MOTION OF GAS BUBBLES IN VISCOPLASTIC FLUIDS

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Abstract. *One of the most troublesome problems in the petroleum industry is annular gas migration. Gas invasion occurs when pressure is lower in the annulus than at the formation face during drilling or well completion procedures. The gas might migrate to a lower pressure zone, or possibly to the surface The objective of our research is to determine stagnant conditions, terminal velocity and formation parameters for gas bubbles occurring in viscoplastic fluids, in order to establish under which conditions gas migration might occur. For this matter we use Carbopol dispersions to simulate the properties of cement slurries. Glycerol was also used to compare the results obtained in our experiments to those available in the literature for Newtonian fluids. Laser visualization of the flow around the bubbles was also carried out.The bubble velocity is measured both experimentally, using a chronometer, and through sequential pictures.*

Keywords: *bubble motion, viscoplastic fluids, rheology, gas migration ...*

1. INTRODUCTION

Annular fluid migration may occur during drilling or well completion procedures, and has long been recognized as one of the most troublesome problems of the petroleum industry. It consists of the invasion of formation fluids into the annulus, because of a pressure imbalance at the formation face (Parcevaux *et al.* (1990)). The fluids may migrate to a lower pressure zone, or possibly to the surface leading to a kick (when it's possible to control) or, in case it is uncontrollable, to a blowout. A blowout can lead to loss of life, environmental damage and great cost for the operator.

Another big problem is when the gas restrained in the pores of the formation is released from the gravels. Gas invasion occurs when pressure is lower in the annulus than at the formation face. Although gas may enter the annulus by a number of distinct mechanisms, the prerequisites for gas entry are similar. There must be a driving force to initiate the flow of gas, and space within the cemented annulus for the gas to occupy (Bonett and Pafitis (1996)).

Many work has been done investigating the gas migration problem, especially on fluid density control, mud removal, cement slurry properties, cement hydration, and cement/casing/formation bonding. Regarding the motion of gas bubbles, many studies were performed in Newtonian (Pinczewski (1981); Terasaka and Tsuge (1990); Pamperin and Rath (1995)) and shear-thinning fluids (Astarita and Apuzzo (1965); Gummalam and Chhabra (1987); Kee *et al.* (1990); Terasaka and Tsuge (1991); Li *et al.* (2002); Dziubinski *et al.* (2003)). However, studies of motion the of bubbles in viscoplastic media is rather scarce. It is known that for this type of fluid the bubble will not move unless the buoyancy force exceeds the yield stress of the fluid (Terasaka and Tsuge (2001); Dubash and Frigaard (2007); Sikorski *et al.* (2009)).

Hence, the objective of our research is to determine some aspects of the behavior of gas bubbles in viscoplastic fluids, such as stagnant conditions, terminal velocity and formation parameters, in order to establish under which conditions gas migration might occur.

2. THE EXPERIMENT

Our experimental setup, as shown in 1, consists of a 20cm x 20cm x 60 cm acrylic reservoir with a small metal tube with a bore diameter of 1/8", whereby we inject air using syringes with 1 mL, 5 mL and 10 mL capacity. We also have a digital camera to capture the bubble movement, a syringe pump that controls the air flow in the syringe, and one auxiliary reservoir from which the fluid is pumped with a progressive cavity pump to the main reservoir to ensure homogenization of the fluid and removal of stagnant bubbles before the experiment. Moreover, two lasers are used (one on top and one at the bottom of the reservoir) to visualize the flow around the bubble.

