Influences on Film Properties

Polyethylene Film Training Program

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Introduction

- Polyethylene film properties are strongly affected by resin parameters and processing conditions
- Resin parameters that affect properties include density, molecular weight and polymer type
- Most effects on film properties from processing are due to changes in molecular orientation
- Not all properties can be improved together - product optimization must be considered

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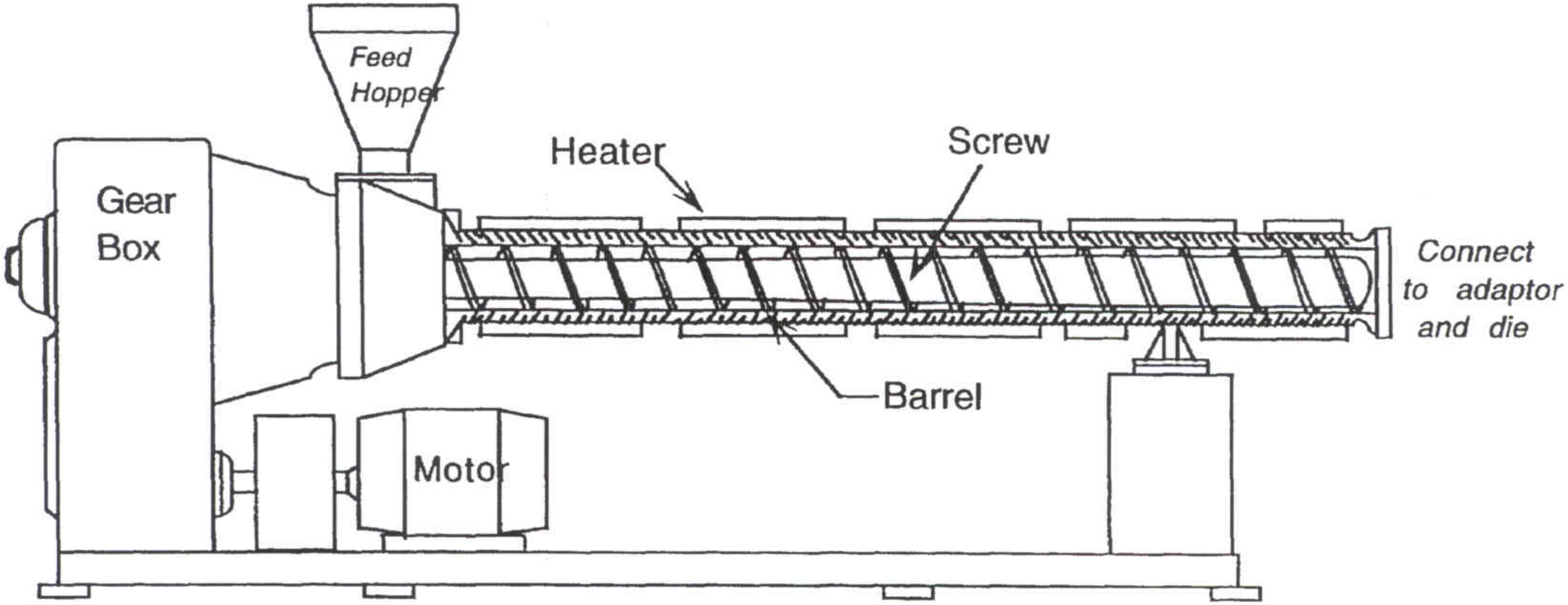
Extruder Components



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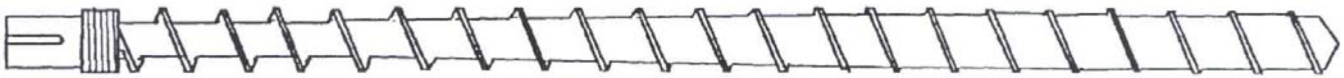
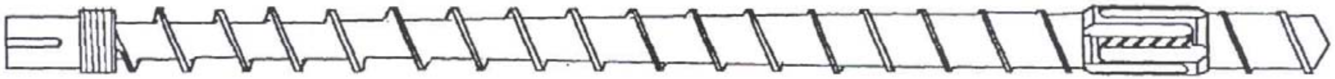
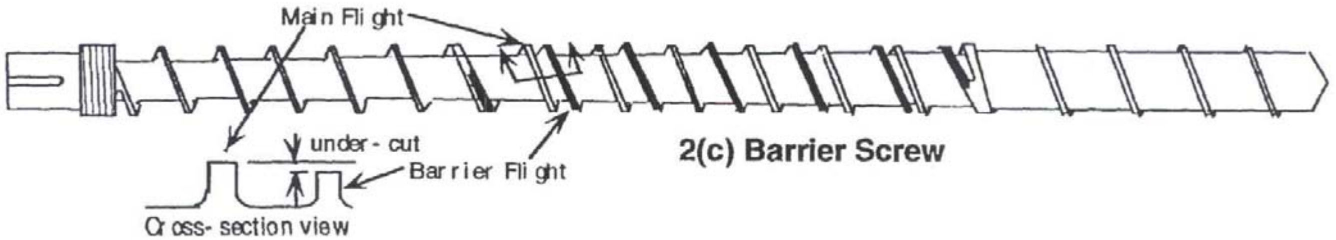
Polyolefin Screw Designs



