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Meeting report

Workshop on multicomponent and multiphase fluid dynamics

J. Feng[a,*], H.H. Hu[b]

[a]*The Levich Institute for Physicochemical Hydrodynamics, City College of the City University of New York, 140th Street and Convent Avenue, New York, NY 10031, USA*

[b]*Department of Mechanical Engineering and Applied Mechanics, University of Pennsylvania, Philadelphia, PA 19104, USA*

A workshop on Multicomponent and Multiphase Fluid Dynamics was held on the campus of the University of Pennsylvania, March 12–13, 1999, to honor Professor Daniel D. Joseph on his 70th birthday.

Daniel D. Joseph received his B.S., M.S. and Ph.D. degrees from the Illinois Institute of Technology in 1959, 1960 and 1963, all in Mechanical Engineering. He also holds an M.A. in Sociology from the University of Chicago. He began his academic career at the Illinois Institute of Technology in the Mechanical Engineering Department. Soon afterwards he moved to the Aerospace Engineering and Mechanics Department at the University of Minnesota, where he has been since 1963. Currently, he is the Russel J. Penrose Professor of Aerospace Engineering and Mechanics and Regent's Professor of the University of Minnesota. Professor Joseph has made many important contributions to Fluid Mechanics, Applied Mathematics and Rheology, and his work is highly regarded worldwide. He is an elected member of all three US academies of scientific learning: the National Academy of Science, the National Academy of Engineering and the American Academy of Arts and Sciences. In addition, he has received the G.I. Taylor Medal from the Society of Engineering Science, the Bingham medal from the Society of Rheology, the Timoshenko Medal from the American Society of Mechanical Engineers and the distinguished service award from the US Army. Professor Joseph has written five books, edited four books and published over 260 scientific articles. He is also the holder of 6 US patents.

The workshop was attended by approximately 80 researchers from the US, Brazil, Venezuela, France and Italy. The technical program consisted of 28 invited talks, which may be divided loosely into five topical groups.

* Corresponding author.

E-mail address: feng@lisgil.engr.ccny.cuny.edu (J. Feng).

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1. Particulate flows

This group included three hour-long lectures and six 20-minute presentations. R. Glowinski described 'A wave-like equation method for the treatment of the advection in incompressible viscous flow models' with applications to particulate flows. The method is based on the Marchuk–Yanenko operator splitting scheme. Numerical results were presented for the driven cavity flow and sedimentation of a pair of particles in a Newtonian fluid. The former demonstrates a bifurcation from steady to periodic solutions at $Re \approx 8500$. The latter shows the drafting–kissing–tumbling scenario that Joseph and co-workers first observed in experiments. L.S. Fan's lecture on 'Dynamics of high pressure gas–liquid–solid fluidization' focused on high-pressure, high-temperature transport processes in fluidized beds. Using experimental techniques such as flow visualization and PIV and various in situ sensors, the flow, heat-transfer, density, viscosity and bubble surface tension are measured. Numerically, Lattice–Boltzmann and volume-of-fluid methods are used to simulate gas–liquid–solid fluidization. Interesting results were presented on bubble breakup and particle–particle collision. G.P. Galdi's lecture on 'Sedimentation of slow particles in Newtonian and second-order fluids' revisited the problem of the preferred orientation of settling long particles. Using a perturbation method and the Lorentz reciprocal theorem, the force and torque on an arbitrary particle are calculated, and the results agree with previous calculations by L.G. Leal for slender particles and experimental observations in Joseph's laboratory.

In his talk entitled 'Shear-induced particle diffusion in concentrated suspensions: some recent and partially unexplained results,' A. Acrivos described puzzling experimental observations of particle segregation in a suspension. A suspension of neutrally buoyant particles in a highly viscous Newtonian liquid fills about 95% of the space inside a horizontal Couette cell with the inner cylinder rotating slowly. The particles are seen to segregate into bands along the span of the cylinder. J.P. Gollub talked about experimental observations on 'Phase coexistence in granular fluids.' A monolayer of solid grain is excited by a flat plate that vibrates vertically. The crystalline phase of the grain becomes unstable under certain conditions, and 'melts' into a fluid phase with an advancing melting front. M. Maxey proposed 'Approximate dynamic-coupling models for particle-laden flows.' The fluid is assumed to fill the entire domain with the solid particles affecting the flow through distributed forces acting over the volume that they occupy. For the flow around a sphere at vanishing and finite Reynolds (Re) numbers, the model gives reasonably accurate predictions. Simulations for a pair of settling spheres show the familiar drafting-kissing-tumbling scenario. C.K. Aidun used the Lattice–Boltzmann equations to simulate the 'Dynamic behavior of suspended particles in shear and confined sedimentation.' For a long particle in simple shear, increasing inertia causes deviation from the Jeffery orbit and eventually leads to steady orientation of the particle. Two particles settling in a channel exhibit periodic patterns with period doubling at high Re. P. Singh's talk on 'Direct numerical simulation of multiphase flows' presented recent results on particle sedimentation using a fixed-grid, Lagrange multiplier method and droplet deformation and breakup using the level set method. V. Sarin described 'A preconditioned linear system solver for a 2D particle mover.'

