NUMERICAL AND EXPERIMENTAL STUDIES ON DIE SWELL IN POLYMER MELT EXTRUSION

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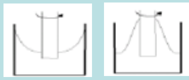
Introduction

Following issues pose significant challenges to polymer flow and swell simulations

- **Flow prediction**
  - Free surface for die swell
  - Lip and corner vortices
  - Stress in flow (birefringence)

- **Computational difficulties**
  - High Weissenberg Number Problem
  - Numerical instability
  - FE/FV mesh size
  - Simulation time step



Newtonian   Polymer

- **Causes**
  - Visco-elastic nature / memory
  - Coupling of extension and shear
  - Numerical and geometric singularities

Coupling between shear and extensional flow

Objective

To develop simulation tool for polymer flow and extrudate swell prediction using Arbitrary- Lagrangian-Eulerian (ALE) finite element method

ALE Framework

Lagrangian

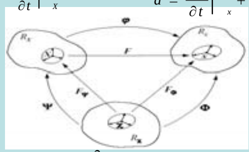
- Easy memory tracking and no convective derivatives
- No special treatment for free surface
- Faster simulation, reduced number of time steps
- High mesh distortion and need for frequent remesh

ALE ⟷

Eulerian

- Looking at a fixed window (Typical of extrusion)
- No mesh related problems
- Difficulties in treatment of convection
- Special free surface treatment

$$a = \left.\frac{\partial u}{\partial t}\right|_X \qquad a = \left.\frac{\partial u}{\partial t}\right|_x + u.\nabla u$$



$$a = \left.\frac{\partial u}{\partial t}\right|_\chi + c.\nabla u$$

$$\left.\frac{\partial f}{\partial t}\right|_\chi + c_i \frac{\partial f}{\partial x_i} = \left.\frac{\partial f}{\partial t}\right|_x$$

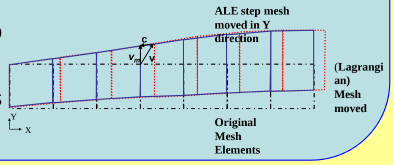
ALE - kinematics

- Computational mesh moves in an arbitrary manner, independent of the material motion

ALE fractional step method

- Lagrangian material motion (v) and mesh motion (v_m) are solved separately
- Convective velocity, $c = v - v_m$
- The variables are convected to account for mesh motion
- Easy to deal with convective terms in the constitutive equation

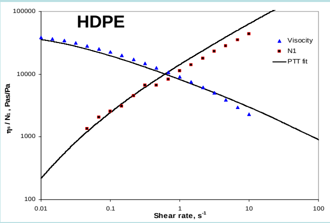
ALE-mesh motion



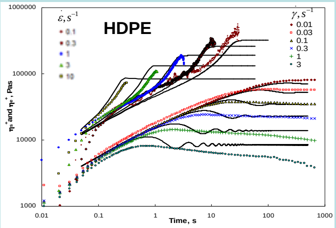
Experiments

LDPE (170A) & HDPE (DMDH6400) supplied by DOW Chemicals

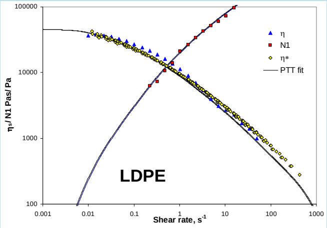
- **Rheological characterization**

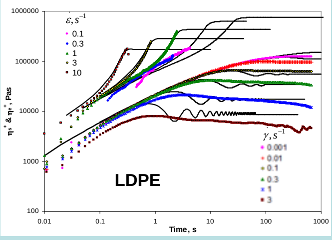


PTT fits for shear viscosity and 1st normal stress difference



PTT fits for step shear and transient uniaxial extensional viscosity

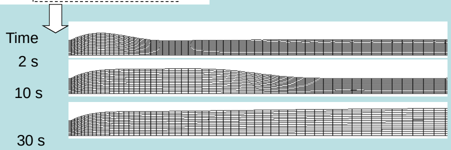




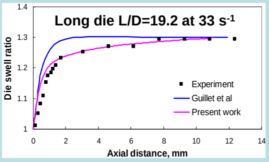
- **Extrusion: extrudate swell**
  - **Die of 2 mm diameter and L/D is 10**
  - **LDPE and HDPE melt is extrudate at 190 °C**
  - **Extrudate swell profile is captured using CCD camera**
  - **Equilibrium swell is measured at 190 °C**

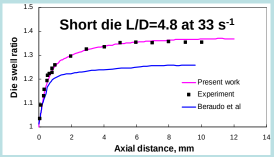
Extrudate Swell Prediction

- **Transient swell analysis**



- **Validation**





- **Comparison**

Shear Rate, s^{-1}	Swell ratio HDPE (DMDH6400)		Swell ratio LDPE (170A)	
	Experiments	Simulations	Experiments	Simulations
16	1.64	1.715	1.74	1.88
160	1.82	1.772	1.94	2.11

Conclusions

- Our simulations were validated with previously published experimental and numerical studies on swell
- Swell simulations with PTT model show good match with experiments

References

Be´raudo C., Fortin A., Coupez T., Demay Y., Vergnes B., Agassant J.F , J. Non-Newtonian Fluid Mech. 75(1998) 1–23

Guillet J., Carrot C., Kim B.S., Agassant J.F., Vergnes B., Be´raudo C., Clermont J.R., Normandin M., Be´reaux Y., in: Piau J.M., Agassant J.F. (Eds.) Rheology for Polymer Melt Processing, Elsevier 1996

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