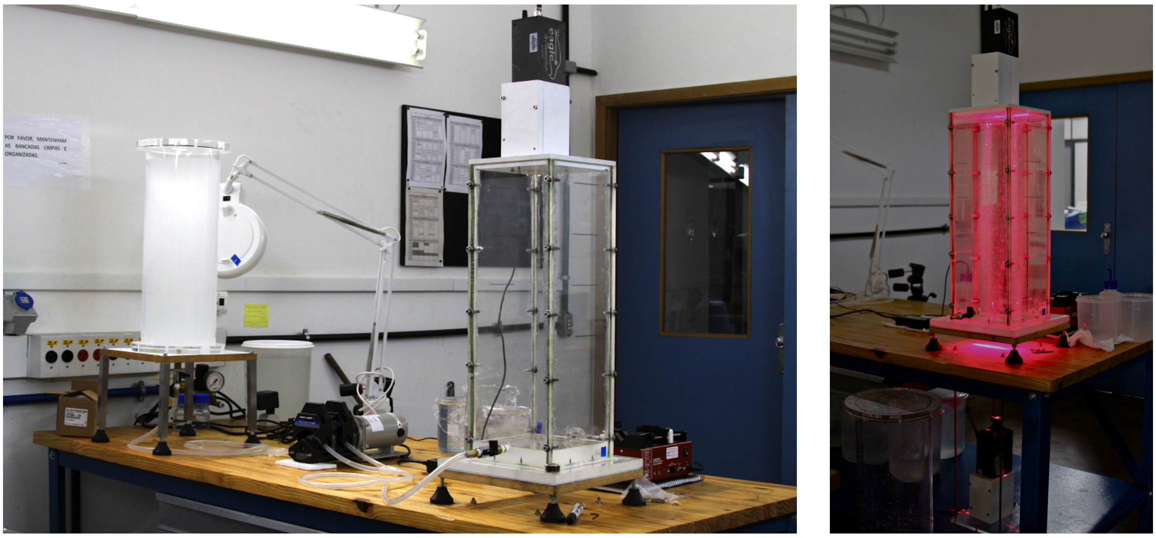


Figure 1. Experimental Set-up.

A Carbopol dispersion is a great model fluid for viscoplastic materials. Its main advantages are the easiness with which it is possible to control its yield stress and viscosity only by varying its concentration, and its transparency, which is really important in the visualization of gas bubbles. The rheology of all Carbopol dispersions, concentrations equal to 0.1%, 0.15%, and 0.2%, were performed and are shown in terms of flow curves and oscillatory stress sweeps tests in Figs. 5, 6, and rheol3. Flow curves are fitted with the Herschel-Bulkley model.

The acrylic reservoir is divided into segments of 10 cm. The bubble velocity is calculated as the ratio of displacement over time, and can be measured experimentally - the time of displacement is measured using a chronometer -, or through sequential pictures - by tracking the bubble movement from picture to picture:

$$v_{b_{meas}} = \frac{\Delta h}{\Delta t_{cronom}} \qquad or \qquad v_{b_{photo}} = \frac{\Delta h_{ruler}}{\Delta t_{camera}} \tag{1}$$

We have also been using a glycerol solution trying to set parameters for the experiment, since it is a Newtonian fluid with well known behavior. We use tracer particles (little spheres of glass of around 8-12μm diameter) mixed in the glycerol to visualize the displacement of fluid.

3. RESULTS

The first step was to establish the zone where the bubble would reach its final velocity. We divided the reservoir in 4 segments of 10 cm each starting 15 cm above the metal tube, numbered as shown in Fig. 2, and used a 0.1% Carbopol dispersion. The velocity was measured at each segment, and the results obtained are presented in Tab. 1.