2(a) Conventional Screw



2 (b) Conventional Screw with Maddock Mixing Section



2(c) Barrier Screw

2(d) Barrier Screw with Maddock Mixing Section

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Typical Torque Levels for PE Extrusion

Extruder Size in/(mm)	Max. Screw Speed Blown	Cast	Torque Requirement, hp/rpm LDPE	LLDPE	Exceed mLLDPE	Plastomer	mPP
2.5 (65)	105-125	125-150	0.25	0.35	0.40	0.45	0.20
3.5 (90)	90-115	110-140	0.65	1.10	1.20	1.25	0.50
4.5 (115)	75-105	105-125	1.40	2.20	2.40	2.50	1.30
6.0 (150)	60-85	90-110	3.30	5.10	5.60	6.10	3.00

- Typical extruder screw speeds and toque levels
- Taken from 24:1 L/D systems

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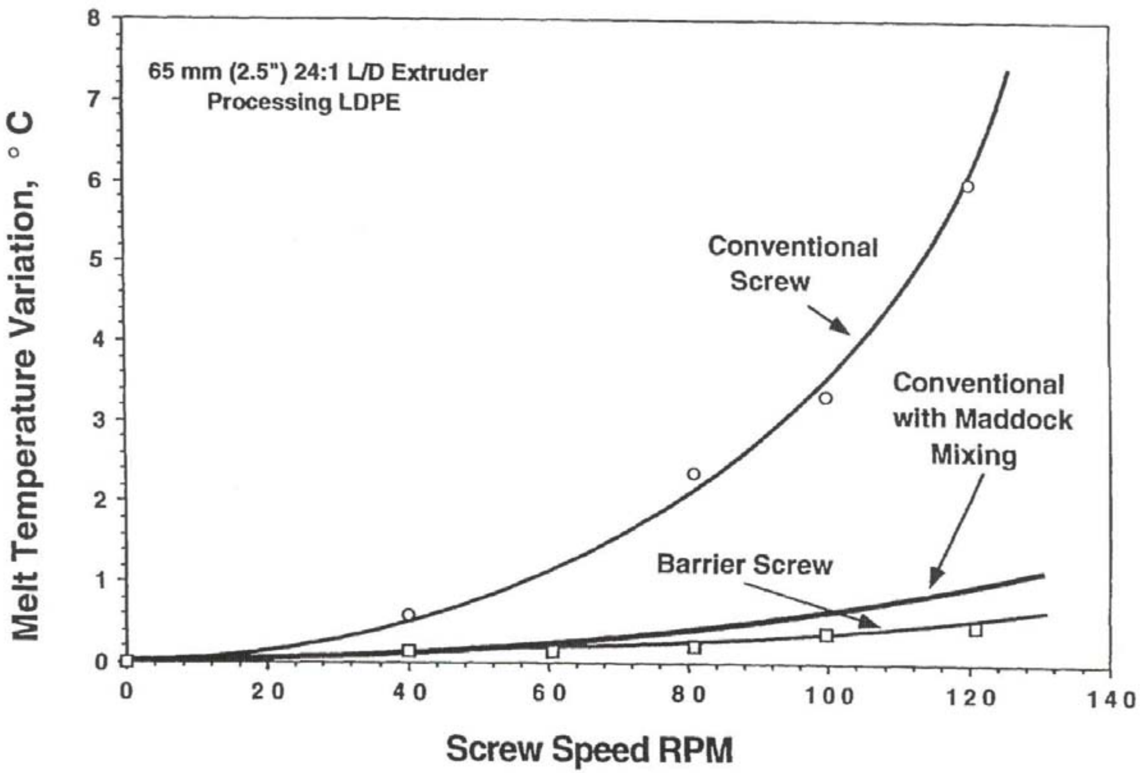
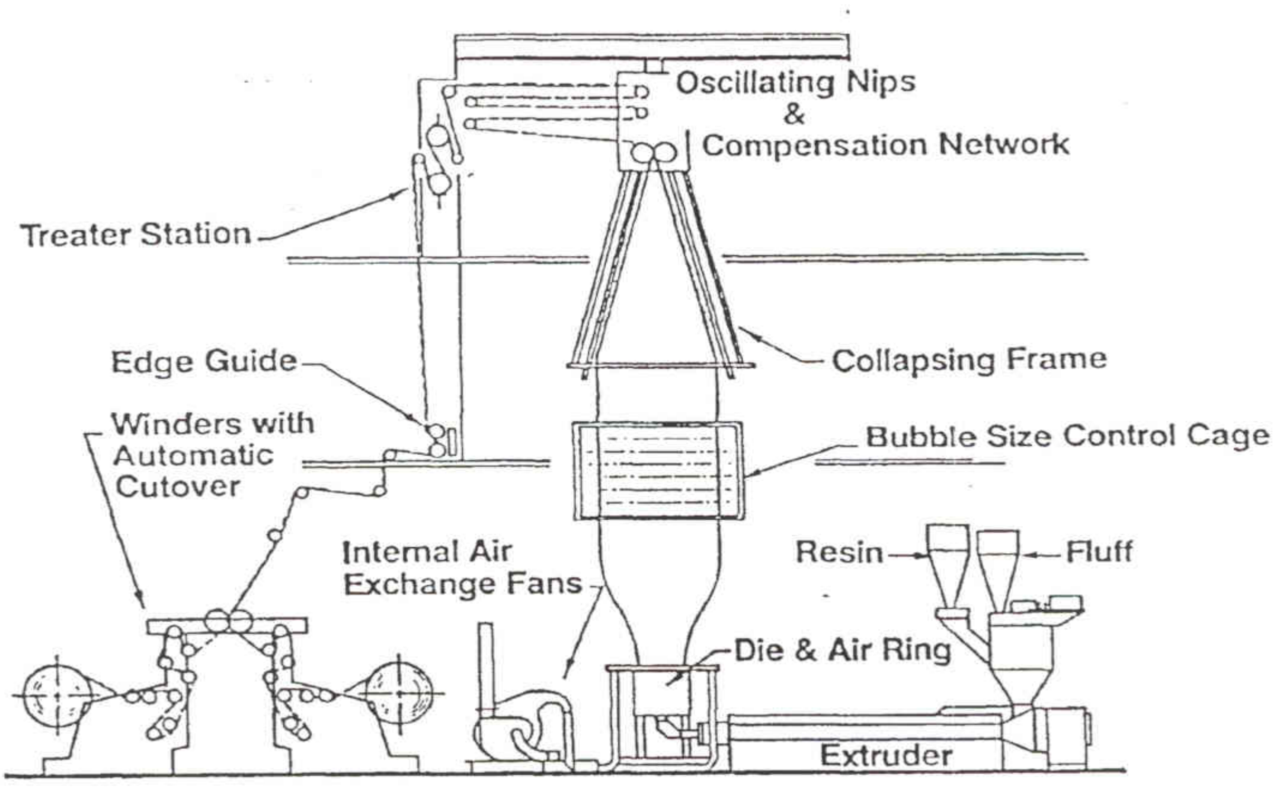
Melt Temperature Variations



