CONTRIBUTED ORAL PRESENTATIONS

Session I (Monday)

I,1 **Stretching, coiling and folding of viscoelastic micellar jets**

Matthieu Varagnat (supervisor Gareth McKinley)
Massachusetts Institute of Technology

The study of fluid jets impacting on a flat surface has industrial applications in many areas, including processing of foods and consumer goods, bottle filling, and polymer melt processing. Previous studies have focused primarily on purely viscous, Newtonian fluids, which exhibit a number of different dynamical regimes including dripping, steady jetting, and steady coiling. Here we add another dimension to the problem by focusing on mobile (low viscosity) viscoelastic fluids, with the study of two wormlike-micellar fluids, a cetylpyridinum-salicylic acid salt (CPyCl/NaSal) solution, and an industrially relevant shampoo base. We investigate the effects of viscosity and elasticity on the dynamics of the jets as they impact an impermeable rigid plate. Experimental methods include shear and extensional rheology measurements to characterize the fluids, high-speed digital video imaging, and the use of crossed polarizers to visualize the evolution in the elastic stress difference within the thinning threads. Because of these additional stresses, in sufficiently elastic micellar flows the jet widens at its base as it decelerates, a behaviour reminiscent of delayed die-swell. In addition to the regimes observed in purely viscous systems, the non-Newtonian jets can also exhibit the well-known 'beads on a string' morphology. We also find a novel regime in which the elastic jet buckles and periodically folds on itself instead of coiling. Phase diagrams and scaling laws for the coiling and folding frequency are proposed through a systematic exploration of the experimental parameter space (height of fall, imposed flow rate, elasticity of the solution).

I,2 **Manipulating a Bouncing Drop by the Use of Virtual Drops**

Marcos Caballero, Michael Schatz
Georgia Institute of Technology

Coalescence of a droplet with a fluid bath can be inhibited by oscillating the bath vertically. We propose a form of transport for this system that is non-destructive, reprogrammable, and near-frictionless. Below the Faraday threshold, stable bouncers can be moved using a pulsed infrared laser impinging on the fluid surface. The motion is similar to the interaction of two stable bouncing drops except it may be attractive or repulsive. The pulsed laser deformation, a virtual bouncer, can form a bound state with a single bouncing droplet. Near the Faraday threshold, walkers can be redirected using selective heating of the substrate. Laser pulses act as singular sources of waves; virtual bouncers. Through this wave interaction, non-trivial trajectories are observed. The transport of these nanoliter sized droplets is quite fast when compared to other forms of transport, on the order of centimetres per second.

I,3 **Bubble dynamics in an inkjet printhead**

Roger Jeurissen
University of Twente

I,4 **Filling dynamics in the Cassie Baxter-Wenzel transition**

Christophe Pirat
University of Twente

Drops deposited on rough and hydrophobic surfaces can stay suspended with gas pockets underneath the liquid, then showing very low hydrodynamic resistance. When this superhydrophobic state breaks down, the subsequent wetting process can show different dynamical properties. A suitable choice of the geometry can make the wetting front propagate in a stepwise manner leading to square-shaped wetted area: the front propagation is slow and the patterned surface fills by rows through a zipping mechanism. The multiple time scale scenario of this wetting process is experimentally characterized and compared to numerical simulations.

Session II (Tuesday)

II,1 **Influence of evaporation on a moving contact line**

Guillaume Berteloot
Université Paris Diderot

II,2 **Meandering Streams**

Keith Mertens
Colorado State University

In nature rivers tend to meander. The exact mechanism of this meandering has been an active topic of debate among geomorphologist's for over 80 years. Because of the extreme complexity of this system (i.e erodible boundary, contact angle hysteresis, turbulence, seasonal flow rate variations, etc) theoretical quantification has been challenging and limited. We therefore study the related but simpler system of flows on non-erodible partially wetting plane surfaces and begin to draw connections between these flows and those in nature. Through this process we derive a model to explain the laboratory experiments from first principles. From there we go on to show the curious statistical connection to real world flows, even without erosion. We postulate that contact angle hysteresis is not a necessary condition for the construction of a first order approximation, rather that noise is the important feature which must be considered in such models. This assumption allows for a model which can predict the spectral decomposition of such flows, the meandering exponent (a measure of curvature), as well as giving a quantitative and qualitative way to explain the third regime of Hack's Law which relates the length of a fully developed stream to the area of its basin.

