

CPP 26: Micro and Nano Fluidics I: Liquids at structured materials

Time: Wednesday 14:00–16:00

Location: C 264

Invited Talk

CPP 26.1 Wed 14:00 C 264

The Capillary Rise of Liquids in Nanopores — ●PATRICK HUBER — Faculty of Physics, Saarland University, D-66041 Saarbruecken

Liquid flow driven by capillary forces is one of the most intriguing transport mechanisms in nature and technology. It is governed by a fascinating interplay of interfacial, inertia, viscous drag as well as gravity forces which liquids encounter upon invasion into geometries with often complex topologies, such as capillary networks of trees or interconnected pores and fractures in soils and ice. Whereas a detailed understanding of this phenomenon has been achieved on macroscopic scales, it is poorly explored on the meso- and nanoscale, where predictions regarding its mechanisms are hampered due to a possible breakdown of continuum hydrodynamics, conflicting reports with respect to the conservation of the fluidity and capillarity of liquids upon spatial confinement. Here we present optical and gravimetric measurements on the capillary rise of liquids as a function of their complexity (water, chain-like hydrocarbons and rod-like liquid crystals) in networks of silica capillaries with 2.5 nm and 5 nm radii (monolithic mesoporous Vycor). We find classical Lucas-Washburn square-root-of-time invasion dynamics over the entire capillary rise time investigated (up to several hours). We demonstrate that conserved macroscopic capillary rise hydrodynamics are intimately related to the capillary condensation/evaporation hysteresis characteristic of the thermodynamic state of spatially nanoconfined liquids.

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Simulation of fluid flow in hydrophobic rough microchannels — ●JENS HARTING and CHRISTIAN KUNERT — Institute for Computational Physics, Pfaffenwaldring 27, D-70569 Stuttgart

Surface roughness becomes relevant if typical length scales of the system are comparable to the scale of the variations as it is the case in microfluidic setups. Here, an apparent boundary slip is often detected which can have its origin in the misleading assumption of perfectly smooth boundaries. We investigate the problem by means of lattice Boltzmann (LB) simulations and introduce an “effective no-slip plane” at an intermediate position between peaks and valleys of the surface. Our simulations show good agreement with analytical results for sinusoidal boundaries, but can be extended to arbitrary geometries and experimentally obtained surface data which cannot be treated analytically. We find that the detected apparent slip is independent of the detailed boundary shape, but only given by the distribution of surface heights. Further, we show that the slip diverges as the amplitude of the roughness increases which highlights the importance of a proper treatment of surface variations in very confined geometries. At last, we extend our work to rough hydrophobic surfaces and show that the coupling of both effects can lead to non-linear effects.

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Morphological clues to wet granular pile stability — ●MARIO SCHEEL¹, MARCO DI MICHIEL², MARTIN BRINKMANN¹, RALF SEEMANN^{1,3}, and STEPHAN HERMINGHAUS¹ — ¹MPI for Dynamics and Self-Organization, Bunsenstr. 10, D-37073 Göttingen — ²European Synchrotron Radiation Facility, BP 220, F-38043 Grenoble Cedex — ³Experimental Physics, Saarland University, D-66041 Saarbrücken

When a dry granulate is mixed with a wetting liquid, the macroscopic stiffness of the latter is increased dramatically by virtue of the surface tension of the liquid. This macroscopic mechanic behavior is constant in a large range of the liquid content. Only if nearly all pores are filled with liquid, the stiffness weakens. Using X-ray microtomography we explore the liquid morphologies that form within the granular pile, as function of liquid content, packing density and grain shape. We can clearly separate air, liquid and grains from each other, which allows to identify the emerging liquid morphologies. Capillary bridges were found for small liquid contents. If more liquid is added, the capillary bridges grow in size and eventually merge into larger liquid cluster. As even more liquid is added, the liquid cluster grow in size and merge with surrounding clusters. For randomly close packed grains this ‘building principle’ is still valid for large liquid contents and always results in a ramified liquid structure. This ‘building principle’ was verified numerically by minimizing the surface energy of particu-

lar cluster morphologies. The experimental observed constancy of the mechanic behavior follows from the ramified liquid structure.

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Liquid morphologies in random assemblies of spherical beads — ●MARTIN BRINKMANN¹, MARIO SCHEEL¹, DANIEL HORNUNG¹, MARCUS SCHWAMBERGER¹, RALF SEEMANN^{1,2}, and STEPHAN HERMINGHAUS¹ — ¹MPI for Dynamics and Self-Organization, 37073 Göttingen — ²Saarland University, D-66041

Small amounts of wetting liquids mixed into a random assembly of spherical glass beads are present in the form of capillary bridges between adjacent beads. At higher liquid content these bridges coalesce into larger liquid structures that eventually percolate the whole assembly. Inspired by recent X-ray microtomography data we examine the liquid morphologies in local triangular configurations of spheres where two pairs of spheres are in mutual contact while the remaining pair forms a small gap. Using numerical minimizations of the interfacial energy we predict the appearance of certain liquid morphologies as controlled by their volume, respectively, Laplace pressure, contact angle, and gap separation. The morphology diagram can be quantitatively compared to wetting experiments using isolated triangular configurations of spherical beads. Based on these results we propose a simple model to describe the consecutive coalescence of capillary bridges. This model allows to predict the percolation transition of liquid structures in a pile of beads solely based on the contact angle and the local packing geometry.

