lar revisions as we probe it at different wavelengths. Although Greenberg relies (probably correctly) on the inferred properties of 'cometary' meteors, there is an increasing fraction of interplanetary particles that are now thought of as being of asteroidal origin. Comet trails, observed by the Infrared Astronomical Satellite (IRAS) and by ground based radar, are turning up ever larger particles. Interstellar particles, of course, cannot be probed by radar. But I wonder if the simple models that astronomers and astrophysicists have laboured to infer from their data might suffer from an analogous blindness owing to the inevitable limitations in observing these distant environments.

Halley's Comet, of course, is just a single object, and it has no doubt evolved from its original condition since it first entered the inner Solar System. There are contradictory indications about whether most comets are essentially identical in physical and chemical constitution or whether they are as varied as the asteroids are. It will behove us to study more comets — both with telescopes and by spacecraft visits — before we ascribe to all comets the characteristics of Halley's. Meanwhile, Greenberg's elaborate model for comets as aggregates of interstellar grains remains one of the paradigms in this field. Despite my nitpicking, Greenberg and Hage's work is the most rigorous demonstration to date of the association between inferred properties of interstellar grains and the dust in our best-observed comet. ☐

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FLUID DYNAMICS

Separation in flowing fluids

Daniel D. Joseph

Two liquids of different viscosities will stratify with the heavy liquid below, when stationary. But when these stratified liquids are made to flow down a pipe, the less viscous liquid will tend to encapsulate the more viscous liquid, even lubricating it, regardless of their relative densities (Fig. 1). Calculations on page 523 of this issue try to make sense of this behaviour.

The segregation of two liquids by viscosity which manifests itself in pipes as encapsulation is one example of the tendency of the low-viscosity constituent to migrate into regions of high shear. There are many applications, current and potential, for this trait, ranging from the coextrusion of molten plastics, to segregation in forming layered materials of superior strength, to the water-lubricated transport of viscous liquids and dense suspensions of solid particulates. Water-lubricated pipelining of crude oils is one emerging technique by which drag on the oil flow can be reduced by factors of the order of the viscosity ratio, 10^{-4} or less (C. L. Merkle & S. Deutsch in *Viscous Drag Reduction in Boundary Layers* **123**, (eds D. M. Bushnell & J. N. Hefner) 396–402 (*Am. Inst. Aeronaut. Astronaut.*, 1990)).

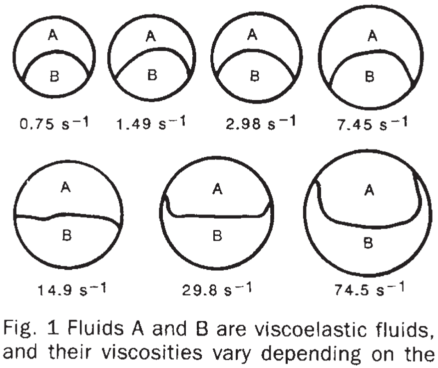

Fig. 1 Fluids A and B are viscoelastic fluids, and their viscosities vary depending on the apparent wall shear rate (given here in reciprocal seconds). In the upper set of arrangements, fluid B is the more viscous, and fluid A tends to wrap around fluid B. In the lower left, the viscosities of the fluids are about equal and the flat interface is retained. In the lower middle, fluid A is the more viscous and fluid B tends to wrap around fluid A. In the lower right arrangement, fluid A is the more viscous. (From J. H. Southern & R. L. Ballman *Appl. Polymer Symp.* **20**, 175–189; 1973.)

Many different flow configurations occur in such flows, each giving rise to a different drag. It is possible to see perfect core–annular flows, bamboo and corkscrew waves of oil in water (Fig. 2), or slugs, bubbles and dispersions of water in oil. Understanding how one flow evolves to another is a mystery of fluid dynamics whose solution would help in the optimization of lubrication. The evolution can be formulated as an initial-boundary-value problem for two immiscible liquids satisfying the Navier–Stokes equation and interface conditions between liquids. This difficult study is at best computationally intensive and at worst either too expensive or even beyond the capabilities of modern supercomputers.

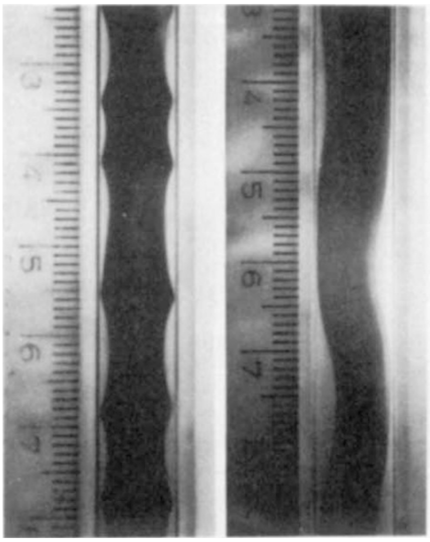

Fig. 2. Water-lubricated pipelining of a 14-poise oil in water in a vertical U loop. Bamboo waves (left) arise in the up flow of the U loop where buoyancy stretches the oil. Corkscrew waves (right) arise from the buckling under compression of gravity of water in oil in down flow, where the gravity and the pressure gradient are opposed.

The mechanisms underway in the flows which segregate by viscosity can be partly understood by studies of the stability of core–annular flows and more directly by variational principles. For example, it has been postulated that the realized configuration of flows of two liquids is the one that minimizes the viscous dissipation of energy. In fact, several different versions of this principle put the more viscous constituent in the core.

H. W. Stockman, C. T. Stockman and C. R. Carrigan introduce elsewhere in this issue (*Nature* **348**, 523–525; 1990) an entirely new method for studying viscous segregation and the evolution of lubricating flows. They adapt a method of cellular automata to follow the motions of incompressible liquids with different viscosities and interfacial tension in two-dimensional simulations of the initial-value problem. They show how the lubricating configuration with the low-viscosity liquid on the walls can arise. Their method is not, and is not meant to be, an exact description of the flow's dynamics: it models the Navier–Stokes equation only in an average sense. It is greatly encouraging that several variants of the rules for the automata lead to identical results and that they all give rise to lubrication. We can hope that the exact mechanisms which lead to lubrication or its failure may be illustrated by studies of motions of the lattice gas, even if the methods of cellular automata for quantitative prediction are never realized.

The manner in which high-viscosity liquids are lubricated depends strongly on conditions and could never be described by one variational principle. A kind of anthropomorphic variational principle, which like other principles may be believed but not proved, goes like this: "High-viscosity liquids are lazy. Low-viscosity liquids are the victims of the laziness of high-viscosity liquids because they are easy to push around." Perhaps the methods of cellular automata introduced by Stockman *et al.* can help us to better understand and control the lazy fellow and his victim. ☐

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