Foams in Microgravity

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Abstract

Foams are important in industry and pose many interesting questions to the physical scientist. Microgravity offers a new dimension to research by facilitating the formation of wet foams.

Introduction

In 1998 an ESA Topical Team[1] was established to study foams and capillary flows, in relation to the coming opportunities for experiments in microgravity.

Liquid foam is the familiar mixture of liquid and gas, in which bubbles congregate and are deformed into polyhedral cells, separated by thin films. It may be solidified to form a solid foam.

Both types of foam are of immense importance throughout modern industry. Liquid foam is a desirable and carefully designed feature of beverages and cleaning agents, and is used in such industrial processes as the separation of impurities by foam flotation. It also occurs as a nuisance throughout the chemical industry, whenever liquids and gases are being processed. In such cases, anti-foaming agents may be used to destabilise it.

Solid foams are important engineering materials, combining lightness with adequate rigidity, strength and toughness for many purposes. They provide a large proportion of the thermal insulating materials used by the building industry, and their energy-absorbing properties are exploited in packaging and cushioning.

Even glass and metal can be produced in such a state today. Glass foam is an interesting material for the building industry, while metal foam, as for example shown in fig. 1, still awaits large-scale applications.

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[1] ESA Topical Team on "Foams and Capillary Flow". Partners: Weaire (Dublin), Banhart (Bremen), Bergeron (Saint-Fons), Kronberg (Stockholm), Langevin (Orsay), Georis (Pau), Verbist (Ottignies-Louvain-La-Neuve), Phelan (Amsterdam), Vignes-Adler (Meudon), Lunkenheimer, Wantke (Berlin), Legros (Brussels). Project officer: E. Kufner.

Twelve Topical Teams are presently active in Physical Sciences. ESA sponsors scientific meetings as well as workshops involving industry representatives organised by the Topical Teams for the definition and preparation of research programme proposals. Experts may be invited by the teams on an *ad hoc* basis. This sponsorship lasts one year and can then be extended for a second year.

This special issue of the Annales of the European Academy of Sciences and Art reports on the activities of these teams.

ESA strongly encourages European researchers from both academia and industry to consider this support to discuss and elaborate research programmes including microgravity experimentation. They can either propose their expertise or industrial problems to an existing team by contacting directly its co-ordinator, or they can submit to ESA a proposal to initiate a new Topical Team together with other colleagues in their community. ESA is currently soliciting proposals for the formation of new teams.

Funding

ESA can give support in the financing of ground-based research depending on the level of industrial participation, partnership and the industrial applications perspectives of the programme proposal. On the upper end of the scale this can correspond to the level of financing received in the E.U.'s BRITE/EuRam programme, i.e. 300 kECU per year and per team. Only the participation of researchers from academia and research institutions can be financed by ESA, whereas industry is expected to participate at their own expense. It is thought that the free access to conduct space experiments and the ability to enlarge an industrial R&D team with high level scientists from academia should be sufficient incentive for industry. It is important to note that the support by ESA will depend on the level of industrial participation. Maximum use should be made of existing flight experiment facilities. In case that none of these facilities is suitable new ones can be developed that are tailored to the project.
Applications-oriented programmes extending over a number of years that are financially supported by ESA are subject to an evaluation by a peer board at intervals of approximately two years. The continuation and the level of funding for such programmes depends on the outcome of these evaluations.

Further information on ESA's Microgravity programme, on the opportunities to conduct microgravity research, on the facilities available in Europe and on the current Microgravity Applications Promotion projects can be found on the Internet at the following URL: http://www.estec.esa.nl/spaceflight/map/

