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Evaluation and absorption of surfactant-laden droplets on unsaturated porous media

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Understanding the evaporation and absorption of surfactant-laden droplets on porous media is challenging and important for many industrial applications, for example, inkjet printing. The evaporation of droplets containing dispersed solid particles on a solid surface has aroused much interest and has extensively been studied. The non-uniform evaporation pattern, resulting after evaporation, is well known as the coffee ring effect. Deegan et al. [1] found that this pattern is caused by the outward flow within the droplet during evaporation. To obtain a uniform deposition pattern, surfactants are added which suppress this outward flow, which is especially significant in inkjet printing applications to enhance the print quality.

The evaporation of surfactant-laden droplets on a fibrous thin paper sheet is a more complex process, involving spontaneous droplet evaporation, water imbibition into pores causing an unsaturated porous medium, and surfactant transport in both the droplet and the porous medium, as illustrated in Figure 1. We use both theoretical and numerical methods to explore this process. The mathematical model for flow in droplets is based on lubrication theory. For the calculation of the vapor concentration, which determines the evaporation flux, an analytical method is used. For the droplet absorption process, the Richards equation is used, where it should be noted that we do not describe the flow on the scale of the pores, but rather use properties averaged over a number of pores. For the surfactant transport process, a mass conservative convection-diffusion model is employed. A three-stage diagonally implicit Runge-Kutta scheme and a finite volume method are used to simulate the process numerically. We will specifically study how the results are affected by the assumption of unsaturated flow in the pores. We will validate the unsaturated flow model and simulation method by comparison with numerical solutions for transient flow in a thin porous medium obtained by Zhuang et al. [2]

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References

[1] Deegan, R. D., Bakajin, O., Dupont, T. F., Huber, G., Nagel, S. R., & Witten, T. A. (1997). Capillary flow as the cause of ring stains from dried liquid drops. Nature, 389(6653), 827-829. [2] Zhuang, L., Hassanizadeh, S. M., Bhatt, D., & van Duijn, C. J. (2021). Spontaneous Imbibition and Drainage of Water in a Thin Porous Layer: Experiments and Modeling. Transport in Porous Media, 139(2), 381-396.

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