Processing Exceed Metallocene Polyethylenes

Polyethylene Film Training Program

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Overview

- General processing considerations
- General screw / barrel considerations
- General die and air ring considerations
- General downstream equipment considerations
- Recommended temperature profiles for blown and cast film

- *Note: the processing information herein refers to the use of Exceed mPE - a narrow molecular weight distribution resin with no long chain branching. It may not be applicable to other metallocene produced polymers.*

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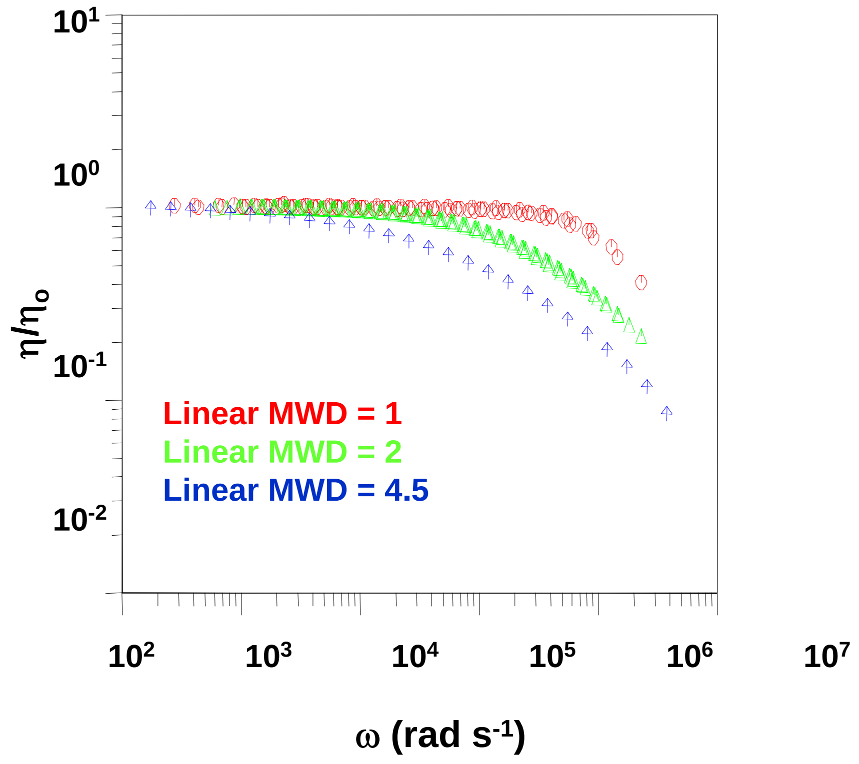
Why mPE Extrudes Differently than LLDPE



- Polyethylenes made by metallocene catalysts have narrower molecular weight distributions (M_w/M_n, MWD) than LLDPE
  - LLDPE (Ziegler-Natta) has MWD 3.5 to 4.5
  - mLLDPE (example Exceed™ polyethylene) has MWD 2.5 to 3.0
  - Plastomers (example Exact™) have MWD 2.0 to 2.5
- Narrower MWD results in melt viscosity that is less responsive to shear

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Considerations for Processing Exceed mPE

- Almost all modern extruders designed for LLDPE can process Exceed mLLDPE without difficulty, but some adjustments will optimize the process (i.e., screw, air ring, and to some extent die modifications)
- mLLDPE processes very much like Z-N LLDPE
- Plastomers are slightly harder to process in monolayer structures
- Co-ex structures present few processing problems

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Considerations for Extruding Exceed mPE

- Exceed mPE is slightly less shear sensitive than Z-N LLDPE due to narrow MWD resulting in:
  - More viscous behavior at typical extrusion shear rates
  - More shear heat generation with existing LLDPE screws, which require cooler barrel temperature profiles or lower work screws (i.e. screws with lower compression ratios that generate less shear)
  - Somewhat higher torque and motor load requirements (5-15%) but generally no limitation of film productivity with addition of 3 - 10% LDPE (little to no property sacrifice)

