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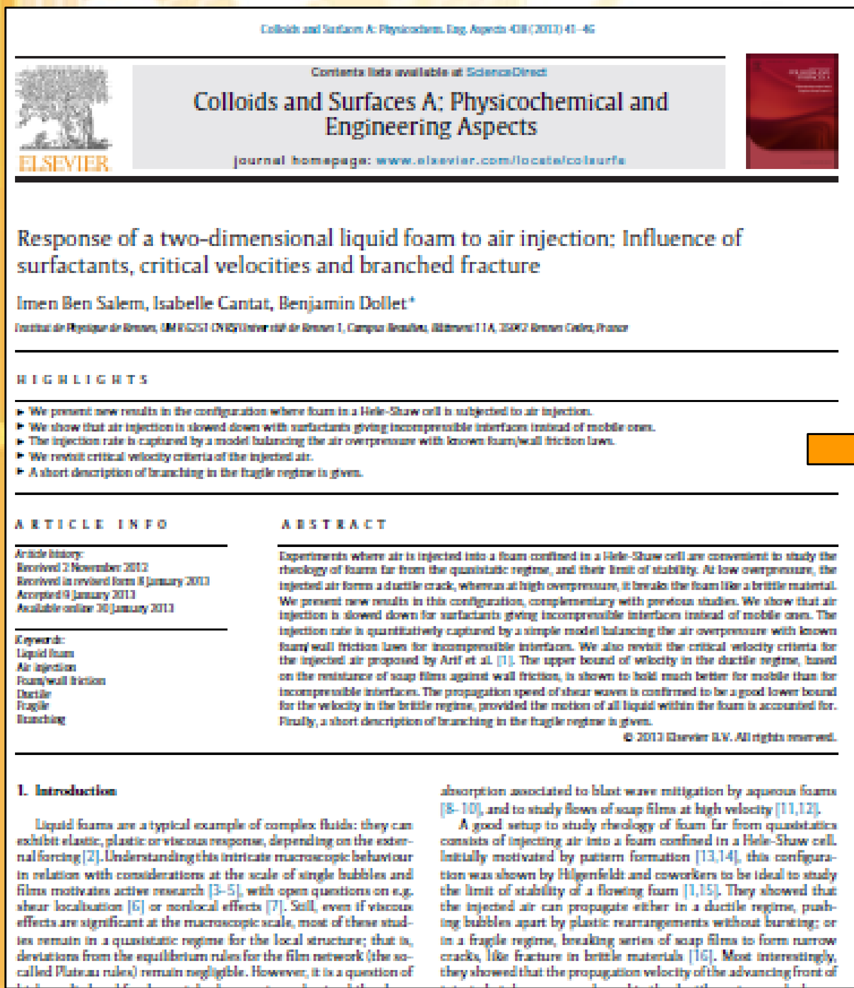

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Response of a two-dimensional liquid foam to air injection: Influence of surfactants, critical velocities and branched fracture

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HIGHLIGHTS

- We present new results in the configuration where foam in a Hele-Shaw cell is subjected to air injection.
- We show that air injection is slowed down with surfactants giving incompressible interfaces instead of mobile ones.
- The injection rate is captured by a model balancing the air overpressure with known foam/wall friction laws.
- We revisit critical velocity criteria of the injected air.
- A short description of branching in the fragile regime is given.

