[PHYSICS IN SPACE]

FOAMS AND EMULSIONS IN SPACE

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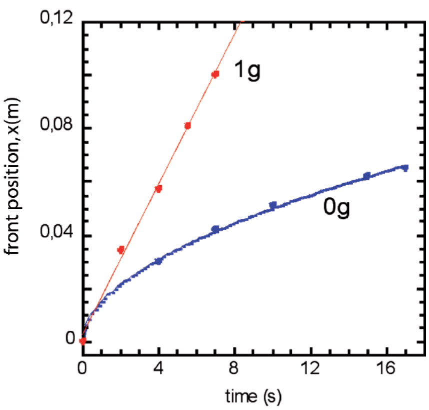
In the physics of fluids, gravity is often an unwelcome intruder because it gives rise to instabilities and inhomogeneities. Microgravity environments such as that of the International Space Station (ISS) offer the opportunity to turn off its unwelcome effects. This strategy is being pursued for the study of three closely related complex fluids: aqueous foams, emulsions, and liquid metallic foams, the latter owing their importance to being the precursor of solid products. Studies of soap or metallic froths and complex emulsions are inherently interdisciplinary as is often the case with condensed and soft matter; interdependent effects take place on three length scales as well as several time scales, each of which requires treatment with appropriate tools:

- *Molecular level* surfactant properties: foam and emulsion chemistry
- *Mesoscopic level* film structure and local behaviour: numerical simulation
- *Macroscopic level* rheology, drainage: hydrodynamic theories

Foams and emulsions are ubiquitous in nature and in industrial products and technologies. Their stability against phase separation is achieved with blends of molecules (surfactants, electrolytes, polymer, protein) which segregate to the interface between the two fluids and hinder droplet or bubble aggregation and coalescence. Seeding with particles also becomes very attractive because of the outstanding stability it provides to the structure of the fluid. Foams and emulsions share common structures and show many physicochemical analogies. They feature liquid films between bubbles or drops and transition zones called the Plateau borders.

European groups have a strong record in this area of research on the ground as well as in microgravity, including both parabolic flights and sounding rocket missions [1-6]. Adsorption dynamics and dilational rheology of surfactants at liquid interfaces were investigated onboard the Space Shuttle, which allowed models adopted for surfactant adsorption to be validated [7], [8]. The younger generation has also been exposed to the delights of foam physics, when undergraduate students earned high commendation for their successful achievement of the extension of one of Plateau's classic wire-frame experiments to the microgravity environment of a parabolic flight [9].



◄ **FIG. 1: Position of the liquid front in forced drainage experiments: red circles, on ground, the liquid velocity is constant; blue circles, in 0g: the propagation is diffusive and slower, allowing one to reach much larger volume fractions – instabilities seen on ground are prevented [2].**

The structure and properties of foams

Foams are made of closely packed gas bubbles in a liquid, typically water with a surfactant. The liquid volume fraction φ may vary from less than one percent (dry foam) to around 35% (wet foam). When $\varphi > \varphi_c \sim 35\%$, the bubbles are spherical and move freely in a "bubbly liquid". A "jamming" transition takes place at the critical liquid fraction that brings bubbles into contact. Such wet foams are rather inaccessible under gravity, at least in equilibrium (except for very small bubbles). The froth on your beer, if you wait for it to settle, is "dry". The addition of liquid at the top can create steady-state drainage, with a constant volume fraction. This can be used to study wet foams in a steady state but only up to a liquid fraction of about 20%, beyond which various dynamic instabilities (primarily convection) occur – hence the need for microgravity which allows the production of such wet foams (see Fig. 1).

Metallic foams

Metallic foams [10] are of considerable interest for light structures or shock absorption applications. But they can suffer from pronounced drainage in the liquid state under the influence of gravity, unless appropriate measures are taken to prevent fluid flow. The reasons for this drainage lies in the high density of most metals – 2.5 g/cm^3 for liquid aluminium – and a viscosity-to-surface tension ratio which is less than 1/10 of water, combined with the usually high liquid fraction (>10%) in most liquid metal foams. As the films become thinner, they rupture at critical thicknesses around 50 µm, something that must be eliminated to obtain a useful engineering material. This can be done by incorporating solid oxide particles within the films and Plateau borders in order to keep the two interfaces apart and efficiently block flow [11]. This stabilisation technique is largely inspired from the similar effect of powders on emulsions first observed by Pickering.

Foams in microgravity

Microgravity experiments can probe the details of foam *structure* (the shapes and arrangements of bubbles), *conductivity* (which can be related to liquid fraction), coarsening (due to diffusion of gas: growth of large bubbles, shrinkage of small ones), drainage and capillarity (both due to gravity), *rheology* (a foam being a good example of a *complex fluid*, combining liquid-like and solid-like properties) and *bubble coalescence*.

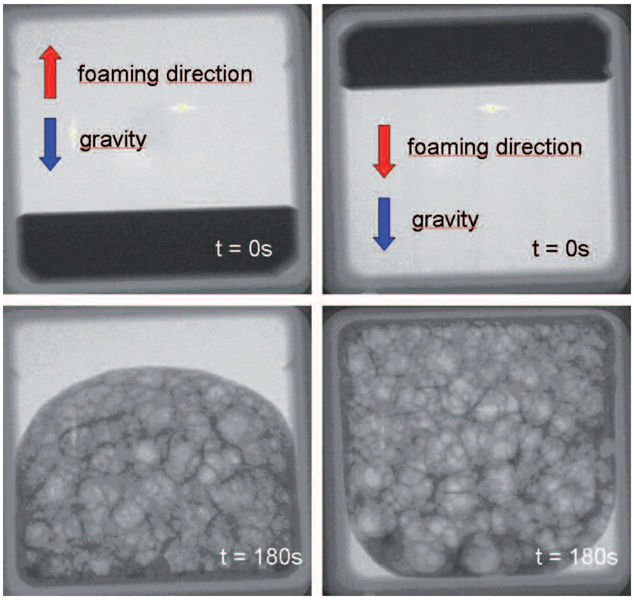
The bubble growth laws (coarsening) must be different in the wet and dry foam limit, but this evolution has never been fully checked. The same difficulty occurs with rheology: how do wet foams flow? So wet foams as well as dynamic effects are still a terra incognita of many fascinating problems. Their eventual solution will provide a scientifically valid alternative to the necessarily conservative empiricism currently used to evaluate the operational window and design for foam handling in many industrial processes.

Objectives within present ISS research programmes include the measurement of all these properties to be measured for aqueous foams in a single instrument. A full set of data on capillary drainage has already been obtained during parabolic flight experiments [2] giving better understanding of the liquid repartition inside the foam at high liquid fractions. First tests are performed in gravity with foams made of solutions containing surfactant and solid particles (such as fumed silica): this is a direction towards which intense terrestrial research is turning, with strong commercial motivation *e.g.* in the food industry.

The interplay between drainage and coalescence in *metallic* foams is obscured by the presence of gravity and it is highly desirable to study rupture without disturbing liquid flows and while holding the liquid fraction at a constant level. However insight into the internal configuration of the foam is necessary in order to quantify both drainage and rupture, which is realizable by X-ray radioscopy, as already used in the laboratory [12]. Integration of such facilities into a microgravity environment is an engineering challenge because of safety aspects and miniaturisation.

Aluminium alloy foam is created inside a small ceramic furnace: with a microfocus X-ray tube and a flat panel detector, one can observe in situ the mass density projection of the growing foam. In the left panel of fig. 2, foam is shown to expand from bottom to top and gravity hinders vertical expansion and causes drainage. In the right panel, gravity helps the foam to expand, but liquid still drains to the bottom. Zero gravity experiments on parabolic flights or on sounding rockets will show how foams evolve without drainage for up to minutes.

In the long run, one should be able to reliably produce homogeneous solid foams on Earth: new scientific findings will enable better materials to be produced for a market which offers many opportunities for cellular metals [12].



▲ **FIG. 2:** **X-ray radiograph of ground tests of the aluminium foam furnace successfully used in the sounding rocket experiment of April 2008. Various configurations were tested, including foaming against gravity (left panel, "1g") and supported by gravity (right panel, "-1g") and tests were also performed on parabolic flights. All flight data are being analysed.**

Emulsions in microgravity

Applications call for efficient and low cost methods for stabilisation or destabilisation of emulsions. In order to fill the knowledge gap between the present semi-empirical practice and a more deliberate design of emulsifiers, ESA supports a programme involving different European teams from academia and industry, working on terrestrial investigations as well as on microgravity experiments scheduled to take place within the next two years on board Columbus. Research topics range from the adsorption of surface-active components of emulsifiers to the collective behaviour of emulsion droplets as well as the dynamics of the liquid film between droplets. Droplet aggregation and coalescence are mostly conditioned by the physicochemical properties of films where dilational surfactant transport and interfacial rheology - the dynamic interfacial tension response to extensions of the interfacial area - play a key role. Weightlessness entails various simplifications allowing for an accurate measurement of kinetic parameters concerned with surfactant transport, adsorption and interfacial rheology. It also provides for simplified and controlled conditions under which the process of destabilisation of emulsions and specific interactions between droplets can be investigated. The elimination of buoyancy allows an effective study to be made of the processes of droplet coalescence or aggregation, which under terrestrial conditions are strongly coupled with gravity segregation. Experiments are planned that will focus on the dilational rheology of mixed surfactant layers subject to adsorption and to partitioning between the liquid phases.

Further experiments on ISS employing specifically designed diagnostics will address the stability of emulsions formed with surfactants and/or particles [13,14]. The objective of these experiments is the investigation of droplet-size distribution ▶

▲ **FIG. 3: The future of foam research on the ISS? (courtesy of Wiebke Drenckhan).**

evolution during destabilisation, of droplet pair-wise interactions and coalescence, and of the droplet dynamics in order to study regimes driven by capillary flows.

So far, important industrial processes and products have been developed without the benefit of well established science-based models. With the gravity level becoming a variable parameter, scientists in academia and industry are enabled to formulate more tractable models. Today ESA has brought together three scientific communities and related industry whose cooperation makes the future of foam and emulsion research very promising (see Fig. 3). ■

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