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Stability Analysis of Viscoelastic Fountain Flows

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Introduction

The occurrence of unstable secondary flows during the injection molding process can results in severe surface defects of the final polymer products. These defects are often referred to as ‘flow marks’ or ‘tiger stripes’ and have been observed in many polymer systems including polypropylene (fig. 1) [1].

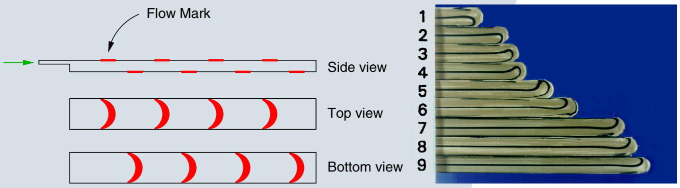

Figure 1: *Flow marks in a model injection molding flow (left). Short shot experiments by M. Bulters and A. Schepens [1] using a two-color injection molding technique (right)*

Important questions are:

- What are the critical flow conditions?
- How does this relate to the polymer rheology?

Numerical Tools

The stability behavior of the fountain flows is analyzed using a transient finite element method. Direct time integration of the linearized governing equations yield the growth (or decay) rates of randomly imposed perturbations. Essential features of the finite element technique are [2]:

- Stable & efficient time integration (Θ-scheme)
- Perturbations of the domain and the free surface

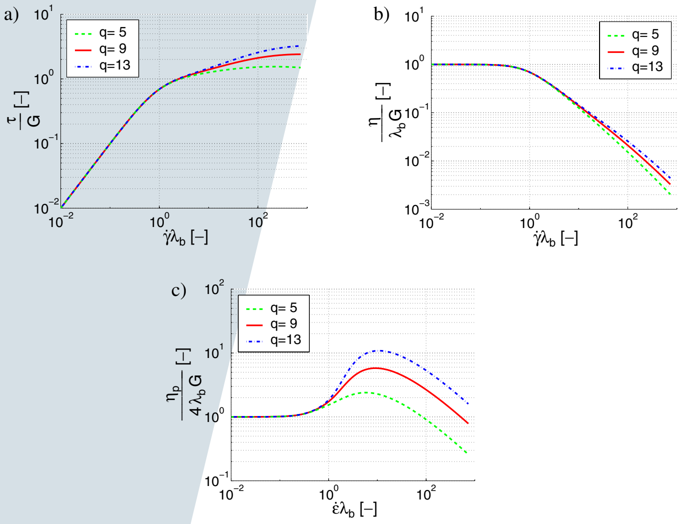

Figure 2: *Steady state viscometric functions a) shear stress – shear rate b) viscosity – shear rate and c) planar elongational viscosity – extension rate, for different numbers of arms q and $r = 2$.*

Constitutive Behavior

The eXtended Pom-Pom (XPP) model of Verbeeten *et al.* [3] is used to represent the dynamic behavior of the polymer melts. In order to investigate the influence of the fluid rheology on the onset of the instability, different sets of nonlinear data are selected. Viscometric functions of the XPP model for these sets of data are shown in figure 2.

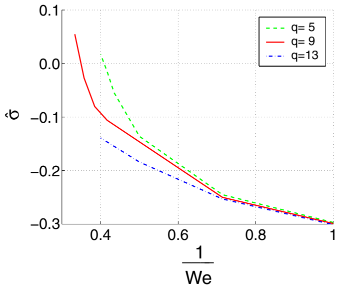

Figure 3: *Computed growth rates of randomly imposed perturbations of the fountain flows.*

Stability of Fountain Flows

It is found that a linear instability sets in at We ≈ 2.5 for $(r,q) = (2,5)$ and We ≈ 2.8 for $(r,q) = (2,9)$ (fig. 3). The occurrence of instability, as a function of the dimensionless processing rate (We), is delayed when the number of arms in the XPP model is increased. This has a major effect on the extensional properties of the fluid which might indicate that the flows can be stabilized by fluids with increased strain hardening.

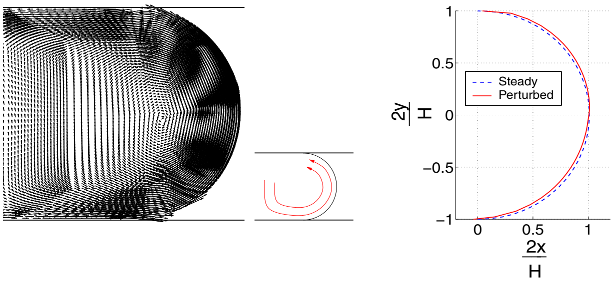

Figure 4: *Results of the linear stability analysis for an XPP fluid for $(r,q) = (2,5)$ and We $= 2.5$. Shown are the perturbation velocity near the free surface (left) and the linearly perturbed shape of the free surface (right).*

After exponential growth of the perturbation, a swirling flow near the fountain flow surface is obtained which is consistent with the experimental observations (fig. 4).

References:

[1] M. Bulters, A. Schepens: *Proceedings of the 16th Annual Meeting of the Polymer Processing Society, Shanghai (2000).*

[2] A.C.B. Bogaerds et al: J. Non-Newt. Fluid Mech., submitted (2002)

[3] W.M.H. Verbeeten et al: J. Rheol. 45(4), 823-844 (2001)

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