

EFFECTS OF THE INJECTION PERIOD ON THE RISE VELOCITY AND SHAPE OF A BUBBLE IN A NON-NEWTONIAN FLUID

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The present work aims at studying the influence of the injection period on the bubble rise velocity and their corresponding shape. Three different fluids were employed: a Newtonian fluid (99.5% glycerol); an inelastic shear thinning fluid (2% carboxymethylcellulose—CMC in water) and an elastic shear thinning fluid (0.5% polyacrylamide—PAAm in water). Five different injection periods ranging from 0.3 to 60 s were applied to bubble volumes from 20 to $1000 \times 10^{-9} \text{ m}^3$. Except for the case of the injection period of 0.3 s, the rise velocity in the glycerol and CMC solutions does not depend on the injection period. However, the rise velocity decreases significantly with the injection period in the PAAm solution. In the glycerol solution, bubbles take an oblate spheroid shape, and are flattened vertically. On the other side, in the CMC and PAAm solutions, bubbles are vertically elongated and have a teardrop shape with a tail. However, the recent flow field results around a rising bubble obtained by PIV tend to show a disconnection between the bubble shape and surrounding flow field.

Keywords: bubble; rise velocity; shape; bubble injection period; non-Newtonian fluids.

INTRODUCTION

The dispersion of gas bubbles in liquids is frequently encountered in many chemical and physical processes in order to bring about efficient mass transfer, heat transfer and chemical reactions between two phases. More and more fluids used in polymer, food industry, metallurgy, wastewater treatment and biotechnology are non-Newtonian in nature. Increasingly, the dependence of volume, shape and terminal velocity of bubbles upon the rheological properties of fluids is thought to be of key importance in the design of gas–liquid contacting equipments (Carreau *et al.*, 1997). With respect to the voluminous literature devoted to bubbles in Newtonian fluids (Grace *et al.*, 1976; Clift *et al.*, 1978; Jamialahmadi *et al.*, 1994; Rodrigue, 2001), fundamental knowledge is still lacking about the behaviour of bubbles in non-Newtonian fluids as pointed out by Chhabra (1993). For example, it is quite difficult to predict the rise velocity and shape for a given bubble volume in a non-Newtonian fluid. Both the fluid's shear thinning and elastic characteristics affect noticeably these parameters. In this paper, we study the motion of bubbles rising in a viscoelastic fluid, in particular, the influence of the injection period on the evolution of the bubble shape. To better delimit the role of the

viscoelasticity, similar experiments are carried out in two other fluids, one is Newtonian and another shear thinning but inelastic. As shown, bubbles have different behaviour in these three fluids, for both the rise velocity and shape.

MATERIAL AND METHODS

Experiments were conducted in a 0.30 m diameter and 0.50 m height cylindrical Plexiglas column surrounded by a square tank. Our bubble column comprised a single 1 mm diameter orifice in the centre of the tank. A great reservoir was used to avoid any fluctuations due to bubble formation and detachment. An electronic solenoid valve of rapid response ($\leq 8 \text{ ms}$) controlled by a personal computer permitted injection of bubbles of determined volume with desired injection period T (Figure 1). A camera visualization system allowed to measure the volume of the released bubbles and confirmed that the bubbles formed in line had the same shape and the identical volume with a standard deviation within 1%. It was shown that for a given pressure in the reservoir, the bubble volume increased with the open duration of the electronic solenoid valve. For all experiments, there was no formation of multiple bubbles within the range of open duration: 10–100 ms.

The velocity of the bubble was obtained by two laser beams—diode apparatus distant from 0.1 m located 0.2 and 0.3 m above the bottom of the tank. Contrary to the rise of bubbles in water, the rise trajectory of bubbles in these viscous fluids was always straight so that bubbles

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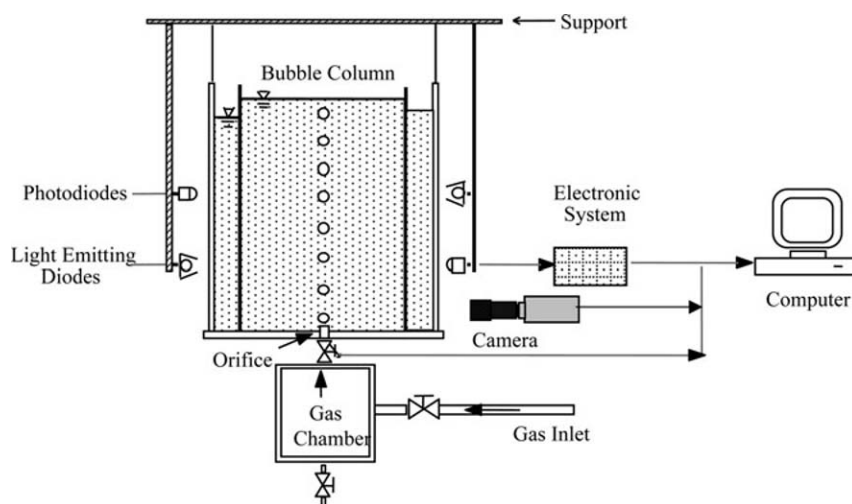