2. Dynamics of deformable interfaces

D.D. Joseph lectured on 'Drop breakup in a shock tube at ultra-high Weber numbers.' Based on observations using a high-speed video system, the mechanism for drop deformation and breakup is identified as a Rayleigh–Taylor instability associated with the acceleration of the droplet. Calculations based on this physical picture yield reasonable agreement with experimental measurements of the critical Weber numbers. Interestingly, breakup experiments with drops of polymer solutions indicate that the instability is enhanced by viscoelasticity. G.I. Barenblatt discussed 'Thin film extension along a solid surface — three-phase flow with challenging contact line boundary conditions.' A continuum model of the three-phase contact line was proposed to resolve the difficulty of the loss of solution of the model equations, if conventional boundary conditions are used. In his work on 'Transport of oil spill in the ocean,' S. Leibovich models the formation of oil streaks in the ocean after a spill by the wind-driven vortical convection under the surface. A theory for drop breakup in a turbulent stream was proposed to predict the size distribution of oil droplet in the ocean. D. Rumschitzki's talk on 'Convective and absolute instability in a two-fluid jet' presented temporal and spatial analyses of the stability of composite jets. Y. Renardy described 'Numerical simulation of two-layer Couette flow and core-annular flow.' Solving the full Navier–Stokes equation with a VOF scheme, she predicts cusps and fingering on the interface and the 'bamboo wave' that have been observed experimentally by Joseph and co-workers. G.S. Ribeiro first presented experimental results on 'Displacement of a heavy oil frozen inside a duct by light oil.' He then discussed three models for the interfacial morphology during the displacement.

3. Multiphase heat and mass transfer

H. Brenner talked about 'Enhanced heat- and mass-transport rates induced by laminar chaos in convection–diffusion systems.' In particular, he discussed the extraction of solute from a non-neutrally buoyant droplet in a shear flow, in which case the internal flow is laminar and chaotic. J.P. Brill's presentation on 'Paraffin deposition in multiphase pipelines' focused on the complex physical processes (e.g., melting, diffusion and possibly chemical reaction) involved in removing wax that solidifies inside pipelines through which hot crude oil from undersea wells is transported to the surface. In his talk entitled 'Coolant flow in grinding,' A.Z. Szeri discussed a desirable instability of the coolant film formed on a grinding wheel. Flow visualization shows that under favorable operating conditions, beads form on the heated coolant film, which are subsequently thrown off the wheel. The phenomenon is analyzed based on the Rayleigh–Taylor instability. A. Narain lectured on 'Computational simulation and flow physics for annular/stratified condensing flows.' The mass, momentum and energy conservation equations are solved numerically; interfacial boundary conditions are imposed on an evolving interface that is determined as part of the solution. Special attention was given to the effects of exit conditions.

4. Colloids and emulsions

In his hour-long lecture on 'Simulation of colloidal dispersions,' J.F. Brady discussed near-equilibrium behavior in colloids based on the Green–Kubo formulation. Brownian dynamics simulations were then presented on startup of simple shear and flow cessation. A 'boundary layer' of the pairwise distribution function is identified, which provides the microstructural basis for the stress relaxation behavior. M. Cloitre talked about 'Flow structuration in concentrated colloidal pastes.' The shear flow of polyelectrolyte microgels was studied using video microscopy, and the origin of the stress plateau was explored in detail. C. Verdier reported recent experiments on 'Coalescence in polymer emulsions' using a PIB in PDMS system. C. Mata presented experimental results on 'Sedimentation of highly concentrated oil-in-water emulsions.' The settling velocity of the largest drops in a polydisperse system was measured to be three times larger than that predicted by treating the smaller drops and water as an effective continuum with an empirical viscosity. A. Kamp proposed a mixture-theory formulation to treat 'Two-phase flow of foamy heavy crude oil in porous media,' which could significantly improve the models currently used in oil-field operation.

5. Dynamics of polymeric fluids

K.R. Sreenivasan spoke about 'Polymer action in turbulent flows.' Using a theoretical model attributed to de Gennes and Tabor, he presented predictions of the onset of drag reduction in turbulent flows. The results show better agreement with experiments than previous theories which regard the coil-stretch transition as the cause of drag reduction. Special emphasis was given to the dependence of drag reduction on the polymer concentration, which cannot be explained by the coil-stretching mechanics. In his talk entitled 'The fluid dynamics of nematic polymers: a fusion of continuum mechanics and molecular modeling,' J. Feng offered nematic polymers as an example of 'non-simple materials' with a nonlocal stress tensor. Combining the Marrucci–Greco theory on nematic potential energy and continuum mechanical concepts of virtual deformation, a new theory was derived which incorporates both the dynamics of polymer molecules and distortional elasticity. M.G. Forest presented 'A framework for defects and textures in flows of liquid crystal polymers.' Using the Doi theory with the Marrucci–Greco potential, he predicted a periodic texture of the material in equilibrium, with alternating stripes of isotropic and nematic materials. A. Robertson analyzed 'Flows of second-order fluid in curved pipes: effects of second normal stress coefficients.' Using a perturbation scheme in a toroidal coordinate system, she obtained results showing secondary recirculation in curved pipes.

