Extrudate Swell of Monodisperse Polystyrenes

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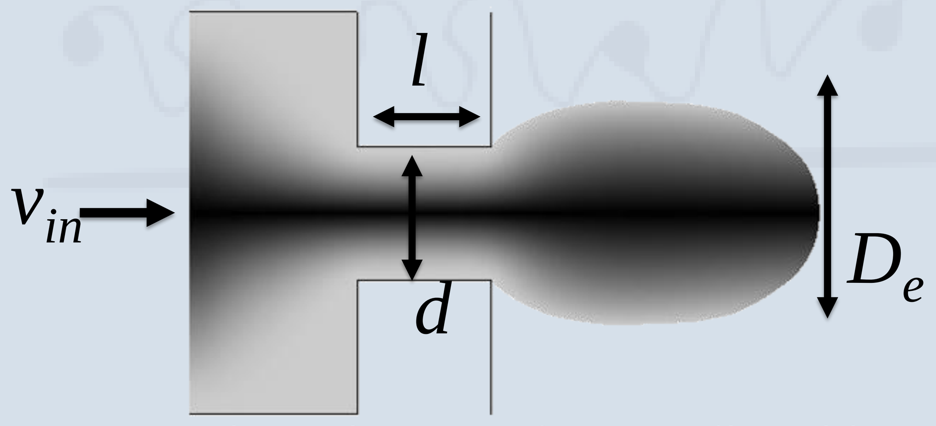
Introduction

Extrudate (or die) swell happens when a polymer melt flow exits a contraction. It is a problem in industrial polymer extrusion, potentially deforming the extruded product.



Terms Describing the Extrudate Swell Problem

The swelling ratio, $B=D_e/d$ describes how much the flow swells by upon leaving the extruder.

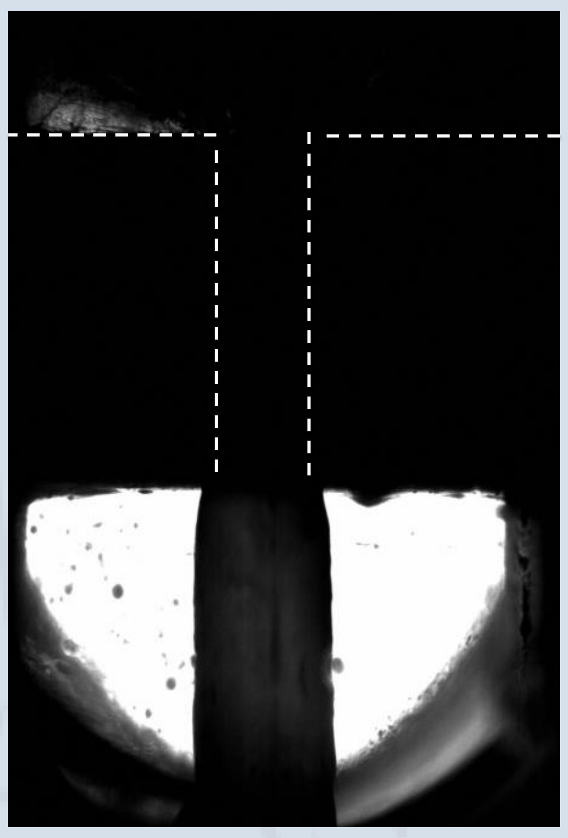
The important parameters here are the Rouse and reptation Weissenberg numbers; $W_{Rouse} = \dot{\gamma}\bullet\tau_R$ and $W_{reptation} = \dot{\gamma}\bullet\tau_d$ which increase with the flow input velocity. They describe how much the polymer chains are stretched by or oriented by the process flow. Relaxation of this chain stretch and orientation occurs at the die exit in the form of extrudate swell.

