NUMERICAL STUDY THE THICKNESS OF THE FILM THAT IS FORMED BETWEEN THE FREE SURFACE OF A BUBBLE AND THE CYLINDRICAL WALLS AROUND THE INJECTION ORIFICE

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Summary We study numerically the thickness film that is formed between the free surface of a bubble and the cylindrical walls around the injection orifice. The bubble is formed by gas of negligible viscosity and formed into a vertical tube filled with fluid of viscosity μ. The calculation is performed under the Stokes approximation by changing the values of capillary number *Ca* and Bond number *Bo*. We find that effectively the thickness film is a function of Ca and Bo, these dimensionless numbers are scaled by radius of the tube where the bubble is formed. We discuss experiments that validate the numerical results.

INTRODUCTION

The growth and detachment of bubbles generated by the continuous injection of gas into a quiescent liquid has been very much studied in conditions where the viscosity of the liquid plays no important role [1-5]. The results of these studies are of interest in metallurgical and chemical industries, for example, where liquids of low viscosity, such as liquid metals and aqueous solutions, need to be handled.
The generation and dynamics of bubbles in very viscous liquids is also of interest but has not been so much studied. Thus, while many aspects of the dynamics of bubbles in unbounded viscous liquids are well understood and some models are in [6-8], the formation and detachment of bubbles in confined systems has received less attention, this can be seen in [9-11]. Bubbles in very viscous liquids are commonly found when dealing with polymers in their liquid phases, in the flows of lava, and in processes of oil extraction from production pipelines, among others. In this present work we consider as a basic investigation the problem of the thickness film that is formed between the free surface of a single bubble and the wall when the is growing into vertical circular tube filled with a quiescent liquid of high viscosity in the articles [12,13] shows some these cases and the effect of the walls in bubble shapes therefore the effect on the thickness of the film. In this paper, we show that the shape of the tube in the vicinity of the injection orifice, or the use of properly shaped injection nozzles, may cause substantial distortion of the growing bubbles, volume at detachment and thickness of the film.

EQUATIONS FOR BUBBLES GROWING IN A CONFINED LIQUID

The model used here is for bubbles in a very viscous regime, obeys the equations of continuity and Stokes, whose dimensionless forms are respectively

$$\nabla \cdot \mathbf{v} = 0,$$

$$0 = -\nabla p + \nabla^2 \mathbf{v} - Bo\,\mathbf{i},$$

Where p is the pressure, $\mathbf{v}$ is the velocity field, $\mathbf{i}$ is the normal vector pointing in the vertical direction (x is the vertical coordinate) and Bo is the Bond number

$$Bo = \frac{\rho g a^2}{\sigma},$$

where σ is the surface tension and g is the acceleration due to gravity. When the bubble detachment we assume that the dimensionless gas flow rate is $dV_0/dt=Ca=ctnt.$; *i.e.*, the dimensionless flow of gas that forms the bubble is exactly the capillary number, given by

$$Ca = \frac{\mu Q}{\sigma a^2}.$$

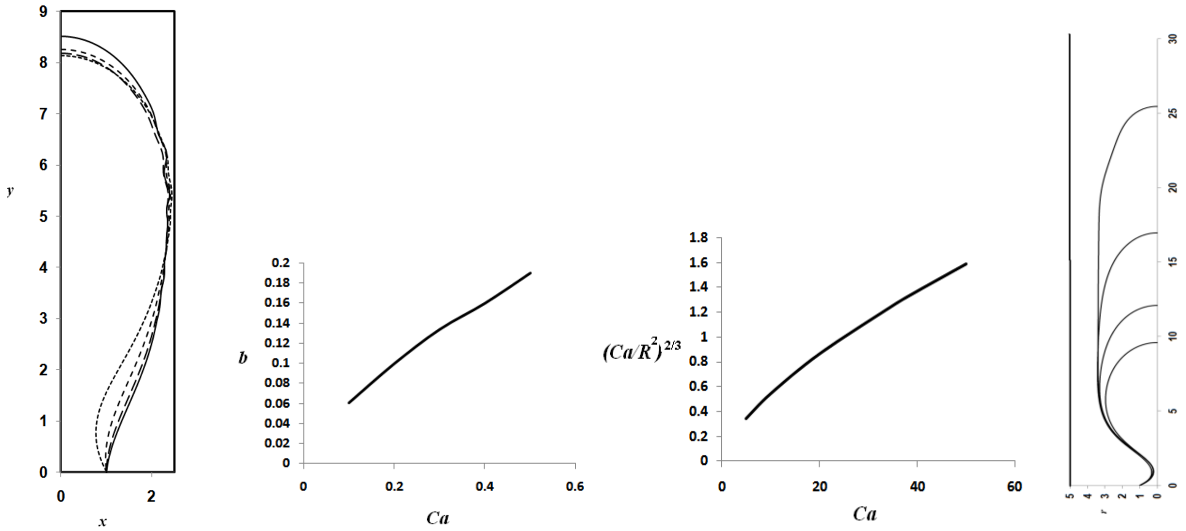
In the liquid $f(\boldsymbol{x}, t) > 0$.
The problem contains the five dimensionless parameters which are a Bond number, a capillary number, the dimensionless radius of the base and height of the tube, and the contact angle of the liquid with the base. The set of equations given above will satisfy the boundary conditions of quit flow at infinity, the non slip conditions on walls and the quasi static pressure balance. The Evolution of the free surface is given by $Df/dt=0$ [14].

