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Foam Research in Microgravity

Martin ANDERSSON[1], John BANHART[2], Hervé CAPS[3], Douglas DURIAN[4], Francisco GARCIA-MORENO[2], Stefan HUTZLER[5], Bengt KRONBERG[1], Dominique LANGEVIN[6], Olivier PITOIS[7], Mohammad SAADATFAR[5], Arnaud SAINT-JALMES[8], Nicolas VANDEWALLE[3], Michèle VIGNES-ADLER[7], Denis WEAIRE[5]

[1]Institute for Surface Chemistry, Stockholm, Sweden, bengt.kronberg@surfchem.kth.se
[2]Technical University, Berlin, Germany, banhart@hmi.de
[3]University of Liege, Belgium, nvandewalle@ulg.ac.be
[4]University of Pennsylvania, Philadelphia, United States, djdurian@physics.upenn.edu
[5]Trinity College, Dublin, Ireland, dweaire@tcd.ie
[6]University Paris-Sud, Orsay, France, langevin@lps.u-psud.fr
[7]University Paris-Est-Marne-la-Vallée, France, adler@univ-mlv.fr
[8]University of Rennes I, France, arnaud.saint-jalmes@univ-rennes1.fr

Abstract

Closely associated European teams are engaged in microgravity research on aqueous and metal foams in the framework of two MAP projects from ESA. They deploy a wide range of techniques in terrestrial experiments and are experienced in the design and execution of microgravity experiments. We outline their recent achievements and present plans

- measurement of local liquid fraction using conductivity and capacitance probing;
- multiple light scattering, either with transmission measurements (DTS) or with diffusive wave spectroscopy (DWS), which probe foam structure and its evolution.

Gravity plays an important role in the formation of a liquid foam and its subsequent evolution. Its primary effect is to cause excess liquid to drain rapidly away. Eventually the gravitational force is balanced by a vertical pressure gradient in the liquid (which entails a vertical profile of liquid fraction). The addition of liquid to such a "dry" foam (at the top) results initially in a solitary wave with an approximately constant profile during its downward passage. Subsequently, a state of uniform drainage, with a constant volume fraction, is established. A sample undergoing such "forced" drainage can be used to study wet foams, but only up to about 20% liquid fraction, beyond which various dynamic instabilities (primarily convection) occur. It is known that the bubble growth laws (coarsening) must be different in the wet and dry foam limit, but this evolution has never been checked, the wet foam limit being inaccessible (2).

The same difficulty occurs with rheology, in relation to the same interesting transition to a fluid state that occurs at the wet limit which remains largely inaccessible on earth.

Thus the present trend of the subject is towards wet foams as well as dynamic effects, the *terra incognita* of Fig.1.

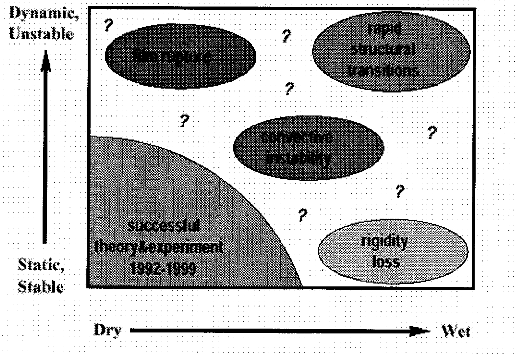

Fig. 1 Regions still largely unexplored in foam research

3. The scales of foam research

Foam research is inherently interdisciplinary since it involves effects on various interdependent scales: *molecular*: surfactant properties and foam chemistry; *mesoscopic*: film structure and local behaviour, simulation; *macroscopic*: rheology, drainage, continuum theories.

Roughly speaking, these involve *chemists, physicists,* and *engineers*. The subject faces the same "multiscale" challenge as do other branches of condensed matter science.

4. Using microgravity for aqueous foams

A micro or zero gravity study of wet foam hydrodynamics will allow us to overcome the limits imposed by gravity. This broader experimental characterization will provide a scientifically valid alternative for the necessarily conservative empiricism currently employed to estimate the operational window and design for foam handling in industrial processes (such as gas/liquid contacting, flotation and pumping).

Our specific plans arose out of detailed consultations with ESA and NASA, ultimately aimed at the design of ISS facilities for foam research. This objective included various physical properties to be measured in a single instrument: drainage, coarsening, rheology and stability.

After a preliminary development of the corresponding instrumentation in a series of parabolic flights of the project (5), a more complete test was performed in a Maxus flight. A numerical simulation tool was developed in parallel in order to estimate liquid fraction temporal variations and account in particular for g-jitter. Suitable foaming systems were selected in order to have different boundary conditions at the bubble surfaces.

Practical and economic considerations now dictate that we concentrate on a more limited objective, aimed mainly at coarsening of wet foams. We foresee that the technically demanding rheology study will be postponed by a few years.

5. Some recent experiments

Experimental results previously obtained in parabolic flights for an initially 2D dry foam being wetted from the bottom were analysed with continuum drainage theory. Imbibition (the uptake of water by a dry foam) experiments in a 3D geometry were also performed. Performed in a Maxus flight, the experiment was "quasi-2D" because of the shape of the cell, which thickness varies with the distance to the injection point. In the parabolic flights, we were able to vary some parameters, injected flow rates, type of liquid injection (pulsed), chemicals used to stabilize the foam (different surface viscoelastic properties).

In figure 2, one sees that the liquid front propagation in the dry foam is isotropic under μg conditions (at the difference from earth, where liquid moves more quickly in the vertical direction). In microgravity, capillarity is the only driving force for such propagation, and is responsible for imbibition.