The Multi-Pass Rheometer

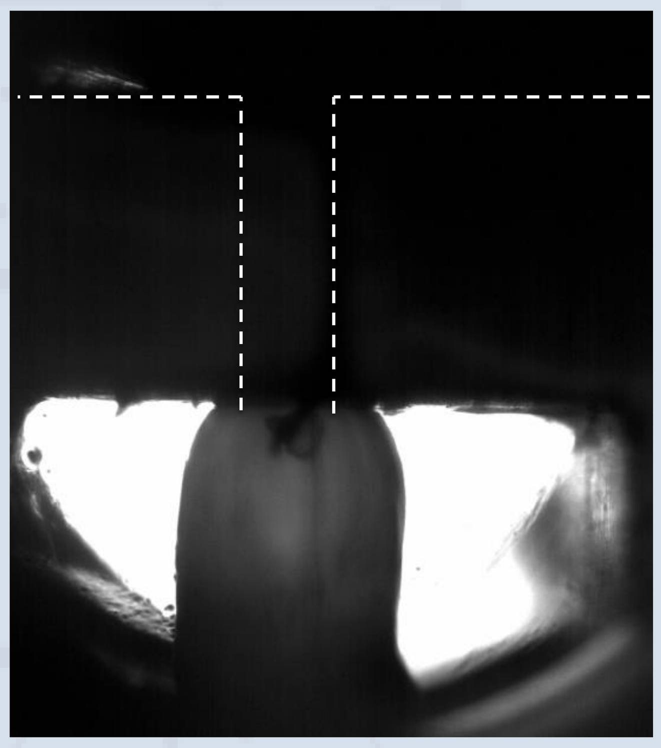
The Multi-pass rheometer (MPR) can be used to observe polymers under flow.

Moving a single piston at a controlled rate can provide extrudate swell measurements to compare to simulations.

We have designed a capillary test section to perform isothermal extrusions in which observation of swelling ratios as a function of time is possible up to high shear rates. A direct comparison with *flowSolve* is now possible.



Low W_R extrudate Swell



High W_R extrudate Swell

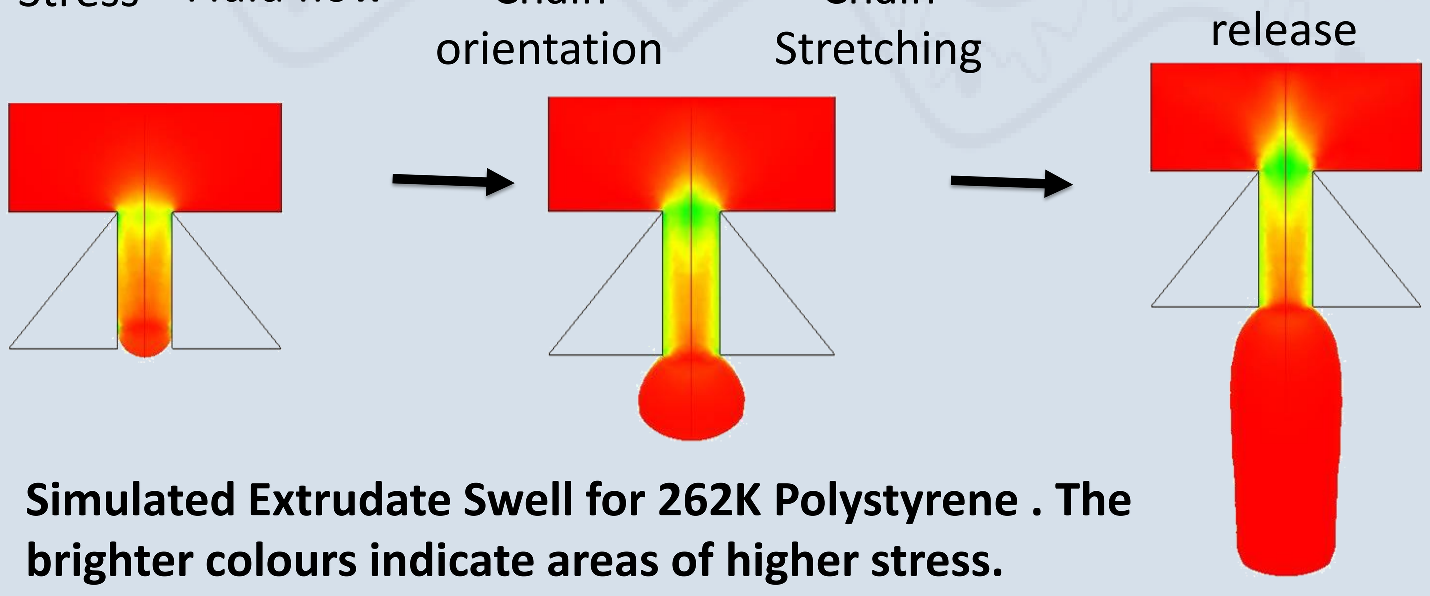
Computer Simulations

Flow simulations were performed using the fluid dynamics package/ finite element solver *flowSolve.*