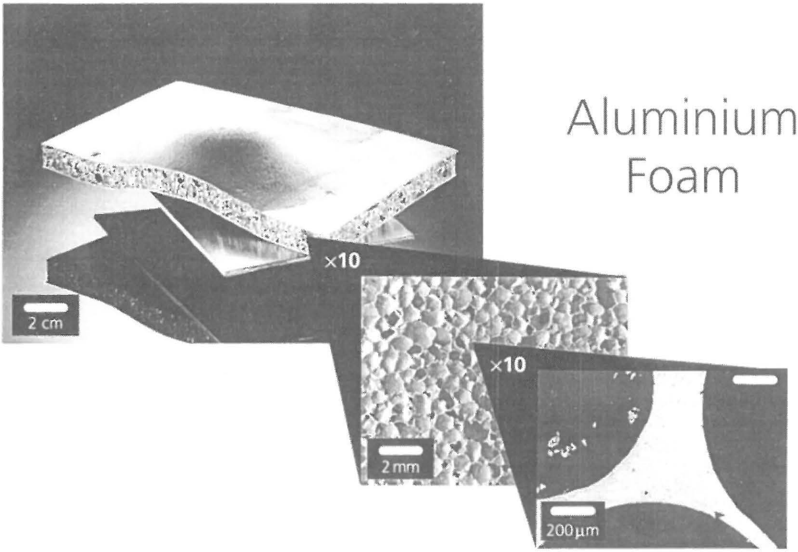

Fig. 1. Surprisingly, even metals can now be made into foams. This is a sample of an aluminum foam from the Fraunhofer Institut für Angewandte Materialforschung, Bremen. The pore structure of the foam and a single Plateau border are shown in detail. Solid fractions are around 20% in these foams.

Enormous progress has been made in the last twenty years, in the analysis and modelling of foam. Until then, the disordered nature of its structure had discouraged attempts at any basic understanding, and much of the subject remained within the realm of empiricism.

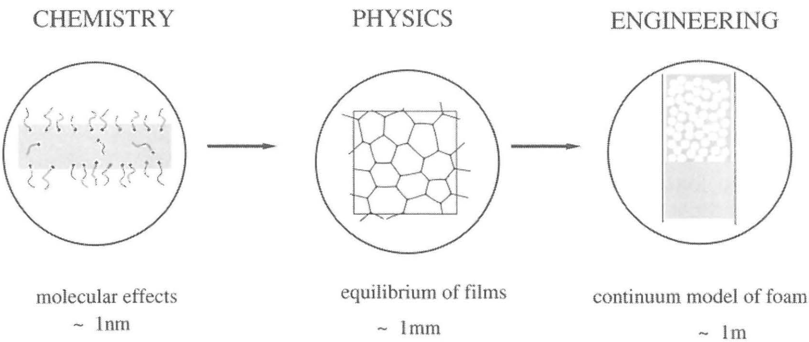

Fig. 2. The subject is interdisciplinary, in part because it can be pursued at many levels.

Today a wide range of scientists and engineers is engaged in foam science, and they meet at regular conferences to exchange ideas. These may focus on the *microscopic* level at which surfactants stabilise thin films, the *mesoscopic* description of the mechanics and fluid dynamics of these films and their intersections (known as Plateau borders), or *macroscopic* models of foam properties in terms of continuum theories; see fig. 2.

Dry and wet foam

Depending on the conditions, and its average bubble size, a foam in equilibrium may have any liquid fraction in the range 0-35%. Foams at the two extremes are called "dry" and "wet", as illustrated in fig. 3. Most successful theory has been developed for dry foams. Wet foams offer interesting new phenomena for study.

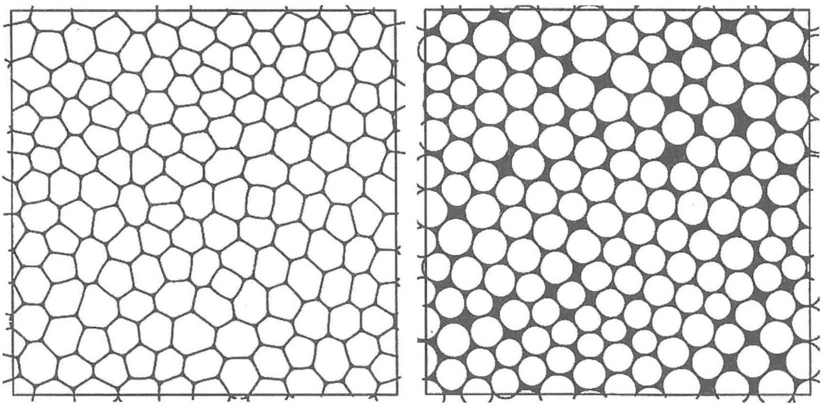

Fig.3. These simulated two-dimensional foams illustrate the difference between dry and wet foams. (A 2d foam can be made by squeezing soap froth between two glass plates.)