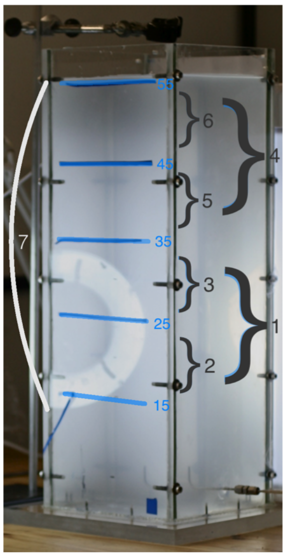
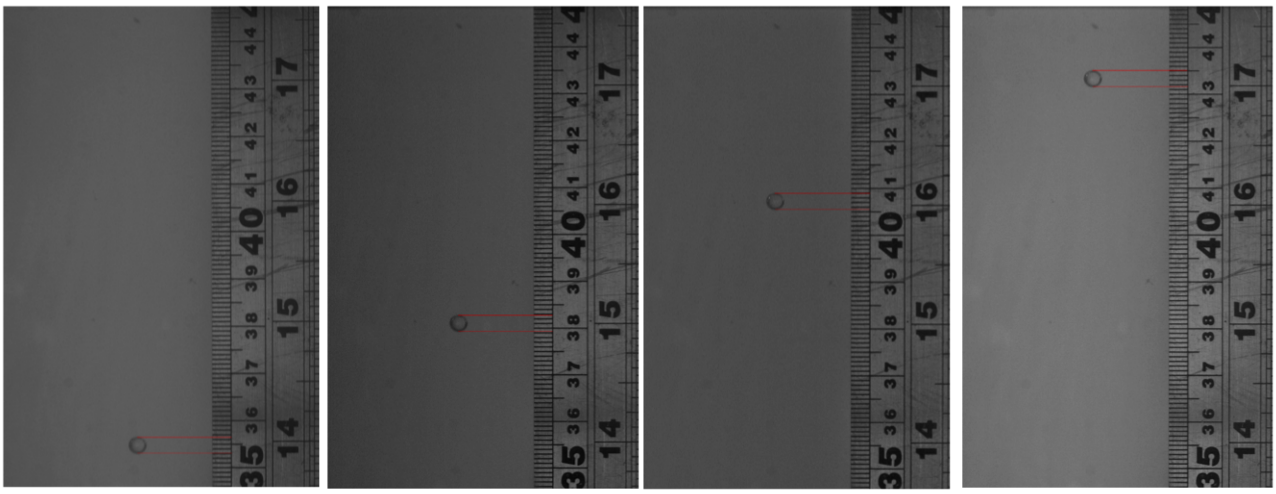


Figure 2. Reservoir segments to track the final velocity.

Table 1. Results for the 0.1% Carbopol dispersion.

Segment	Velocity (cm/s)	Difference (%)
1	12.75	
2	13.51	5.64
3	13.26	1.89
4	13.33	0.54
5	13.29	0.30
6	13.56	1.94
7	13.69	0.98

As a conclusion, we found that it was better to discharge the first segment. New measurements were done with the reservoir covered and uncovered. A slight change in the results was noticed, so we decided to perform all the measurement with it uncovered. We also took several pictures with a 0.2s break between them, and calculated the velocity of the bubbles by their displacement between the photos (Fig. 3) to see if they would match the velocity calculated experimentally, which it did.



$$v_b = \frac{38{,}3 - 35{,}65}{0{,}2} = 13{,}25\,\frac{cm}{s} \qquad v_b = \frac{40{,}9 - 38{,}3}{0{,}2} = 13{,}0\,\frac{cm}{s} \qquad v_b = \frac{43{,}5 - 40{,}9}{0{,}2} = 13{,}0\,\frac{cm}{s}$$

Figure 3. Motion of gas bubbles in 0.1% Carbopol dispersion.

As can be seen in Fig. 3, bubbles rising in the 0.1% Carbopol solution are spherical, similar to bubble shapes in Newtonian fluids like glycerol Fig. (4).

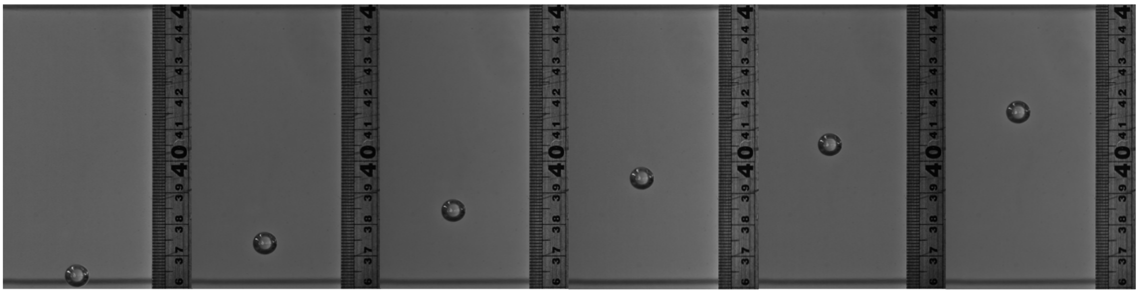


Figure 4. Motion of gas bubbles rising in pure glycerol.