- Screw design can have a significant effect on melt temperature variation

Blown Film Schematic



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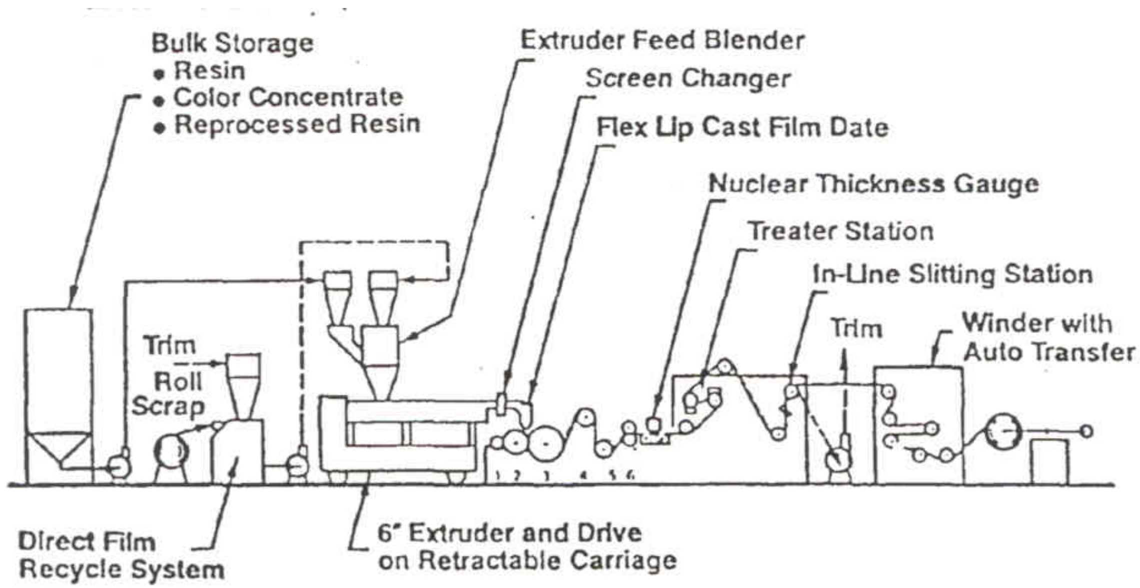
Cast Film Schematic



