Statisical features of the global velocity of imbibition fronts in disordered media

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Imbibition is a process of fluid transport in a medium in which the resident fluid is displaced by a second immiscible invading fluid that preferentially wets this medium. When this process occurs in a disordered medium the system develops long range correlations along the interface due to the competing forces acting on different length scales: fluctuations in capillary forces, heterogeneities in the permeability, viscous pressure drop and surface tension. As a result, the system evolves out of equilibrium towards a statistically stationary state with critical fluctuations of the interface. The dynamics is highly heterogeneous both in space and time.

Our experimental system consists on large Hele-Shaw models of disordered media (described in detail in Ref.[1] and Refs. within). The gap spacing between the two plates of the cell takes two values randomly distributed in space. The invading fluid is a silicone oil. It is injected into the system at constant flow rate, displacing the resident air. The advancing of the oil-air front is recorded using a fast camera, allowing us to capture the local motion of the interface, $h(x,t)$. Therefore we can obtain the waiting time matrix, $wt(x, y = h(x,t))$, computed as the amount of time the front has spent on each position. Taking the inverse of $wt(x,t)$ we obtain the local velocity map, $v(x,t)$. This method was developed by Måløy et al.[2] for studying the intermittent dynamics of crack fronts.

In this work we analyse the average velocity of the invading front as a function of time. This global signal is given by $V_l(t) = \frac{1}{l}\int_l v(x,t)dx$ for an observation window of size l. It exhibits burst-like dynamics, with power-law distributed avalanches[3].

The shape of these avalanches is studied as a function of both the imposed mean velocity (v) and the size of the averaging window (l). We observe that the shape is asymmetric, particularly for short durations. In addition, an evolution of avalanche shape as a function of its duration, T, is noticed. The larger the duration, the flatter the shape and the larger the values of $V_l(t) - V_c$, where V_c is a clip velocity.

We also study the increments of the global velocity, $\Delta V_l(\tau) = V_l(t+\tau) - V_l(t)$. Distributions of ΔV_l show an evolution through time scales, τ, from fat tail distributions at small time increments to almost Gaussian distributions. In Fig. 1 we show this variation in the shape of the pdf as a function of τ for a given injection velocity v. It seems reasonable to define a critical increment, τ_c, to distinguish the Gaussian from the non-Gaussian behaviour. The statistical properties of the ΔV_l distributions have been analysed in order to determine this critical increment. Specifically, the skewness and the kurtosis of the pdf have been computed. The skewness (proportional to the third moment) gives information about the asymmetry of the pdf. It is different from 0 for the non-Gaussian distributions, i.e. for small τ. The degree of asymmetry depends systematically on the size of the observation window, l: the larger l, the smaller the asymmetry. The kurtosis (proportional to the fourth moment) measures the flatness of the pdf. For a Gaussian pdf the kurtosis is 3. In our experiments the kurtosis takes values larger than 3 at small τ. This effect is more evident at small l.

Statistics of global observables in correlated systems can be related to extreme value problems and to fat tail pdfs statistics[4]. In our case the temporal correlation in the ΔV_l arises from the long range correlations along the front interface. The characteristic length of these spatial correlations (l_c) together with v determines τ_c. The dependence of τ_c on l comes from the definition of V_l. When considering $l < l_c$ all the local velocities considered in the average are correlated, while for $l > l_c$ non-correlated $v(x,t)$ are also added.

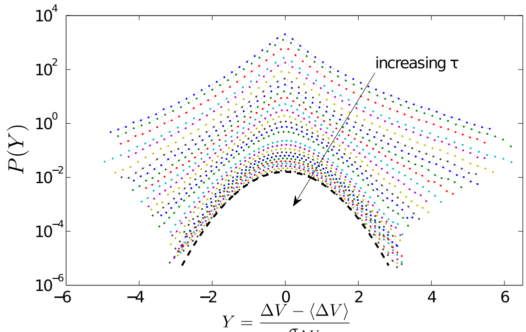

FIG. 1. Pdfs of $\Delta V_l(\tau)$ (dotted lines) for an experiment at v = 0.131 mm/s and $l = L/8$, where $L = 136$ mm is the system size. The pdfs are shifted in the vertical direction for clarity. τ ranges from 0.06 s to 33 s and changes logarithmically. A Gaussian pdf is also plotted as a guide to the eye (dashed line).

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