Inkjet Technology: Printing, Materials Processing, and Microfluidics Fundamentals Topical Conference
Room: B3 - Session IJ+BI+MN-WeM

Microfluidic Fundamentals and Inkjet Technology
Moderator: G.E. Mårtensson, Mydata Automation AB

8:00am **IJ+BI+MN-WeM1 The Life and Death of a Drop: Topological Transitions and Singularities in Fluids**, *S. Nagel*, ***N.C. Keim***, University of Chicago **INVITED**

The exhilarating spray from waves crashing into the shore, the distressing sound of a faucet leaking in the night, and the indispensable role of bubbles dissolving gas into the oceans are but a few examples of the ubiquitous presence and profound importance of drop formation and splashing in our lives. They are also examples of a liquid changing its topology. Although part of our common everyday experience, these transitions are far from understood and reveal delightful and profound surprises upon careful investigation. For example in droplet fission, the fluid forms a neck that becomes vanishingly thin at the point of breakup. This topological transition is thus accompanied by a dynamic singularity in which physical properties such as pressure diverge. Singularities of this sort often organize the overall dynamical evolution of nonlinear systems. I will first discuss the role of singularities in the breakup of drops. I will then discuss the fate of the drop when it falls and eventually splashes against a solid surface.

8:40am **IJ+BI+MN-WeM3 Liquid Fragmentation**, ***E. Villermaux***, Marseille Universite, France **INVITED**

Fragmentation phenomena will be reviewed with a particular emphasis on processes occurring with liquids, those giving rise to drops --in the broad sense, the process of atomization--. Various observations converge to propose a unifying scenario describing the overall transition between a compact macroscopic liquid volume and its subsequent dispersion into stable drops. In liquids, primary instabilities always give birth to more or less corrugated ligaments whose breakup induce the shape of the drop size distribution in the resulting spray. Examples include the fragmentation of jets and liquid sheets, the formation of spume by the wind blowing over a liquid surface, bursting phenomena, impacts and raindrops.

9:20am **IJ+BI+MN-WeM5 Dripping and Jetting: Mechanisms of Droplet Formation in Two- and Three-Phase Flows**, *A.S. Utada*, Harvard University and University of Tokyo, Japan, ***A. Fernandez-Nieves***, Georgia Institute of Technology, *D.A. Weitz*, Harvard University **INVITED**

Drop formation is an ubiquitous process familiar from our daily life. For example, water flowing through a faucet will break into droplets through one of two different mechanisms: discrete droplets will drip from the tap at low flow rates or a continuous jet will flow from the tap at higher flow rates. A qualitatively similar process happens when drop formation occurs within a second immiscible liquid. However, in this case, the presence of surface tension between the two immiscible liquids fundamentally alters the dynamics. We describe the transition between dripping and jetting in a coflowing stream within a microfluidic device and show that this transition can be understood with a general phase diagram [1]. Building on this understanding, we use a modified microfluidic device to generate monodisperse double emulsions from which we use to form novel core-shell structures [2].

[1] A. S. Utada, A. Fernandez-Nieves, H. A. Stone, D. A. Weitz, Phys Rev Lett **99**, 094502 (2007).

[2] A. S. Utada *et al*., Science **308**, 537 (2005).

10:40am **IJ+BI+MN-WeM9 Interplay between Simulation, Theory, and Experiment in Nonstandard Inkjet Printing: From New Devices to Complex Fluids**, ***O.A. Basaran***, Purdue University **INVITED**

During its early days, applications of inkjet printing were restricted almost exclusively to the graphic arts. In the late 1990s, the method found widespread application in DNA arraying. More recently, the applications of inkjet technology have broadened considerably to span areas as diverse as direct printing of electronic circuits and solar cells and drop-by-drop construction of organs and other biological structures. Inkjet printing involves the formation of drops from nozzles and the subsequent impact and deposition of such drops on suitable substrates. Both drop formation and drop impact are prototypical free surface or free boundary problems involving large deformation and breakup of fluid-fluid interfaces. Given the ever decreasing time and length scales inherent to inkjet printing, e.g. micron size drops are formed from an inkjet nozzle in time scales of microseconds, and that inkjet printing is a free boundary problem that involves finite time hydrodynamic singularities, e.g. pressures and velocities blow up in finite time as the drop surface approaches breakup or pinch-off, simulation, theoretical description, and experimental visualization of the dynamics of inkjet drops are challenges to the modeler, the theorist, and the experimentalist alike. Moreover, many of the emerging applications of inkjet printing involve fluids that can be characterized as complex fluids in that their bulk rheologies are non-Newtonian and/or their surface tensions vary in time. Motivated by research being carried out in the PI's group on inkjet printing of drops of complex fluids containing pharmaceutical active ingredients on edible substrates, this talk will focus on how computation, theory, and experiment are being used in concert to advance the state-of-the art in the field. Examples that will be used to highlight the computations will include construction of phase diagrams that help identify regions of the parameter space where high quality drops can be produced and efforts aimed at producing nanoscopic drops from microscopic nozzles. To tie the simulations and theory, the excellent agreement between computed predictions and scaling theories of pinch-off will be demonstrated. The excellent agreement between the simulation results and the experiments will be highlighted by means of photographs obtained with an imaging system that is capable of capturing 100 million frames per second. Since complex fluids cannot be characterized by their shear viscosity alone and drop formation involves predominantly extensional deformations, efforts underway to infer the extensional viscosity of such fluids will also be described.

11:20am **IJ+BI+MN-WeM11 The Microfluidics of NonSpherical Colloidal Particles and Vesicles with Application to Blood Additives**, ***E.S.G. Shaqfeh***, Stanford University **INVITED**

Many dispersions of colloidal particles with application in materials processing, biological assays, or medicine, contain elongated particles (e.g. ellipsoidal disks, rods, etc.) Recently these particles have been used in drug delivery applications because of the inability of leukocytes to easily rid them from the circulation. Moreover such particles are useful at the nanoscale for application in cancer therapies, either for detection of tumor vasculature or for the delivery of anti-cancer agents to tumor endothelial cells. Thus, the study of anisotropic particulate flows with adhesion in microchannels especially in mixtures with vesicle flows (i.e. red blood cells) has taken on a particularly important set of engineering applications. We will review our computer simulations of these processes with a view toward virtual prototyping and engineering these therapies.

Authors Index

Bold page numbers indicate the presenter