Typical Annual Output For 6" Extrusion Line

6-7 $\overline{M}$ lb/yr. PE
4-6 $\overline{M}$ lb/yr. PP

Embossing/Chill Roll Stand

1. Doctor Roll
2. Back-Up Roll
3. Embossing or Chill Roll
4-5. Cooling Rolls
6. Primary Nip

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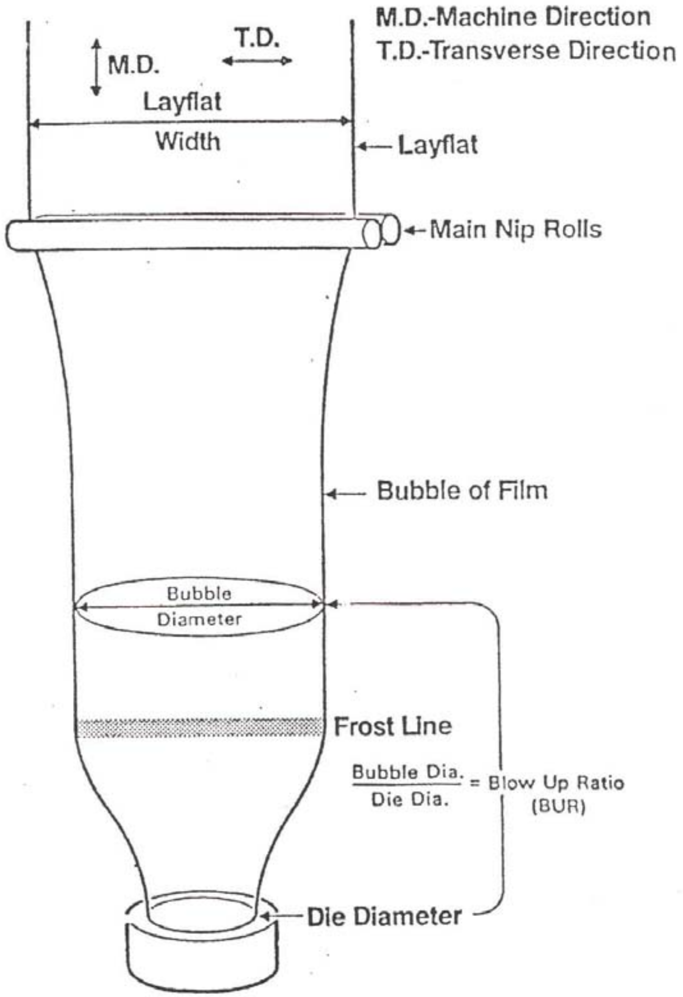
Blown Film Definitions



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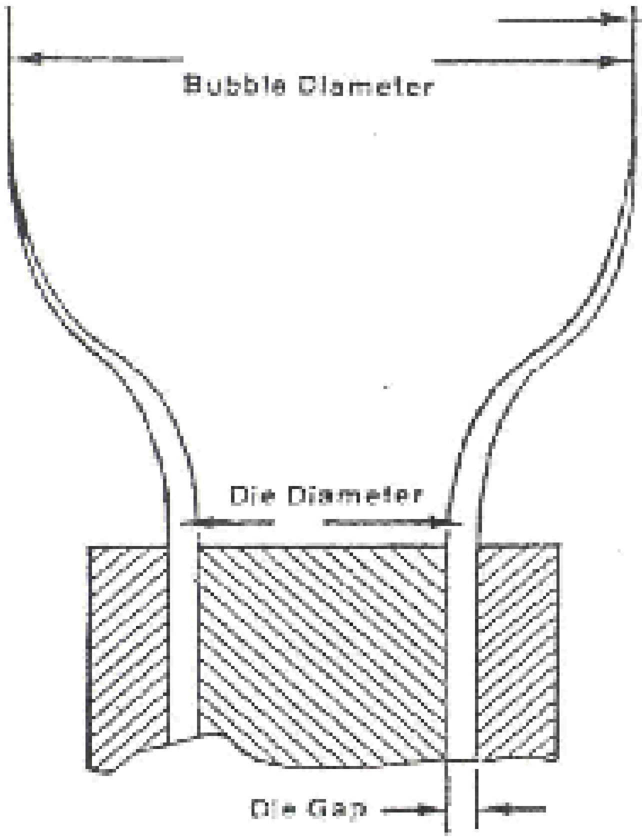
Blown Film Bubble Calculations



$$\text{Blow-Up Ratio (BUR)} = \frac{\text{Bubble Diameter}}{\text{Die Diameter}}$$

$$\text{Draw-Down Ratio (DDR)} = \frac{\text{Die Gap}}{\text{Film Thickness}}$$

$$\text{Machine Direction Orientation} = \frac{\text{Die Gap}}{\text{Film Thickness} \times \text{BUR}} = \frac{\text{DDR}}{\text{BUR}}$$

e.g.

Case I	
Die Gap	32 mils
Film Thickness	1 mil
BUR	2:1
DDR =	32:1
MDO =	16:1

Case II	
Die Gap	32 mil
Film Thickness	4 mil
BUR	2:1
DDR =	8:1
MDO =	4:1

Case III	
Die Gap	32 mil
Film Thickness	1 mil
BUR	4:1
DDR =	32:1
MDO =	8:1

Case IV	
Die Gap	32 mil
Film Thickness	4 mil
BUR	4:1
DDR =	8:1
MDO =	2:1

Film Thickness

- Concepts
  - Gauge profile - Measurement of film gauge across web
  - Average gauge - average across web
  - Gauge variation - thickness fluctuation across web
- Common thickness units
  - Mil - 1/1000 inch = 0.001 inch
  - Micron - 1/1000 mm = 0.001 mm
  - 1 mil = 25.4 micron
- Film thickness measured by
  - Micrometer - hand-held device
  - Gauge profilers - usually radioactive source, transmission or backscatter
  - Basis weight - average thickness for square footage of film

