# Flow of Foams

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Chapter 5

# Outlook

In this final concluding chapter we briefly will set our findings in perspective, focussing on some open issues and outlining emerging avenues for the study of the dynamics of foams as well as other complex, disordered materials. First, we will present a tentative explanation for the observed differences in interbubble drag force exponent $\beta$ in chapters 2 and 3. Second, we will briefly discuss how major open questions concerning jamming might be answered by experiments on foams, and suggest to explore analogies between granular media and foams.

## 5.1 Viscous drag, fluctuations an kymographs

In this thesis we have focussed on the averaged stresses and strainrates — even though, clearly, disorder and fluctuations are crucial in setting the values of the averaged stresses. While the drag force between bubbles and the glass plate appears to scale robustly with the bubble velocity raised to a fixed exponent $\alpha$, and while this behaviour has also been understood theoretically, it is the scaling exponent of the interbubble drag forces that appears to vary from one experimental geometry to the other and which theorists have only recently begun to investigate.

By tracking of bubble positions and velocities in foams it was recently revealed [75] that the globally measured viscous stresses (which are directly related to the interbubble drags) and the fluctuations in the foams are intimately related. Performing such analysis for all different geometries is beyond the scope of this thesis, we therefore aim instead to gain

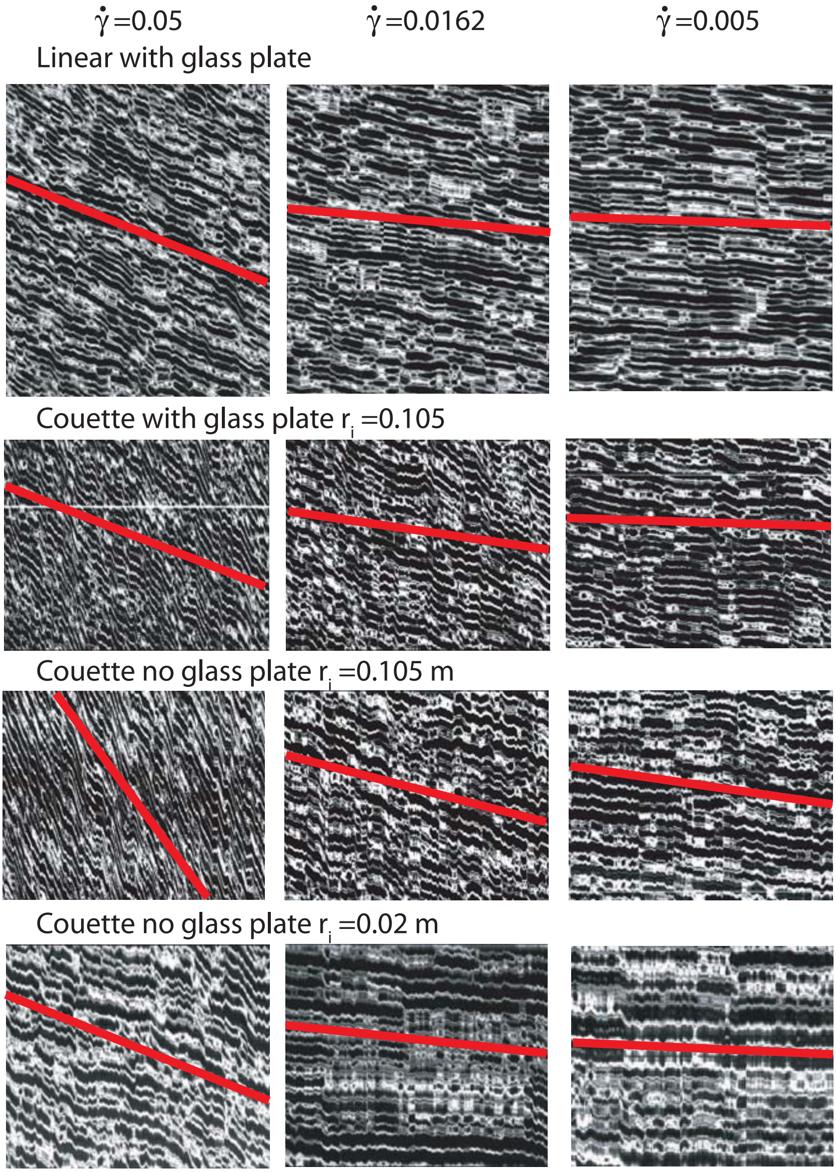


FIGURE 5.1: Kymographs (space-time plots) of the fluctuating foam flow at different local strain rates and in various experimental geometries. Solid lines indicate the average velocities at the corresponding positions in the experiments.

insight in the nature of fluctuations in our various experimental geometries by more simple qualitative methods.

We do this by drawing *kymographs* — which is a fancy word for space-time plots. To this end we select experimental runs where $v_0 \approx 0.8$ mm/s. in the linear geometry with a glass plate, the Couette geometry with and without glass plate (with inner radius $r_i = 10.5$ cm) and the Couette rheometry geometry ($r_i = 2$ cm). We determine where in each geometry the local strain rate $\dot{\gamma}_l$ equals 0.05 $s^{-1}$, 0.0164 $s^{-1}$ and 0.005 $s^{-1}$ and we draw the space-time plot of the corresponding image lines from 1000 frames.

The kymographs are plotted in Fig. 5.1 and are ordered along the columns by $\dot{\gamma}_l$ and along the rows by from top to bottom: the linear geometry, the Couette geometry with a top plate, the large Couette geometry without a top plate and the small rheometrical Couette geometry without top plate. We observe strong jittery fluctuations for the open geometries, whereas the fluctuations for the bounded geometries seem more smooth and slow, c.f. row 1 and 2 with row 3 and 4.

