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Ultra-cleaning with drop impact

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The asymmetry in fluid mechanics flows, for example caused by the presence of a solid surface, can generate very strong mechanical stresses at the interface as observed during the implosion of a cavitation bubble near a surface or the spreading of a very fast microdroplet. This effect can be used to clean and strip solid surfaces, such as when a spray of ultra-fast micron droplets is applied to a dirty surface. This cleaning process is widely used in the private sphere but also in the industry, especially in microelectronics where the miniaturization puts drastic constraints of cleanliness on the manufacturing processes of electronic circuits: the transistors used today are so small that a residue of silica no larger than twenty nanometers may cause an electrical short circuit and hinder the electronic operation of the device. Despite this extensive use, what determines the macroscopic efficiency of spray cleaning - defined as the ratio of the number of particles detached from the surface after cleaning to the number of particles initially present on the surface - is still very poorly understood.

To understand this problem, we have experimentally quantified the cleaning efficiency of a controlled spray on a surface artificially contaminated with silica nanoparticles of 60 nm in diameter. The experimental results obtained show that the macroscopic cleaning efficiency can only be understood by analyzing at the nanoscale the shear action exerted by the highly unsteady and inhomogeneous flow generated by the spreading drop on the nanoparticle stuck to the surface. In this theoretical framework, the comparison between theory and experiment is excellent. Moreover, by confronting our predictions with those of the literature [1], we discuss the influence of various parameters such as the time of application of the spray, the flow rates of liquid or gas and the limits of our modelling.

Generally speaking, these results show that the impact of microdroplets in spray allows to probe the adhesion energy between nanoparticles and surfaces. As classically observed in many systems, we observe that the particle-surface adhesion energy increases with time. Moreover, we also show that the hygrometry of the atmosphere is a key parameter. This suggests an adhesion induced by the appearance of capillary menisci between the particles and the surface [2]. However, the orders of magnitude of the adhesion energy as well as the characteristic time of adhesion aging measured are much too large to impute adhesion aging to capillary effects alone. We propose an alternative scenario to explain these observations.

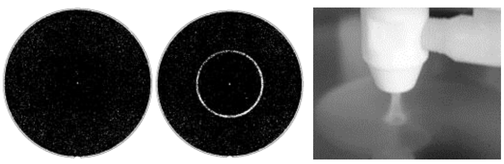

Figure 1 : On the left, a surface that appears black because it is contaminated by particles – on the middle, a ring of cleanliness appears after the application of the spray. On the right, an image of the spray generator

[1] K. Xu et al. Solid State Phenomena, 145; 31–34 (2009)

[2] L. Bocquet et al, Phys. Nature. 396, 24 (1998)