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The Rising of Taylor Bubble at the Inception to an Annulus

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ABSTRACT

In the drilling of petroleum wells, gas from high-pressure zones may enter the drilling fluid. This gas inflow might cause a gas kick that can result in a blowout from the well. Prediction of the dynamics of such gas inflows is important for safety modeling and procedures. In this work, experiments are carried out to study the dynamic rise of the bullet-shaped bubbles pattern known as the Taylor bubble. The shape and rise velocity of Taylor bubbles are different in circular pipes and annuli. The bullet shape is changed into elongated doughnut bubbles which are only partly connected circumferentially. The rise velocity is linked both to the interface-frictional drag and also to the recirculation zone behind the bubble. While the interfacial drag is linked mainly to the shear rheology of the drilling fluid, the recirculation zone depends also on viscoelasticity. In addition, the interfacial tension is important for bubble breakup with additional pressure loss. These experiments were done with a new flow rig that involves a vertical pipe with a concentric annulus inserted. Polyanionic Cellulose and Carbopol polymeric additives were used in the experiments to compare the Newtonian with non-Newtonian behavior. To determine the effect of the liquid dynamic viscosity on the bubble at the incipient to the annulus, high-speed video is used, and the results are further analyzed by using digital image processing.

INTRODUCTION

When an uncontrolled flow of formation fluids from a wellbore occurs, a blowout is likely to happen. This is termed a gas kick or influx of gas into the wellbore. The situation needs control and the most widespread methods used are called the driller's method and wait-and-weight method[1]. These methods are generally considered to be the safest and most efficient. An alternative method is a bullheading technique. This technique involves forcing drilling fluid back into the well from the surface. Fig. 1 shows a schematic representation of the bullheading process during well control[2].

As the common goal in designing drilling well is to maintain the pressure in the wellbore, several factors are involved in bullheading technique. These include investigation of the effect of drilling fluid properties, injection rate or average annular velocity, fracture gradient, amount, and height of gas. In this study, a new rig has been built to carry out an experimental investigation and transient flow modelling of bullheading process[2]. Furthermore, the setup has been extended to study the rising of Taylor bubble at the

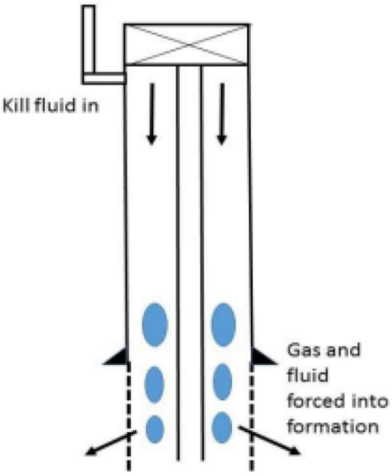

FIGURE 1: Bullheading process

inception of an annulus. According to existing theories and research, the rising velocity of gas (air) bubble can be calculated analytically. Equation 1 has been mentioned[3] to be a result of a large amount of compiled data by Dumitrescu in 1943 and further investigated by several authors.

$$U = 0.351\sqrt{gD} \tag{1}$$

Here, g is gravitational acceleration and D represents the diameter of a circular pipe.

The measurement of a rising bubble in an annulus is significantly dependent on the annulus size and is proven by many analytical and experimental research.

The velocity of the bubble rising in an annulus was predicted by a combination of experimental and theory analyses conducted by Das et al.[4]. The velocity of the Taylor bubble rising in the annulus was calculated as:

$$U = 0.323\sqrt{g(D1 + D2} \tag{2}$$

where D1 and D2 are the corresponding inner and outer concentric tube diameters. Both observations and theory show that velocity is a only a function of the annulus dimension, such as the Froude number.

