Modeling of heat and mass transfer in drying colloidal drops and films

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This short review deals with the mathematical modeling of heat and mass transfer in drying drops and films on a solid surface. These are open systems with variable mass that are used in various applications. Often, liquids contain dissolved or suspended substances. For example, colloidal particles that are transported by the flow of a liquid that occurs during evaporation. It is possible to control the process by controlling the intensity and non-uniformity of evaporation along the free surface of the liquid layer. This idea lies in the evaporative lithography. For instance, it is possible to influence the character of evaporation by placing a mask or a heat source over the liquid. Mathematical models are needed to learn how to obtain micro- and nanostructures of the desired shape with high accuracy. These models will predict the result depending on the parameters of the system. But first we need to understand the observed phenomena at the conceptual level. The complexity of the systems being studied lies in their nonlinear behavior. Sometimes the process is accompanied by various phase transitions ("liquid–vapor", "sol–gel", "sol–glass", etc.). Physical parameters such as viscosity and others may depend on the temperature of the liquid and the concentration of the particles. There are many approaches to mathematically describe these effects such as discrete, continuum, and semi-discrete models. It is more convenient to use a continuum approach to describe systems of relatively large volume and high concentration. In this case, the model includes the equation of continuity, the equation of motion, the convection-diffusion equation, the heat transfer equation, and the like. There is also a quasi-stationary approach where the flow rate is not time-dependent explicitly. Using the lubrication approximation simplifies some of the equations of the model. The nonlinearities associated with the curvature of the surface disappear. Such approximations are valid for slow evaporation when the two-phase boundary is almost flat (films and thin droplets). Otherwise, we have a complex case with non-stationary equations.

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