Controlling Water Evaporation through Self-assembly

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The evaporation of water from an aqueous medium to a dry gas phase is a ubiquitous phenomenon in nature. Evaporation can occur freely, as from oceans into the air, or be hindered by membranes or barrier films. Land-living organisms face the challenge of adjusting to the relative humidity of ambient air, which varies from a few percent to saturation at 100%, while the living cell water chemical potential corresponds to a relative humidity (RH) of above 99%. This difference drives water transport from the cells to the ambient air, exposing life to a drying-out threat.

Different strategies have emerged to counter this threat. Plant leaves are covered with a waxy cuticle layer composed of polymers and associated lipids, while animals like mammals are protected by a skin composed of dead cells embedded in a lipid matrix, and a lipid film on the tear liquid in the eyes.
Water transport across an inert diffusional barrier is proportional to the difference in water chemical potential between the inside and the outside. Total water loss through an inert membrane would thus vary in response to changes in the environmental humidity, with the risk of massive water loss in dry conditions. This phenomenon is typically observed in the plant cuticular film that coats the leaves. On the contrary, several studies show that for healthy human stratum corneum, the outermost layer of skin, the evaporation rate increases with lowering RH at high humidities, while it it is virtually constant and independent of the outside humidity for RH<85%.

We show that the same behavior can be reproduced using aqueous solutions of amphiphilic molecules. We uncover the underlying mechanism using these models systems and a controlled drying setup coupled to a set of characterization techniques (small-angle X-ray scattering, gravimetry, polarized and infra-red microscopy). We show that evaporation leads to the build-up of a concentration gradient from the air/liquid interface, which results in a structure gradient and thus a permeability gradient.
We show that a dry phase of low permeability forms at the air/liquid interface and adapts its thickness to counter changes in the air humidity, while setting a constant water chemical potential to the rest of the liquid. This responsive shield is a universal feature of systems for which the structure, and thus the permeability, change with the water content. This coupling between both the driving force and the pathway of water evaporation leads to the macroscopic compensation of effect. Water evaporation can be made humidity-independent.
Unveiling this mechanism paves the way to the preparation of responsive ointments/coatings to treat damaged biological external membranes (skin diseases, dry eye syndrome). These findings also lead to new possibilities to design robust and homogeneous coatings if amphiphilic molecules are present in the formulation.

[1] K. Roger*, M. Liebi, J. Heimdal, D. Pham, Emma Sparr, *PNAS*, 2016, under review