Fundamentals and Application in Microfluidics

IPRIME Midyear Workshop

Tuesday, January 12, 2021
9:00 AM – 12:00 PM (Central Time Zone)
Virtual Zoom Event (Details provided upon registration)

Description. This workshop will address the fundamentals and applications of microfluidics. Microscale platforms offer key advantages across a variety of fields, from operational advantages of small sample volumes and high throughput to scientific advantages of probing materials at length and time scales challenging to access on the macroscale. In this workshop, we will explore these topics from diverse perspectives, encompassing fundamental fluid dynamics of thin films, foams and complex fluids, to applications in 3D printing, biology, and energy industry. Each invited talk is 20 minutes long followed by a 10 minute discussion. This workshop is organized by the IPRIME program Coating Process Fundamentals Program with interest from Biomaterials and Pharmaceutical Materials and Microstructured Polymers programs.

9:05 Welcome and Introduction

9:15 Thin Film Flows on a Substrate of Finite Width: The Influence of the Edge and a Novel Similarity Solution
Prof. Howard A. Stone, Department of Mechanical and Aerospace Engineering, Princeton University

9:45 Microfluidic Applications in the Energy Industry
Mr. Tom de Haas, Chief Operating Officer and Co-Founder, Interface Fluidics Ltd

10:15 Break

10:30 Microfluidics for Studying Aerosols, Emulsions, and Foams
Prof. Cari Dutcher, Department of Mechanical Engineering and Department of Chemical Engineering and Materials Science, University of Minnesota

11:00 Advanced 3D Printing for Microfluidics
Prof. Greg Nordin, Department of Electrical and Computer Engineering, Brigham Young University

11:30 A Mechanical Micro-dissection Platform for Applications in Biology
Prof. Sindy KY Tang, Department of Mechanical Engineering, Stanford University

12:00 Adjourn
There are many examples of thin-film flows in fluid dynamics, such as for coating flows, and in many cases similarity solutions are possible, which help understand experimental trends. In the typical, well-known case the thin-film shape is described by a nonlinear partial differential equation in two independent variables (say x and t), which upon recognition of a similarity variable, reduces the problem to a nonlinear ODE. In this talk I describe work we have done on 1) Marangoni-driven spreading on pre-wetted films, where the thickness of the pre-wetted film affects the dynamics, and 2) the drainage of a film on a vertical substrate of finite width. In the latter case we find experimentally a structure to the film shape near the edge, which is a function of time and two space variables. Analysis of the corresponding thin-film equation shows that there is a similarity solution, collapsing three independent variables to one similarity variable, so that the PDE becomes an ODE. The solution is in excellent agreement with the experimental measurements.

Bio: Professor Howard A. Stone received the Bachelor of Science degree in Chemical Engineering from the University of California at Davis in 1982 and the PhD in Chemical Engineering from Caltech in 1988. Following a postdoctoral year in the Department of Applied Mathematics and Theoretical Physics at the University of Cambridge, in 1989 he joined the faculty of the (now) School of Engineering and Applied Sciences at Harvard University. In 2000 he was named a Harvard College Professor for his contributions to undergraduate education. In July 2009 he moved to Princeton University where he is Donald R. Dixon ’69 and Elizabeth W. Dixon Professor in Mechanical and Aerospace Engineering.

Professor Stone's research interests are in fluid dynamics, especially as they arise in research and applications at the interface of engineering, chemistry, physics, and biology. He is a Fellow of the American Physical Society (APS), is past Chair of the Division of Fluid Dynamics of the APS, and is currently on the editorial or advisory boards of Physical Review Fluids, Langmuir, Philosophical Transactions of the Royal Society, and Soft Matter, and is co-editor of the Soft Matter Book Series. Professor Stone is the first recipient of the G.K. Batchelor Prize in Fluid Dynamics, which was awarded in August 2008, and the 2016 recipient of the Fluid Dynamics Prize of the APS. He was elected to the National Academy of Engineering in 2009, the American Academy of Arts and Sciences in 2011 and the National Academy of Sciences in 2014.
Microfluidic Applications in the Energy Industry
Mr. Tom de Haas
Chief Operating Officer and Co-Founder, Interface Fluidics Ltd

Microfluidic systems have achieved commercial success in the biomedical industry over the past 30+ years. However, the energy industry has not adopted these methods, despite early microfluidic models of oil and gas reservoirs having been developed in the 1960s. Over the past five years, Interface Fluidics has commercialized a microfluidic system that allows for rapid measurements of industrially relevant fluids at high-temperature and high-pressure - all aimed at improving efficiency, effectiveness, and environmental performance. Here we overview three specific applications: Analysis of foam generation and flow in porous media at field-relevant flow velocities (<1 mm/min); quantification of surfactant-aided oil displacement in nanoporous media; and quantification of petroleum phase behaviour in microfluidic systems.

Bio: Tom de Haas received his BASc from the University of Victoria in 2010 and his MASc in Mechanical Engineering from the University of Toronto in 2013 where he developed some of the first microfluidic systems for energy applications with Prof. David Sinton. Tom left Toronto to work at Canada’s largest energy company (Suncor Energy) in the Subsurface New Technology group as a reservoir engineer. In 2016 he left Suncor Energy to co-found Interface Fluidics with David Sinton and Stuart Kinnear.