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Film Thickness

- Film thickness influenced/controlled by
  - Line speed (take-off) speed
  - Screw speed (extruder output)
  - Die gap size, uniformity
  - Bubble symmetry
  - Output surging
- Potential problems in end use
  - Film toughness, tensile strength, yield strength
  - Permeability
  - Film handling - tracking through converting equipment, uneven tension control, curling due to stretch (laminates)
  - Converting conditions - sealing temperatures, shrink temperatures

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Yield Strength

- Ranges for various polyethylenes (test ‘normalizes’ to 1 mil x 1 inch wide specimen)
  - EVA 700 - 1200 psi
  - LDPE 1000 - 1600 psi
  - LLDPE 1300 - 2000 psi
  - HDPE 4000 - 6000 psi
- Influenced/controlled by
  - Resin density (significant): higher density = higher yield strength
  - Cooling rate (slight): faster cooling = lower yield strength
  - Orientation (slight): greater orientation = higher yield strength
- Important for end use
  - Machinability (e.g. diaper backsheet)
  - Load containment (e.g. handle bags)

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Tensile Strength

- Ranges for various polyethylenes (test 'normalizes' to 1 mil x 1 inch wide specimen)
  - LDPE/EVA 2000 - 3500 psi
  - LLDPE 4000 - 8000 psi
  - HDPE 10,000 - 15,000 psi
- Influenced/controlled by
  - Polymer type (LDPE vs LLDPE, broad MWD vs narrow MWD)
  - Molecular weight (i.e. Melt index)
  - Blow up ratio
  - Draw down ratio
  - Additives (e.g. antiblock, pigment)
- Important for end use
  - Load capacity in bags (produce, trash, etc.)
  - Good indicator of film toughness

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Ultimate Elongation

- Absolute value - not normalized for gauge
- Influenced/controlled by
  - Polymer type (LDPE vs LLDPE, broad MWD vs narrow MWD)
  - Molecular weight
  - Density
  - Blow up ratio
  - Draw down ratio
  - Additives (e.g. antiblock, pigment)
- Important for end use
  - Predictor of film splittiness
  - Indicator of film stretchability (important in stretch film)

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Modulus

- 1% Secant Modulus used for film – stiffness measure
- Ranges for various polyethylenes (normalized to 1 mil x 1 inch wide specimen)
  - EVA 10,000 - 25,000 psi
  - LDPE 25,000 - 40,000 psi
  - LLDPE 30,000 - 50,000 psi
  - HDPE 130,000 to 250,000 psi
- Influenced/controlled by
  - Polymer type
  - Density
  - Molecular weight
  - Blow up ratio
  - Draw down ratio
  - Frostline height

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Modulus

- Important for end use
  - Overwrap films (machinability)
  - Converting (soft films stretch)
  - Ability to withstand high speed deformations (low modulus better)
  - Machinability
  - Sealing (low modulus easier to seal)

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Impact Strength

- Resistance of film to shocks, such as from dropping and hard blows
- Tests to measure
  - Dart impact
  - Total energy impact
  - Spencer impact
- Dart Impact (A version) most common
- Usually not normalized to 1 mil

Impact Strength

- Influenced/controlled by
  - Polymer type (LDPE vs LLDPE)
  - Density
  - Molecular weight
  - Blow up ratio
  - Draw down ratio
  - Frostline height
  - Gauge
  - Additives (antiblock, pigment)
- Important for end use
  - Packaging films
  - Trash bags

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Tear Resistance

- Resistance of a material to tearing
- Tests to measure
  - Elmendorf tear (high speed propagation)
  - Trouser tear (low speed propagation)
  - Graves tear (low speed initiation)
- Elmendorf tear most common
- Units normally in grams, sometimes grams/mil

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Tear Resistance

- Influenced/controlled by
  - Polymer type
  - Density
  - Blow up ratio
  - Draw down ratio
  - Gauge
  - Additives (at high concentrations)
- Important for end use
  - Overwrap films
  - Stretch films
  - High impact packaging films
  - Trash bags

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Understanding the Different Strength Tests

- Generally, the strength properties track each other and are functions of:
  - Polymer Type
  - Melt Index
  - Density
  - Die gap size (which changes Drawdown Ratio)
  - Blow Up Ratio
- Think of:
  - Tensile as the failure from a constant pressure widespread on the film
  - Puncture as related to a force in a small concentrated are
  - Dart as an impact resistance

Coefficient of Friction (COF)

- Coefficient of friction (COF)
  - Slip - lubricity of two surfaces in contact
  - Friction - resisting force of surface of film sliding over another
- COF = $\dfrac{\text{Force required to move}}{\text{Weight pressing surfaces together}}$ → $\dfrac{\text{What is measured in test}}{\text{ASTM fixed weight (sled)}}$
- Types of COF
  - Static - represents force required to start movement
  - Kinetic - represents force required to maintain movement
  - Static COF > kinetic COF
- Ranges (unitless values)
  - High slip 0 to 0.2
  - Medium slip 0.2 to 0.5
  - Low slip over 0.5
  - More customers are targeting even tighter ranges