The Rolie-Poly constitutive equation was used to fit the rheology of polystyrenes.

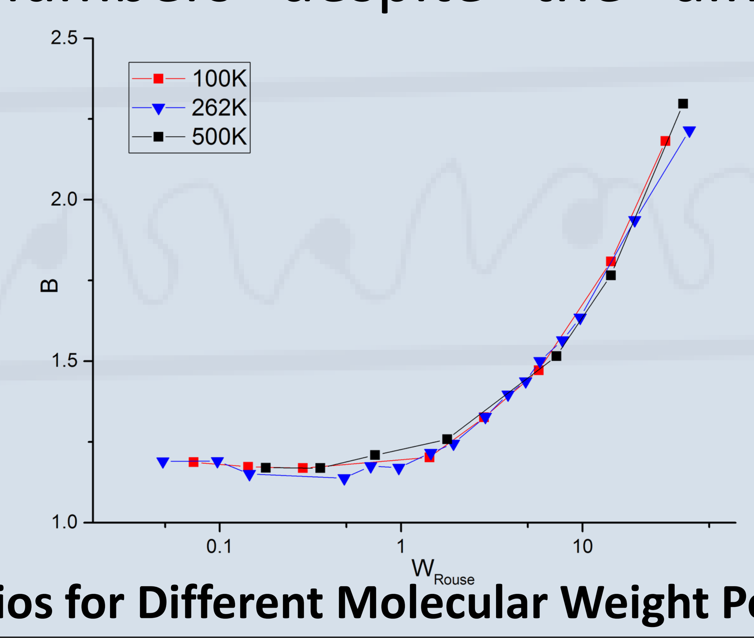
$$\frac{d\sigma}{dt} = \kappa\bullet\sigma + \sigma\bullet\kappa^T - \frac{1}{\tau_d}(\sigma - I) - \frac{2}{\tau_r}\left(\frac{\lambda-1}{\lambda}\right)\sigma - \frac{2\beta}{\lambda\tau_r}\left(\frac{\lambda-1}{\lambda}\right)(\sigma - I))$$

Stress | Fluid flow | Chain orientation | Chain Stretching | Constraint release



Simulated Extrudate Swell for 262K Polystyrene . The brighter colours indicate areas of higher stress.

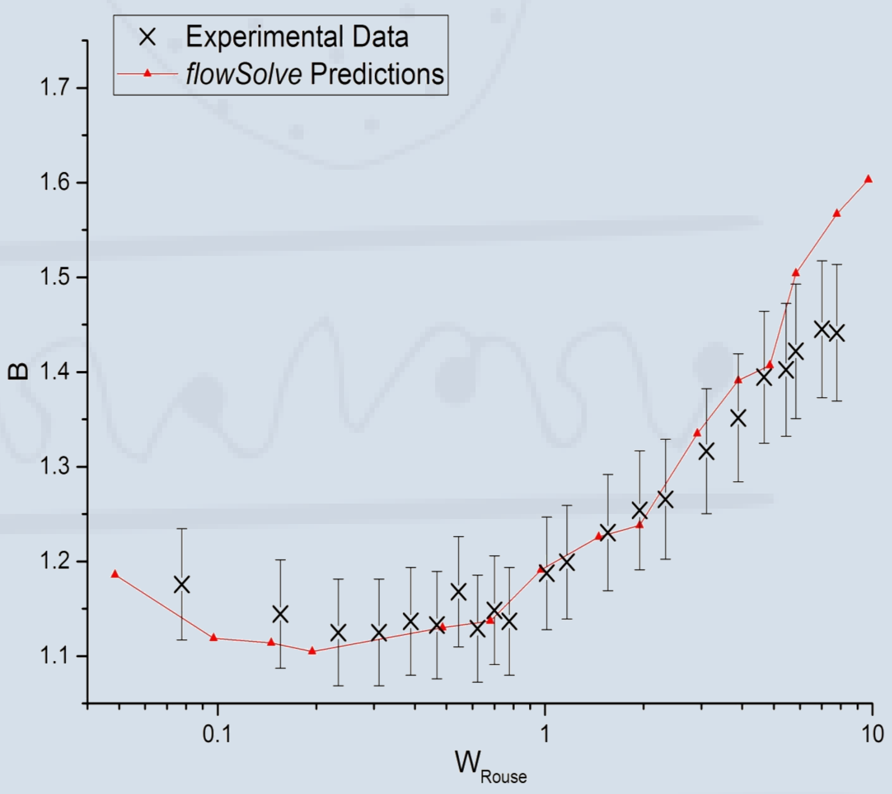
Swelling ratios fit well to a single curve at high Rouse Weissenberg numbers despite the different molecular weights.



