Flow instabilities of fiber spinning

Flow Instabilities in Fiber Spinning

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Introduction

In solution spinning of ultra-high molecular weight polyethylene (UHMwPE), a gel is processed by an extruder through a spinneret. The extrudate is drawn through the air at high speeds and then cooled in a water bath. The end-result is a fiber with a high degree of molecular orientation and therefore exceptional tensile strength. Flow instabilities in the form of draw resonance, unwanted wave like phenomena, impose limitations on the production rates and the quality of the fibers [1, 2]. Additionally, in solution spinning of UHMwPE is the pull out of a filament from the spinning die due to pronounced shear thinning behavior combined with wall slippage [3]; see Figure 1.

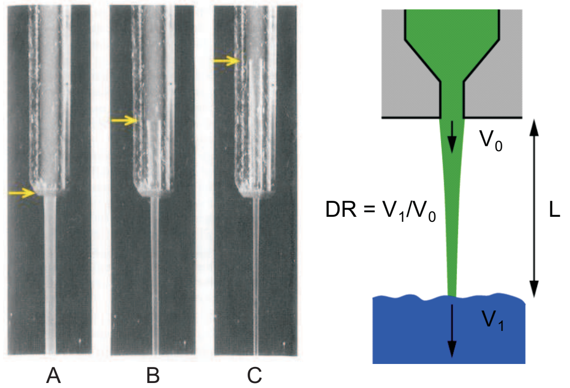

Figure 1 *(Left) Pull out of a filament from a glass capillary as observed experimentally in [3] with increasing draw ratio from A to C. (Right) Schematic drawing of a single filament in the air gap.*

Objective

The objective of this work is to investigate the influence of the pull out effect on the stability of a single isothermal filament in the air gap.

Modeling Strategy

The pull out effect can be understood according to [3] by equating in the detachment point the spinning tension necessary to obtain a prescribed draw ratio, *DR*, (which pulls the fluid from the wall) with the first normal stress difference that occurs during shear flow in the upstream region (hence pushes the fluid towards the wall). See the intersection of the red and blue line in Figure 2. The first normal stress difference is determined by the applied shear rate and the polymer's viscoelasticity. The spinning tension is determined by the elongational viscosity, the draw ratio, and the stretching length.

The position of the detachment point fluctuates and this is determined by the intersection angle of the spinning tension line and the first normal stress difference line. It is known that if the speed is prescribed the filament becomes unstable beyond a critical draw ratio. On the other hand spinning with a fixed force leads to no instabilities [4]. Including pull out, we are somewhere between these two cases. Hence, our working hypothesis is that freedom of the position of the detachment prevents instabilities from happening elsewhere, e.g., draw resonance. We will proceed with our modeling strategy as follows:

- Assume different profiles for the averaged normal stress difference indicated by the red line in Figure 2.
- Determine the transient solution of the 1D isothermal model with a moving boundary.
- Investigate how the angle of intersection between the two lines in Figure 2 effects the stability of the detachment point and the filament formation.

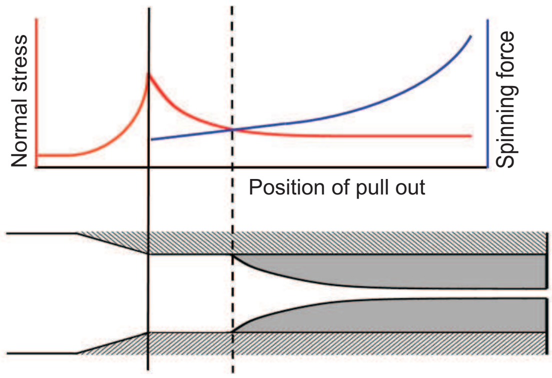

Figure 2 *Development of the averaged normal stress as a function of the detachment point and the spinning tension as function of the capillary length. The intersection of the two lines determines the detachment point.*

Future Work

- Determine the averaged normal stress difference through modeling and experiments.
- Investigate different constitutive models to describe the behavior of UHMwPE in elongation.
- Incorporate the non-isothermal characteristics of the spinning line into the model.

References:

[1] Petrie C.J.S. and Den M.M., Instabilities in Polymer Processing (American Institute of Chemical Engineers Journal, 1976).

[2] Hatzikiriakos S.G. and Migler K.B., Polymer Processing Instabilities, Control and Understanding (Marcel Dekker, New York, 2005).

[3] Bulters M.J.H. and Meijer H.E.H., Analogy Between the Modeling of Pullout in Solution Spinning and the Prediction of the Vortex Size in Contraction Flows (Journal of Non-Newtonian Mechanics, 1990).

[4] Renardy M., Draw Resonance Revisited (Journal of Applied Mathematics, 2006).