The role of gravity

As in most fluid phenomena, gravity has an important role in the physics of foams. The local pressure within the network of Plateau borders varies with height according to the usual hydrostatic law. This in turn implies a vertical variation of Plateau border width, as is indicated in fig. 4.

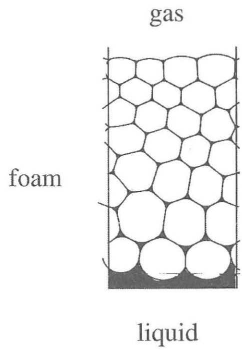

Fig. 4. The density (or wetness) of a foam under gravity varies with height.

The effect of this is to ensure that for bubbles of diameter, say, 1 mm, the liquid fraction Φ_l decreases rapidly with height. Even if the bottom of the foam is rather wet (as it must be if in contact with bulk liquid), the rest is very dry.

Gravity is also essential to the usual process of drainage, by which liquid is drained off to establish the equilibrium which we have described. Recent experiments have also used forced drainage, which involved the continuous addition of liquid to the foam.

Making wet foams in microgravity

Wet foams are elusive to both theory and experiment. They can be made in equilibrium only by using very small bubbles (much less than 1mm in diameter). Alternatively, forced drainage can be used to create a rather uniform wet foam, but this is not truly equilibrium: moreover it is limited by convective instabilities.

It follows that the possibility of forming a wet foam in microgravity is attractive. In this way, models successfully developed and tested for dry foams may be reliably extended to higher liquid fractions - ultimately to the point at which the bubbles come apart.

Observing and monitoring foams

The observation of foam structure has progressed to a sophisticated level, with the introduction of optical and NMR tomographic techniques. Optical tomography has already been carried out to a limited extend in microgravity, by Monnereau and Adler; see figure 5.

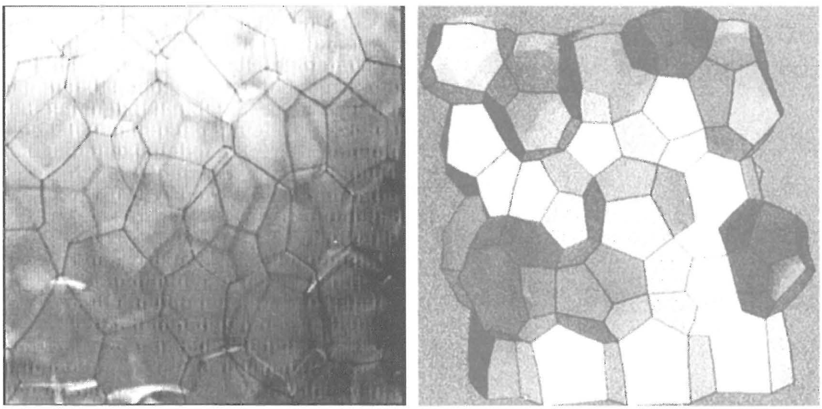

Fig. 5. Raw and reconstructed images of a foam, obtained by optical tomography. A simulation program is used to refine the image.

In some contexts (such as the study of drainage) a vertical density profile may be sufficient, and this may be obtained by measurement of resistance using an array of electrodes. Figure 6 shows an example of data taken in this way.