II,3 **Landau-Levich dynamical menisci**

Maniya Maleki, David Quere, Christophe Clanet
PMMH, ESPCI

When a solid plate is extracted from a bath of a wetting liquid at a constant velocity, a film of the liquid will form at the surface of the solid. The film has a constant thickness far from the bath, which attaches to the free surface of the bath through a dynamical meniscus. The thickness of the film is given by Landau-Levich law and the shape of the dynamical meniscus is a monotonous exponential-like curve. If the motion of the coated solid is reversed (it enters the bath instead of leaving it), the whole meniscus shape changes: instead of the previous monotonous evolution, the meniscus buckles and presents a stationary wavy shape. We find the shape of the meniscus in both cases numerically and experimentally and show that in a range of velocities they are in a good agreement.

II,4 **Development of a fluid film model for automobiles**

Kevin Njifenju
PMMH, ESPCI

In external automobile aerodynamics, the study of fluid films is important for understanding the drainage of water on windscreens and side windows.
In fact, the flow of water on side windows and on the upright frame under rain constitutes a problem in terms of safety (the side-view mirror may be obstructed) and comfort (waterproofness). The pertinent physical phenomenon is the drainage of a thin liquid film on a glass substrate subject to gravity as well as shearing due to air counter currents. This configuration leads to hydrodynamic instabilities; preliminary experimental results show the emergence of particular patterns and interesting physical phenomena such as droplet breakup and deposition, which are currently under further investigation.

***Keywords**: Thin liquid films; hydrodynamic instabilities; gravity flow; counter current air shearing.*

II,5 **Experimental study of the instability of a film flowing down a vertical fibre**

C. Duprat, F. Giorgiutti-Dauphin´e, C. Ruyer-Quil, and S. Kalliadasis
Universités Pierre et Marie Curie et Paris Sud

Fibre coating is of practical importance and occurs in a wide variety of applications, for example in optical fibre manufacturing process. Here we study the instability of a viscous liquid film flowing down a vertical cylinder as a model for fibre coating. An original experimental set up has been designed in order to ensure the axisymmetry of the base flow and limit the entrance noise. We study the system response to white noise (ambient noise) and to periodic perturbations with a wide range of forcing frequencies. Depending on the flow rate and the fibre radius, different regimes are observed, e.g. regimes of rather symmetrical drops and solitary waves. At high flow rates or fibre radii (in the order of the capillary length: $R \sim \kappa^{-1}$), the instability is mainly induced by inertial effects as observed on liquid films falling over planar substrates. The system then behaves as a noise amplifier. We identify the cut-off frequency as the frequency at which the forcing stops affecting the dynamics of the system. For lower forcing frequencies, we obtain a periodic train of stationary saturated waves (travelling waves). The experimental data (frequency, speed, shape and amplitude) compare well to the travelling wave solutions of a model consisting in two evolution equations for the flow rate q and the film thickness h. For small fibre radii ($R < 0.28\ \kappa^{-1}$), the influence of a Rayleigh-Plateau instability becomes predominant. A different regime arises when the instability dominates over the advection of the waves by the flow: a selection of a regular pattern with a well-defined intrinsic frequency is then observed. We identify the critical flow rate at which the transition between the regular (absolute) and the noise driven (convective) instability occurs. The experimental data are in good agreement with the transition obtained from the Orr-Sommerfeld equation.

Session III (Wednesday)

III,1 **Gravity Free Hydraulic Jumps supported by surface-tension**

Ratul DasGupta
Jawaharlal Nehru Center for Advanced Scientific Research

It is known from experiments reported in literature that the radial location of the circular hydraulic jump is significantly changed if the acceleration due to gravity is varied. Gravity thus forms a key factor in determining where will the jump occur. We examine a range of Froude and Weber numbers where surfacetension would be dominant compared to gravity, to explore the possibility of a surfacetension supported jump even without gravity. The numerical solution of the NS equations with boundary layer kind of viscous terms and pressure gradient caused only due to surfacetension, shows that the profile of film height versus radius, blows up at a finite radial location, for a wide range of initial conditions. This is reminiscent of the wellknown blow up of the height profile as obtained from viscous shallowwater equations. We thus examine the possibility that in the presence of viscosity, a wave where the restoring force is that of surfacetension can develop into a shock discontinuity at a fixed radial location, thus causing a jump.