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Considerations for Blown Film Exceed mPE

- Slightly lower melt strength / bubble stability than Z-N LLDPE
  - Easier to draw down to thin gauges from wide die gaps (cost savings)
  - Not an issue in cast film but blown film systems may exhibit lower rates if cooling limited. Can be improved by:
    - Blending 3-10% HP LDPE
    - Screws having larger barrier clearances (lower melt temperatures)
    - Air rings having enhanced bubble stabilization features
    - Lower pressure dies and coarser screen packs (lower extrusion pressures and heat generation)

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Considerations for Cast Film Exceed mPE

- Cast film processing of mPE is very similar to ZN-LLDPE
  - Can downgauge through typical die gaps (20-30 mil) by 10-15% without draw resonance vs. Z-N LLDPE
  - Can run at higher temperatures to reduce motor load
  - Rule of thumb - 3 MI mLLDPE extrudes like 2 MI Z-N LLDPE at like temperature profiles

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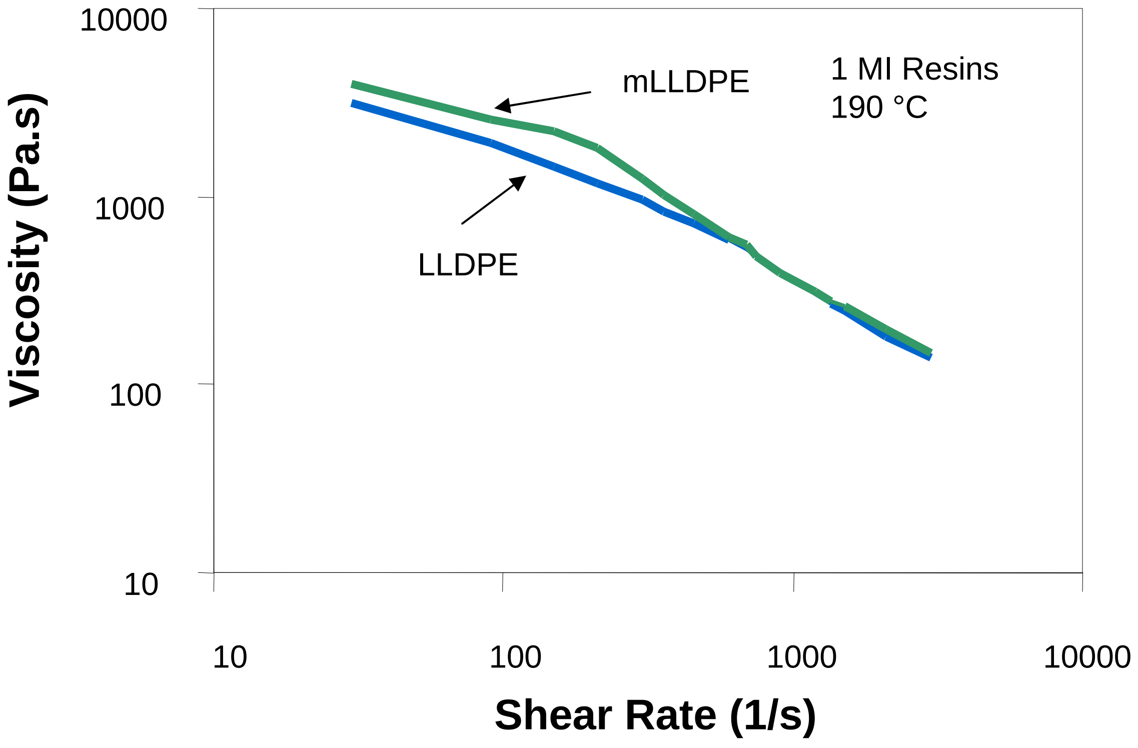
Rheology of mLLDPE and LLDPE