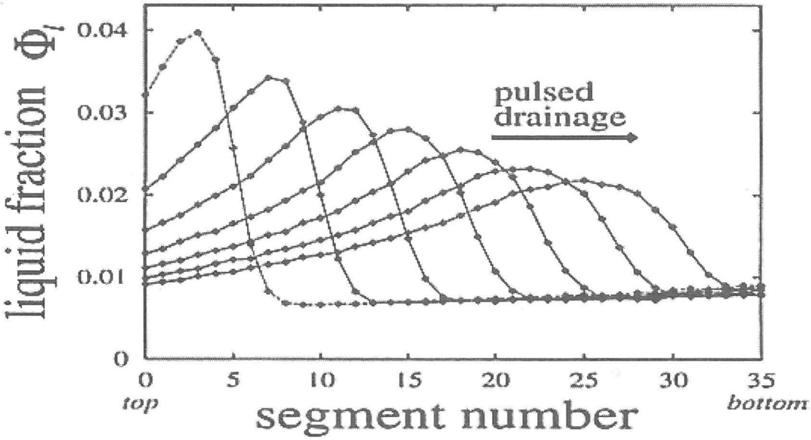

Fig. 6. Instantaneous vertical profile of resistance in a drainage experiment. A pulse of liquid was introduced at the top of a dry foam and is seen to propagate downwards.

Not all such techniques are well adapted to microgravity work. NMR, in particular is much too cumbersome, at least for the time being. However, equipment for resistance profiling is compact and robust.

Other modern techniques include diffusive light scattering. The multiple scattering of dense foam is frustrating to visual observation but can be turned to advantage by appropriate theory. It becomes a source of information on the mean bubble diameter (which increases with time as the diffusion of gas causes small cells to shrink and vanish) and related effects.

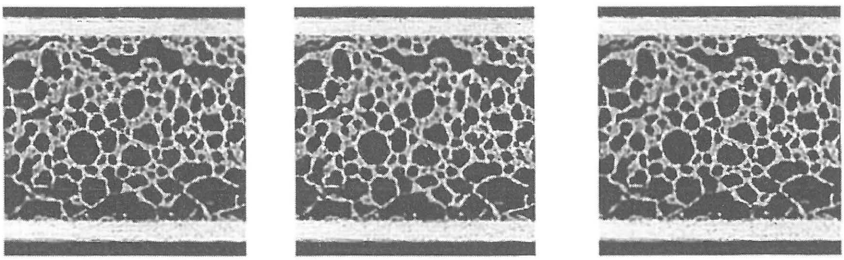

Fig. 7. X-ray computer tomography image of a metallic foam sandwich.

Liquid and solid metallic foams cannot be observed by the same means as aqueous foams due to their opaqueness and electromagnetic shielding properties. X-ray computer images, however, can be used to obtain images of the interior of a metallic foam (see fig. 7).
Density profiles of metallic foam columns can be obtained more simply by scanning with X or gamma rays or even with neutrons. Gamma ray scanning could be suitable for microgravity experiments.

Getting rid of gravity

As we have seen, gravity plays a strong role in the physics of foams. For some purposes, including the study of wet foams, it is desirable to somehow avoid its effects. This was recognised in the early history of the subject, when Plateau used the combination of two liquids of similar density to study the effect of surface tension at their interface. Another strategy is to use a foam of very small bubbles, and/or a foamy liquid of very high viscosity. Despite these alternatives, there is great appeal in a zero-gravity experimental environment, in which any foaming system can be analysed. Only very preliminary experiments of this kind have been performed to date.

Microgravity experiments could also be useful to investigate the formation and stability of metallic foams. The influence of surface tension and viscosity on the way it foams is not well understood. It is difficult to adjust each of these parameters separately because both vary with temperature and chemical composition. Turning off gravity would enable us to study the influence of surface tension on the formation and growth of pores without having to deal with liquid draining out of the foam quickly.

Conclusion

Rapid progress in the understanding of foams has been largely restricted to static, dry foams. Microgravity facilities provide an avenue of exploration to widen our understanding of wet foams. At the same time they should offer opportunities to begin to develop "the data base necessary to develop reliable and efficient space technologies" in relation to liquid and solid foam. This goal was stated in the assessment of European low-gravity physical sciences by Prigogine *et al.* in 1995. It applies well to the case of foams, which are promising materials for future space technology.

Acknowledgement

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