbly liquids in a vertical channel, it was shown that drag is increased when bubbles travel close to the wall and this depends on the deformability and motion with respect to the wall. In a more recent work of Shawkat *et al.* (2008) involving a 200 mm diameter vertical pipe and using hot-film anemometry it was reported that the gas or bubble velocity would always be lower than the liquid velocity. A study on prediction of bubble size in bubble column was made using Artificial Neural Network, through which the bubble diameter was reported to be a function of six parameters: gas velocity, column diameter, diameter of orifice, liquid density, liquid viscosity and liquid surface tension (Ibrehem and Hussain, 2009).

The existence of bubbles in liquid flow causes problems in various applications involving pipelines, such as decrease in the oil mobility (Maini, 2001) and this affects the oil production rate. At large air volume fractions and small water velocities, the bubbles become highly deformed (Razzaque *et al.*, 2003). The characteristics of bubbles in flowing liquid are complicated, due to the effect of drag, fluid viscosity, friction and wall shear stress. Thus, a fundamental study of the behavior of bubbles in liquid flow in pipe is required.

The objective of the present project is to study the behavior of bubbles in flowing liquid in a vertical pipe. Since the flow of crude oil is highly complicated, a simplified flow system involving the flow of water and air bubbles at near ambient condition is used in order to understand the fundamental nature of such flow. The information from this work would enable further investigations of the effects of the bubbles in various pipeline applications.

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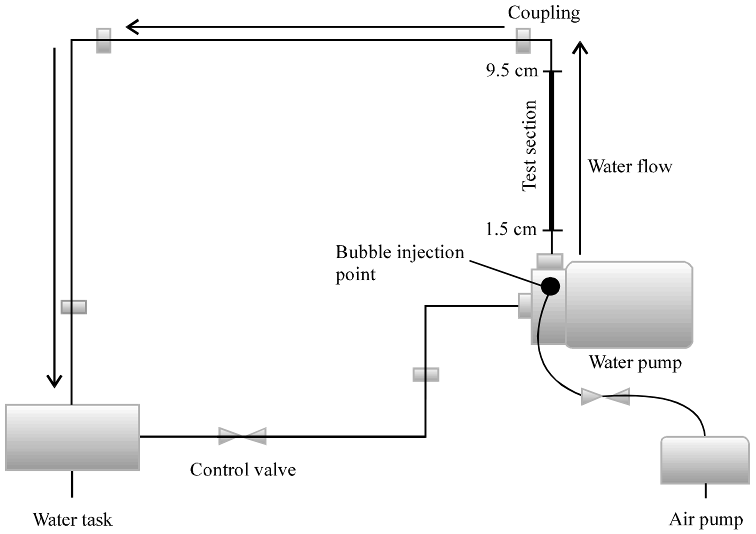

Fig. 1: The experiment rig

MATERIALS AND METHODS

In order to study the liquid flow, an experiment rig consisting of a water tank, a water pump, a water flow meter and a control valve were set up as shown in Fig. 1. The water pump was of a customized centrifugal pump of 150 mm diameter, which was driven by GE Industrial motor with a maximum speed of 1725 rpm.

Air bubbles were introduced into the water flow at the outlet of the pump or 1.5 cm upstream of the test section by using an air pump with bubble injector typically used in fish aquariums. The maximum air velocity that the air pump could deliver was 1.5 m sec^{-1}. Transparent plastic pipes used in the test section of the system allowed laser to penetrate through the pipe wall to reach the bubbles, which was necessary for the non-intrusive measurement used in this study. The clear pipe enabled the laser beam to be transmitted to the desired point of interest within the flow.

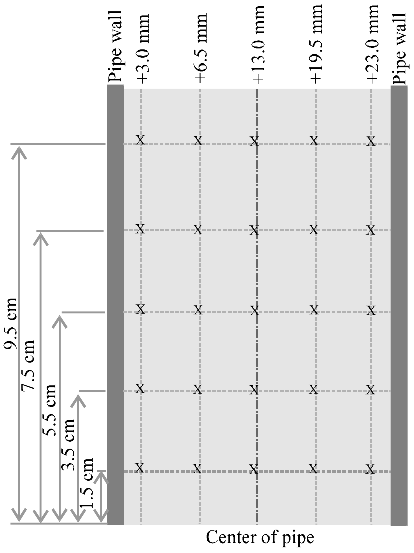

Fig. 2: Data points of the vertical pipe

Experiments were conducted with flow rates of 5, 10 and 15 gallons per minute (gpm) with measurements of bubble size taken within the test section of the vertical upwards pipe as shown in the cross section of the pipe's test section in Fig. 2. The vertical distance indicated in the figure represents the distance measured from the upstream point of the test section. The point on the wall could not be measured due to the limitation of the system and thus the closest measurements to the internal wall of the pipe were taken at 3.0 mm away.