III,2 **Assymmetric, helical and mirror-symmetric travelling waves in pipe flow**

Chris Pringle
University of Bristol

New families of three-dimensional nonlinear travelling waves are discovered in pipe flow. In contrast to known waves (Faisst & Eckhardt *Phys. Rev. Lett.* **91**, 224502 (2003), Wedin & Kerswell, *J. Fluid Mech.* **508**}, 333 (2004)), they possess no discrete rotational symmetry and exist at significantly lower Reynolds numbers *Re*. First to appear is a mirror-symmetric travelling wave which is born in a saddle node bifurcation at Re=773. As *Re* increases, 'asymmetric' modes arise through a symmetry-breaking bifurcation. These look to be a minimal coherent unit consisting of one slow streak sandwiched between two fast streaks located preferentially to one side of the pipe. Helical and non-helical rotating waves are also found emphasizing the richness of phase space even at these very low Reynolds numbers. The gap in *Re* from when the laminar state ceases to be a global attractor to turbulent transition is then even larger than previously thought.

III,3 **Particle-turbulence interaction**

Aurore Naso
University of Twente

We study the interaction between a turbulent flow and a fixed spherical particle. Our approach is based on the Physalis method. This method, designed for the simulation of Navier-Stokes flows with rigid spheres, exploits the no-slip condition to linearize the flow around a rigid body motion in the vicinity of each particle. In this way, an analytical solution, valid well inside the boundary layer, is available. The flow at a greater distance is calculated by using a standard finite-difference projection method.
In order to study the interaction between particle and stationary turbulence, we impose a linear forcing, proportional to the velocity. Preliminary results are shown for a rather large particle kept fixed in a turbulent flow with periodic boundary conditions in all directions. Volume-averaged profiles of the mean kinetic energy and of the mean energy dissipation show a local modification of the flow due to the presence of the particle.

III,4 **Control of Wind Turbine Flows using Vortex Generators**

Clara M. Velte (supervisor: Martin O. L. Hansen)
Technical University of Denmark

The operating conditions of wind turbines are affected by varying wind characteristics as well as blade geometry. Wind speed, direction and turbulence levels can fluctuate significantly. This causes wind turbines to often operate with flow separation on at least some part of the blades. By the use of small winglets on the surface of the blades that are placed at an inclination to the mean flow direction, separation can be obstructed or even prevented. These devices, called Vortex Generators, create line vortices that transfer high momentum from the mean flow into the boundary layer, which leads to an enhancement in wall shear stress, thereby obstructing separation.
The model used in this study is a bump (2D profile shaped as a circular segment) in a low speed wind tunnel (custom designed for the current experiments) with a turbulent boundary layer. The bump gives rise to a pressure distribution and flow separation which is similar to the conditions on the suction side of an airfoil. The flow is investigated using an experimental technique called Stereoscopic Particle Image Velocimetry (SPIV), which provides the experimenter with measurements of the three velocity components in a 2D plane.
In the present work, data from measurements of the flow in the clean bump configuration and the configuration with vortex generators attached is presented. The objective of these measurements is to investigate the effect of the presence of the vortex generators on the adverse pressure gradient boundary layer. These measurements are also used for code validation of the DTU-Risø in-house code Ellipsys3D and different ways of modeling the effect of the vortex generators.

