IOWA STATE UNIVERSITY

Department of Mechanical Engineering

Low Reynolds number flows through shaped and deformable conduits

Ivan C. Christov

Center for Nonlinear Studies at Los Alamos National Laboratory

February 10, 11:00-11:50 a.m.

2004 Black

Abstract

Unconventional fossil energy resources are revolutionizing the US energy market. While the techniques developed over the last 50 years lead to viable and profitable extraction of, e.g., trapped gas and hydrocarbons from almost-impermeable rock formations via hydraulic fracturing, the abysmal extraction rates (typically 15%) suggest the fluid mechanics of these processes is not well understood. In this talk, I will describe three basic theoretical fluid mechanics problems inspired by unconventional fossil fuel extraction. The first problem is flow in a deformable microchannel. Fluid-structure interaction couples the shape of the conduit to the flow through it, drastically altering the flow rate--pressure drop relation. Using perturbation methods, we show that the flow rate is a quartic polynomial of pressure drop for shallow channels, in contrast to the linear relation for rigid conduits. The second problem involves two-phase (gas-liquid) displacement in a horizontal Hele-Shaw cell with an elastic membrane as the top boundary. This problem arises at the pore-scale in enhanced oil recovery for large injection pressures. Once again, fluid-structure interaction alters the problem, leading to stabilization of the Saffman--Taylor (viscous fingering) instability below a critical flow rate. Using lubrication theory, we derive the stability threshold and show that it agrees well with recent experiments. The third problem involves the spread of a viscous liquid in a vertical Hele-Shaw cell with a variable thickness in the flow-wise direction, as a model for the spread of a plume of supercritical carbon dioxide through the non-uniform passages created by hydraulic fracturing. We show that the propagation regimes in such a shaped conduit are set by the direction of propagation. While the rate of spread in the direction of increasing gap thickness (and, hence, permeability) can be obtained by standard scaling techniques, the reverse scenario requires the construction of a so-called second-kind self-similar solution, leading to nontrivial exponents in the rate of spread.

Biography

Ivan Christov received his Ph.D. in Engineering Sciences and Applied Mathematics from Northwestern University. Subsequently, he was awarded an NSF Mathematical Sciences Postdoctoral Research Fellowship and spent two years with the Complex Fluids Group at Princeton University.

Currently, he is the Richard P. Feynman Distinguished Postdoctoral Fellow in Theory and Computing at the Center for Nonlinear Studies at Los Alamos National Laboratory. He regularly participates in international collaborative research (most recently at the Oxford Centre for Collaborative Applied Mathematics). Previously, he has worked at the U.S. Naval Research Laboratory and the ExxonMobil Upstream Research Company. His research interests are primarily in the area of modeling and numerical simulation of transport phenomena with an emphasis on complex and nonlinear systems and an outlook towards problems arising in next-generation energy resource utilization.

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

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