Polymers under strong forcing: Flow or fracture?

By

Ole Hassager and Qian Huang.

Rheologists often refer to extensional flow as a strong flow. The reason is that in flows of constant rate, particles subjected to extension separate exponentially in time, while in shear the rate of separation is much weaker. As a result, extensional flows are in principle well suited for studying non-linear properties of fluids. In practice, however, it is challenging to provide well-defined extensional flows of controlled rates in a laboratory. Viscoelastic filaments extended at constant (imposed) nominal rate often have a limiting deformation as pointed out by Malkin and co-workers[1]. We here show first of all, how this limiting deformation may be predicted from the stability criteria of Hoyle-and Fielding[2]. Clearly, under such conditions it is not possible to extract material functions such as an extensional viscosity. Secondly, we show that by adjusting the nominal deformation by means of a control-loop, it is possible to extract steady extensional viscosity as well as true stress-relaxation material functions even under conditions of filament instability according to the Hoyle-Fielding criteria. With this background we go back to the Malkin diagram, compare with experiments and show that if the nominal deformation is replaced by the true deformation, then the resulting diagram has only two regions: Flow and fracture. The flow regime requires in principle no new physics for its description, except of course for the relevant rheological material functions. By contrast, the continuum description breaks down near the fracture tip. In closing we will review available experimental evidence on liquid fracture and suggest outstanding questions.

[1] Malkin, Arinstein and Kulichikhin, Prog. Polymer Sci. (2014)

[2] Hoyle and Fielding, J. of Rheology (2016)