Violation of the Incompressibility of Liquid by Simple Shear Flow

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ずり粘性の密度依存性に起因する流れと密度揺らぎの結合を考慮に入れることによって、単純剪断流であっても、非圧縮性状態が破れうることを示す。ずり粘性の圧力に関する微分の逆数によって与えられる臨界剪断率を超えると、液体が力学的に不安定になりうることが示された。今回の結果から、非常に粘性の高い液体では、この剪断誘起不安定性が実験的に容易に実現しうる程度の剪断率でも起こると予測される。実際、高粘性の潤滑剤において観察された異常な剪断誘起不安定性を、今回の結果により説明できる。

In standard fluid dynamics, the density change associated with flow is often assumed to be negligible, implying that the fluid is incompressible. For example, this has been established for simple shear flows, where no pressure change is associated with flow: there is no volume deformation due to viscous stress and inertial effects can be neglected. Accordingly, any flow-induced instabilities (such as cavitation) are unexpected for simple shear flows. Here we demonstrate that the incompressibility condition can be violated even for simple shear flows, by taking into account the coupling between the flow and density fluctuations, which arises owing to the density dependence of the viscosity. We show that a liquid can become mechanically unstable above a critical shear rate that is given by the inverse of the derivative of viscosity with respect to pressure. Our model predicts that, for very viscous liquids, this shear-induced instability should occur at moderate shear rates that are experimentally accessible. Our results explain the unusual shear-induced instability observed in viscous lubricants and may illuminate other poorly understood phenomena associated with mechanical instability of liquids at low Reynolds number; for example, shear-induced cavitation and bubble growth, and shear-banding of very viscous liquids such as metallic glasses and the Earth's mantle.

References

1) A. Furukawa and H. Tanaka, Nature **443** (2006), 434.

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