論文の内容の要旨

The Behaviour of tiny particles within rising foams

「上昇する泡沫中における微粒子の挙動」

ベナニ　ノラ　アン

1. Introduction

Bubbly flows are often used in environmental industry applications such as aeration, mixing or cleaning processes. The motion of those bubbles and the specific composition of the liquid phase generate foams. Among those processes, flotation is a technique that utilizes bubbles and foams to remove or to separate components present in the liquid phase. It is especially employed in wastewater treatment or within minerals processing industry; those methods have a small environmental load because they do not require adding chemical product. The motion of particles and liquid within foams has a major importance for the efficiency of those processes. Indeed, through the understanding of foam gas cells behavior and of liquid flow for different surfactant concentrations and particle sizes, those processes can be optimized.

Joseph Plateau (19th century), of the well-known Plateau's laws, is one of the first to define foam structure [1]. Foams are network of Plateau borders (connection of 3 gas cells) and nodes (connection of Plateau borders). A quasi two-dimensional foam is a layer of foam between two parallel plates and the junction of only three Plateau borders forms a node in order to reach dynamic equilibrium.

The flow of liquid within foams, called drainage, has been studied by many groups [2, 3, 4, 5]. The velocities profiles of flows within Plateau borders depend on the surface dissipation occurring at Plateau borders walls. This dissipation is in the form of a surface shear viscosity, μ_s [kg/s]. Therefore, depending on μ_s, two types of flows are occurring within Plateau borders. The first one is a Poiseuille-like flow for high value of μ_s which corresponds to *rigid foams*. The second one is a plug-like flow for small value of μ_s, which corresponds to *mobile foams*. They introduce a dimensionless parameter called mobility, defined as $M=\mu r/\mu_s$, with μ [kg/m/s] the liquid viscosity, and r [m] the curvature radius of the Plateau border. Particles behavior within those two types of foams is presented in that study.

Concerning the motion of solids in rising foams, Neethling et al. (2002) [6] developed a numerical model for a high amount of solids in foams. They introduce viscous drag to predict the velocity the particles in the foam. They obtain realistic trends of the fractional liquid content and of the concentration of solids in foams. It is difficult to compare their results with our data because some parameters such as the volume fraction of liquid within Plateau borders are challenging to evaluate in our study.

In order to gain a better understanding of the particles motions in foams, here, we present the results of an experimental study of particles motion in quasi two-dimensional rising foams.

2. Experimental Set-Up

In the present study, we limit the case to quasi two-dimensional foams because visualization within three-dimensional ones is challenging [7].

As shown in Fig.1a, air was injected using a compressor and entered an acrylic water-filled channel (height H = 1 m, width W = 0.15 m and depth D = 4 mm) from its bottom part. The air went through a porous plate (beads size was 10 μm). We defined the height at which the bubbles were injected to be y=0 m.

Saponin and casein were used as surfactants. They had the same density as water. Polydispersed rising foams were generated. Saponin foams are known to have high mobility, therefore are mobile foams. Casein foams are known to have low mobility, therefore are rigid foams.

Particle Tracking Velocimetry was used to capture the trajectory of the falling particles. A laser sheet of 3 mm thickness was generated using an (2 Watts) argon laser (emission wavelength was 532 nm) and a combination of lenses. The position of the test section was at the height of y = 0.5 m. Hydrophilic fluorescent particles were used for the tracking. They were ion-exchange resin stained by the fluorescent dye Rhodamine-B (absorption and emission wavelengths are 540 nm and 600 nm respectively) from Diaion Mitsubishi and had a density of 974 kg/m3. They were chosen because of their light emission. The particle diameters were in the range of 50 to 150 μm. About one hundred particles were beforehand added to the liquid phase in order to observe particles motion from the bottom part of the foam. In order to capture only fluorescent particles, a cut-off filter (wavelength 560 nm) was attached to a CCD camera. The particle motions were obtained using MATLAB and camera photographs (Fig.1b). Foams generated with this set-up are polydispersed quasi two-dimensional ones. The diameter of tracked particles are within the same order as the Plateau border width since the ratio between the particle diameter and the encircled of cross-section of Plateau border is larger than 0.3.