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ABSTRACT

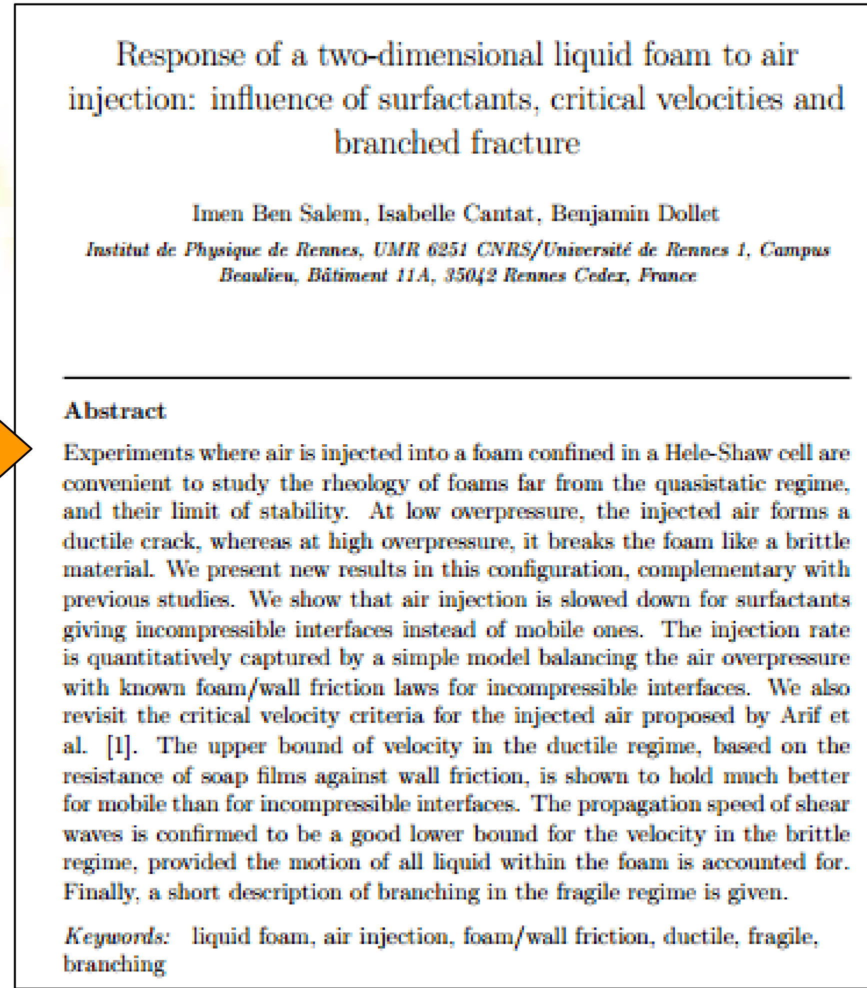
Experiments where air is injected into a foam confined in a Hele-Shaw cell are convenient to study the rheology of foams far from the quasistatic regime, and their limit of stability. At low overpressure, the injected air forms a ductile crack, whereas at high overpressure, it breaks the foam like a brittle material. We present new results in this configuration, complementary with previous studies. We show that air injection is slowed down for surfactants giving incompressible interfaces instead of mobile ones. The injection rate is quantitatively captured by a simple model balancing the air overpressure with known foam/wall friction laws for incompressible interfaces. We also revisit the critical velocity criteria for the injected air proposed by Arif et al. [1]. The upper bound of velocity in the ductile regime, based on the resistance of soap films against wall friction, is shown to hold much better for mobile than for incompressible interfaces. The propagation speed of shear waves is confirmed to be a good lower bound for the velocity in the brittle regime, provided the motion of all liquid within the foam is accounted for. Finally, a short description of branching in the fragile regime is given.

1. Introduction

Liquid foams are a typical example of complex fluids: they can exhibit elastic, plastic or viscous response, depending on the external forcing [2]. Understanding this intricate macroscopic behaviour in relation with considerations at the scale of single bubbles and films motivates active research [3–5], with open questions on e.g. shear localisation [6] or nonlocal effects [7]. Still, even if viscous effects are significant at the macroscopic scale, most of these studies remain in a quasistatic regime for the local structure; that is, deviations from the equilibrium rules for the film network (the so-called Plateau rules) remain negligible. However, it is a question of

absorption associated to blast wave mitigation by aqueous foams [8–10], and to study flows of soap films at high velocity [11,12].

A good setup to study rheology of foam far from quasistatics consists of injecting air into a foam confined in a Hele-Shaw cell. Initially motivated by pattern formation [13,14], this configuration was shown by Hilgenfeldt and coworkers to be ideal to study the limit of stability of a flowing foam [1,15]. They showed that the injected air can propagate either in a ductile regime, pushing bubbles apart by plastic rearrangements without bursting; or in a fragile regime, breaking series of soap films to form narrow cracks, like fracture in brittle materials [16]. Most interestingly, they showed that the propagation velocity of the advancing front of



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Abstract

Experiments where air is injected into a foam confined in a Hele-Shaw cell are convenient to study the rheology of foams far from the quasistatic regime, and their limit of stability. At low overpressure, the injected air forms a ductile crack, whereas at high overpressure, it breaks the foam like a brittle material. We present new results in this configuration, complementary with previous studies. We show that air injection is slowed down for surfactants giving incompressible interfaces instead of mobile ones. The injection rate is quantitatively captured by a simple model balancing the air overpressure with known foam/wall friction laws for incompressible interfaces. We also revisit the critical velocity criteria for the injected air proposed by Arif et al. [1]. The upper bound of velocity in the ductile regime, based on the resistance of soap films against wall friction, is shown to hold much better for mobile than for incompressible interfaces. The propagation speed of shear waves is confirmed to be a good lower bound for the velocity in the brittle regime, provided the motion of all liquid within the foam is accounted for. Finally, a short description of branching in the fragile regime is given.

Keywords: liquid foam, air injection, foam/wall friction, ductile, fragile, branching