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Coefficient of Friction (COF)

- Influenced/controlled by
  - Polymer composition (LDPE, EVA, LLDPE, HDPE)
  - Slip additives (type and amount)
  - Antiblock
  - Pigments (slip absorption)
  - Tackifiers, antifog agents, etc.
  - Roll hardness (tighter winding inhibits slip migration to surface)
  - Film age (medium slip films)
  - Film treatment level
  - Low molecular weight material content (high hexane extractables)

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Coefficient of Friction (COF)

Requirements for various end use applications

High Slip	Medium slip	Low or No Slip
Form, Fill, and Seal	Overwrap Films	Potato/Produce Bags (RF)
Most Side Weld Bags (bread, dry food, etc.)	Shrink Bundling Films (automatic palletizers)	Laminating & Metallizing Films
Some Shrink Films	Pass Through Stretch Films	Some Shrink Films
Some Carpet Wrap Films		Some Carpet Wrap Films
Diaper Bags		Sealed Air Bubble Film
Some Bale Warps		

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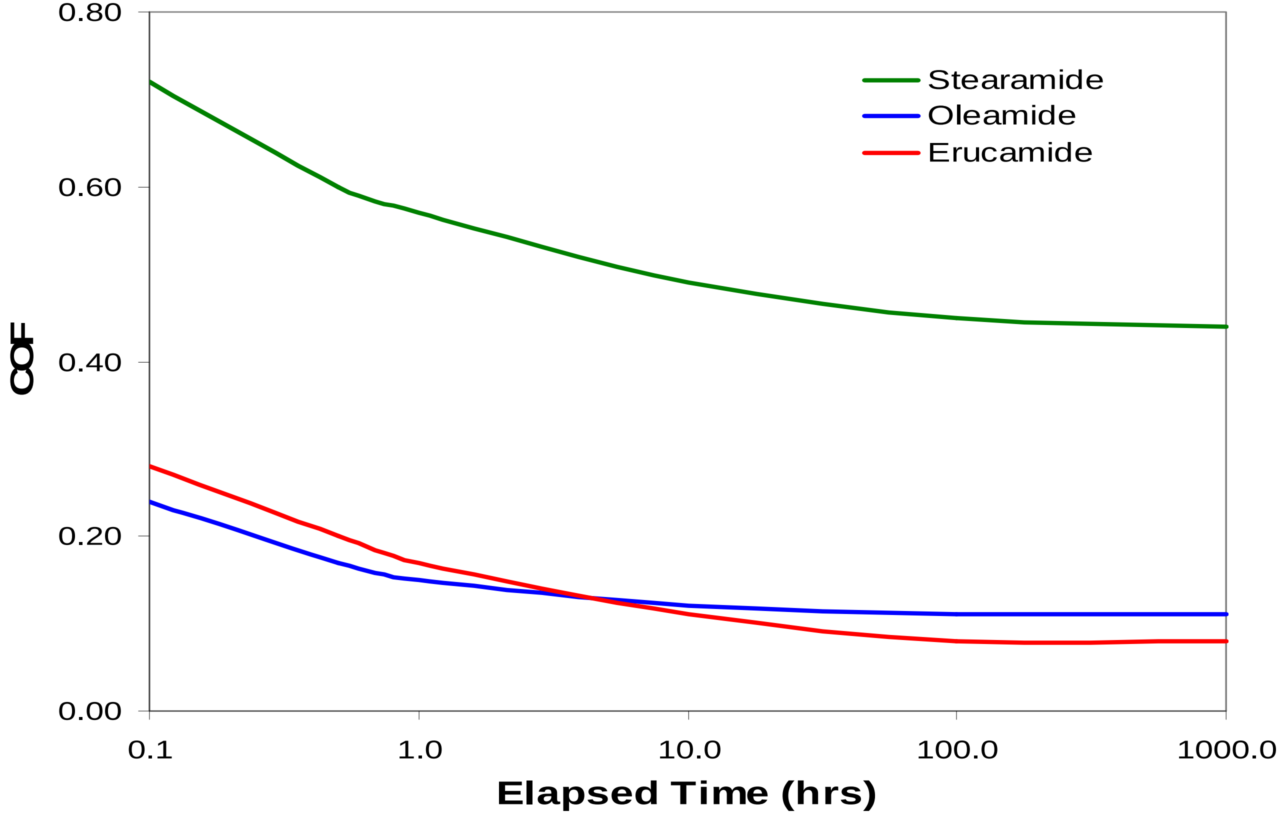
Coefficient of Friction (COF)



- Slip concentration 1000 ppm in LDPE

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Blocking

- Blocking is an adhesion between plastic films
- Tests
  - Parallel plate (laboratory)
  - Coin drop (field test, place coin in bag, subjectively determine how long it takes to reach bag bottom)
- Types of blocking
  - Standard - film blocks as produced on line
  - Induced - films compressed by weight, usually at elevated temperatures
- Antiblock additives do not migrate