-Exceed mLLDPE has slight higher viscosity than Z-N LLDPE at same melt index

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Screw and Barrel Considerations

- Metallocene catalysts are very high efficiency
  - Very clean polymer with low total ash
  - No acidic nature’
  - Very thermally stable
- Extruder types
  - Generally the same as for ZN-LLDPE
  - 24 - 30:1 L/D smooth bore barrels work well
  - Grooved feed bushings also used successfully but to date usually produce lower specific throughput due to sifter pellets; more evident with plastomers
- Melt filtration requirements are minimal
  - 40 mesh for blown film
  - 80 mesh for cast film

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Ideal Blown Film Extrusion Temperatures

Resin Type	Melt Index (g/10 min)	Density (g/cc)	Target Melt Temperature (°F)
ZN-LLDPE	1.0	≥ 0.918	400 to 430
Exceed mLLDPE	1.0	≥ 0.910	390 to 420
Exact Plastomer	1.0	< 0.915	370 to 390

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Screw and Barrel Considerations

- Extruder Screws
  - Dual channel, low shear barrier mixing screws preferred for smooth bore extruders (~.050" undercuts)
  - Must be able to handle blends with HP LDPE
  - New screw considerations - slightly larger barrier clearance and slightly deeper metering depth but must accommodate HP blends

    - Very low work (VLW) screws (.065 - .075" straight undercut) reduce melt temperature and increase rate for 100% mLLDPE but are probably inadequate for blends
    - New low work (LW) variable depth barrier clearance screws from feed section to metering (~0.080 to 0.045 undercut) have demonstrated reduced melt, excellent homogenization and increased rate for 100% mLLDPE and in blends to 30%

Screw and Barrel Considerations

- High shear screws are not recommended for mPE resins since the polymer has very low gel content and has low shear sensitivity; can be adequately homogenized at moderate shear
- High shear also results in higher melt temperatures which can reduce bubble stability and resin output
- Metering screws are not recommended for mPE because they result in lower output and decreased melt homogenization and quality
- Low to medium shear mixing device, e.f. Maddock mixer, recommended at screw tip to two to three turns from screw tip

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Low Shear Screw Comparison

Parameter	Conventional LLDPE Screw	Low Shear Test Screw
Solids channel	deep, narrow	shallower, wider
Barrier flight clearance	0.050 inch	0.065 inch
Maddock mixer barrier clearance	0.050 inch	0.075 inch
Metering zone channel depth	0.325 inch	0.320 inch

- Comparison of 3.5 inch, 24L/D barrier screws
- Ramp temperature used for this work - 330, 340, 350, 370, 380 °F
- Hump profile now recommended 310, 390, 370, 340, 340 °F