3. Results and Discussion.

The physical chemistry of surfactant solutions have a real importance on the rheology of the interfaces Plateau borders and therefore on particle sedimentation. For that reason, two surfactants that have different properties have been used in this study: saponin and casein. Saponin Plateau borders are knows to have mobile walls. Therefore, the profile of liquid flow velocity within Plateau border is a plug-type flow. Whereas casein Plateau borders are knows to have rigid walls. Therefore, the profile of liquid flow velocity within Plateau border is a Poiseuille-type one. Particles were tracked within those two different foams that were generated with different gas flow rates and surfactant concentrations. They were tracked along a large amount of Plateau borders and nodes. And it was found that the velocity profiles of particles sedimenting with respect to the gas flow rates, within those foams are similar. At the scale of a Plateau border, if particles were tracked along several Plateau borders and nodes, we could observe different behaviour between saponin and casein Plateau border. Within saponin foams, particle velocities reach a local maximal when the particle is passing through a node. On the contrary, within casein foams, particle velocities reach a local minimal when the particle is passing through a node.

There are others parameters that characterise the type of foams and that influence particles sedimentation. They are the same for saponin and casein foams. One of them concerns the liquid content within foams. If the liquid content is large, the foam is a wet one, whereas if the liquid content is not large, the foam is rather a dry one. Determining the limit between dry and wet foams is challenging with our set-up, therefore, we used the width of Plateau border as a parameter. Indeed, the larger the width is, the more the foam is wet. This parameter depends one the gas flow rates that is used to generate the foam. Since the particles have a diameter that is within the same order of the Plateau border width, it will have some influence on their sedimentation. Hence, particles will flow more freely if the Plateau borders are larger. Therefore, particles sedimentation velocities within saponin and casein foams are larger within wet foams than within dry ones since Plateau borders are larger. Moreover, for the same gas flow rate, casein foams are wetter than saponin ones. Therefore, particles sedimentation velocities are larger within casein foams than the ones within saponin ones.

In addition to the influence on the liquid content, the gas flow rate is also influencing the shape of the foams. Since particles are meandering around foams gas cells, their sizes influence their paths and consequently, their velocities. Indeed, when foam gas cells have a large size, the paths of particles are longer and consequently, they have a smaller sedimentation velocity.

4. Conclusion

To conclude, the important parameter to control the efficiency of cleaning processes such as flotation process is the gas flow rate used to generate the foams. An optimal one should be finding, taking account of the concentration of the liquid to clean and the size of the particles to remove.

References:

(1) D. Weaire and S. Hutzler, *The Physics of foams*, Oxford University Press, 1999.

(2) R. A. Leonard and R. Lemlich. A study of interstitial liquid flow in foam, 1965.

(3) G. Verbist, D. Weaire and A. M Kraynik. The foam drainage equation. Journal of Condensed Matter, 8(21), 1996.

(4) S. A. Koehler, A. Hilgenfeldt and H. A. Stone. Liquid flow through foams. PRL, 1999.

(5) S. A. Koehler, A. Hilgenfeldt and H. A. Stone. Generalized view of foam drainage. Langmuir, 2000.

(6) S. J. Neethling and J. J. Cilliers. Solids motion in flowing froths. Chem. Eng. 2002.

(7) S. Cox, D. Weaire and M. F. Vaz. The transition from two-dimensional to three-dimensional foam structures. Euro. Phys. J. E. 2002.

(8) N. A. Bennani, A. Fujiwara, S. Takagi and Y. Matsumoto. Coarse particles sedimentation within a quasi two dimensional rising foam. Colloids and Surfaces A: Physicochem. Eng. Aspects 309 (2007) 7–12.