Capturing drops with fibrous materials

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The passive filtration of liquid droplets from aerosol streams or emulsions is done by placing a porous (generally fibrous) structure in the path of the mist. As the flow goes through the filter, the droplets it carries are captured by the fibres, and are then drained or imbibed inside the structure. This situation is encountered in many systems, from coalescence filters used to remove liquid from aerosols, cloud water interception by plants, the collection of fresh water from fog or the capture of respiratory droplets with facemasks, to sprays of liquids on textiles for coating or functionalization. Depending on the application, several capture mechanisms are at play, and these systems exhibit a wealth of phenomena coupling aerodynamics, capillarity, and elastic deformation of the network. In this talk, I will illustrate some of the mechanisms at play in such fiber-liquid interactions with several model experiments.

If the droplets are much smaller than the fiber diameter, as for fog collection, the dominant mechanism is inertial impaction; there is a minimum velocity below which the droplets are slowed down by viscous effects and thus follow the streamlines, avoiding the fibers. On the contrary, if the droplets are larger than the fibers, e.g. when spraying a textile, there is a maximum velocity above which drops are not slowed down enough to be stopped and captured by the fibers. These capture criteria and the drops dynamics all strongly depend on the fibres characteristics and mesh geometry, which we will investigate using models of increasing complexity, from a single fiber to a complex network. Furthermore, as the liquid wets the structure, capillary force may deform the network by collapsing adjacent fibers together, which strongly affect the liquid deposition. In many situations, the liquid can further imbibe inside the fibers as well as between the fibers, leading to swelling and deformation. Using model experiments with elastomeric fibres, we show that swelling enables capillary imbibition and favors fiber collapse. On a thin fibrous network, such as a woven mesh or a non-woven fibrous sheet, the combined effects of capillary-driven flow and swelling lead to strong out-of-plane deformations of the thin substrate. We rationalize all these observations with models coupling wetting, poroelasticity and elasto-capillarity.