III,5 **Switching of Vortex Shedding in Excited Kármán Street**

Osama A. Marzouk and Ali H. Nayfeh
Virginia Polytechnic Institute and State University

A bluff body causes perturbations when obstructing a flow, resulting in a regular vortex structure (the well-known von Kármán vortex street). The vortices in the near wake exert an oscillatory hydrodynamic force on the body due to the continuously changing shear and pressure distributions on the body surface. This force is typically resolved into drag and lift components in the free-stream and cross-stream directions, respectively.
In this study, the von Kármán vortex street in the wake of a fixed cylinder is excited by vibrating the cylinder in the cross-stream direction. We use high-order numerical simulations to solve the Reynolds-averaged Navier-Stokes equations that govern the motion of the flow around the structure. We observe a very narrow range of excitation frequency where the vortex structure switches in time, leading to two remarkably different wake modes. This critical narrow range is slightly below the Kármán street shedding frequency. The temporal switching is delayed as the excitation frequency increases. Differences between the two excited wake modes are illustrated in terms of the drag and lift components in the time domain and in the phase planes. The change in amplitude is significant for the lift; whereas it is not noticeable for the drag. The drag undergoes a shooting phenomenon before the switching occurs, which is not observed in the lift.

Entrainment of Hydrodynamic Response to Structural Motion

Osama A. Marzouk and Ali H. Nayfeh
Virginia Polytechnic Institute and State University

When mechanical oscillation is applied to a cylindrical structure in a uniform stream, the exerted hydrodynamic force is altered. For a range of structural frequencies near the natural Strouhal frequency, the new frequency of the hydrodynamic force is entrained to the structural frequency. The entrained force can be lower or higher than the original one depending on the structural frequency. This problem can represent oscillating flows past a stationary high-aspect ratio object. This case occurs in many offshore structures; such as spar, fixed, and tension leg platforms (TLP); and in mooring cables.

We employ the computational fluid dynamics technique and examine the case of a mechanically oscillating cylindrical structure, which is a building block toward investigating the full fluid-structure interaction for this problem. The hydrodynamic frequency is entrained to the structural frequency over a frequency band known as the entrainment range, and the exerted hydrodynamic force becomes periodic with a frequency equals the structural frequency. As the structural frequency (input) is varied, the hydrodynamic force (output) changes with continuous and discontinuous behavior, resulting in respective changes in its correlation with the structural motion. The observed discontinuities are nonlinear phenomena indicating the existence of more than one solution of the governing equations where the resolved flow switches abruptly from one to another due to losses of stability and bifurcations.

Session IV (Thursday)

IV,1 **Crawling Beneath the Free Surface**

Sungyon Lee, John Bush, A.E. Hosoi, Eric Lauga
Massachusetts Institute of Technology

The ability of land snails to traverse extreme terrains has been investigated theoretically and experimentally in recent years. However, little is known about how water snails travel inverted underneath a free surface. Based on our experimental observations, we present a lubrication model of water snail locomotion.

IV,2 **Experimental investigations of elastic tail propulsion at low Reynolds number**

Tony S. Yu, Eric Lauga, and A. E. Hosoi
Massachusetts Institute of Technology

A simple way to generate propulsion at low Reynolds number is to periodically oscillate a passive, flexible filament. Here we present a macroscopic experimental investigation of such a propulsive mechanism. A robotic swimmer is constructed and both tail shape and propulsive force are measured.
Filament characteristics and actuation are varied, and the resulting data are quantitatively compared with existing linear and nonlinear theories.
Finally, we present preliminary experimental measurements of the steady-state swimming velocity.

IV,3 **Transport and aggregation of self-propelled particles in fluid flows**

Colin Torney
University College, Dublin

I will present some results from our investigations into the behaviour of idealized swimming particles in laminar fluid flows. The impact of particle aspect ratio on the presence of transport barriers and on the ability of particles to aggregate in some simple flow models will be discussed. In rotating flows I will show a swimming velocity threshold exists for the existence of transport barriers which is dependent on the aspect ratio of the particles and that this threshold vanishes for thin rod-like particles.

