Capillary Break-up Rheometry of Low-Viscosity Elastic Fluids

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Abstract:

We investigate the dynamics of the capillary thinning and break-up process for low viscosity elastic fluids such as dilute polymer solutions. Standard measurements of the evolution of the midpoint diameter of the necking fluid filament are augmented by high speed digital video images of the break up dynamics. We show that the successful operation of a capillary thinning device is governed by three important time scales (which characterize the relative importance of inertial, viscous and elastic processes), and also by two important length scales (which specify the initial sample size and the total stretch imposed on the sample). By optimizing the ranges of these geometric parameters, we are able to measure characteristic time scales for tensile stress growth as small as 1 millisecond for a number of model dilute and semi-dilute solutions of polyethylene oxide (PEO) in water and glycerol. If the final aspect ratio of the sample is too small, or the total axial stretch is too great, measurements are limited, respectively, by inertial oscillations of the liquid bridge or by the development of the well-known beads-on-a-string morphology which disrupt the formation of a uniform necking filament. By considering the magnitudes of the natural time scales associated with viscous flow, elastic stress growth and inertial oscillations it is possible to construct an “operability diagram” characterizing successful operation of a capillary break-up extensional rheometer. For Newtonian fluids, viscosities greater than approximately 70 mPas are required; however for dilute solutions of high molecular weight polymer, the minimum viscosity is substantially lower due to the additional elastic stresses arising from molecular extension. For PEO of molecular weight $2 \cdot 10^6$ g/mol, it is possible to measure relaxation times of order 1 ms in dilute polymer solutions with zero-shear-rate viscosities on the order of 2 – 10 mPas.

Zusammenfassung:

Wir untersuchen die Dynamik der Kapillarverdünnung und des Zerreissens niedrig-viskoser elastischer Fluide wie verdünnte Polymerlösungen. Die standardisierten Messungen der Veränderung des Durchmessers in der Mitte des einschnürenden flüssigen Filaments werden durch Hochgeschwindigkeitsdigitalvideoaufnahmen der Zerreissdynamik verbessert. Wir zeigen, dass eine erfolgreiche Bedienung eines Kapillarverdünnungsgeräts von drei wichtigen Zeitskalen bestimmt wird (die die relative Bedeutung von trägen, viskosen und elastischen Prozessen charakterisieren), und darüber hinaus von zwei wichtigen Längenskalen (die die Ausgangsgrösse der Probe und das Verstreckverhältnis der Probe spezifizieren). Durch Optimierung dieser geometrischen Parameter sind wir in der Lage, die charakteristischen Zeitskalen des Zugspannungswachstums bis 1 ms für mehrere Modelllösungen aus Polyethylenoxid (PEO) in Wasser und Glyzerin zu messen. Wenn das Aspektverhältnis der Probe zu klein ist oder die absolute axiale Verstreckung zu gross, werden die Messungen durch Trägheitsoszillationen der flüssigen Brücke oder der Entwicklung der bekannten Perlen-auf-der-Kette-Morphologie begrenzt, die die Bildung eines gleichmässig einschnürenden Filaments verhindern. Durch Betrachtung der Grösse der natürlichen Zeitskalen, die mit dem viskosen Fliessen, dem Wachstum der elastischen Spannungen und den Trägheitsoszillationen verbunden sind, ist es möglich, ein "Bedienungsdiagramm" zu erstellen, das die erfolgreiche Bedienung eines Kapillaraufbruchdehnrheometers darstellt. Für Newtonsche Fluide sind Viskositäten grösser als ca. 70 mPas erforderlich; für verdünnte Lösungen von hochmolekularen Polymeren ist die minimale Viskosität jedoch wesentlich kleiner aufgrund der zusätzlichen elastischen Spannungen, die aus der molekularen Verstreckung resultieren. Für PEO mit Molekulargewicht 2 x 10**6 g/mol ist es möglich, Relaxationszeiten in der Grössenordnung von 1 ms in verdünnten Polymerlösungen mit Schernullviskositäten der Grössenordnung von 2 – 10 mPas.

Résumé:

Nous avons étudié la dynamique des mécanismes d’amincissement et de rupture capillaire dans le cas de fluides élastiques de faible viscosité tels que des solutions diluées de polymère. Des mesures standard de l’évolution du diamètre médian du filament de fluide sous striction sont augmentées par des images vidéo digitalisées

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