DROP EVAPORATION ON AN ISOTHERMAL OR ADIABATIC SOLID SURFACE

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Summary A quasi-steady state diffusion model is developed to simulate numerically the evaporation of a pinned or depinned sessile drop of water. A numerical approach based on the finite volume method is adopted to assess heat and mass transfer rates.

MATHEMATICAL FORMULATION

Many authors investigated the evaporation of a sessile drop which usually occurs under constant wetting radius and variable contact angle or inversely [1- 5].

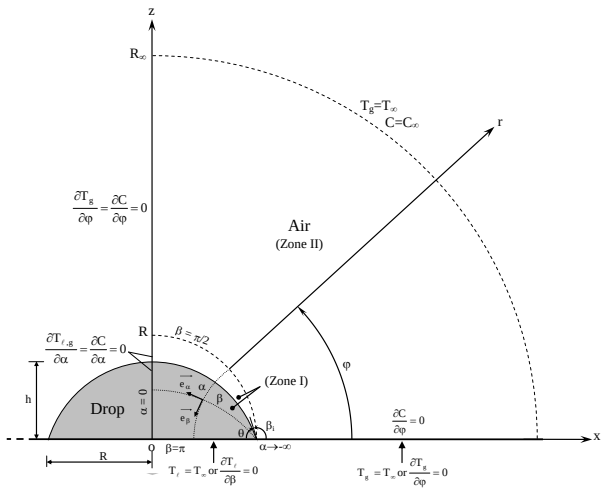

Figure 1: Water drop of spherical cap shape deposited on a horizontal substrate.

A 10 mm^3 droplet of pure water is deposited on a non heating horizontal solid surface, as shown in Fig. 1. The evaporation of the drop occurs in surrounding moist air at room temperature T_∞ of 25 ℃ and relative humidity H_a of 40%. The drop has a shape of a spherical cap controlled by surface tension effect. We assume that the evaporation occurs either in pinned mode where the contact radius R is kept constant and the contact angle θ variable in time or in de-pinned mode where inversely R is variable and θ constant in time. The formulation of the problem is based on the energy equation in both phases and the concentration equation in the gas phase. The dimensionless governing equations are written in toroidal coordinates (α, β) in zone (I) and in spherical coordinates (r, φ) in zone (II), see Fig. 1.

i) in the liquid phase of zone (I),

$$\frac{\partial}{\partial\alpha}\left(H\,H_\phi\,\frac{\partial T_\ell^*}{H\partial\alpha}\right)+\frac{\partial}{\partial\beta}\left(H\,H_\phi\,\frac{\partial T_\ell^*}{H\partial\beta}\right)=0 \qquad (1)$$

ii) in the gas phase of zone (I),

$$\frac{\partial}{\partial\alpha}\left(H\,H_\phi\,\frac{\partial T_g^*}{H\partial\alpha}\right)+\frac{\partial}{\partial\beta}\left(H\,H_\phi\,\frac{\partial T_g^*}{H\partial\beta}\right)=0 \qquad (2a)$$

$$\frac{\partial}{\partial\alpha}\left(H\,H_\phi\,\frac{\partial C^*}{H\partial\alpha}\right)+\frac{\partial}{\partial\beta}\left(H\,H_\phi\,\frac{\partial C^*}{H\partial\beta}\right)=0 \qquad (2\,b)$$

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iii) in zone (II),

$$\frac{\partial}{\partial r^*}\left(r^{*2}\cos(\varphi)\frac{\partial T_g^*}{\partial r^*}\right)+\frac{\partial}{\partial \varphi}\left(r^*\cos(\varphi)\frac{\partial T_g^*}{r^*\partial \varphi}\right)=0 \qquad (3\ a)$$

$$\frac{\partial}{\partial r^*}\left(r^{*2}\cos(\varphi)\frac{\partial C^*}{\partial r^*}\right)+\frac{\partial}{\partial \varphi}\left(r^*\cos(\varphi)\frac{\partial C^*}{r^*\partial \varphi}\right)=0 \qquad (3\ b)$$

The variables are scaled with respect to the initial contact radius R_0 , far field temperature T_∞, while the dimensionless concentration $C^* = (C - C_\infty)/\Delta C$ where $C_\infty = H_a C_v(T_\infty)$, $\Delta C = (1 - H_a) C_v(T_\infty)$, $C_v(T_\infty)$ being the saturation concentration at T_∞. Boundary conditions associated with the governing equations are indicated in Fig. 1. Conditions of no temperature or concentration jump as well as conditions of heat or mass flux continuity are applied at the interface between zones (I) and (II).