IV,4 **How swifts control their glide performance with morphing wings**

D. Lentink, U.K. Müller, E.J. Stamhuis, R. de Kat, W. van Gestel1, L.L.M. Veldhuis, P. Henningsson, A. Hedenström, J.J. Videler, J.L. Van Leeuwen
Wageningen University

Gliding birds continually change the shape and size of their wings1-6, presumably to exploit the profound effect of wing morphology on aerodynamic performance7-9. That birds should adjust wing sweep to suit glide speed has been predicted qualitatively by analytical glide models2,10, which extrapolated the wing's performance envelope from aerodynamic theory. Here, we describe the aerodynamic and structural performance of actual swift wings, as measured in a wind tunnel, and on this basis build a semi-empirical glide model. By measuring inside and outside swifts' behavioural envelope, we show that choosing the most suitable sweep can halve sink speed or triple turning rate. Extended wings are superior for slow glides and turns; swept wings are superior for fast glides and turns. This superiority is due to better aerodynamic performance - with the exception of fast turns. Swept wings are less effective at generating lift while turning at high speeds, but can bear the extreme loads. Finally, our glide model predicts that cost-effective gliding occurs at speeds of 8-10 m s-1, whereas agility-related figures of merit peak at 15 to 25 m s-1. Swifts in fact roost at 8-10 m s-1 11, thus our model can explain this choice for a resting behaviour[11,12]. Morphing not only adjusts birds' wing performance to the task at hand, but could also control the flight of future aircraft[7].

1. Rosén, M. & Hedenström, A. Gliding flight in a jackdaw. J. Exp. Biol. 204,1153-1166 (2001).
2. Tucker, V.A. Gliding birds: the effect of variable wing span. J. Exp. Biol. 133, 33-58 (1987).
3. Pennycuick, C.J. Gliding flight of the fulmar petrel. J. Exp. Biol. 37, 330 338 (1960).
4. Newman, B.G. Soaring and gliding flight of the black vulture. J. Exp. Biol. 35, 280-285 (1958).
5. Pennycuick, C.J. Wind-tunnel study of gliding flight in the pigeon Columba livia. J. Exp. Biol. 49, 509-26 (1968).
6. Müller, U.K. & Lentink, D. Turning on a dime. Science 306, 899-1900 (2004).
7. Weiss P. Wings of change: shape-shifting aircraft ply future skyways. Science News 164 (23), 359 (2003).
8. Rayner, J.M.V. Form and Function in avian flight. In Current Ornithology Vol. 5, ed. R.F. Johnston. Plenum Press New York (1988).
9. Hoerner S.F. & Borst, H.V. Fluid-dynamic lift. Published by L.A. Hoerner, Bakersfield (1985).
10. Azuma A. The Biokinetics of Flying and Swimming. AIAA Education Series, Reston, 2nd edition (2006).
11. Bäckman, J. & Alerstam, T. Confronting the winds: orientation and flight behaviour of roosting swifts, Apus apus. Proc. R. Soc. B 268, 1081-1087 (2001).
12. Bruderer, B. & Weitnauer, E. Radarbeobachtungen über Zug und Nachtflüge des Mauerseglers (Apus apus). Rev. Suisse Zool. 79, 1190-1200 (1972).

IV,5 **Singular forces in the Navier-Stokes equations to enforce the prescribed motion of rigid boundaries**

Sheng Xu
Southern Methodist University

In the immersed interface/boundary method, boundaries in a fluid are generated by singular forces in the Navier-Stokes equations. In this talk, I will present an inverse approach which explicitly calculates singular forces to enforce the prescribed motion of rigid boundaries.
The inverse approach has no stiff solid models and no implicit or iterative treatment. It is stable, efficient, and accurate.

Session V (Friday)

V,1 **Crystalline micro-foams**

Antje van der Net (Supervisor Dr. Stefan Hutzler)
Trinity College Dublin

Currently, researchers are working hard on creating foams with tiny, equal-sized bubbles for various industrial applications. We used a technique called microfluidic flow focusing to generate microbubbles of diameters in the range of 200-500 microns. When these bubbles are deposited on a liquid pool, they form a wet microfoam where the bubbles take on nearly spherical shapes. Surprisingly, one finds that the bubbles order in various familiar crystalline structures, such as those found in metals [1]. The reason for the ordering remains unclear, the phenomenon is not observed for equal size hard spheres whose deposition generally gives a disordered Bernal packing.
The internal structure of the bubble crystals can not be seen due to diffusive character of light propagation in a foam. However, from the observed fractal-like optical patterns of the crystals and computer simulations we can deduce ordering up to several layers into the bulk.
By removing water from the microbubble crystals, ordered dry foams can be made. The bubbles become polyhedral and are separated by thin water films. It remains to be seen whether this technique is useful for finding the Weaire-Phelan structure, a computed foam structure which minimizes surface area for monodisperse bubbles, experimentally.
Three-dimensional crystal structure, spontaneously formed by small bubbles (diameter 200 microns) in a wet foam. The composite figure shows a photograph of the surface of the foam (right), together with a raytracing simulation (left), confirming the packing sequence ABC consistent with an fcc packing.

