Polyolefin Plastics
Still a challenge for Chemical Engineers?
R. J. Koopmans
Corporate R&D
Dow Benelux BV
Polyolefin Plastics

- What does it take to make it
- Applications
- Processing
- Chemistry
- Feedstock
- History
- Future
What does it take to make Plastics?

- Plastics
  - An ensemble of polymers and other organic and/or inorganic components

- Polymers
  - An ensemble of macromolecules of equal chemical composition but of different molecular mass

- Macromolecules
  - An ensemble of large molecules of same chemical composition and molecular mass
What does it take to make Plastics?
What does it take to make Plastics?

**The Plastics Industry**

- **Western Europe**
  - 1.1 mm employed
  - 135 billion Euro
  - 45 Global Companies
  - 30,000 SME

- **World**
  - > 120 mm T
  - 5% average growth
What does it take to make Plastics?

Primary Resource Development

Raw Materials
- Mineral oil, Natural gas, coal, minerals, animal & vegetable products, salt

Plastic Products
- Powder, granules, pastes, liquids, dispersions, compounded polymers and resin systems for structural uses

Additives
- Plasticisers, lubricants, stabilisers, colourants, antioxidants

Heat

Pressure

Plastic Processing
- Extrusion, injection and compression, moulding, calendering, casting, foaming, laminating

Fabrication and use
- Assembly into finished products for consumer and industrial use

End Use & Recycling

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What does it take to make Plastics?
Plastics Applications & Use by Sectors in Europe

- Thermoplastics
  - Commodity plastics
  - Engineering plastics
- Thermosets

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Plastics Applications & Use by Sectors in Europe

- Building / Construction: 19%
- Electrical / Electronic: 8%
- Agriculture: 3%
- Other Household / Domestic: 18%
- Large Industry: 4%
- Automotive: 7%
- Packaging: 41%
Application Performance

- Low Cost
- Light Weight
- Though
- Easy processing
- Sustainable – recyclable
- ....
Applications:
Brittle and Ductile failure

Brittle tear

Ductile tear
Applications: Tensile Testing

Stress Strain Behavior

Crazes
Shear bands
Localized neck

Load
Extension

“FAST”
“SLOW”

Yield
Post yield drop
Strain hardening

Consider temperature also

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Applications:
Crystallisation
Extrusion Blown Film Application
Processing of Film:
Extrusion Casting process
Extrusion Blowing process

Output driven
Extrusion Blown Film Process

Collapsing Frame

Stabilizing cage

Air Ring

Extruder

Die

Nip rolls

Winder

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Processing Challenges

Film distortions come in many shapes
Melt Flow Instabilities

\[ \eta_0 \text{ key metric of the flow curve} \]
Capillary Rheometer

Rheometer barrel

Die diameter 2R

Capillary die

Extrudate diameter 2R_ex

Pressure

Die entry pressure drop P_{ent}

Capillary pressure gradient

Die exit pressure drop P_{ex}

Shear Viscosity Only!

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Melt Flow Instabilities

- Examples: LLDPE, HDPE, PP, PS
  - all distortion types

- volume distortions
- entrance
- surface distortions
- exit
- free surface
- die land
- spurt distortions

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Extrusion Blow Molding of Bottles

A programmed parison designed to fit a particular mold configuration.
Cast Extrusion

Sheets & Films
-Single or multilayer

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Cast Sheet Extrusion
Cast Extrusion

3 Kinematic hypotheses: 
\[ \dot{\epsilon} = \begin{bmatrix} \frac{du}{dx} & 0 & 0 \\ 0 & f(x) & 0 \\ 0 & 0 & g(x) \end{bmatrix} \]
Membrane approximation \((\sigma \cdot e_z = 0)\)
\[ u(x); v(x, y) = y \cdot f(x); w(x, z) = z \cdot g(x) \]

Mass conservation: 
\[ \frac{\partial (eL)}{\partial t} + \frac{\partial (eL \dot{u})}{\partial x} = 0 \]

Force Equilibrium: 
\[ \text{div}(\varepsilon \sigma) = 0 \]
(inertial, gravity, surface tension << drawing force)

Constitutive equations: 
\[ \begin{cases} 
\sigma = \sigma' - \rho I \\
H(\sigma')\sigma' + \frac{\lambda}{\eta} \frac{\partial \sigma'}{\partial t} = 2\eta \dot{\epsilon} \\
H(\sigma) = \exp \left[ \frac{\varepsilon \lambda}{\eta} tr(\sigma) \right] I \\
\frac{\partial \sigma'}{\partial t} = \frac{\partial \sigma}{\partial t} + (u \nabla) \sigma' - \varepsilon \cdot u \sigma' - \sigma'' \cdot \nabla \cdot u 
\end{cases} \]

Boundary conditions: 
\[ \sigma \cdot n = 0, \quad U \cdot n = 0 \]
(Edge of the film is a free surface)

Dimensionless numbers: 
\[ Dr = \frac{u_{\text{roll}}}{u_0}, \quad A = \frac{X}{L_0}, \quad De = \frac{\lambda u_0}{X}, \quad \frac{1}{E} = \frac{FX}{\eta_0 L_0 u_0} \]

Cast Film Stability Map

Viscoelasticity introduces web breaks
Unattainable = Rupture