We thus seem to observe qualitatively different fluctuations depending on whether the foams are confined by a glass plate or not. This difference might give rise to the different scaling of $\beta$ between the two geometries and a next step would be to quantify this notion by particle tracking.

Note further that the fluctuations in the instantaneous velocities and hence in the local strain rates are really large. The same holds for the average stresses one can measure by rheometry. While relating both highly noisy and strongly averaged quantities has basically been the focus of this thesis, investigating the local dynamics of these foams by bubble tracking will yield additional and deeper understanding of foam rheology.

## 5.2 Foam as a granular material: jamming and flow

In this section we speculate on possible experiments that can be performed with foam in the context of the jamming phase diagram. Also, we will suggest to translate key granular experiments to those with foams. In the last chapter we have already discussed a variety of experiments with which we have taken first steps towards probing the jamming transition with foam bubbles. We have extracted static measures such as $p(f)$ and $p(A)$ and $G$, which we can directly compare to theory.

Another measure that we could extract from our foam data is a lengthscale $\xi$. There are two definitions, one for static and one for flowing packings. For static packings this lengthscale probes the spatial extension of force fluctuations [107], while for flowing packings it is associated with the spatial extension of correlated motion [97, 108, 109] in other words, with the size of the so-called dynamical heterogeneities. Since we can resolve the force network as well as the fluctuations in bubble motions both measures could in principle be extracted from experimental data, and we will certainly attempt this in the near future.

In two-dimensional foam systems, a further challenge lies in understanding the oscillatory rheology. Could the scaling of the visco-elastic moduli $G'$, $G''$ for instance be related to the dynamics at the bubble scale? Would one observe the large scale rearrangements associated with shear reversal and shear start-up [72, 110]?

Finally, another promising route is to redo granular experiments, but then with foam bubbles. Recently, gravity-driven flow of bubbles in either silo's [111] and rotating drums [112] has been investigated and results similar to the granular case have been obtained. One experiment that would also be feasible is that of investigating chute flows [113] in three-dimensional bubble systems, to investigate the formation of shearbands, the interface between flowing and stationary regions and the existence of a critical tilt angle. Such experiments could strengthen the ties between two fascinating macroscopic and strictly athermal examples of soft matter.