WELL-CHARACTERIZED LOW VISCOSITY ELASTIC LIQUIDS

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ABSTRACT
A series of low and constant viscosity elastic liquids are constructed and are studied rheologically. Steady shear viscosity and normal stresses, dynamic properties, and an apparent extensional viscosity are measured using well-established techniques. The rheological characteristics of the solution are used to help explain the physical basis for non-Newtonian phenomena in short time scale processes such as jet breakup, splash, spray atomisation and swirling flow. It is demonstrated that even when the shear viscosity is maintained at a constant value, significant differences occur in processes due to the differences in the elasticity of the fluids. Some implications for these observations are discussed. The paper is an overview on our work on elastic effects in the flow of low viscosity fluids. It reflects the verbal presentation made at the Professor John D. Ferry Symposium at the 71st Annual Meeting of the Society of Rheology.

ZUSAMMENFASSUNG
Eine Reihe von niederviskosen und elastischen Flüssigkeiten mit konstanter Viskosität wurden hergestellt und rheologisch untersucht. Die stationäre Scherviskosität und die Normalspannungen, sowie dynamische Eigenschaften und eine scheinbare Dehnviskosität wurden mittels etablierten Methoden gemessen. Die rheologischen Eigenschaften der Lösung wurden verwendet, um den physikalischen Ursprung nicht-newtonschen Verhaltens in schnellen Prozessen wie sie beim Jet Break-up, Splash, bei Sprühzerstäubung und in Wirbelströmungen auftreten, zu erklären. Es wird gezeigt, dass sogar bei konstanter Scherviskosität signifikante Unterschiede aufgrund verschiedenen elastischen Verhaltens auftreten. Einige Auswirkungen dieser Beobachtungen werden diskutiert. Dieser Artikel gibt einen Überblick über unsere Arbeit an elastischen Effekten beim Fliessverhalten niederviskoser Flüssigkeiten. Es spiegelt den Vortrag am Professor John D. Ferry Symposium während des 71st Annual Meeting of the Society of Rheology wider.

RÉSUMÉ
Une série de liquides élastiques avec une viscosité faible et constante sont élaborés et étudiés rhéologiquement. La viscosité de cisaillement en régime établi ainsi que les contraintes normales, les propriétés dynamiques et une viscosité extensionnelle apparente sont mesurées à l'aide de techniques bien établies. Les caractéristiques rhéologiques de la solution sont utilisées afin d'aider à expliquer les principes physiques qui sont à l'origine des phénomènes non-Newtoniens rencontrés dans les procédés impliquant une échelle de temps courts, tels que la dispersion par jet, l'éclaboussement, la pulvérisation et l'écoulement tourbillonant. Il est démontré que, même lorsque la viscosité de cisaillement est maintenue constante, des différences significatives prennent place dans les procédés, à cause des différences dans l'élasticité des fluides. Les implications de ces observations sont discutées. Cet article est une revue de nos travaux sur les effets élastiques pendant l'écoulement de fluides de basses viscosités. Il rend compte de la présentation orale donnée pendant le Symposium Professeur John D. Ferry à l'occasion de la 71ème rencontre annuelle de la Société de Rhéologie.

KEY WORDS: Elastic liquids, Boger fluids, jet breakup, splash, swirling flow

1 INTRODUCTION

For low viscosity elastic liquids (< 50 cP), a complete rheological characterization is difficult. The lower limits on the resolution of commercial rheometers is tested when small amounts of high molecular weight polymer are added to low viscosity Newtonian solvents. Normal stresses are frequently undetectable or within the experimental error of the measuring instrument. Despite the experimental difficulties in making these measurements, a complete rheological characterization, in both shear and extensional flow, is often necessary to understand the physics behind many rheological phenomena. In recent years, differences in extensional properties of a non-Newtonian fluid have been shown to have a major impact on rheological phenomena. For example, it is well-known that the extensional viscosity of a polymer solu-

