Proceedings of CHT-15
ICHMT International Symposium on Advances in Computational Heat Transfer

May 25-29, 2015, Rutgers University, Piscataway, USA

CHT-15-260

HEAT AND MASS TRANSPORT IN LIQUID FILMS: COMBINING ANALYTICAL AND NUMERICAL APPROACHES

Tatiana Gambaryan-Roisman

Institute of Technical Thermodynamics and Center of Smart Interfaces, Technische Universität Darmstadt, Alarich-Weiss-Str. 10, 64287, Darmstadt, Germany

Numerical simulation of hydrodynamics, heat and mass transport as well as phase change in thin liquid films is an extremely challenging task, owing to large discrepancy between the involved length scales and to complex interface dynamics (interfacial waves, film de- and rewetting etc.). The degree of complexity further increases for films on substrates with topography or on substrates with graded properties. Combining analytical and numerical methods allows an accurate description of film hydrodynamics and transport processes with reasonable effort. In this talk the modified long-wave theory, Graetz-Nusselt theory and multiscale modelling approach are reviewed, and their application to description of heat and mass transport in liquid films on plain and modified substrates is demonstrated.

Long-wave theory (Oron et al. [1997]) is a typical example of successful combination of analytical and numerical methods for solution of film flow problems. The full system of governing equations reduces in the framework of this theory to a single evolution equation for the film thickness. The theory is applicable for situations, in which the length scale of the film deformation is much larger than the characteristic film thickness. In addition, the Reynolds number is assumed to be of a unity order. The long-wave theory has been successfully applied to description of heat transport in liquid films on substrates with topography (Kabova et al. [2006]). An additional modelling step is necessary if the transport processes in the wall wetted by the film or in the ambient gas can't be treated using the long-wave approximation. In this case the description of the film evolution should be coupled with full-scale mathematical description of heat and mass transport in the adjacent phase (Gambaryan-Roisman [2011]).

The Graetz-Nusselt approach is usually applied to description of thermally developing region in channels and ducts (Kakaç et al. [1987]). This theory has been extended to describe the heat transport in liquid films flowing down walls with longitudinal grooves of arbitrary cross-section geometry (Yu et al. [2010]). Depending on the Peclet number and on heat transfer coefficient between the liquid and the ambient gas, the thermally developing region in liquid films can extend over a length of several meters.

The flow of liquid along modified walls may take place in rivulet regime, in which the wetted areas of the substrate are separated from the dry areas by contact lines. The contact lines are characterized by extremely high evaporation rates, which significantly contribute to overall heat transfer. Theoretical and numerical description of hydrodynamics, heat and mass transport in the vicinity of contact line must take into account the micro- and nanoscale phenomena, including the effect of disjoining pressure and the molecular-kinetic resistance to evaporation (Stephan and Busse [1992]). However, these micro- and nanoscale phenomena don't play any role in the liquid flow and heat transport away from the contact line. Moreover, these phenomena can’t be resolved by the numerical grid embracing the whole macroscopic system. The best modelling strategy in this case is the multiscale modular modelling approach, which has been originally devised for numerical simulation of heat pipes (Stephan and Busse [1992]) and applied later for description of boiling (Kunkelmann and Stephan [2009]), drop impact (Herbert et al. [2013]), for transport phenomena in falling films (Gambaryan-Roisman and Stephan [2003]) and shear-driven films (Helbig et al. [2005]).

REFERENCES

Gambaryan-Roisman, T. and Stephan, P. [2003], Analysis of Falling Film Evaporation on Grooved Surfaces, *J. Enhanced Heat Transfer*, Vol. 10, No. 4, pp 445-457.

Gambaryan-Roisman, T. [2011], Marangoni-Induced Deformation of Evaporating Liquid Films on Composite Substrates, J Eng Math, Vol. 73, pp 39-52.

Helbig, K., Alexeev, A., Gambaryan-Roisman, T. and Stephan, P. [2005], Evaporation of Falling and Shear-Driven Films on Smooth and Grooved Surfaces, *Flow, Turbulence and Combustion*, Vol. 75, pp 85-104.

Herbert, S., Fischer, S., Gambaryan-Roisman, T. and Stephan, P. [2013], Local Heat Transfer and Phase Change Phenomena during Single Drop Impingement on a Hot Surface, *Int. J. Heat Mass Transfer*, Vol. 61, pp 605-614.

Kabova, Yu.O., Alexeev, A, Gambaryan-Roisman, T and Stephan, P. [2006], Marangoni-Induced Deformation and Rupture of a Liquid Film on a Heated Microstructured Wall, *Phys. Fluids*, Vol. 18, 012104.

Kakaç, S., Shah, R. K. and Aung, W. [1987], *Handbook of Single –Phase Convective Heat Transfer*, Wiley-Interscience Publication, New York.

Kunkelmann, C. and Stephan, P. [2009], SFD Simulation of Boiling Flows Using the Volume-of-Fluid Method within OpenFOAM, *Numer. Heat Tr. A.-Appl.*, Vol. 56, No. 8, pp 631-646.

Oron, A, Davis, S.H. and Bankoff, S.G. [1997], Long-Scale Evolution of Thin Liquid Films, *Rev. Mod. Phys*, Vol. 69, pp 931-80.

Stephan, P. and Busse, C.A. [1992] Analysis of Heat Transfer Coefficient of Grooved Heat Pipe Evaporator Walls, *Int. J. Heat Mass Transfer*, Vol. 35, pp 383-391.

Yu, H., Löffler, K., Gambaryan-Roisman, T. and Stephan, P. [2010], Heat Transfer in Thin Liquid Films Flowing down Heated Inclined Grooved Plates, *Computational Thermal Sciences*, Vol. 2, No. 5, pp 455-468.