Onsager Principle and the Electrorheological Fluid Dynamics*

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We present the formulation of a two-phase, electrical-hydrodynamic model for the description of electrorheological fluid dynamics, based on the Onsager principle of minimum energy dissipation. By considering the energetics of (induced) dipole-dipole interaction between the solid particles in terms of a field variable $n(\vec{x})$, we employ the Onsager principle to derive the relevant coupled hydrodynamic equations, together with a continuity equation for $n(\vec{x})$. Numerical solution of the relevant equations yields predictions that display very realistic behaviors as seen experimentally. In particular, we show that while the predicted results have features that resemble Bingham fluids, there can be important differences. For example, the yield stress obtained by extrapolating the shear rate to zero is 30-40% lower than that obtained from the maximum of the stress-strain relation. Moreover, the stress vs. shear rate exhibits very significant dependence on electrode configuration. For the conventional electrode configuration where the field is perpendicular to the shearing direction, there is very clear shearing-thinning effect that has been seen experimentally. However, for the inter-digitated electrode configuration there is no shear thinning effect, thus suitable for high shear-rate applications.

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