EXPERIMENTAL

Experimental setup

Fig. 2 shows a sketch of the new flow rig that was built for bullheading process. It involves two acrylic pipes mounted vertically in parallel and connected from the bottom. Those two pipes, pipe A and pipe B were connected by a ball valve 1 meter above the ground. Before the ball valve, a 2 mm ID-sized pipe and a valve were attached to pipe A to initiate airflow into the system during the period of the experiment. By closing the valve, the bubble volume can be adjusted. The smaller pipe is where the concentric annulus is inserted which is also the focus of this paper.

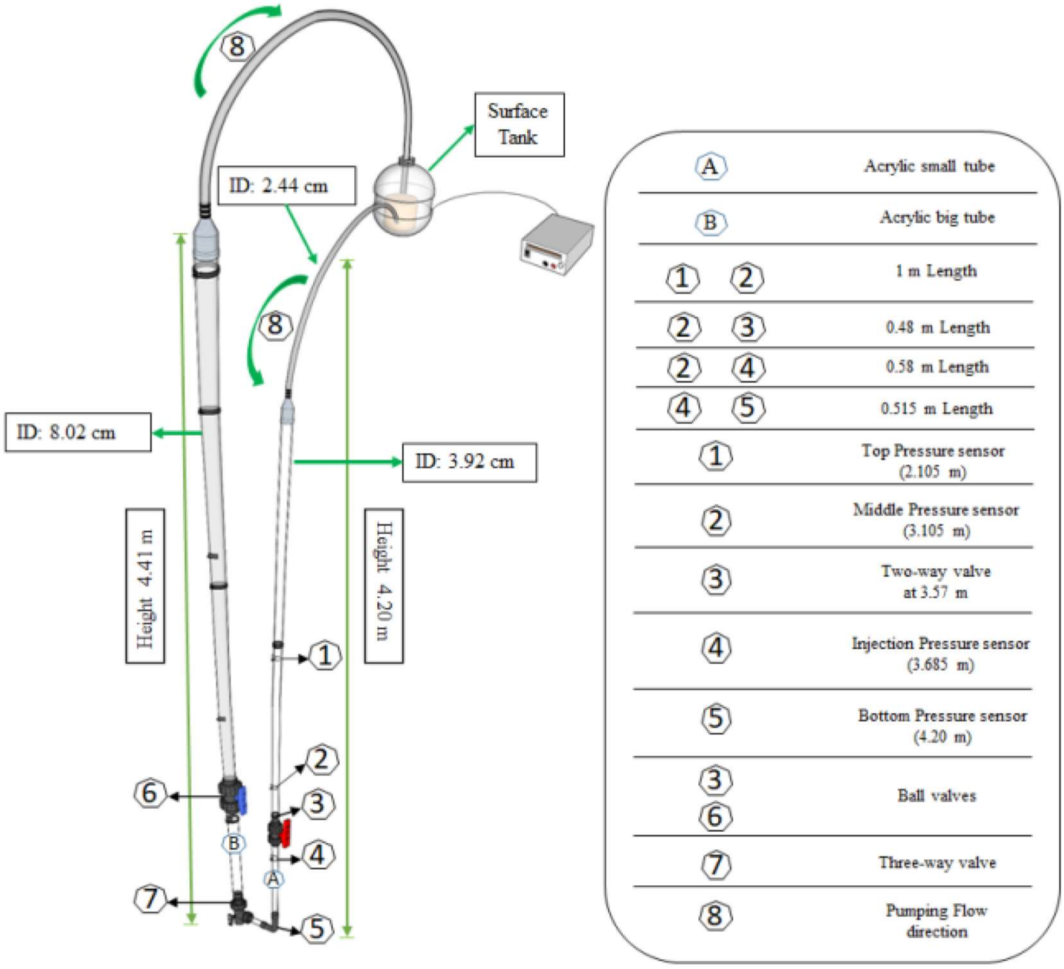

FIGURE 2: Sketch of the setup with the labels and dimensions[2]

Initially, the experimental procedure consists of opening valves 3 and 6 to allow fluid to pass through the system. The surface tank must be filled with fluid to ensure that the system is totally filled. The next step is to close the valve 3 as seen in Fig. 2. The volume of the bubble is controlled by displacing the fluid with the same amount of air until the Injection mark as seen in Fig. 4. A closer view of the annulus is sketched in Fig. 3.