[1], A. van der Net, W. Drenckhan, D. Weaire, S. Hutzler; "The Crystal Structure of Bubbles in the Wet Foam Limit.", Soft Matter, 2006, Vol 2, Issue 2, 129-134.

V,2 **A mass conservative level set method for two-phase flows with moving contact-lines**

Maged Ismail and Ali Nadim
Claremont Graduate University and Keck Graduate Institute

Problems involving incompressible two-phase flows with moving interfaces arise in a wide range of physical and engineering applications. Among the various computational methods available to model such flows, the level set method has become increasingly popular for implicitly representing the fluid-fluid interface. However, this method usually suffers from poor mass conservation properties. In this study, a recently developed conservative level set method [E. Olsson & G. Kreiss, J. Comput. Phys., 210, 225–246 (2005)], is verified on several benchmark test-cases, including a rising bubble and a falling droplet. The extension of the current method to simulate moving contact-lines is also investigated. In this case, a Navier-slip boundary condition is utilized to relax the stress singularity at the contact line. Our preliminary results demonstrate the feasibility of achieving exact numerical mass conservation.

V,3 **Debonding of a Model Adhesive: From a Viscous Liquid to an Elastic Solid**

Julia Nase
PMMH, ESPCI

A good adhesive has to show liquid and elastic properties at the same time. The liquid character promotes good molecular contact at the interface between the adhesive and the substrate and the elastic character is necessary to resist a certain stress level during debonding. This is why commercial adhesives are typically complex viscoelastic materials. The debonding mechanisms and therefore the adhesive's performance are controlled by these properties.

We work with a family of model adhesives that are specifically designed to study the role of the liquid and elastic properties respectively. To do so, we use a weakly crosslinked polymer (PDMS) where the number density of crosslink points can be controlled to go continuously from a viscous liquid to an elastic solid. We then study the debonding mechanism in the so called “probe tack test”, a well known experimental set-up to determine adhesive properties.
During debonding, air penetrates from the edge of the adhesive layer typically leading to the formation of air fingers propagating between the two surfaces bond together.
The observed patterns depend on the properties of the model adhesive and can, for example, be characterized by the wavelength and the perimeter of the debonding line. We observe a transition from an interfacial to a bulk mechanism, leading to different patterns. For the viscous regime, the pattern is determined by the film thickness and the capillary number, whereas the elastic case is only a function of the film thickness and independent of the elastic modulus.
The results obtained will give important insight in the parameters determining the debonding mechanism and might thus be useful for the design of commercial adhesives.

V,4 **Equilibrium Partitioning and Depletion Effect of Macromolecules in Confining Channels**

Yanwei Wang[1], Günther H. Peters[2], Flemming Y. Hansen[3], Ole Hassager[1]
[1] *Danish Polymer Center, Department of Chemical Engineering, Technical University of Denmark*
[2] *MEMPHYS, Department of Chemistry, Technical University of Denmark*
[3] *Department of Chemistry, Technical University of Denmark*