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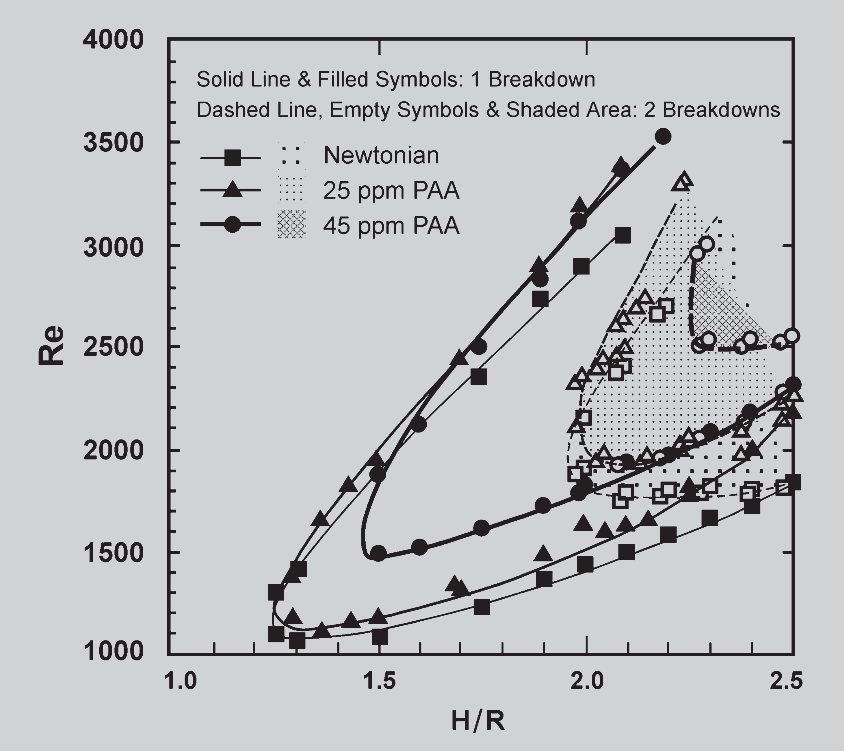

Figure 13: Existence domain for vortex breakdown of low viscosity polyacrylamide Boger fluids and the Newtonian solvent.

"crown" and the ejected drops are readily visible. Finally, in the model swirling flow, the elasticity in the polymer solutions caused a shift (or a delay to higher parameter values) in the criteria for the breakdown bubbles.

5 CONCLUSIONS

When polymer molecules are exposed to extensional flow fields, they become significantly deformed. Phenomenological results from this laboratory have been presented for some low (shear) viscosity elastic liquids. These fluids have a constant shear viscosity. The impact of the extensional properties has been highlighted through the use of flow geometries that feature a large extensional component of flow capable of causing significant elasticity in the polymer solutions. It is shown that the different extensional properties of fluids cause major differences in the flow behaviour even when the shear viscosity is maintained constant. In many cases, the addition of polymer results in behaviour that may be considered enhanced, or more desirable, than that associated with a Newtonian fluid of an identical shear viscosity. These results demonstrate the necessity of understanding, even if it is only in a qualitative sense, the extensional properties of a polymer solution. Fitting model parameters simply by using the shear data is insufficient when attempting to model processes that involve any extensional flow component whatsoever.

In the case of the observations made for the swirling flow, all variables have been carefully controlled and the results shown clearly demonstrate the influence of elasticity as a result of the polymer molecule. For the free surface flows, however, jet breakup, atomisation and splash, an additional variable may be the interfacial tension. It was demonstrated in the work presented that the static surface tension is essentially constant. But, during the free surface generation it is the dynamic surface tension which may be the important variable and therefore the conclusion in regard to the influence of elasticity in the free surface flows may not be entirely correct, as the dynamic surface tension may be a variable which has not been controlled. The work in our laboratory now is concerned with looking at two timescales: one associated with the time taken for a surfactant to reach the surface of the interface being produced relative to the timescale of the process, and the other being the timescale associated with the elasticity of a polymer present in the liquid phase relative to the processing timescale. The interaction of the two timescales associated with dynamic interfacial tension and elasticity of a low viscosity polymer fluid is an exciting, very relevant and, we believe, new area of research.

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