Near-Critical Viscosity Divergence, Viscoelasticity, and Shear Thinning: Space Shuttle Measurements of Xenon Confirm Theory

Robert Berg [C, S] and Michael Moldover
Process Measurements Division, National Institute of Standards and Technology, Gaithersburg, MD, U.S.A.

Minwu Yao
Ohio Aerospace Institute, Cleveland, OH, U.S.A.

Gregory Zimmerli
NASA Glenn Research Center, Cleveland, OH, U.S.A.

As the critical point of a pure fluid is approached, the large, slowly-relaxing density fluctuations cause four phenomena that are manifest in shear flows: (1) the shear viscosity diverges, (2) viscoelasticity appears at large frequencies (the fluctuations stretch and store energy), (3) shear thinning appears at large shear rates (the breaking of fluctuations decreases the viscosity), and (4) normal stress appears at large shear rates (the stretched fluctuations create a force orthogonal to the flow direction). Phenomena (2)-(4) are readily detected in complicated fluids such as polymer solutions; however, theory predicts that they also occur in a fluid as simple as xenon sufficiently close to its critical point. We measured the damping of an oscillating screen immersed in xenon at its critical density. The data extend within 0.001 K of its critical point (289 K, 5.8 MPa). The measurements were conducted on board the Space Shuttle to circumvent the compression of near-critical xenon by its own weight in Earth's gravity. The measured divergence of the shear viscosity quantitatively agrees with the theory. The observed viscoelasticity, and shear thinning require improvements to the theory. These measurements were not designed to detect the normal stress.