RESULTS

The values found for the thickness of the film b between the tube wall and the surface of the bubble depends on the values of capillary number Ca and Bond number Bo. In this case these numbers are based on the radius R of the tube the dynamics of the film is described by

$$\frac{b}{R} \sim \left(\frac{Ca}{R^2}\right)^{\frac{2}{3}}.$$

For small values of Ca and R can be seen in the Fig. 1, we can see that the profiles show some "corrugations", this is because they become unstable when the height of the tubes is very large compared with the radius tube, *i.e.* in this case height tube is 30 times the radius tube. In experiments it was observed that when $Ca<<1$ the small bubbles be unstable.



a) b) c) d)

Fig. 1 a) Thickness film between the bubble and the wall with Ca = 0.5, 0.4, 0.3, 0.2 and 0.1, shows that $b \to 0$, in b) and c) we see the good agreement of the our result and the equation $(Ca/R^2)^{2/3}$, and c) shows that $b \to$constant for $Ca>>1$, *i.e.* Ca=35, 20, 10 and 5 and R=5.

CONCLUSIONS

For small values of Ca and Bo the thickness of the film follows the rule $(Ca/R^2)^{2/3}$ and conversely for the case where $Ca>>1$ thickness film tends to a constant value that depends on the radius of the tube. Good qualitative agreement has been found between numerical and experimental results [14].

References

[1] Kumar R., Kuloor N. R.: The formation of bubbles and drops. *Adv. Chem. Engng*. 8: 255-368 1970
[2] Longuet-Higgins M.S., Kerman B. R., Lunde K.: The release of air bubbles form and underwater nozzle. *J. Fluid Mech*. 230: 365-390 1991
[3] Oguz H. N., Prosperetti A.: Dynamics of bubble growth and detachment from a needle. *J. Fluid Mech*. 257:111-145 1993
[4] Corchero G, Medina A., Higuera F. J.: Effect of wetting conditions and flow rate on bubble formation at orifices submerged in water. *Colloids and Surfaces A: Physicochem. Eng. Aspects* 290: 41-49 2006
[5] Higuera F. J., Medina A.: Injection and coalescence of bubbles in a quiescent invicid Liquid. *Eur. J. Mech. B/Fluids* 25:164-171 2006
[6] Manga M., Stone H. A.: Interactions between bubbles in magmas and lavas: Effects of the deformation. *J. Vulcanol. Res*. 63:269-281 1994
[7] Wong H., Rumschitzki D., Maldarelli C.: Theory and experiment on the low-Reynolds-number expansion and contraction of a bubble pinned at a submerged tube tip. *J. Fluid Mech*. 356: 93-124 1998
[8] Higuera F. J.: Injection and coalescence of bubbles in a very viscous liquid. *J. Fluid Mech*. 530:369-378 2005
[9] Davidson J. F., Schuler B. O. G.: Bubble formation at an orifice in a viscous liquid. *Trans. Inst. Chem. Engrs*. 38:144-154 1960
[10] Bi Q. C., T. S. Zhao T. S.: Taylor bubbles in miniaturized circular and noncircular channels. *Int. J. Multiphase Flow* 27:561-570 2001
[11] Ajaev V. S., Homsy G. M.: Modeling Shapes and Dynamics of Confined Bubbles. *Annu. Rev. Fluid Mech*. 38: 277-307 2006
[12] Bretherton F. P.: The motion of long bubbles in tubes. *J. Fluid Mech*. 10:166-188 1960
[13] Coutanceau M., Thizon P.: Wall effect on the bubble behaviour in highly viscous liquids. *J. Fluid Mech*. 107: 339-373 1981
[14] López-Villa A., Medina, A., Higuera F. J..: Bubble growth by inyection of gas into viscous liquids in cylindrical and conical tubes. Phys. Fluids **23**:102102 2011.