Fundamental Concepts of Extrusion Design

Presented By:
Lou Piffer
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Extruder Components

- extruder screw
- extruder barrel
- feed throat
- hopper
- extruder drive
- reducer
- barrel heating and cooling
AC / DC Drives & Motors
Drive Motor

- 6” - 400/500 HP
- 4 1/2” - 250 HP
- 3 1/2” - 150 HP
- 2 1/2” - 75 HP
GearBox
Gearbox

• Converts high speed output shaft from drive (1750 RPM) to screw speed
Gearbox

- Closed loop oil circulation system insures gears do not see excessive heat
Thrust bearing
B-10 Life

Expected Life of 9 out of ten bearings at a given condition
Predictive Maintenance

• Bronze in oil - out of round thrust bearing
• Steel in oil - bad bearing or gear tooth
• Cast iron powder in oil - moving part against gear box casting
Feedsection
Feed Section

- Cast iron jacketed
- Initial point where resin is introduced
- Space between gear box and resin feeding point
Resin Hopper

- Hopper often cooled to prevent bridging
PARTS OF THE EXTRUDER

- Hopper
- Feed section
- Gear box
- Screw cooling
- Belt drive
- Screw
- Cooling
- Drive
- Screen changer
- Heaters-coolers
- Cylinder (barrel)
- Structure
Extruder Barrel

• 1/16” Bimetalic Alloy
• Bolted to feedsection
• The barrel is harder than the screw.
• Sliding barrel support
Barrel Types

- Non abrasive environments - Chromium-modified boron-iron alloy.
- Abrasive environments - Tungsten carbide in a matrix of nickel alloy.
- Abrasive style barrel may cost 25% more but last 3X longer!
Barrel Wear

- 1/16” (.0625”) thick when new
- Should look at replacing barrel when there has be .030” of wear.
Screw Wear

- Initial clearance of 1 mil/extruder diameter/side
- Example .4.5” extruder will have initial clearance of approximately .0045/side
- Look to replacing screw when clearance doubles to triples. (In above example when clearance is .009 - .0135”)
Barrel Heater Types

- Ceramic Band (heat only)
- Electric Heat - Air Cooled
- Electric Heat - Water Cooled
Water cooled Heaters

- Jacketed Heater
- Solenoid valves
- Inlet/outlet manifolds.
- Water reservoir
Water cooled Heaters

- Jacketed Heater
- Solenoid valves
- Inlet/outlet manifolds.
- Water reservoir
Air cooled Heaters

- Finned Heater
- Air Blowers
Air cooled Heaters
Extruder Adapter
Extruder Adapter

- Change resin flow
- Change pressure
- House screen pack
Valved Adapter

- Screw
- Pressure sensor
- Movable valve
- Screen pack
- Melt channel
PARTS OF THE EXTRUDER

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Extruder Adapter

- Change resin flow
- Change pressure
- House screen pack
INLET
Heater Bands 180° helix elements induce flow division

Dispersion Lug

Lug

Motionless mixers improves both melt temperature uniformity and color dispersion (4 elements or more)

OUTLET

Static Mixer Principle

INLET

Heater Bands 180° helix elements induce flow division

Dispersion Lug
Fundamental Concepts of Screw Design

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What will I learn?

• Why can’t my screw run all resins?
• Why are barrel profiles unique to a screw design?
• Why can increased barrel temperature sometimes result in less output?
• What happens when my screw wears out?
Viscous Heat Generation

Heat = Viscosity x Shear Rate$^2$
Screw Terminology

- Lead
- Channel Depth
- Helix Angle
- Flight Clearance
- Screw O.D.
- Flight Width
- Bimetallic Liner
- Barrel
Typical Screw Classifications

- Metering Screw
- Mixing Screw
- Barrier Screw
Important Ratio Terms

- **L/D = Length/Diameter**
- **CR = Compression Ratio**
  
  \[
  CR = \frac{\text{Feed Channel Depth}}{\text{Meter Channel Depth}}
  \]

  - Compression Ratio has no meaning for barrier type screw designs
Primary Functions of a Single Screw Extruder

- Optimized screw design must accomplish
  - Solids Conveying
  - Melting
  - Pumping
  - Mixing

- Each component is critical to the extrusion process
Primary Functions of a Single Screw Extruder

- Feeding
- Melting
- Pumping / Mixing
Feeding/Solids Conveying
Solids Conveying

• Formation of a compacted solid bed
Some of the Most Important *Bulk Properties*:

- bulk density
- compressibility
- internal coefficient of friction
- external coefficient of friction
- particle size and particle distribution
- particle shape and particle distribution
Plastic Forms for Extrusion

- Spherical pellet
- Ellipsoidal pellet
- Cylindrical pellet
- Cubical pellet
- Film scrap
- Irregular pellet
- Powder granules
Resin Hopper

- Hopper often cooled to prevent bridging
Drag Induced Conveying
The frictional force at the barrel is responsible for moving the material forward.
For efficient forward conveying we want high friction on the barrel and low friction on the screw.