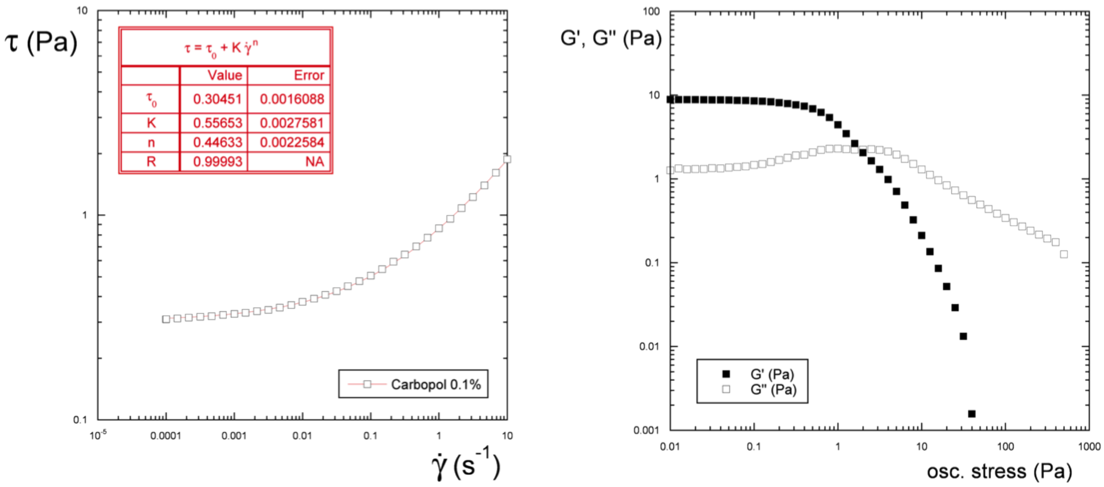


Figure 5. Rheological characterization of the 0.1% Carbopol dispersion (a) Flow Curve and (b) Stress Sweep test.

In fact, if we look at the rheology of the 0.1% Carbopol solution it is possible to identify a very low yield stress (τ_0 = 0.3 Pa) in Fig. 5(a). A low elasticity level (G') can be observed in Fig. 5(b), which is in agreement with the bubble shapes observed. Elasticity in the fluid is known to give rise to bubbles with an elongated tail, usually named "inverted teardrop".

The next step was to investigate more concentrated Carbopol dispersions. Fig. 6 displays the rheology of a concentration of 0.15% :

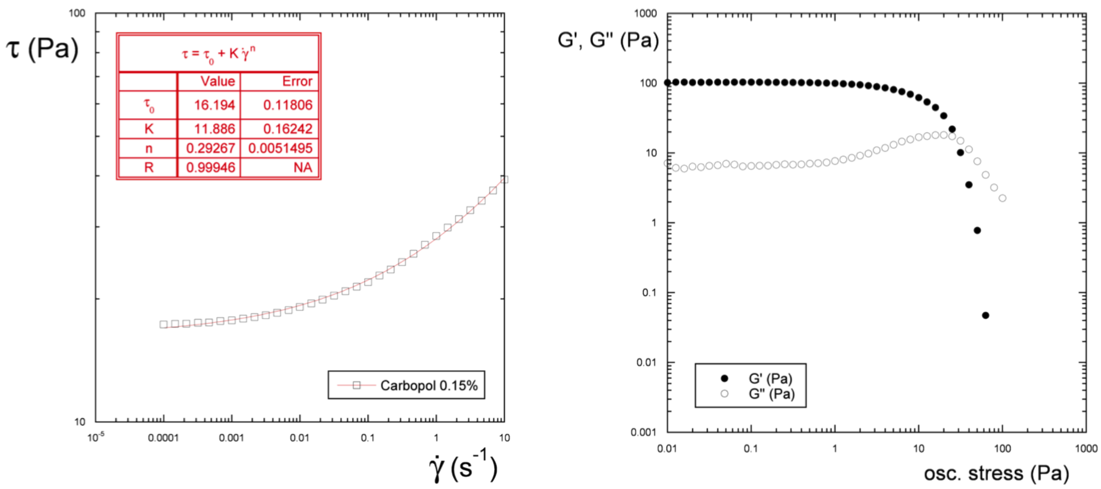


Figure 6. Rheological characterization of the 0.15% Carbopol dispersion (a) Flow Curve and (b) Stress Sweep test.