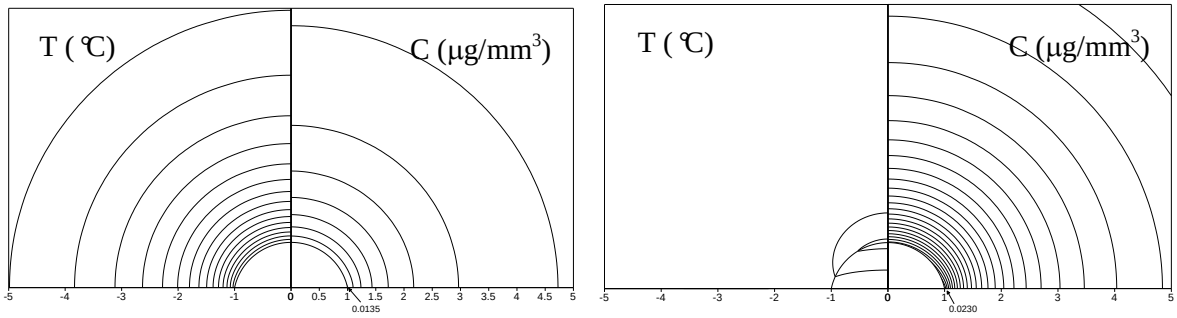
$$T_g^{*I} = T_g^{*II} \quad , \quad \left(\frac{\partial T_g^*}{H\partial\beta}\right)^I_{\pi/2} = -\left(\frac{\partial T_g^*}{\partial r'^*}\right)^{II}_1 \quad \text{and} \quad \left(\frac{\partial C^*}{H\partial\beta}\right)^I_{\pi/2} = -\left(\frac{\partial C^*}{\partial r'^*}\right)^{II}_1 \qquad (4)$$

In addition the dimensionless mass flux of evaporation from the drop J^*, must satisfy the local energy balance:

$$\left(\frac{\Delta C}{\rho_g}\right)\frac{Ja}{Le}J^* - Rk_g^{-1}\left.\frac{\partial T_\ell^*}{H\partial\beta}\right|_{\beta_i} + \left.\frac{\partial T_g^*}{H\partial\beta}\right|_{\beta_i} = 0 \qquad (5)$$

$Ja = h_{\ell g}/(c_{pg}T_\infty)$ is the Jacob number where h_{lg} is the latent heat of evaporation and $Le = (\alpha_T / D)_g$ is the Lewis number.

Results and discussion. Results are presented in this section for a water drop of 10 mm^3 with an initial contact radius of 1.86 mm, placed on an adiabatic or isothermal solid surface covered by a very thin layer of aluminum imposing an initial contact angle of 78 °. Fig. 3 presents temperature and concentration fields.



(a) Adiabatic case ($k_s = 0$) (b) Isothermal case ($k_s \to \infty$)

Figure 3: Isotherms and iso-concentrations distribution at the beginning of evaporation (ΔT=0.25 °C, ΔC=0.0005 μg/mm^3).

CONCLUSION

A quasi steady state diffusion model is considered which combines the heat equation in both liquid and gas phases and the mass diffusion equation in the surrounding air. Coupling between heat and mass transfer is achieved by accounting for temperature dependency of the saturation concentration at the drop surface and the heat balance at the interface.

Acknowledgements: One of the authors (S. Radev) expresses his gratitude to the Bulgarian Scientific Fund for the support in the frame of Project DO 02-338/2008.

References

[1] Song H., Lee Y., Jin S., Kim H.Y. and Yoo J.Y., *Microelectronic Engineering*, ***88***, 3249-3255,2011.
[2] Hu H. and Larson R.G., *J.Phys.Chem.B*, **106**, 13334-1344, 2002.
[3] David S., Sefiane K. and Tadrist L., *Colloids and surfaces A: Physicochemical and Engineering Aspects*, **298**, 108-114, 2007.
[4] Dunn G.J., Wilson S.K., Duffy B.R., David S. and Sefiane K., *J. Fluid Mech.*, **623**, pp. 329-351, 2009.
[5] Ait Saada M., Chikh S. and Tadrist L., *Phys. Fluids* **22**, 1121, 2010.