Roughness and dynamics of a contact line of a viscous fluid on a disordered substrate

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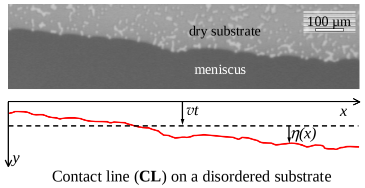
Introduction : Contact line on a disordered substrate



Contact line (**CL**) on a disordered substrate

The shape of the CL is distorted as a result of a competition between its stiffness and the defects of the substrate.

Long-range elasticity of the CL :

$$K_{el}[\eta] = -\frac{1}{\pi}\gamma \sin^2\theta \int dx' \frac{\eta(x')}{(x-x')^2}$$

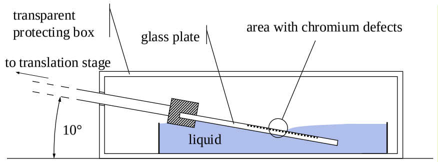
Model:

Quasi-static motion of the CL (Ertas & Kardar)

$$\mu\left(v + \frac{\partial \eta}{\partial t}\right) = F_{appl} + f(x,y) + K_{el}[\eta]$$

viscous dissipation — pulling force — disorder — elasticity

Experimental setup

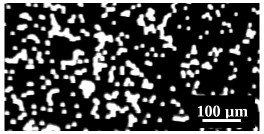


The mean velocity v of the CL is imposed by withdrawing the substrate from the liquid bath with a constant velocity.

Range of *v*: 0.2 μm/s –20 μm/s

Liquid: water or water/glycerol mixture (20× more viscous than water)

Substrate: Glass plate covered, by photo-lithographic process, with 10×10 μm^2 square defects of chromium



receding angles: $\theta_{glass} \approx 30°$

$\theta_{chromium} \approx 40°$

well controlled disorder (ξ = 10 μm)

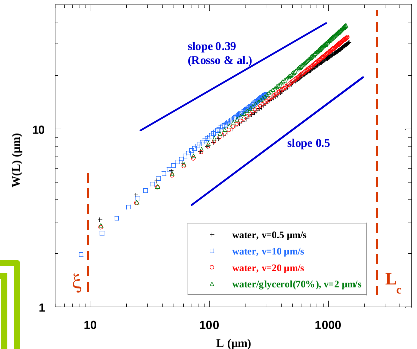
Roughness of the contact line

Definition:

$$W(L) = \left\langle\left\langle \left(\eta(x+L) - \eta(x)\right)^2 \right\rangle\right\rangle^{1/2}$$

Observation:

W(L) depends neither on the velocity v nor on the viscosity.



For 2ξ < L < Lc/2, W(L) ∝ L$^{\zeta}$

with **0.48 < ζ < 0.54**

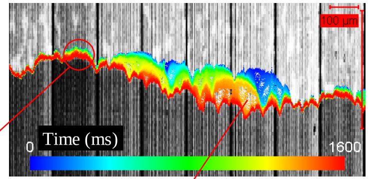
Notations

- v: mean velocity of the CL
- γ: liquid-vapour surface tension
- θ: contact angle of the liquid on the substrate
- ξ: correlation length of the disorder of the substrate
- ζ: roughness exponent
- L_c: capillary length

Dynamics of the contact line

Studies with a fast camera (500 frames per second)

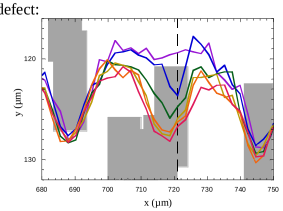
Successive positions of the CL, time is represented by colour:

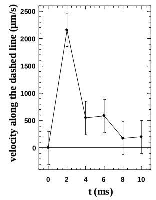


slow motion of the CL on glass

meeting with a chromium defect, fast jump forward: " avalanche "

Meeting with a defect:



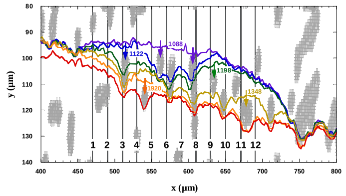


Observation:

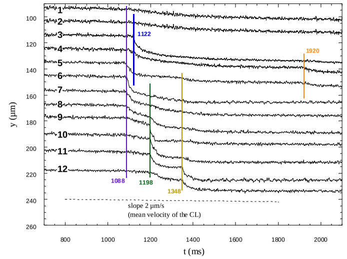
- Maximum velocity ~ 2-3 mm/s, independent of viscosity
- fast decrease of the velocity while the local pulling force has not vanished

For displacement of order of ξ, the CL motion can be considered as overdamped.

Position of the CL just before meeting a new defect (↓)



Temporal evolution of η(x) for fixed values of x (vertical lines in upper graph)



Observation:

"Simultaneous" acceleration of a large part of the CL around the defect

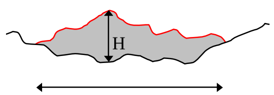
Depinning from neighbouring defects occurs well after the shape of the meniscus has changed.

No retardation effect in the elastic restoring force

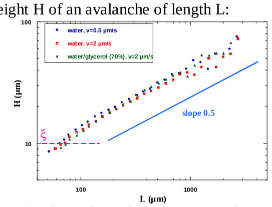
Avalanches

Studies with an ordinary CCD camera (25 frames per second)

Black and red lines represent two successive "pinned" position of the CL.



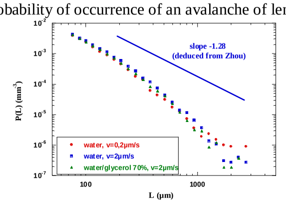
Average height H of an avalanche of length L:



H(L) depends neither on v nor on the viscosity

Confirmation of the roughness exponent close to 0.5

Probability of occurrence of an avalanche of length L:



P(L) depends neither on v nor on the viscosity

P(L) decreases faster than a power law

Discussion

Roughness: ζ = 0.51 ± 0.03

- **Disagreement** with previous theoretical and numerical results
  ex: ζ = 0.39 (Rosso & *al.*)
- **Agreement** with previous experiments with superfluid helium on rough cesium: ζ=0.55 (Prevost & *al.*), but, the motion of this system has been shown not to be quasi-static.

But

- The assumption of quasi-static motion is valid.
- There is no retardation effect in the elastic restoring force.

What is missing?

Doubts still exist about:

- Dissipative term

$$\mu\left(v + \frac{\partial \eta}{\partial t}\right) = F_{appl} + f(x,y) + K_{el}[\eta]$$

Is the dissipation due to viscosity?

Is this term linear in velocity?

Indications:

- The maximal local velocity during an avalanche does not depend on viscosity
- The contact angle hysteresis on bare glass (chromium) proves the existence of microscopic disorder (<<ξ)

- Elastic force:

$$K_{el}[\eta] = -\frac{1}{\pi}\gamma \sin^2\theta \int dx' \frac{\eta(x')}{(x-x')^2} + ???$$

It has been shown (Rosso & *al.*) that, for short-range elastic interaction, small non-harmonic correction can change the roughness exponent. What about long-range elasticity?

Future:

- study single defects to understand the effect of a non-linear dissipation term
- Investigate the dynamics of the system for higher velocities