The bubble sizes were measured using Dantec Dynamics Phase Doppler Anemometer (PDA), in which a pair of laser beams was allowed to pass through the flow. Detailed description of the PDA system can be found in the reference (Sulaiman and Mohd-Nor, 2003). The PDA system is a statistical measurement method, in which information on the droplet sizes are obtained by using BSA flow software of Dantec dynamics.

RESULTS AND DISCUSSIONS

Measurements using the PDA system resulted in a set of bubble diameters at a specified location within a short duration (typically 15 sec). The number of data for each measurement depended upon the number of bubbles

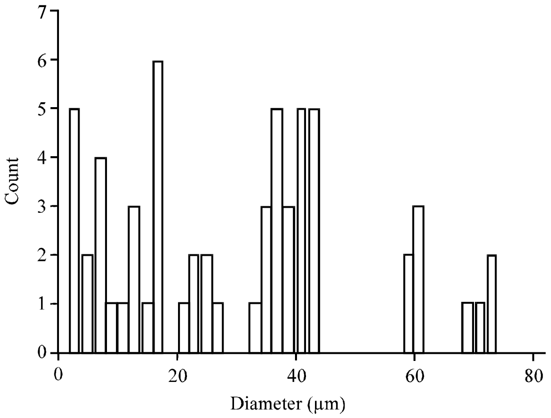

Fig. 3: Typical distribution of diameters of bubbles

passing through the measurement volume or the intersection of the pair of laser. In this work, the number of data was typically around 60. The data was averaged out to obtain the Sauter Mean Diameter (SMD) or D_{32} (Lefebvre, 1989). A typical distribution of diameters of the air bubbles in the pipe obtained from a data sampling at one point is shown in Fig. 3. In general a poly-disperse trend of bubble sizes is displayed.

In this work the D_{32} value for each of the measurement points illustrated in Fig. 2 was obtained. Figure 4 shows a plot of scaled circles representing the D_{32} values (μm or microns) for different locations in the test section at a water flow rate of 5 gpm. The bubbles flowed upward. It is shown that at the right hand side of the figure the bubbles experienced an increase in diameter as they travelled upward. This was probably due to merging of droplets. The reasons for merging of bubbles could be attributed by the reduction of bubbles' velocity and also backward flow at the right hand side caused by the presence of a rotameter located at the upstream of the test section. The no-slip condition experienced by the water flow on the wall surface might have also contributed to the reduction of velocity of water and bubbles. This allowed sufficient time for the bubbles to settle and simultaneously increases the chance for merging. It was also probable that the effect of buoyancy force, resulted by the lower density air, would be more significant in a slow velocity environment experienced in the left hand side of the pipe.