We have found that high liquid fractions can be obtained by such imbibition in microgravity, without the intervention of the usual convective instabilities found on ground.

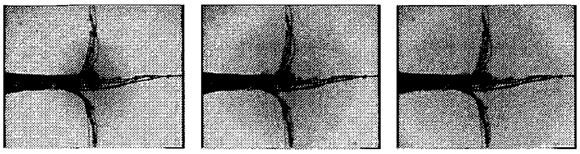

Fig. 2 Imbibition experiments in parabolic flights: picture of a foam at three different times, evidencing isotropic propagation of liquid injected at the center. The wires are connections to electrodes. Note that the wetter foam appears dark. CNES parabolic flight campaign, March 2005 (from ref. 6).

First tests with foams made of solutions containing surfactant and solid particles (fumed silica): this is a direction towards which much terrestrial research is turning, with strong commercial motivation.

6. Organic foams

Foams that can be generated in microgravity (e.g. on-board space-borne vehicles such as the ISS or the future Mars vehicle) in hydraulic organic liquids and fuels represent a real danger for the safety of astronautic missions if they are persistent. The lifetime of surfactant-free organic foams that are short-lived on ground was substantially higher in microgravity (Fig. 3).

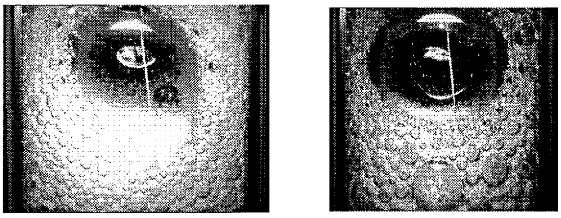

Fig. 3 Foams generated in microgravity from a mixture of mesithylene and methanol at t=44 and 60 sec. after generation. The lifetime of the same foam is ca 30 sec. in corresponding ground-based experiments.

7. Metal foams

Metallic foams are challenging materials for both fundamental and applied research. They combine the distinctive properties of very low density, high specific stiffness, good damping and high energy absorption capability. (They may be thought of as "heavy duty polystyrene".)

In recent years much effort was devoted to improving metal foam homogeneity, driven by industrial demands.

Microgravity conditions are considered vital for the further analysis and improvement of aqueous and metallic foams, for much the same reason as obtains for their aqueous counterparts. This branch of the subject brings an additional bonus, in that solid samples can be recovered and analysed exhaustively on the ground. On the other hand, it requires furnace technology for the creation of the foams, which are made by rapidly cooling a liquid metal foam. Just as in the aqueous case, optimization of chemical constituents is an important and extensive part of the subject.

In addition to testing and optimizing a microgravity furnace, such foam properties as density, drainage, rupture events, foam density, pore diameters, etc. have analysed quantitatively, as well as the influence of external conditions like gas pressure or foaming gas. Hardness and wetting angle for different stabilising particles have been compared, in order to find suitable candidates for aluminium foams. (This is a current development that runs curiously parallel to the corresponding trend in the case of aqueous foams). A monodisperse aqueous foam generator has been designed with a view to adapting its design for metallic foams.

In all of this, once again, gravity-induced drainage is the enemy. It causes a density gradient and then collapse of the foam during its formation. Its straightforward avoidance in microgravity gives the subject an exciting new dimension and the release from very narrow constraints on its applications. Current industrial products are mainly confined to a narrow range of possibilities, based on Al alloys, with additives.

2D X-ray foam projection images (Fig. 4) can provide an informative snapshot (at various times) of a foaming liquid metal and the final product. This has been a basic tool in our work and the pictures generated have been successfully simulated.

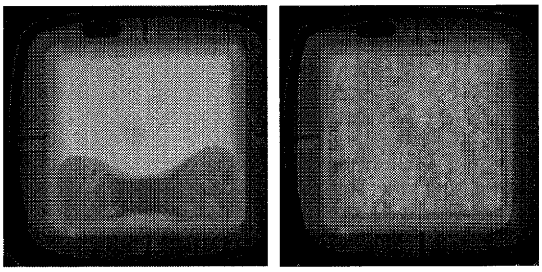

Fig. 4 X-ray projection images of metal foam during its formation.

The team is continuing research in the areas of foam production, drainage, rheology and image analysis. An exciting added possibility is that of X-ray tomography of recovered samples. We have already generated and analysed superb three-dimensional images of terrestrial samples, with the collaboration of ANU Canberra (Fig. 5).

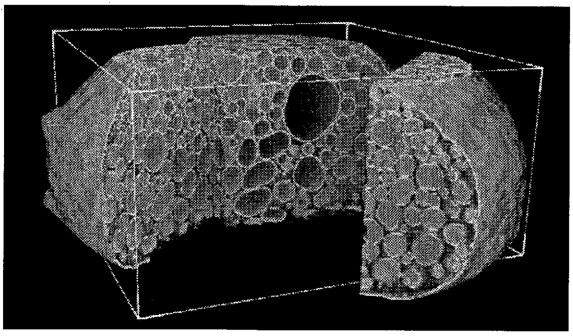

Fig. 5 Snapshot of the 3d tomographic visualization of the metal foam sample (8).

7. Conclusions

Foam research in microgravity has begun to reach a mature stage of technical refinement and collaboration aimed at definite objectives. It has brought together researchers from apparently disparate areas, with great mutual benefit from cross-fertilisation. It has also stimulated a lot of first-class research at the terrestrial level, and played a key part in drawing together and motivating a coherent research community around its goals.

Acknowledgements

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