Interface Fluidics has grown to 22 employees (between Calgary, Edmonton, and Toronto), raised over $8M in investment funding, and participated in the first cohort of the competitive Techstars Energy program in Oslo Norway. Interface is currently providing microfluidic solutions to all five of the largest energy companies in the world as well as dozens of others operating in shale, offshore, oilsands, and conventional reservoirs. Interface is now working with companies to investigate how to implement new carbon-mitigation technologies including CO₂ enhanced oil recovery and CO₂ sequestration.
The presence of droplets suspended in a liquid or gas is known to play an essential role in fields ranging from materials to atmospheric science. Often, the dispersed phase is stabilized by surface active compounds and surfactants, resulting in complex chemical composition and material properties at the fluid-fluid interface. This talk will highlight use of microfluidic platforms for measuring factors that govern emulsion destabilization: (1) dynamic interfacial tension and (2) film drainage time. First, dynamic interfacial tensions measurements of both oily bilgewater (oil-in-water) and water-entrained diesel fuel (water-in-fuel) emulsions were performed using a microfluidic tensiometer. An analysis of the results shows a dependence on if the surfactant approaches the interface from inside (dispersed) versus outside (continuous), implying phase dependent surfactant transport to curved interfaces at the microscale. Second, droplet coalescence and film drainage experiments performed in a microfluidic Stokes trap across a range of viscosity ratios and surfactant concentrations. Results are used to explore the influence of interfacial mobility and Marangoni stresses on film stability with soluble surfactants.

Bio: Cari S. Dutcher is an Associate Professor of Mechanical Engineering (ME) and Chemical Engineering and Materials Science (CEMS) at the University of Minnesota, Twin Cities. Her research interests are in complex fluids and multiphase fluids, including aerosols, emulsions, and foams. Cari currently serves on the Executive Board of the American Association of Aerosol Research (AAAR). She has received the 3M Non-Tenured Faculty Award, NSF CAREER Award, McKnight Land-Grant Professorship, AAAR Kenneth T. Whitby Award, and George Taylor Career Development Award. Prior to her faculty position, Cari was an NSF-AGS Postdoctoral Research Fellow in the Air Quality Research Center at the University of California, Davis. Cari received her B.S from Illinois Institute of Technology (2004) and her Ph.D. from the University of California, Berkeley (2009), both in Chemical Engineering.
While there is great interest in 3D printing for microfluidic device fabrication, the challenge has been to achieve feature sizes that are in the truly microfluidic regime (<100 μm). The fundamental problem is that commercial tools and materials, which excel in many other application areas, have not been developed to address the unique needs of microfluidic device fabrication. Consequently, we have created a series of stereolithographic 3D printers and materials that are specifically tailored to meet these needs. Using our approach, we show that a high degree of component integration can be achieved in truly 3D layouts. As an example, we demonstrate a 10-stage serial dilution device with >60 valves and valve-like structures integrated into 20 pumps. The device simultaneously generates 2-fold serial dilutions that cover 3 orders of magnitude, and can be integrated with other on-chip elements for parallel dose-response assays. We also demonstrate extreme valve miniaturization with valve sizes on the order of 15 μm x 15 μm. Our advances open the door to 3D printing as a replacement for expensive cleanroom fabrication processes, with the additional advantage of fast (5-15 minute), parallel fabrication of many devices in a single print run due to their small size.

**Bio:** Gregory P. Nordin received a Ph.D. in Electrical Engineering from the University of Southern California in 1992. From 1984 to 1992 he also worked at the Hughes Aircraft Company, the last three years of which were at the Hughes Research Laboratories in Malibu, California. From 1992 to 2005 he was in the Electrical and Computer Engineering Department at the University of Alabama in Huntsville where he was founding director of the university's Nano and Micro Devices Center. In 2005 Dr. Nordin joined Brigham Young University as Professor in the Electrical and Computer Engineering Department. His research currently focuses on 3D printing for microfluidics, and micro- and nano-fabricated devices for biosensing, photonics, and MEMS.
Wound repair is a key feature distinguishing living from non-living matter. Single cells are increasingly recognized to be capable of healing wounds (Science 2017). We are interested in studying how cells self-repair, and how to extract principles for manmade self-healing systems. The lack of reproducible wounding methods has hindered these studies. This talk describes our work on a microfluidic guillotine for bisecting single cells in a continuous flow with a cutting throughput >200x faster than current methods (PNAS 2017). It enables new studies such as time-course mechanistic and RNAi measurements requiring >100 cells prepared in a synchronized stage of their repair process. Our guillotine also lends itself to studying the regenerative capacity of artificial tissues and organs (Science 2018). The talk also describes other micro-dissection devices for tissue and organism-level applications.

Bio: Prof. Sindy KY Tang is the Kenneth and Barbara Oshman Faculty Scholar and Associate Professor of Mechanical Engineering and by courtesy of Radiology (Precision Health and Integrated Diagnostics) at Stanford University. She received her Ph.D. from Harvard University in Engineering Sciences under the supervision of Prof. George Whitesides. Her lab at Stanford works on the fundamental understanding of fluid mechanics and mass transport in micro-nano systems, and the application of this knowledge towards problems in biology, rapid diagnostics for health and environmental sustainability. The current areas of focus include the flow physics of confined micro-droplets using experimental and machine learning methods, interfacial mass transport and self-assembly, and ultrahigh throughput opto-microfluidic systems for disease diagnostics, water and energy sustainability, and single-cell wound healing studies. She was a Stanford Biodesign Faculty Fellow in 2018. Dr. Tang’s work has been recognized by multiple awards including the NSF CAREER Award, 3M Nontenured Faculty Award, the ACS Petroleum Fund New Investigator Award, and invited lecture at the Nobel Symposium on Microfluidics in Sweden. Website: http://web.stanford.edu/group/tanglab/