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Phase behavior of fluids between thermally corrugated walls — ●GERRIT GÜNTHER and MARTIN SCHOEN — Stranski-Laboratorium für Physikalische und Theoretische Chemie, Sekretariat C7, Technische Universität Berlin, Straße des 17. Juni 115, D-10623 Berlin, Germany

To investigate the effect of flexible walls on the phase behavior of confined fluids we use the grand canonical ensemble Monte Carlo method (GCEMC). Consider a Lennard-Jones(12,6) fluid between two plane parallel walls which itself consist of single wall particles in a face centered cubic (fcc) (100) order. Wall and fluid particles are of the same type thus interacting via Lennard-Jones(12,6) potentials as well. The wall particles are not fixed to their lattice sites but bound to them by harmonic potentials. The softness of the wall is controlled via the force constant of this harmonic potential. Starting with a sufficiently high force constant the wall resembles a rigid fcc structure. By softening the wall its particles are able to react to thermal fluctuations in the fluid to a greater extent. Fluid and wall particles are then more evenly distributed in space. The structural changes lead to a shift of phase transition in confinement.

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Dewetting dynamics in triangular grooves: A possible way to measure the slip length — ●KRISHNACHARYA KHARE¹, MARTIN BRINKMANN¹, BRUCE M. LAW², STEPHAN HERMINGHAUS¹, and RALF SEEMANN^{1,3} — ¹Max-Planck Institute for Dynamics and Self-Organization, D-37073 Göttingen — ²Kansas State University, Manhattan, KS-66506 — ³Saarland University, D-66041 Saarbrücken

Static wetting morphologies of liquid in triangular grooves and their dynamics are studied experimentally and theoretically. For contact angles smaller than 90° minus half the opening angle of the groove, the liquid forms filaments with negative mean curvature extended along the entire length of the groove. For larger contact angles, liquid either forms elongated filaments of finite length and positive mean curvature or drop-like morphologies. Electrowetting is used to vary the contact angle and to switch between different wetting morphologies. In this way, liquid filaments can be pulled out of a large feeding drop forming elongated filaments in prefabricated surface grooves. When being quenched from the filling to the non-filling regime, the liquid filaments become unstable and break into isolated droplets with a preferred distance. This preferred droplet distance compares favorably with the linear stability model assuming the instability to be driven by the local variation of the Laplace pressure with filament width. Dynamics of the instability is studied via in situ scanning force microscopy at elevated temperature. From the measured time constant of the instability, we derived the slip length for the system which is in good

agreement with the dewetting experiments on plane substrates.

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Intrusion of fluids into nanogrooves — HOLGER BOHLEN¹, ANDREW O. PARRY², ENRIQUE DIAZ-HERRERA³, and MARTIN SCHOEN¹ — ¹Stranski-Lab. f. Physikal. und Theor. Chemie, Technische Universität Berlin, GERMANY — ²Dept. of Mathematics, Imperial College, London, UK — ³Dept. de Física, UNAM, Mexico City, Mexico

We study the shape of gas-liquid interfaces forming inside rectangular nanogrooves. On account of purely repulsive fluid-substrate interactions the confining walls are dry (i.e., wet by vapor) and a liquid-vapor interface intrudes into the nanogrooves to a distance determined by the pressure. By means of Monte Carlo simulations in the grand canonical ensemble (GCEMC) we obtain the density $\rho(z)$ along the midline

($x = 0$) of the nanogroove for various geometries (i.e., depths D and widths L) of the nanogroove. We analyze the density profiles with the aid of an analytic expression which we obtain through a transfer-matrix treatment of an one-dimensional effective interface Hamiltonian. Besides geometrical parameters such as D and L the resulting analytic expression depends on temperature T , densities of coexisting gas and liquid phases in the bulk $\rho_x^{g,l}$ and the interfacial tension γ . The latter three quantities are determined in independent molecular dynamics simulations of planar gas-liquid interfaces. Our results indicate that the analytic formula provides an excellent representation of $\rho(z)$ as long as L is sufficiently small. At larger L the meniscus of the intruding liquid flattens. Under these conditions the transfer-matrix analysis is no longer adequate and the agreement between GCEMC data and the analytic treatment is less satisfactory.