IOWA STATE UNIVERSITY
Department of Mechanical Engineering

Microscale "Turbulence" induced by Electrochemical Interfaces

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Seminar host: Shankar Subramaniam

Abstract
Electrochemical interfaces, e.g., the interface of an aqueous electrolyte with a charge selective surface such as an electrode or a membrane, are host to a range of physical phenomena involving ion-transport, electrostatic interactions, and fluid flow. The equations governing these disciplines are the Nernst-Plank, Poisson, and Navier-Stokes, which are well established for more than a century. Analytical solutions to these equations have contributed to the understanding of various interfacial phenomena such as electric double layers, electroosmosis, and diffusion boundary layers. However, only very recently direct numerical solutions to these equations have become available. Such simulations allow investigation of nonlinear modes of transport, and have revealed a wide range of highly complex dynamical responses. In this presentation, we consider voltage-driven ion transport from an aqueous electrolyte to an ion-selective membrane as a canonical setting with broad applications from electrodialysis for water purification to microfluidic-based lab-on-a-chip systems. We will present results from our numerical simulations demonstrating that, beyond a threshold voltage, such interfaces trigger hydrodynamic chaos with multi-scale vortices similar to turbulent boundary layers. Namely, structures with scales from sub-millimeter down to tens of nanometers can be formed as a natural result of these hydrodynamic effects. These flow structures are shown to impact mixing and enhance net ion transport well beyond nominal diffusion-controlled limiting currents. While predictions of these simulations are consistent with recent experimental observations, simulations allow for non-intrusive capture of fine spatiotemporal details in these flows. We will demonstrate the need for the development of specialized algorithms for computation of these systems, similar to the tools that have been traditionally used for the simulations of turbulent flows. Such calculations require resolving a wide range of scales using unsteady solvers and often require massively parallel computational resources. By presenting various examples, we will discuss how the development of high-fidelity computational tools can lead to fundamental understanding of complex effects in electrochemical interfaces and facilitate their design and optimization.

Ali Mani is an Assistant Professor in the Department of Mechanical Engineering at Stanford University. He received his Ph.D. from Stanford University in 2009, and after a period of postdoctoral Research in MIT Chemical Engineering, he joined Stanford as a Faculty in 2011. His research is broadly focused on fluid dynamics problems that involve strong coupling with mass-transport phenomena and commonly involve turbulence or chaos. Current themes in his research include turbulent multiphase flows, bubbly flows, superhydrophobic surfaces, and fluid dynamics in electrochemical systems with applications in microscale engineering. His group is specialized in the development of efficient numerical simulations that are tailored to the specific physics of multi-disciplinary fluid dynamic systems, and thereby providing unique tools for accurate probing of detailed processes in these systems.

This seminar counts towards the ME 600 seminar requirement for Mechanical Engineering graduate students.

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