Scaling growth and dynamic crossover lengths in viscous fluid fronts

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Interfacial growth in disordered systems has received a considerable attention during the last years. It has been intensively studied both theoretically and experimentally in many different physical phenomena such as fluid invasion in porous media, slow combustion front, or propagation of fracture crack, among others. In particular, the imbibition process of a viscous liquid invading a porous media has shown that contains a rich variety of behaviors depending on some physical parameters such as the mean velocity of the interface or the strength of the disorder[1–3].

In our work, we numerically reproduce the imbibition phenomenon by means of a mesoscopic phase field model. We study the two different situations of imbibition: spontaneous case, where the mean velocity of the interface follows Washburn's law $V \sim t^{-1/2}$, and forced-flow imbibition, where the mean velocity is fixed to constant. In all both cases we observe that the scaling of the interface fluctuations is largely affected by the strongness of the disorder. Indeed, interfaces described by superroughness change to an intrinsic anomalous scaling when the disorder strength is increased. Likewise, in the specific case of having columnar disorder (see Fig. 1), the interfacial growth may pass to be dominated by nonlocal to local interactions. All the numerical results fully agree with experimental work made in a Hele-Shaw cell[4,5].

On the other hand, an important feature of the spontaneous imbibition case is the presence of dynamics crossover lengths as a consequence of Washburn's law. As it has been recently shown in a general context of kinetic roughening[6], the presence of time-dependent crossover lengths in a growth equation can turn into nontrivial scaling properties of the interface fluctuations including anomalous scaling. In this sense, spontaneous imbibition can present a great variety of scaling regimes depending on the interface velocity, as the numerical and experimental results show.

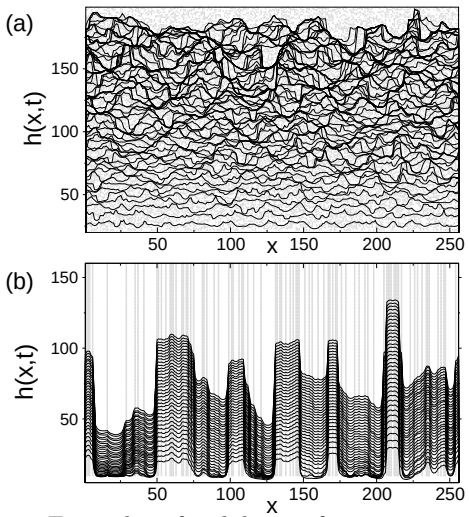

Figura 1. Examples of imbibition fronts in two different disorder configurations: (a) squares disorder, and (b) columnar disorder. Both cases are described in terms of the intrinsic anomalous scaling.

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