Comparing the rheological results of the Carbopol 0.15% with the 0.1%, it it possible to see a considerably higher yield stress (τ_0= 16.2 Pa). Also, the elasticity level, given by G', is ten times higher than for the less concentrated dispersion.

This difference in the rheological behavior can also be seen in the bubble shape (Fig. 7), which exhibits the "inverted teardrop" shape.

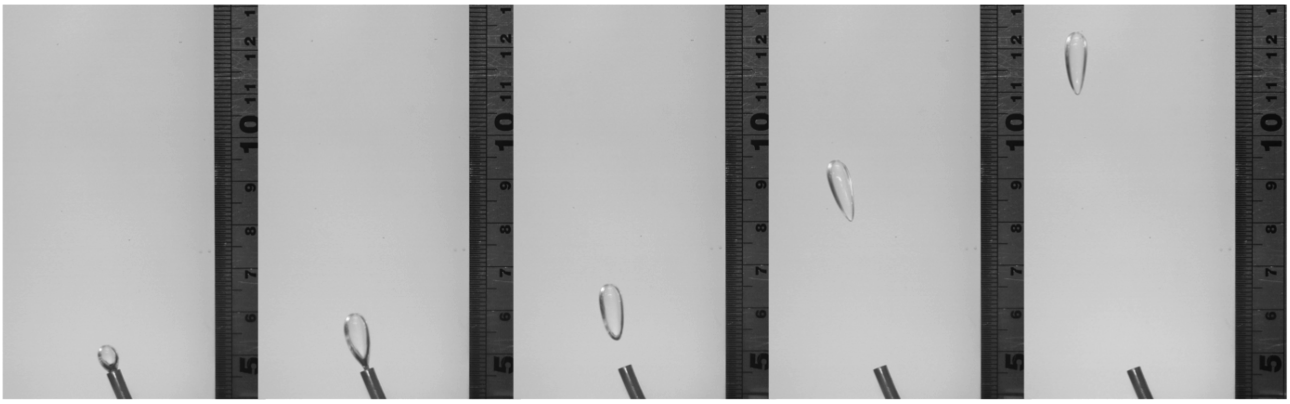


Figure 7. Bubble rising in a 0.15% Carbopol dispersion.

Increasing the concentration of the Carbopol dispersion to 0.2%, more elastic effect can be observed (Fig. 8(b)), as well as a higher yield stress (τ_0 = 35.6 Pa).

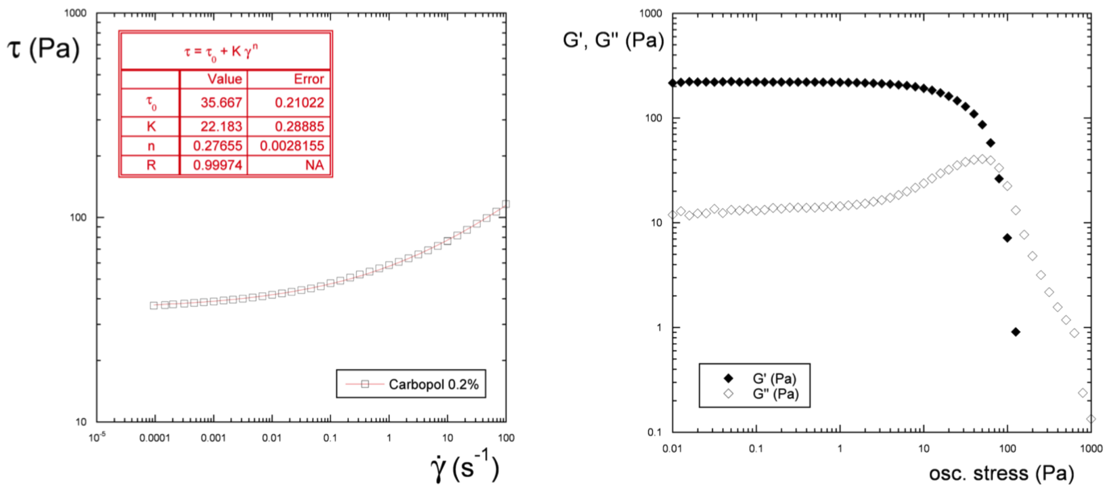


Figure 8. Rheological characterization of the 0.2% Carbopol dispersion (a) Flow Curve and (b) Stress Sweep test.