Swelling Ratios for Different Molecular Weight Polystyrenes

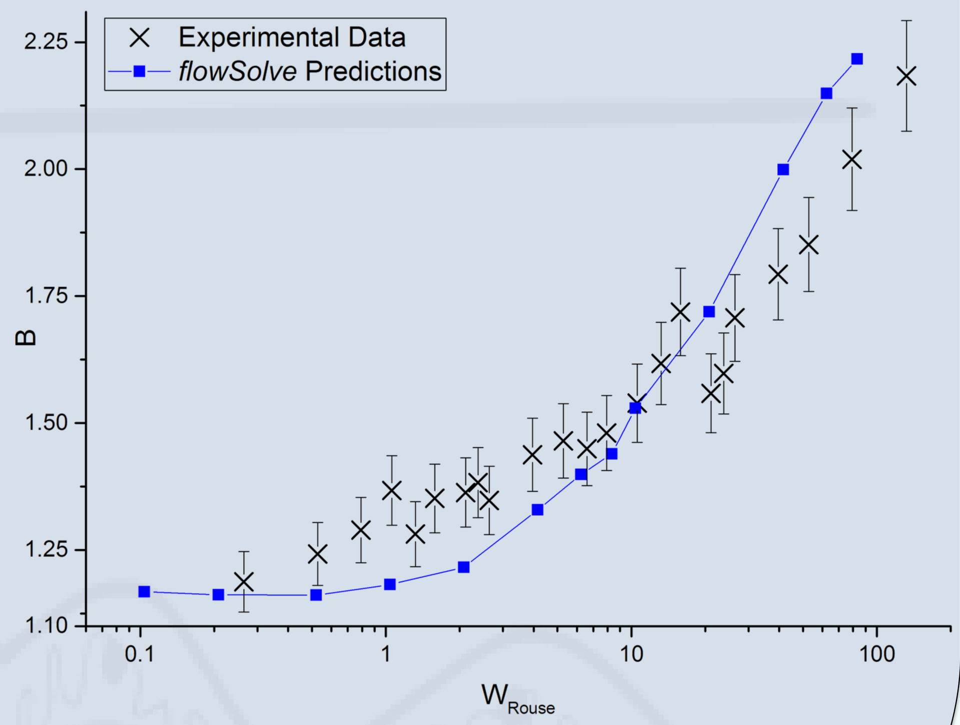
Agreements

flowSolve correctly predicts the low shear extrudate swell and the onset of increased swelling in the chain stretching regime. The theory over-predicts swelling above $W_R \approx 7$ due to limitations in the apparatus.



Experimental and theoretical extrudate swells for 262K polystyrene

Using a higher molecular weight polymer gives a better fit further into the stretching regime (due to the lower shear rates required) but a poorer fit at low shear due to polydispersity of the polymer. This will be corrected for in future work.



Experimental and theoretical extrudate swells for 433K polystyrene

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EPSRC Engineering and Physical Sciences Research Council