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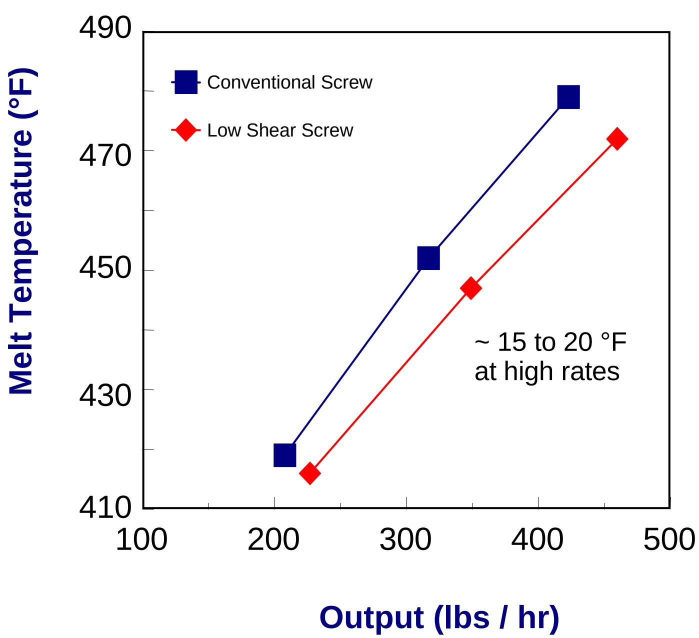
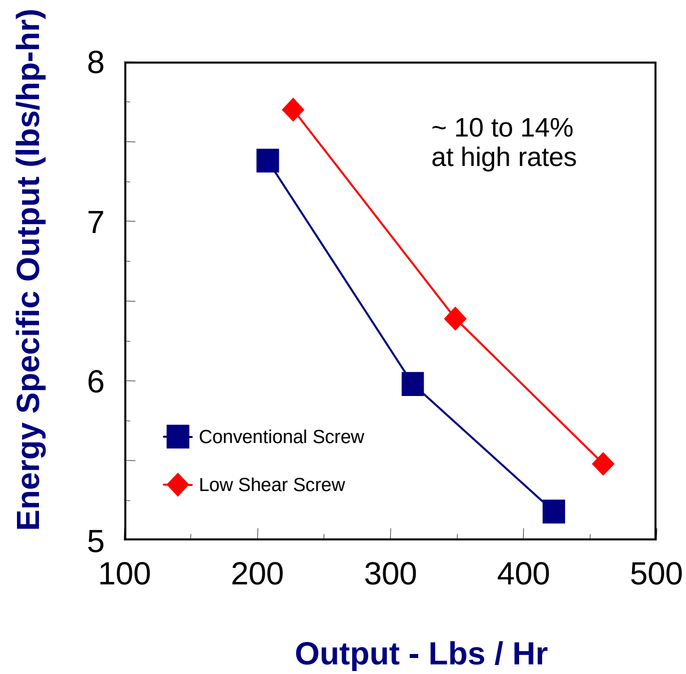
Low Shear Screw Comparison

Melt Temperature vs. Output



Energy Efficiency vs. Output



- Low shear screw results in lower melt temperature and increased output rates

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Smooth Bore Compared to Grooved Feed

Process Performance Parameter	Smooth Bore Barrel	Grooved Feed
Pressure generation, pumping	In metering section, melt phase	In feed section (mainly), solids phase
Pressure profile	Ascending	Descending or near level
Pressure flow	Negative	Positive to near zero
Shear heat generation in polymer melt	High	Moderate to low
Melt temperature control	Challenging	Easier
Performance sensitivity to head pressure	Significant	Low to negligible
Output specific power efficiency (lb/hp-hr or kg/kwh)	Good	Better
Ability to feed hard pellets	Can be difficult	Excellent
Ability to feed soft pellets	Excellent	Can be very difficult
Major design challenge for mLLDPE processing	Melt temperature control at low levels	Feeding of soft pellets without groove fouling

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Smooth vs Grooved Feed Comparison

Resin	Melt Index	MIR (I_{21}/I_2)	Smooth Bore 3.5 inm 24 L/D			Smooth Bore 2.5 in, 24 L/d			Grooved Feed 80 mm, 24 L/D			Grooved Feed 75 mm, 21 L/D		
			lb/ rev	T_m	lb/hp -hr	lb/ rev	T_m	lb/hp-hr	lb/ rev	T_m	lb/hp -hr	lb/ rev	T_m	lb/hp -hr
ZN-LL	1.0	29	7.4	425	8.1	2.2	415	8.8	7.1	408	10.2	4.6 4.7	376 375	9.9 9.9
mLL	1.0	16	7.4	450	7.2	2.2	430	8.2	5.3	430	8.5	3.4 4.5	418 383	7.8 9.0
Plastomer	1.2	15	8.5	415	8.7	2.5	395	9.0	4.3	401	10.3	2.2 2.6	418 406	7.7 9.8
			LLDPE barrier screw with mixer, 50 mil die gap						Barrier screw with mixer			Single channel screw with mixers, 2nd screw has deeper, longer feed		