Again, these changes in the rheological behavior reflect on the bubble shape (Fig. 9). Bubbles are even more elongated due to the higher elasticity present in the fluid.

The stress sweep tests of all three Carbopol dispersions are summarized in Fig. 10. It is possible to see more clearly the difference in levels of G'.

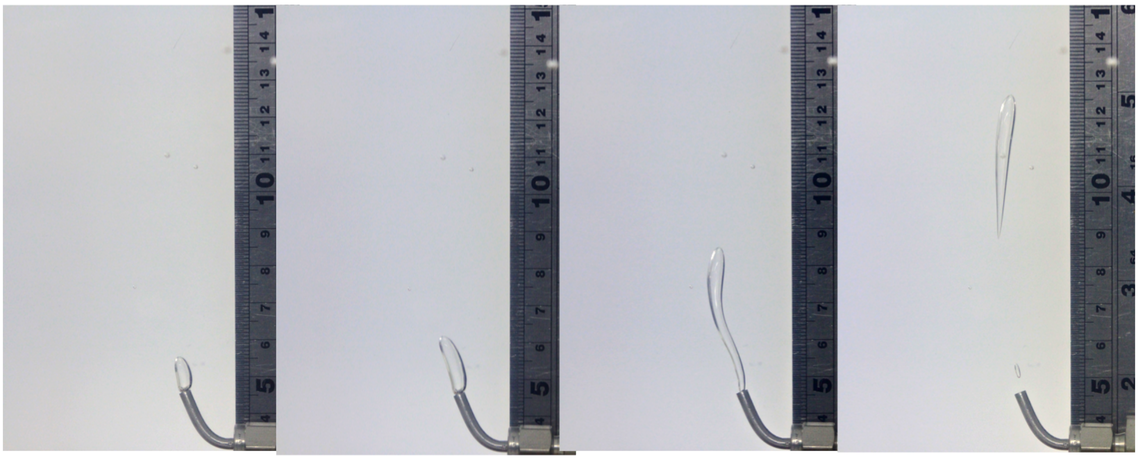


Figure 9. Bubble rising in a 0.2% Carbopol dispersion.

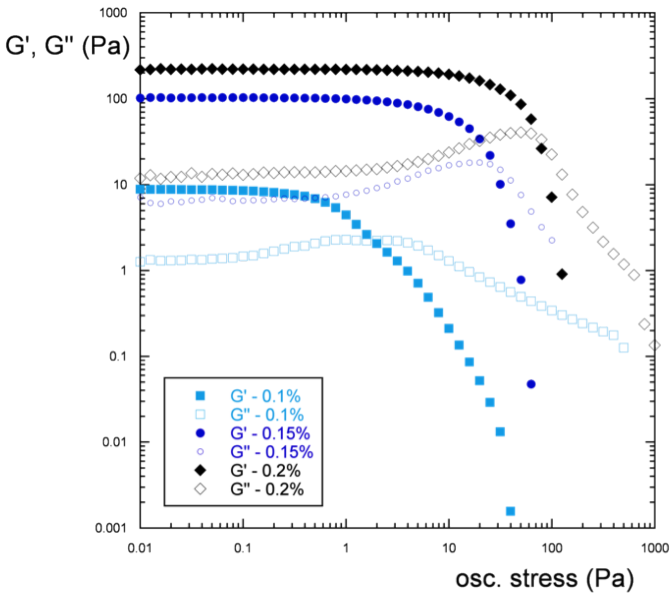


Figure 10. Summary of the rheological characterization of all Carbopol dispersion (a) Flow Curve and (b) Stress Sweep test.

4. FINAL REMARKS

The experimental set-up was successfully built. The region from which the terminal velocity can be measured was investigated. Velocities calculated using the time of displacement, as well as from the photo-to-photo comparison, were compared. Different Carbopol dispersion concentrations, namely 0.1%, 0.15%, and 0.2% were used. Bubble shapes were studied and correlated with the rheological behavior of the fluid. Velocity measurements for the more concentrated dispersions were done, but the results obtained were not repeatable (and thus not included in this paper). We expect to improve the repeatability of our results by homogenizing the fluid before each measurement. To this end, some changes need to be done in the experimental set-up.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE