How antifoams act: a microgravity study

Pavel Yazhgur1, Dominique Langevin1, Hervé Caps2, Vincent Klein1, Emmanuelle Rio1 and Anniina Salonen1

Antifoams are widely used to control or to avoid foam production. In order to work, antifoam particles need to break foam films efficiently, which many antifoams do very well. However, once they have broken a film, to continue to be effective they need to be transported to the next film. We show, for the first time, that buoyancy has an important part in the transport of the antifoam particles. In microgravity, where buoyancy and gravitational drainage are strongly slowed down, diffusion leads to poor antifoam performance. The foam is stable for the duration of the experiment, whereas on Earth the foam starts to disappear immediately. Indeed, microgravity renders highly efficient antifoam practically useless.

ynchronization, diffusion and drainage. We used a surfactant solution of 4 g/l sodium dodecylsulfate that foams very well. Commercial antifoam obtained in parabolic generation, although less so than in 1 g, but it is ineffective after parabolic generation and afterward. In that in 1 g, AF is effective at breaking the foam both during generation, but this depends on the gravity level.

We have previously shown that fast AFs are completely ineffective if no films are present. This would be the case if the gas fraction is below random close packing (64 vol%) so the bubbles remain spherical. In the inset of Figure 2, we plot the average time taken to generate the foam (the time to reach 90% of the final foam volume) at different volume fractions. The AF is ineffective at liquid fractions above 36%, in agreement with previous results. We also see that as the foam becomes drier, the AF becomes more effective during generation, but this depends on the gravity level.

It has been suggested that AFs are more effective during generation because bubble surfaces are not fully covered by surfactants. This should not depend on gravity and cannot be the sole reason why the AF is less effective during generation in μg. Often, foaming methods are rather violent and the Froude number can be used to compare the role of gravity with that of inertia during generation Fr ≈ D/μg, with D = 5 cm the length of the piston and μg = 5 Hz. This gives Fr = 0.1 meaning that vigorous foam production is still rather weak in comparison with gravity. AF is thus more effective in 1 g than in μg, as more films are formed at the top of our sample in 1 g because of gravity-driven drainage.

The AF is almost inactive after generation in μg. We can imagine that straight after generation, the antifoam globules are evenly distributed throughout the foam in films, PBs and nodes. The films drain because of the capillary pressure, P, that sucks the liquid into the PBs. In these foams, P ≈ 3,000 Pa is much higher than hydrostatic pressure (at most 100 Pa), so film thinning proceeds in a very similar way in 1 g and in μg. The time to drain to around 5 μm is a fraction of seconds, after which most of the AF particles find themselves in PBs.

This means that, to continue to be effective the AF now have to make their way back toward the films to break them, as illustrated in Figure 1. In 1 g, the particles move within the PBs because of drainage, buoyancy (AF density not the same as water), and diffusion. We can estimate the time it takes to cross a PB (travel a distance of 10 μm) by means of each of these processes. A typical drainage velocity is 1 mm/s, which gives t_dr ≈ 1 s. The density of the droplets is around 1,050 kg/m^3 from which we calculate a Stokes velocity of 40 μm/s and the corresponding time t_st ≈ 20 s. Finally, the diffusion coefficient of the droplets is 10^{-13} m^2/s, so t_d ≈ 1,000 s. In μg, drainage and buoyancy slow down by several times.
orders of magnitude and they are not sufficiently fast to transport the AF toward the films to break the foam during the experimental time.

We highlight the importance of the transport step, which despite the extensive work carried out on AF mechanisms has been largely neglected (except in ref. 9). We show that buoyancy has a significant role in the transport of AF in the PBs. This result can also help explain why AFs on Earth are inefficient when the drops are too small for buoyancy to work efficiently.

ACKNOWLEDGMENTS

We are very happy to have had the help of Lydia Boudergui, Benjamin Huard, and Bora Lim with the realization of the experimental setup, and Jérôme Hardouin and Justine Robin with the experiments themselves. We are grateful to CNES for financial support. This work was done under the umbrella of COST Action MP-1106. Part of the work was supported by ULG ARC Supercool contract.

COMPETING INTERESTS

The authors declare no conflict of interest.

REFERENCES

1. Cantat I, Cohen-Addad S, Elias F, Graner F, Hohler R, Pitois O et al. Foams—Structure and Dynamics. Oxford University Press: Oxford, UK, 2013, 265.
2. Denkov ND. Mechanisms of foam destruction by oil-based antifoams. *Langmuir* 2004; 20: 9463–9505.
3. Garrett PR. The Science of Defoaming: Theory, Experiment and Applications. Surfactant Science Series, Vol 155. CRC Press: London, UK, 2014.
4. Karakashev SI, Grozdanova MV. Foams and antifoams. *Adv Colloid Interface Sci* 2012; 176–177: 1–17.
5. Caps H, Vandewalle N, Saint-Jalmes A, Saulnier L, Yazhgur P, Rio E et al. How foams unstable on Earth behave in microgravity? *Colloids Surf A Physicochem Eng Asp* 2014; 457: 392–396.
6. Denkov ND, Marinova KG, Tcholakova SS. Mechanistic understanding of the modes of action of foam control agents. *Adv Colloid Interface Sci* 2014; 206: 57–67.
7. Saint-Jalmes A, Cox SJ, Marze S, Safouane M, Langevin D, Weaire D. Experiments and simulations of liquid imbibition in aqueous foams under microgravity. *Microgravity Sci Technol* 2006; 18: 108–111.
8. Safouane M, Durand M, Saint Jalmes A, Langevin D, Bergeron V. Aqueous foam drainage. Role of the rheology of the foaming fluid. *J Phys IV* 2001; 11: 275–280.
9. Bergeron V, Cooper P, Fischer C, GiemanksaKahn J, Langevin D, Pouchelon A. Polydimethylsiloxane (PDMS)-based antifoams. *Colloids Surf A Physicochem Eng Asp* 1997; 122: 103–120.