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Requirements for mLLDPE Extrusion

Extruder Size* (in)	Torque (HP / RPM)	Drive Power (HP)	Max Screw Speed (RPM)
2 1/2	0.5 to 0.6	50 to 75	100 to 125
3 1/2	1.25 to 1.30	125 to 150	100 to 115
4 1/2	2.5	200 to 250	80 to 100
6	5.0 to 5.3	300 to 400	60 to 75

* 24 L/D

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Die Considerations

- Most dies designed for LLDPE work well for both mLLDPE and plastomers
  - As is the case in LLDPE, wider spiral clearances will beneficially reduce die pressure
  - Moderate to wide die gaps (60 - 90 mils) and land lengths of 3/8" - 1/2" reduce the tendency to melt fracture
  - Special dense chrome plating of die body and mandrel also reduce the tendency of melt fracture and ease of purge transition
- Most mPE for blown film extrusion contain process aid to minimize melt fracture

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Air Ring Considerations

- Bubble Cooling / Stabilization
  - Dual-orifice air rings and chilled air ($\leq$65°F) are recommended for mLLDPE and are essential for monolayer plastomer film production at high rates.
  - mLLDPE crystallizes 5-6°C lower than Z-N LLDPE, and has slightly lower melt strength. Plastomers have even lower crystallization temperatures, resulting in lower outputs if cooling limited, and higher frostline heights.

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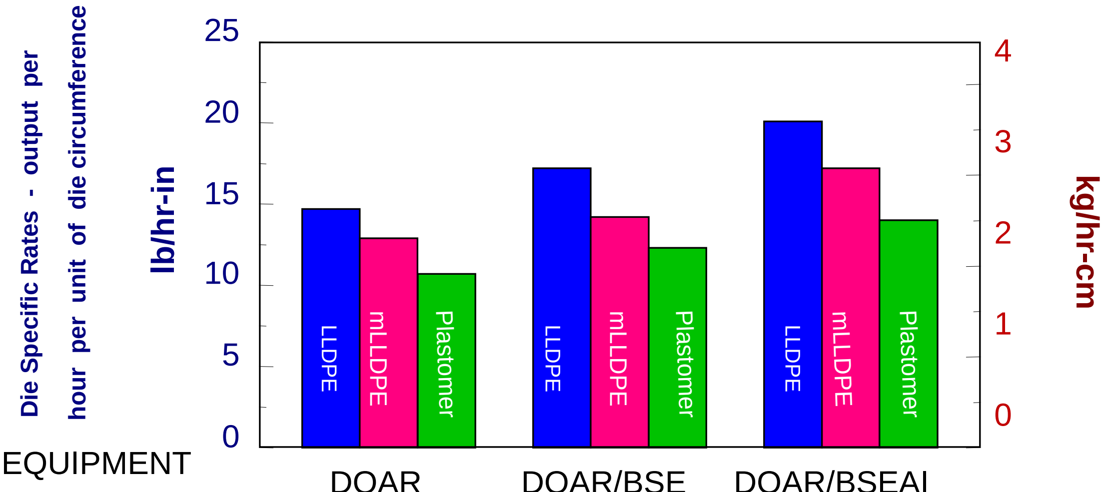
Air Ring Considerations

- Bubble Stability Enhancements
  - Lower melt temperatures
  - Addition of small amounts of HP-LDPE (3-10%)
  - Internal bubble cooling (IBC)
  - Low friction bubble stabilizing cages above the frost line
  - Air ring enhancements
- Recent air ring technologies have demonstrated increased production for mLLDPE versus Z-N LLDPE. Validation work is underway.
  - Earlier advances that increased rates for mLLDPE also demonstrated same rate increase for Z-N

Demonstrated Blown Film Production Rates



EQUIPMENT		DOAR	DOAR/BSE	DOAR/BSEAI
LL-3001.44		14.7	17.2	20.1
Exceed 350D65	(blue)	12.9	14.2	17.2
Exact 3128	(pink)	10.7	12.3	14.0
	(green)			