Research interest in understanding the physics of confined macromolecules is fueled by rapid advances in the design and fabrication of novel microfluidic devices working on length scale of micrometer and smaller. These devices are now used in diverse applications such as separation of macromolecules, DNA sequencing and mapping as well as clinical diagnosis. The focus of this study is on the steric exclusion effect that restricts the conformational entropy available to an individual polymer chain, which is important for a quantitative understanding of the equilibrium partitioning and depletion effect of macromolecules in confining channels [1].
The phenomena of equilibrium partitioning of macromolecules between a macroscopic bulk phase and confining channels underlies various chromatographic and membrane separation processes such as polymer size exclusion chromatography [2]. When a microscopic channel is in equilibration with a dilute bulk polymer solution, polymer molecules will be partitioned between the microscopic confined solution and the bulk. As the molecule-to-confinement size ratio increases, the migration of polymer molecules into the channel becomes difficult due to an increase in entropic penalty. In addition to the equilibrium partitioning, the steric exclusion effect also causes an inhomogeneous concentration profile inside the confining geometry [3]. Clearly, the steric restraints imposed by any fixed channel walls will cause a local reduction in concentration (the depletion layer) near the wall, and this obviously has practical implications for the design and application of micro- and nano-fluidic devices.
Various theoretical approaches have been employed to model macromolecules in confining geometries [1-3], Recently we have developed an efficient method, which enables us to obtain the equilibrium partition coefficients and concentration profiles as a function of the confinement size [4]. Our method is versatile to the model and type of macromolecules and is capable of handling common confining geometries like slits, square channels and rectangular cavities. A novel size measure for macromolecules, the steric exclusion length, can be deduced from our model, which is related to the separation principle of SEC.
[1] I. Teraoka, ‘polymer solutions in confining geometries’, Prog. Polym. Sci. 21, 89, 1996

[2] E. F. Casassa and Y. Tagami, 'an equilibrium theory for exclusion chromatography of branched and linear polymer chains', Macromolecules, 2, 14, 1969
[3] J. C. Giddings, E. Kucera, C. P. Russell and M. N. Myers, 'statistical theory for the equilibrium distribution of rigid molecules in inert porous networks. Exclusion Chromatography', J. Phys. Chem. 72, 4397, 1968
[4] Y. Wang, G. H. Peters, F. Y. Hansen. O. Hassager, to be submitted to J. Chem. Phys. , 2007

V,5 **Optically-Controlled Thermocapillary Actuation of Microdroplets at a Fluid Interface**

D. Borrero-Echeverry, E. F. Greco, J. E. Widloski, D.L. Vainshtein, R. O. Grigoriev, M. F. Schatz
Georgia Institute of Technology

Laser actuation can be used to perform microfluidic operations on droplets floating at a liquid-air interface by exploiting the thermocapillary effect. A model has been developed to describe the velocity field in the interior of such droplets. Measurements of the temperature field in the substrate, which are crucial for accurate numerical simulations of the system, are presented. Fluorescent tracers are used to visualize the three-dimensional flow inside the droplet using dual microscopes.

V,6 **Topology optimization of chemical microreactors**

Misha Marie Gregersen, Fridolin Okkels, Ole Hansen, Henrik Bruus
Technical University of Denmark

Microreactors offer several advantages including accurate spatial and temporal temperature control throughout the reaction chambers, small reactant consumption, and fast analysis. Generally, this allows for improved production rates, environmental considerations and safety.
We adapt the topology optimization method enabling us to optimize general chemical microreactors with respect to the production rate. An auxiliary design field is incorporated in the governing equations to link the flow pattern of the reactants to the reaction kinetics. Specifically, we focus on chemical reactions involving catalysts. Traditionally the (solid) catalyst is either placed as small particles of a specific shape packed in the reaction chamber or simply as a uniform layer covering one side of the chamber. Our idea is to place the catalyst in a pattern, which optimizes the overall production rate in the chamber. Topology optimization is well suited for this kind of problem as no prior knowledge is required of the catalyst pattern: the catalyst material in the chamber is redistributed by iteratively solving the governing equations for fluid velocity, reactant concentration, pressure and temperature. We present the method and the results we have obtained on a specific catalytic microreactor for the carbon monoxide oxidation process.

V,7 **Examples of micro-PIV applications**

Melker Sundin
Technical University of Denmark

When micron resolution particle image velocimetry (micro-PIV) is applied for microfluidic acoustic studies extra caution and consideration have to be taken, as particles under the influence of acoustic fields no longer function as true independent tracers in all situations. In this presentation I will show examples from my own experiences in working with piezo activated microfluidic devices, and in particular, my efforts in characterising the behaviour and performance of the same.