Blocking

- Influenced/controlled by
  - Polymer type (EVA vs LDPE vs LLDPE)
  - Surface smoothness (gloss)
  - Antiblock additives (type and amount)
  - Tackifiers
  - Surface treatments/backside treat
  - Printing inks (oxy-dry powder)
  - Low molecular weight fractions (hexane extractables)
- Important for end use
  - Unwinding in converting operations
  - Bag production - internal and bag-to bag

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Corona Treating

- Treat level is measure of film surface wetting tension
- Tests
  - Ink pick off (printed film)
  - Inclined angle (what angle will water flow)
  - Contact angle (water droplets)
  - Wetting tension (dyne solutions, will"bead" at specific treat levels)
- Treat ranges
  - Untreated — less than 35 dynes
  - Normal treat — 35 - 37 dynes (printing)
  - Heavy treat — 38 - 42 dynes (laminating)

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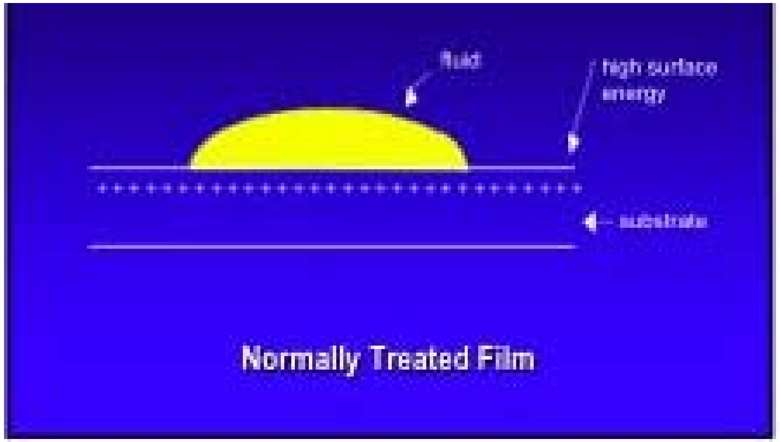
Corona Treating

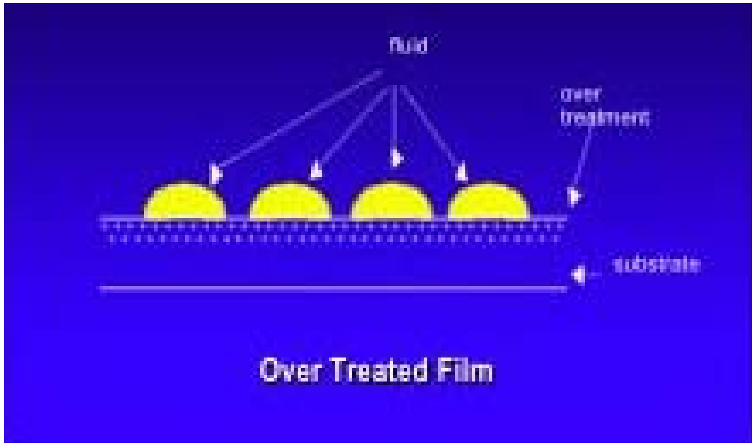
- Influenced/controlled by
  - Treater power
  - Treater gap (distance to film)
  - Slip content
  - Web temperature
- Important for end use
  - Printing
  - Coating
  - Gluing/laminating
  - Metallizing
  - Heat sealing to paper

Corona Treating

- Most common problems
  - Light or under treat
    - Poor ink adhesion
    - Poor coating or glue adhesion
    - Poor heat seal to paper
  - Heavy or over treat
    - Poor print quality
    - Film blocking
    - Poor seal strength
    - Heavy oxidized layer on film surface (poor ink and glue adhesion)
    - Burned odor
    - Accelerated oxidation ("rotting")

Over-Treatment Can Be a Problem





- For undertreatment, ink doesn’t wet out and adhere.
- Many production facilities use a dyne pen and just check for a minimum, not maximum, treat level.

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Corona Treating

- Most common problems
  - Streaky or skip treat
    - Some ink pick-off
    - Channeling in laminates
    - Usually no severe consequences
  - Backside treat
    - Film blocking on roll
    - Ink pick off
    - Coated rolls adhere into solid “log”
    - Severe static
    - Weak seams (low seam impact)

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Shrinkage

- Shrinkage is irreversible and rapid reduction in linear dimensions occurring in film subjected to elevated temperature
- Influenced/controlled by
  - Polymer type (LDPE vs LLDPE)
  - Long chain branching
  - Molecular weight
  - Molecular weight distribution
  - Blow up ratio
  - Drawdown ratio
- Important for end use
  - Shrink films - bundling and fully encapsulating
  - Side weld bags
  - Printing
  - Coating and laminating

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Puncture

- Puncture is measure of film resistance to penetration at controlled rate
- Influenced/controlled by
  - Polymer type
  - Density
  - Molecular weight
  - Film orientation
  - Frostline height
  - Additives (antiblock, pigments)
- Important for end use
  - Stretch films
  - Trash bags
  - Converted high impact (ice bags, hardware)