DOAR= Dual Orifice Air Ring
DOAR/BSE= Dual Orifice Air Ring with Bubble Stability Enhancer
DOAR/BSEAI= Dual Orifice Air Ring with Bubble Stability Enhancer and IBC

* Medium Sized Dies (~10"), Refrigerated Air (~50 deg F, 10 deg C)

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Downstream Equipment Considerations

- Overall film handling considerations from die to nip-coolest possible chilled air without causing condensation is preferred.
  - Higher tower heights are preferred if economically feasible
  - Lowest possible nip pressure without air loss is recommended
  - If available nip cooling is beneficial
  - Use of bubble sizing cage is recommended even w/o IBC

- Bubble collapsing frames / tension control
  - Low friction collapsers such as Teflon®rollers, or air boards preferred, especially for plastomers
  - Use lowest possible tension consistent with good web tracking from primary nips to winder
  - New conveyor belt technology

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Downstream Equipment Considerations

- Slitting, trimming
  - Very sharp blades are required to cut these tough flexible films- Slit mLLDPE like Z-N LLDPE. Plastomers may require ceramic blades
  - For plastomer densities $\leq$ .885, score slitting is recommended

- Winding
  - Center winders with low lay on pressure and taper tension work well
  - Surface winding with adjustable lay on or gap winding also used successfully on mLLDPE
  - Gap winding may also be employed for plastomers
  - Handle plastomers like HEVA (soft elastic) films and mLLDPE like pallet stretch film when considering winding needs

Typical Extrusion Conditions- Smooth Feed

	Blown Film		Cast Film	
MI	1.2	1.0	3.5	3.5
Density	0.900	0.918	0.900	0.918
Resin	Plastomer	mLLDPE	Plastomer	mLLDPE
	°F	°F	°F	°F
Target Melt Temperature	395	410	490	520
Extruder				
Zone 1	310	320	330	350
Zone 2	370	390	480	520
Zone 3	360	370	470	500
Zone 4	340	350	450	470
Zone 5	340	350	450	470
Adapter	370	390	480	500
Screen Changer	370	390	480	510
Die	370	390	480	510
Die Lips (Opt.)	400	410	500	520
Die Gap (Mils)	60-90		20-30	
Chilled Air/Chilled Roll (°F)	≤65		80	
Screen Pack	20/40/20		20/40/80/20	
Extrusion Rate (lbs / hr)	~310		~550	
Gauge (mils)	1.25	0.80	1.25	0.80

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Typical Extrusion Conditions - Grooved Feed

	Plastomer		mLLDPE	
MI	1.0		1.0	
Densitv	0.900		0.918	
Grooved System	1	2	1	2
	°F	°F	°F	°F
Target Melt Temperature	~390	~410	~410	~415
Extruder				
Zone 1	310	320	395	320
Zone 2	300	350	365	350
Zone 3	290	350	325	350
Zone 4	290	350	325	350
Zone 5	290	350	300	350
Adapter	400	380	410	380
Screen Changer	400	380	410	380
Die	400	390	410	390

Note: These are profiles that have been used successfully on two different grooved bushing systems at ~9-10 lbs/in die (~10" die).

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Summary

- Most existing LLDPE equipment can process Exceed mLLDPE and Exact Plastomers well
- Compared to LLDPE, mLLDPE and plastomers will extrude hotter and exhibit lower melt strength
- On cooling limited equipment, rates may be reduced 5 to 10%
- Rates may be improved by implementing:
  - Screws with larger barrel clearances for reduced melt temperature, provided melt homogeneity is not unacceptably sacrificed
  - Lower pressure dies with special coatings and coarser screen packs (smooth bore extruders only)
  - Air ring with enhanced bubble stabilizing features such as irises, extended cones, protective shrouds, or adjustable primary/secondary air lips to balance air flow to bubble

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