If there is no barrel friction, then there can be *no* forward conveying.
Solids Conveying
A wide distribution in particle size makes the material more difficult to convey and can lead to separation.
Melting
Melting

- Formation of a compacted solid bed
- Development of a melt film
Melting

• Formation of a compacted solid bed
• Development of a melt film
• Removal of melt into an accumulating melt pool
Contiguous Solids Melting
EFFECT OF BARREL TEMPERATURE

Viscous Heating

Heating From The Barrel Heaters

Heat vs. Barrel Temperature
Viscous Heat Generation

Heat = Viscosity x Shear Rate^2
Factors that effect the melt rate

• Melt Film Thickness
Contiguous Solids Melting
Factors that effect the melt rate

• Melt Film Thickness
• Barrel Temperatures
Contiguous Solids Melting
Factors that effect the melt rate

• Melt Film Thickness
• Barrel Temperatures
• Screw Speed
Barrier vs. Single Screw Melting
Single Stage Mixing Screw vs. Barrier Screw

Mixing and Barrier Screws
Melting Model – Single Flighted Screw

B A R R E L

Material Flow
MELTING MECHANISM SEEN IN SCREW PUSH-OUTS

BARRIER SCREW

CONVENTIONAL SCREW
Solid Bed Break-Up

- Cyclic variation in pressure profile
- Movement of solid bed
Solid Bed Break-Up

Movement of Solid Bed

Solid bed in solids channel

Full melt in solids channel
Melting Barrier Screw

• Barrier flight isolates solid bed from melt pool
• Solids and melt channel depths vary independently to accommodate accumulating melt pool and diminishing solid bed
• Critical design variables:
  – Solids channel compression
  – Barrier flight undercut
Melting - Barrier Screw
Mid Barrier Cross-Sectional Photos
Melt Temperature

Influenced primarily by two factors:

• **Conduction**
  \[ = f (\text{residence time, barrel set-points, limitations of heating/cooling units...}) \]

• **Viscous Energy Dissipation (VED)**
  \[ = f (\text{viscosity, shear rate...}) \]
Mixing in
Single Screw Extrusion
Mixing

• DISTRIBUTIVE
  – Increase of interfacial area between two miscible components
  – Splitting and recombination of flow streams

• DISPERSIVE
  – Shear induced particle size reduction of immiscible components
Mixing and Quality

- Poor mixing can affect:
  - Physical properties
  - Product Uniformity
  - Aesthetics

Micro-graphs 100X 0.15 MI HDPE+5% CBMB
Mixing Sections

DISTRIBUTIVE
• Pineapple Mixer
• Saxton Mixer
• Dulmage Mixer

DISPERSIVE
• Union Carbide Mixer
• Helical UCC
• Cavity Transfer Mixer
Pineapple Mixing Section
Pineapple Mixing Section

Streamlines Showing Distributive Mixing

100X HDPE+5% CBMB
Helical Union Carbide Mixing Section (UCC-T)
Helical Union Carbide Mixing Flow Pattern

Channel Cross Section

100X HDPE+5% CBMB
EGAN Mixer

- Similar to UCC mixer
- Higher pressure drop
- Intensive shearing
- Surface of barrel not wiped by flight (completely under-cut)
Screw Designs for Extrusion Coating Applications
Conventional Mixing Screws

- Workhorse design for processing extrusion coating resins since the 1960’s
- Typical Design
  - 28:1 - 32:1 L/D
  - Shallow Metering Depth
  - 4:1 Compression Ratio (CR)
  - Single mixing section (Egan or UCC)
Double Mixing Screw

• A conventional screw with two barrier mixing sections introduced in the 1980’s
  – Boost output rate (10-15%)
  – Improve reliability of adhesion at higher outputs

• Higher output applications necessitate the use of a static mixer to improve melt temperature homogeneity across the melt curtain
Barrier Screw Designs

- Recommended for LLDPE and engineering resins in extrusion coating applications
- Also beneficial for lower temperature / higher output polyolefin applications
- Offers superior melting rates and process stability
Performance Comparison

8”, 30L/D Extruder
Resin: LLDPE Dowlex 3310
Conventional vs. Barrier

Barrier screw provides higher rate and lower melt temperatures
SCREW COMPARISON
What will I learn?

• Why can’t my screw run all resins?
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• Why can increased barrel temperature sometimes result in less output?
• What happens when my screw wears out?
## LDPE VS PP COMPARISON

<table>
<thead>
<tr>
<th>Property</th>
<th>LDPE</th>
<th>PP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Density (kg/m³)</td>
<td>920</td>
<td>907</td>
</tr>
<tr>
<td>Melt Density (kg/m³)</td>
<td>750</td>
<td>735</td>
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<tr>
<td>Thermal Conductivity, Solid (J/s.m.°C)</td>
<td>0.28</td>
<td>0.22</td>
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<tr>
<td>Thermal Conductivity, Melt (J/s.m.°C)</td>
<td>0.24</td>
<td>0.15</td>
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<tr>
<td>Heat Capacity, Solid (J/kg.°C)</td>
<td>2300</td>
<td>1700</td>
</tr>
<tr>
<td>Heat Capacity, Melt (J/kg.°C)</td>
<td>2300</td>
<td>2100</td>
</tr>
<tr>
<td>Melting or Softening Temp, °C</td>
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<td>163</td>
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<tr>
<td>Freezing or Hardening Temp, °C</td>
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<tr>
<td>Frictional Coefficient, f</td>
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<tr>
<td>Degree of Crystallinity</td>
<td>Low</td>
<td>High</td>
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<tr>
<td>Molecular Weight Distribution</td>
<td>Narrow</td>
<td>Broad</td>
</tr>
</tbody>
</table>
Solid Conveying - PP vs. LDPE

• PP more crystalline, pellets are harder and less elastic. Lower friction between PP and barrel.

• PP has higher melt temperature. Requires longer feed before compression starts.
Melt Conveying - PP vs. LDPE

• Melting rate is limiting factor for PP.
• Melt conveying rate is limiting factor in LDPE
General Screw Design - PP vs. LDPE

- LDPE screw would have shorter feed and faster transition.
- PP screw would have a shallower metering section to help in melting.
Thank You

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