Figure 1. Experimental set-up.

passed always symmetrically through the laser beams. The passage of the bubble induced a light extinction on the diode by reflection of the light beam on its surface. The diode signal was acquired on the computer and treatment gave the rise velocity of the bubbles.

We used a CCD camera with a zoom located at 0.3 m above the bottom of the column. The transient motion of the bubbles did not last more than 0.1 m above the orifice, so that the velocity and shape remained unchanged above this height. Good contrast, necessary for the image analysis, was obtained by adequate illumination of the bubble facing the camera. Bubbles that appeared black on a white back-drop could be reworked with the software Visilog (Noesis

S.A.). The volume of the bubbles was computed by integration, making the axisymmetric assumption that is the case for our bubbles in these three fluids. The spatial resolution of our system was about $30 \mu\text{m}/\text{pixel}$.

The gas used was normal quality nitrogen. Three liquids of different rheological properties, measured by a Rheometrics Fluid Spectrometer RFS II (Rheometrics Inc.), were used in this study (Figure 2):

- A Newtonian fluid: 99.5% wt glycerol (Dow Europe S.A.) in water. The viscosity was 1.2 Pa s^{-1}
- An inelastic shear thinning fluid: 2% wt carboxymethylcellulose (CMC) medium viscosity (Sigma Chemical Co.)

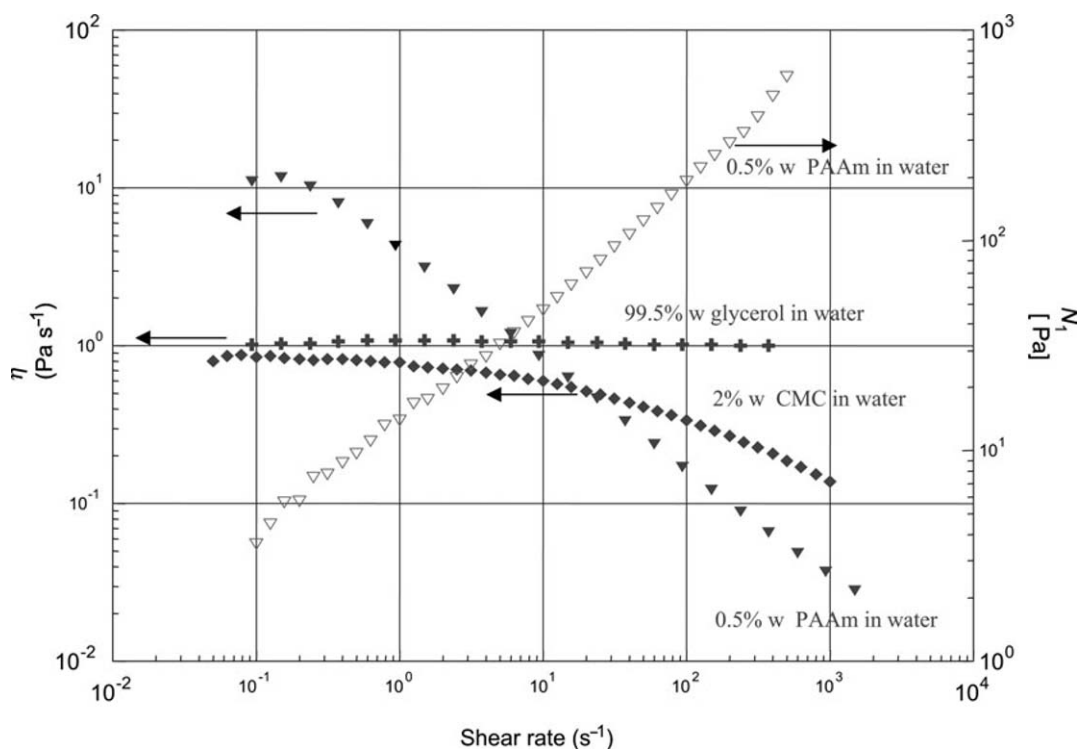


Figure 2. Rheological characterization of three fluids used (shear rate dependent viscosity η and first normal stress difference N_1).

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