The high speed-video used in these experiments was an iPhone 13 Pro Max and the framerate was set to 120fps. A ruler was placed outside of the pipe to serve as a length scale. The region of interest (ROI) is at the inception to the annulus as seen in Fig. 3. The high-speed image processing was conducted using the video analysis and modelling tool Tracker software developed by Douglas Brown et al.[5]. No color adjustments were needed to perform accurate tracking of the bubble nose.

Fluid rheology

Two different additives Polyanionic Cellulose (PAC) and Carbopol were used to prepare non-Newtonian testing fluids. The dynamic viscosity of the solutions was measured by using the viscometer model ELV-8. During this experiment, we considered 40 cP as a

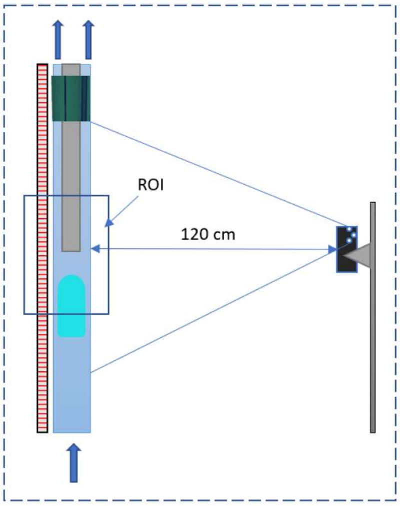

FIGURE 3: Illustration of the annulus, rise of Taylor bubble and video recording. The arrows show the direction of the flow.

FIGURE 4: Bubble volume

reference dynamic viscosity. This was chosen to ensure that a large number of additives can be avoided. As for the preparation of fluid with Carbopol additives, initially, 4 samples were prepared with different amounts of Carbopol: 0.2 g/L, 0.3 g/L, 0.4 g/L, and 0.5 g/L.

RESULTS AND DISCUSSIONS

The result from the Carbopol addition fluid preparation is presented in Figure 5. As seen in Fig. 5, 0.43 g/L of Carbopol is needed to achieve 40 cP as the reference viscosity. For the PAC, 2g/L was needed to get 40 cP dynamic viscosity.

Figure 6 represents the overall velocities for the Taylor bubble before the incipient and into the annulus. It could be seen that the measured averaged velocity of the Taylor bubble in water between the time interval 0 to 0.38s is 0.228 m/s. According to Eq. 1 the velocity is calculated to be 0.219 m/s. Furthermore, from the time interval of 1.17 to

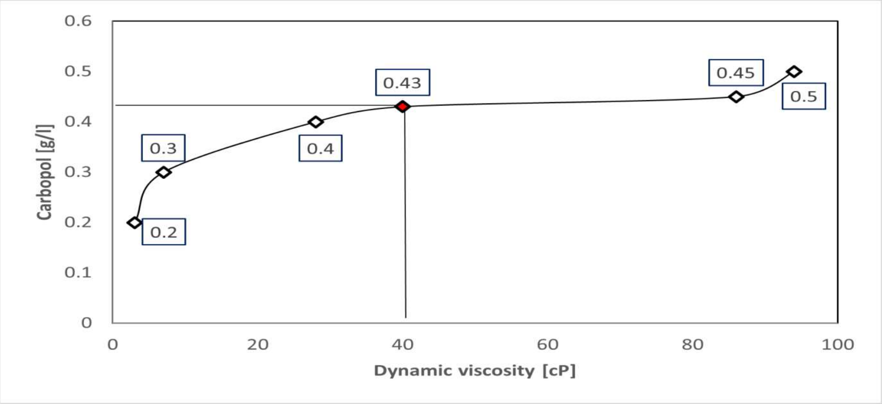

FIGURE 5: Amount of Carbopol as a function of dynamic viscosity

1.42s the Taylor bubble velocity in the annulus was measured to be 0.269 m/s. This is also consistent with the analytical solution in Eq. 2, which is 0.275 m/s.

