DOE DEFG-03-94-ER25192

C. Pozrikidis

RECEIVED

JUL 27 1998

OSTI

FINAL PROGRESS REPORT

DOE/ER/25192--T/

The central objective of this research has been to develop efficient numerical methods for computing multi-fluid flows with large interfacial deformations, and apply these methods to study the rheology of suspensions of deformable particles with viscous and non-Newtonian interfacial behavior. The mathematical formulation employs boundary-integral, immersed-boundary, and related numerical methods. Particles of interest include liquid drops with constant surface tension and capsules whose interfaces exhibit viscoelastic and incompressible characteristics; two examples are a partially polymerized drop and a red blood cell.

In one family of problems, we have considered the shear-driven and pressure-driven flow of a suspension of two-dimensional liquid drops with ordered and random structure. The results are used to deduce the relationship between the effective rheological properties of the suspension and the state of the microstructure, and to illuminate the changes in behavior as a suspension becomes increasingly more concentrated and eventually reduces to a foam. The numerical simulations for channel flow revealed certain surprising differences in the behavior of shear-driven and pressure-driven flow. The results of the hydrodynamic simulations were used to conduct numerical studies of the optical properties of evolving suspensions, with an objective to establish a relationship between light transmittance and the geometry of the microstructure.

In a second series of investigations, we carried out dynamic simulations of two-dimensional, unbounded, doubly-periodic shear flows with random structure. The development of an efficient method for computing the necessary doubly-periodic Green's function of Stokes flow was a crucial component of the numerical method. The efficiency of the computations was enhanced by implementing the method of multi-pole expansions and interpolation through look-up tables. The new and improved numerical procedure has been tested with satisfactory results, and large-scale simulations were performed.

Another family of problems addresses the deformation of three-dimensional capsules whose interfaces exhibit isotropic surface tension, viscous, elastic, or incompressible behavior, in simple shear flow. The numerical results extend previous asymptotic theories for small deformations and illuminate the mechanism of membrane rupture. One important problem in this category is the deformation of a droplet adhering to a solid surface under the action of an over-passing simple shear flow. These computations become feasible with the novel implementation of the boundary element method which accounts for interfacial rheology in an efficient manner. In a related effort, we develop and implement Immersed Boundary Methods for interfacial flow at finite Reynolds numbers.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

pgs
final

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

**Portions of this document may be illegible
electronic image products. Images are
produced from the best available original
document.**

A further area of research concerns the physics of viscous flow over irregular boundaries and over a wall with a cavity, a protrusion or an orifice. These computations became feasible with the reformulation of the boundary integral method, employing Fourier expansions in a manner that allows for accurate numerical solutions with minimal computational effort. We also study the motion of rigid particles in unbounded and bounded domains and within channels with parallel-sided walls with applications in bioengineering.

Research papers that acknowledge the support of the DOE include:

- 1 POZRIKIDIS, C. 1994 The motion of particles in the Hele-Shaw cell. *J. Fluid Mech.* **261**, 199-222.
- 2 POZRIKIDIS, C. 1994 Shear flow over a plane wall with an axisymmetric cavity or a circular orifice of finite thickness. *Phys. Fluids*, **6**, 68-79.
- 3 ZHOU, H. & POZRIKIDIS, C. 1994 Pressure-driven flow of suspensions of liquid drops. *Phys. Fluids*, **6**, 80-94.
- 4 POZRIKIDIS, C. 1994 Effects of surface viscosity on the deformation of liquid drops and the rheology of dilute emulsions in simple shearing flow. *J. Non-Newt. Fluid Mech.* **51**, 161-178.
- 5 POZRIKIDIS, C. 1994 A bibliographical note on the unsteady force on a spherical drop. *Phys. Fluids* **6**, 3209.
- 6 ZHOU, H. & POZRIKIDIS, C. 1995 Deformation of capsules with incompressible interfaces in simple shear flow. *J. Fluid Mech.* **283**, 175-200.
- 7 LI, X., ZHOU, H. & POZRIKIDIS, C. 1995 A numerical study of the shearing motion of emulsions and foams. *J. Fluid Mech.* **286**, 379-404.
- 8 SHETH, K. & POZRIKIDIS, C. 1995 Effects of inertia on the deformation of liquid drops in simple shear flow. *Computers & Fluids*, **24**, 101-119.
- 9 ZHOU, H. & POZRIKIDIS, C. 1995 Adaptive singularity method for Stokes flow past particles. *J. Comp. Phys.* **117**, 79-89.
- 10 POZRIKIDIS, C. 1995 Finite deformation of liquid capsules enclosed by elastic membranes in simple shear flow. *J. Fluid Mech.* **297**, 123-152.
- 11 POZRIKIDIS, C. 1996 Computation of periodic Green's functions of Stokes flow. *J. Eng. Math.* **30**, 79-96.
- 12 POZRIKIDIS, C. & SHETH, K. 1996 A note on light transmission through an evolving suspension of liquid drops. *Chem. Eng. Comm.* **148-150**, 477-486.
- 13 LI, X. & POZRIKIDIS, C. 1996 Shear flow over a liquid drop adhering to a solid surface. *J. Fluid Mech.* **307**, 167-190.
- 14 LI, X., CHARLES, R., POZRIKIDIS, C. 1996 Simple shear flow of suspensions of liquid drops. *J. Fluid Mech.* **320**, 395-416.

DOE DEFG-03-94-ER25192

C. Pozrikidis

3

15 POZRIKIDIS, C. 1996 Shear flow over a protuberance on a plane wall. *J. Eng. Math.* 31, 31-

Other publications acknowledging the support of the DOE include the book chapter:

POZRIKIDIS, C. 1994 Stokes flow in the presence of interfaces. *Boundary Element Methods in Fluid Mechanics*. Computational Mechanics Publications, Southampton, England.

and the book:

POZRIKIDIS, C. 1996 *An Introduction to Theoretical and Computational Fluid Dynamics*. Oxford University Press.