The workshop was sponsored by the National Science Foundation, the Air Products Foundation and the School of Engineering of the University of Pennsylvania, and organized by Howard H. Hu (University of Pennsylvania), John Bassani (University of Pennsylvania), Jimmy Feng (City College of New York) and G. Paolo Galdi (University of Pittsburgh). A list of the workshop participants are as follows:

Professor A. Acrivos (The City College of CUNY)
Professor Cyrus Aidun (Institute of Paper Science and Technology)
Professor G.K. Ananthasuresh (University of Pennsylvania)
Dr. Mike Arney (Anderson Corporation)
Dr. Runyan Bai (University of Minnesota)
Professor Grigory I. Barenblatt (University of California, Berkeley)
Professor John L. Bassani (University of Pennsylvania)
Professor Haim Bau (University of Pennsylvania)
Professor John F. Brady (California Institute of Technology)
Professor Howard Brenner (Massachusetts Institute of Technology)
Professor James Brill (University of Tulsa)
Professor Shlomo Carmi (University of Maryland, Baltimore County)
Professor Pedro Ponte Castaneda (University of Pennsylvania)
Professor Kangping Chen (Arizona State University)
Professor Stuart W. Churchill (University of Pennsylvania)
Dr. Michel Cloitre (CNRS/Elf-Atochem, France)
Professor Ira M. Cohen (University of Pennsylvania)
Professor L.S. Fan (Ohio State University)
Professor Bakhtier Farouk (Drexel University)
Professor Jimmy Feng (The City College of CUNY)
Professor M. Gregory Forest (University of North Carolina at Chapel Hill)
Professor Antonio F. Fortes (Universidade de Brasilia, Brazil)
Professor G. Paolo Galdi (University of Pittsburgh)
Professor Eduardo Glandt (University of Pennsylvania)
Professor Roland Glowinski (University of Houston)
Professor Jerry P. Gollub (Haverford College)
Dr. Dan Green (DuPont Central Research)
Professor Richard Goldstein (University of Minnesota)
Dr. Ved Gupta (Bell Laboratories)
Mr. Todd Hesla (University of Minnesota)
Professor Howard H. Hu (University of Pennsylvania)
Dr. Peter Huang (University of Minnesota)
Mr. Dave Hultman (University of Minnesota)
Professor Daniel D. Joseph (University of Minnesota)
Dr. Arjan Kamp (INTEVEP S.A., Venezuela)
Dr. Kostas Kontomaris (DuPont Central Research)
Professor Sidney Leibovich (Cornell University)
Dr. Yaoqi Joe Liu (3M, St. Paul)
Dr. Wolfgang Losert (Haverford College)
Dr. Clara Mata (INTEVEP S.A., Venezuela)
Professor Martin Maxey (Brown University)
Professor Amitabh Narain (Michigan Technological University)
Dr. Gustavo A. Nuñez (INTEVEP S.A., Venezuela)
Professor Tsorng-Whay Pan (University of Houston)

Ms. Louise Pope (University of Minnesota)
Professor Luigi Preziosi (Politecnico di Torino, Italy)
Professor Mary Pugh (University of Pennsylvania)
Professor YueHong Qian (Columbia University)
Professor John A. Quinn (University of Pennsylvania)
Professor Yuriko Y. Renardy (Virginia Polytechnic Institute and State University)
Dr. Geraldo Spinelli Ribeiro (PETROBRAS/CENPES, Brazil)
Professor Ronald S. Rivlin (Lehigh University)
Dr. M. C. Roco (National Science Foundation)
Professor Anne M. Robertson (University of Pittsburgh)
Professor David Rumschitzki (City College of CUNY)
Dr. Vivek Sarin (Purdue University)
Professor Warren D. Seider (University of Pennsylvania)
Professor Pushpendra Singh (New Jersey Institute of Technology)
Professor Petros Sofronis (University of Illinois at Urbana-Champaign)
Professor K.R. Sreenivasan (Yale University)
Professor Sergio Turteltaub (University of Pennsylvania)
Dr. Claude Verdier (Chercheur CNRS/Domaine Universitaire, Grenoble, France)

(University of Pennsylvania Graduate Students and Postdocs:)

Mr. David Artigliere
Mr. Michael Braginsky
Mr. Robert Breslowski
Mr. Jonathan Briggs
Mr. Joel Esposito
Ms. Hongxia Gao
Mr. Zhenhua Hu
Mr. George Jefferson
Ms. Elizabeth Lai
Mr. Sarangi Patel
Mr. Anupam Saxena
Mr. Tom Sugar
Dr. Hanping Xu
Dr. Hongwei Yang
Mr. Mingqiang Yi
Dr. Po Ki Yuen
Dr. Jihua Zhong
Mr. Mingyu Zhu