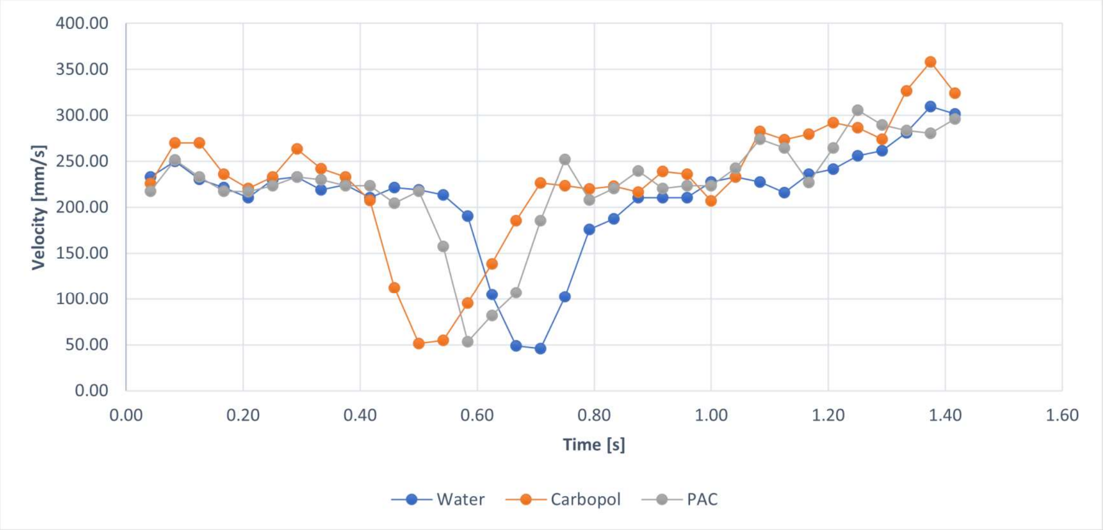

FIGURE 6: Taylor bubble velocities before, at the inception and in the annulus

Figure 6 also shows that the velocity of the Taylor bubble is higher when it flows in water than in non-Newtonian fluids. After getting a flattened head shape as seen in Fig. 7, a local minimum in velocity is apparent for the Taylor bubble in all fluids.

It is obvious from Figs. 6 and 7 that the velocities of the Taylor bubble decrease as the viscosity of fluids increases.

Chaotic bubble flows on the tail of Taylor bubble are more likely to occur for the water case, and it gets intense when Taylor bubble starts to pass through the annulus. This tendency has not been seen for PAC and Carbopol. The flattened head of the Taylor bubble is observed while the Taylor bubble is closer enough at the inception to the annulus in all three fluids. The bullet shape of the Taylor bubble changed into elongated doughnut bubbles, e.g. at 0.95s in water (see Figs. 7) which is only partly connected circumferentially.

The present observations have also been confirmed by different authors including Rohilla and Das[6]. They conducted numerical and experimental study of fully developed

FIGURE 7: Taylor bubble flow before and after inception in to the annulus. The number indicate time in seconds

Taylor bubble in an annular concentric tubes.

CONCLUSION

The behavior of the Taylor bubble at inception into a concentric annular pipe has been carried out. The experiments were done using water, PAC, and Carbopol as working fluids. The dynamic viscosity was used for evaluating how the two non-Newtonian fluids would react on the bubble into the annular concentric tube. We described that the dynamics of a fully bubble at the inception was flattened, and developed to be elongated doughnut-like bubble around the annulus. These situations shold be considered during the drilling operations.

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