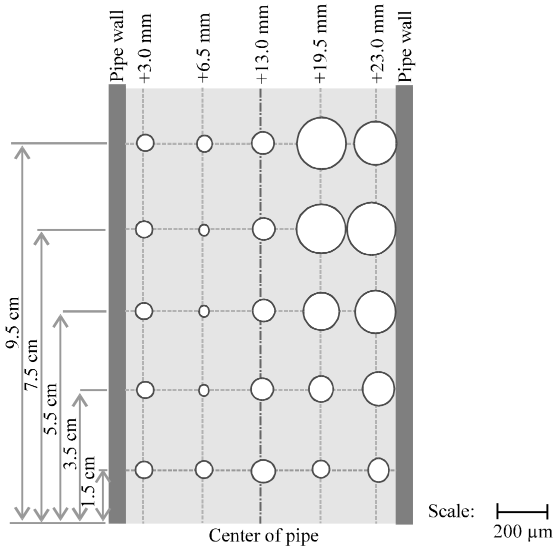

Fig. 4: Distribution of bubbles diameter at 5 gpm

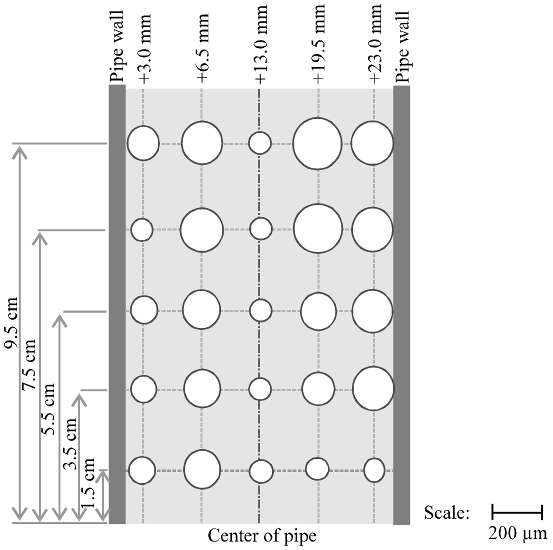

Fig. 5: Distribution of bubbles diameter at 10 gpm

The flow in the test section at 5 gpm was observed to be non-symmetrical due to flow entrance effect. While the right hand side of the test section had a low velocity, the left hand side experienced a faster flow velocity and consequently the relatively higher kinetic energy caused breakup of bubbles and simultaneously minimized merging of bubbles. Similarly, the bubbles at the center of the pipe, which were relatively faster, had less chance to merge. In addition, the sizes of bubbles at center of the pipe were shown to have a nearly constant diameter with a D_{32} value of 65 μm. It must be noted also that the bubbles are shown to be the smallest at 6.5 mm away from the left wall implying that the peak velocity do not occur at the center of the pipe.

Figure 5 shows the distribution of circles that represent the D_{32} values in the test section for water flow

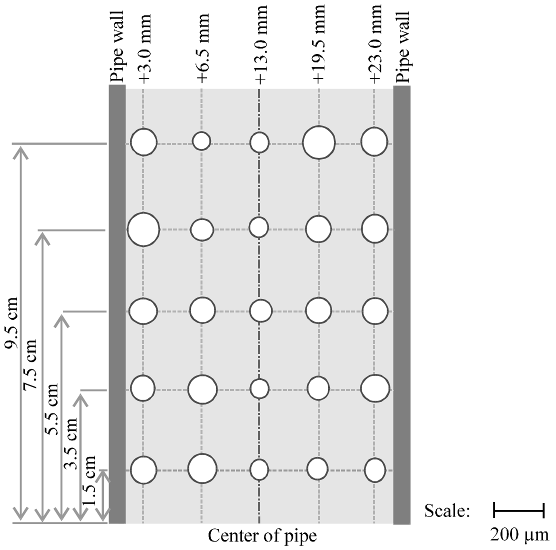

Fig. 6: Distribution of bubbles diameter at 15 gpm

of 10 gpm. The trend of results is nearly similar to that in Fig. 3. The bubbles on the right hand side are shown to increase in size as the elevation increases. In addition, the size distribution of bubbles on the right hand side is nearly the same with that in Fig. 4, with exception for slight decreases at certain points Nevertheless, the left hand side bubbles are shown to increase in size in relation to those in Fig. 4. This suggests that the non-symmetry trend of results in Fig. 4 starts to change when the flow rate increases. Furthermore, along the central region of the pipe the bubbles are shown to have a smallest and consistent diameter. The average bubble diameter was of 64 μm, which was only slightly smaller than the value for flow at 5 gpm.

Figure 6 shows the distribution of D_{32} values in the test section for water flow of 15 gpm. Obviously the distribution of bubbles size is shown to be more symmetrical (Fig. 5). The smallest bubbles are concentrated along the central region of the pipe with an average diameter of 55 μm. hence it is clear now that the size of bubbles decreases with the water flow rate. As for other flow rates, the bubble diameter is shown to be nearly constant along the central region. In Fig. 5 it is also shown that the diameters of bubbles at the left and right hand side of the cross section are nearly the same. In addition, the bubbles sizes at the upstream and downstream of the test section are also observed to be consistent, which suggests that there is minimal merging or breakup of bubbles in the test section.

CONCLUSION

The bubbles in liquid flow changes its characteristics when it travels from center of pipe to near pipe wall and from lower elevation to higher elevation as it move from eddies phase towards steady flow and this is all because bubbles in liquid will create multiphase fluid flow as the result. There are variations of bubbles characteristics in terms of diameter along the liquid flow and the variation also happens because of water flow rates. The higher water flow rate will result in smaller bubbles diameter as it have less chances to merge when travelling along the pipe towards the upper elevation, where the liquid slowly become steady flow. Very large bubbles normally occur near pipe wall at where the heavier medium, which is water, would travel slower.

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