Improving layer control in multi-layered polyester films using Computational Fluid Dynamics (CFD)

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Agenda

• What is a multi-layered film (MLF)?
• Typical DuPont Teijin Films (DTF) coextrusion structures.
• CFD modelling of typical DTF coextrusion structures:
  – An injector block linked to an end fed die;
  – A multi-manifold die (MMD).
• Comparative summary.
What is a multi-layered film (MLF)?

- A film consisting of several different polymer layers.
- Have applications in photovoltaic cells, cards and as reflector film.
- Contrasting polymer melt layers form a single structure in either an injector block linked to a die or a multi-manifold die (MMD).
- Typical MLF structures:
Common DTF coextrusion structures

• Injector block and end fed die:
  - Unified melt structure
  - Tapered outlet – for flow uniformity.

• Multi-manifold die (MMD):
  - Unified melt structure
CFD modelling of an injector block and end fed die

Injector block: 1.5 million mesh cells

Trimmer mesh used with hexahedral template cells.
Base cell size = 2.0 mm.
Minimum cell size = 0.125 mm.

End fed die: 14.5 million mesh cells
# Modelled fluid properties (ABA final film)

<table>
<thead>
<tr>
<th>Melt 1</th>
<th>Melt 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature = 285 °C</td>
<td>Temperature = 285 °C</td>
</tr>
<tr>
<td>Density = 1,250 kg m(^{-3})</td>
<td>Density = 1,250 kg m(^{-3})</td>
</tr>
<tr>
<td>Melt viscosity = 170 Pa s</td>
<td>Melt viscosity = 170 Pa s</td>
</tr>
<tr>
<td>Thermal conductivity = 0.2 W m(^{-1}) K(^{-1})</td>
<td>Thermal conductivity = 0.2 W m(^{-1}) K(^{-1})</td>
</tr>
<tr>
<td>Mass flow rate = 80 kg hr(^{-1})</td>
<td>Mass flow rate = 20 kg hr(^{-1})</td>
</tr>
<tr>
<td>Final volume fraction = 80%</td>
<td>Final volume fraction = 20%</td>
</tr>
</tbody>
</table>

- Fluids initially taken as identical, then viscosity (Melt 2) increased.
- Modelling assumptions: laminar, Newtonian, incompressible flow.
Physics used

- **Code used**: STAR-CCM+ 7.06.009.
- **Computer used**: Dell Precision T7500 Westmere (32 GB memory).

- Eulerian Multiphase;
- Implicit Unsteady (typical time-step = 1.0 s with 20 inner iterations);
- Volume of Fluid (VOF\[^1\]);
- Laminar (Re << 1 - for a 25 mm diameter pipe, Re = 0.0085);
- Cell Quality Remediation.

Progressive volume fraction – injector block
Volume fraction – end fed die

Outlet volume fraction:
(Blank end, air side clear edge width = 7.2 mm)
Total shear rate through the die

At shear rates shown, polyester melts are Newtonian.

User defined field function:

$$\dot{\gamma} = \frac{\partial u}{\partial y}$$

- User defined field function:

$$\text{abs}((\text{abs}((\text{abs}{$$gradvelocityi[1]+$$gradvelocityj[0]})+\text{abs}((\text{abs}{$$gradvelocityj[2]+$$gradvelocityk[1]})+\text{abs}((\text{abs}{$$gradvelocityk[0]+$$gradvelocityi[2]})}))$$
Flow across the outlet

- Small flow difference shows the effectiveness of the wide taper.
Flow across the outlet for increasing viscosity ratios

![Graph showing flow across the outlet for different viscosity ratios. The x-axis represents die width (mm) ranging from 1 to 409, and the y-axis represents flow (m² s⁻¹) ranging from 0.0E+00 to 1.8E-04. Three lines represent different viscosity ratios: 1:5, 1:2, and 1:1.](image-url)
### Injector block and end fed die summary table

<table>
<thead>
<tr>
<th>Viscosity (Melt 1:Melt 2, Pa s)</th>
<th>Blank end, air side clear edge width (mm)</th>
<th>Flow difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>170:170</td>
<td>7.2</td>
<td>0.73</td>
</tr>
<tr>
<td>170:340</td>
<td>7.2</td>
<td>4.14</td>
</tr>
<tr>
<td>170:850</td>
<td>9.8</td>
<td>9.56</td>
</tr>
</tbody>
</table>

- Flow difference *increases* with increasing secondary layer viscosity.
- Clear edge width *increases* with increasing secondary layer viscosity.
CFD modelling of a multi-manifold die (MMD)

Trimmer mesh used with hexahedral template cells.
Base cell size = 1.0 mm.
Minimum cell size = 0.2 mm.

MMD: 12 million mesh cells
Progressive volume fraction - MMD

Velocity vector upon combination of different fluids:

- Fluid properties used as shown for injector block and end fed die modelling.
Outlet volume fraction

Volume Fraction of Melt 1

0.00000  0.20000  0.40000  0.60000  0.80000  1.00000
Flow across the outlet

Flow difference between circled regions = 5.04%

- Small taper gives a larger flow difference than with the end fed die.
Flow across the outlet for increasing viscosity ratios
MMD summary table

<table>
<thead>
<tr>
<th>Viscosity (Melt 1:Melt 2, Pa s)</th>
<th>Clear edge width (mm)</th>
<th>Flow difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>170:170</td>
<td>11.0</td>
<td>5.04</td>
</tr>
<tr>
<td>170:340</td>
<td>10.9</td>
<td>3.11</td>
</tr>
<tr>
<td>170:510</td>
<td>10.7</td>
<td>2.66</td>
</tr>
<tr>
<td>170:850</td>
<td>10.1</td>
<td>2.18</td>
</tr>
<tr>
<td>170:1,700</td>
<td>9.7</td>
<td>2.00</td>
</tr>
</tbody>
</table>

- Clear edge width *decreases* with increasing secondary layer viscosity.
- Flow difference *decreases* with increasing secondary layer viscosity.
Comparative summary

- **Numerical comparisons:**
  - MMD requires 4 million mesh cells less than the other system.
  - End fed die residuals: $10^{-10}$ to $10^{-21}$. Converged at 6,000 iterations.
  - MMD residuals: $10^{-6}$ to $10^{-15}$. Converged at 2,500 iterations.

- **Comparisons between modelling results:**
  - Interface is more uniform and clear edges obtained with an MMD.
  - For wider viscosity ratios, the MMD has the more uniform flow.
  - The end fed die has a wider clear edge with a more viscous secondary layer (as expected). This is not found with the MMD.

- **Planned future work:**
  - Extending to wider, industrial scale geometries.
  - The study of very thin secondary layers.
  - Experimental validation.
Acknowledgements

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Any questions?
Flow across reduced MMD outlet

Flow (m²/s)

Die width (mm)
Flow with increasing primary layer viscosities