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Haze

- Haze is light scattered by film (up to 2.5° by ASTM D1003)
- Approximately > 70% of film haze is attributed to film surface
- Type of measured film haze
  - Total
  - Internal (surfaces coated with oil)
  - External (subtraction of total - internal)
- Range
  - Low 0 - 5%
  - Moderate 5 - 10%
  - High over 10%

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Haze

- Influenced/controlled by
  - Polymer type (EVA vs LDPE vs LLDPE vs HDPE)
  - Density
  - Molecular weight
  - Slip and antiblock additives
  - Frostline height
  - Melt fracture
- Important for end use
  - Packaging films (need clarity for customer appeal)
  - Stretch films (for bar code readers)

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Gloss

- Gloss is the shine, sheen, or luster of film surface
- Range (measured at 45° angle)
  - Low 0 - 5%
  - Moderate 50 - 70
  - High over 70
- Influenced/controlled by
  - Polymer type
  - Frostline height
  - Melt temperature
  - Antiblock and slip additives
- Important for end use
  - Packaging films (customer appeal)
  - High gloss might predict blocking tendency

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Opacity

- Opacity is resistance of a film to transmission of light
- Influenced/Controlled by
  - Pigment
  - Density
- Important for end use
  - Hiding of product (diaper bags, trash bags)
  - UV protection (black film)
  - Insufficient pigment - low opacity
  - Too much pigment - strength deterioration

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Film Extrusion Technology and Influences on Film Properties

Heat Sealability

- Heat sealability vs. heat seal strength
- Minimum fusion temperature
- Seal strength vs. seal energy
- Peel vs. edge failure vs. film failure
- Weld vs. surface seal
- Influenced/Controlled by: Resin Composition
  Melt Index
  Density
  Treat
  Additives (slip, silicone fluid)
  Gauge
  Surface Contamination (oxy dry)
- End use: Virtually all PE packaging applications require good heat sealability and heat seal strength

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Heat Sealability

- Heat sealability is the thermal bonding of films
- Important sealing parameters
  - Seal initiation temperature (SIT) - temperature at which seal strength become acceptable
  - Seal failure
    - Peel - seal peals apart
    - Edge failure - film breaks at seal edge
    - Film failure - film elongates and breaks before seal fails
- Influenced/controlled by
  - Polymer type (EVA vs LDPE vs LLDPE)
  - Molecular weight
  - Density
  - Treat
  - Additives (slip, antiblock)

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Heat Sealability

- Important for end use
  - Almost all polyethylene packaging applications require good heat sealability and heat seal strength
- Critical factors influencing heat seals
  - Resin characteristics (MI, density, blends, copolymers)
  - Surface quality (additives, treat)
  - Heat seal conditions (temperature, pressure, dwell)
  - Heat sealer type (bar nichrome wire, round wire, knife, etc.)
  - Maintenance (alignment, uniform pressure, wear and tear, cleanliness)

Contaminants

- Gels are round or oblong, symmetrical, clear spots, so hard that can be felt
- Fisheyes are large gels
- Caused by
  - Molecular cross linking
  - Catalyst residue
  - Burned/degraded resin
  - Foreign material (wood, paper fiber)
  - Unmelted pellet (poor screening)
- Important for end use
  - Reduced toughness
  - Film breakage, especially in stretch films
  - Esthetically objectionable

Static

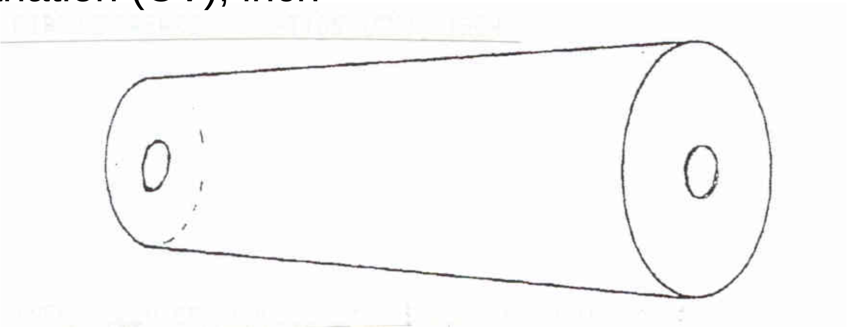
- Stationary charges of electricity which develop in the film
- Influenced/controlled by
  - Drag on idler rollers/stationary machine parts
  - Atmospheric conditions
  - Treating level
  - Static eliminators
  - Antistatic agents
- Potential problems in end use
  - Machinability problems (overwrap, shrink bundling)
  - Stacking problems with bags (side weld and bottom seal)
  - Safety hazard (shock, explosion)

Web Quality

Flatness, in/ft

Belly, puckers, edge droop

Circumference variation (CV), inch



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Web Quality

- Influenced/controlled by
  - Bubble symmetry
  - Nonuniform frostline height
  - Spikes in frostline
  - Gauge variation
  - Overly tight winding
- Potential problems in end use
  - Printing
  - Laminating
  - Bag making

Camber

- Camber is a slight convexity, arching or curvature of a film web
- Unit - inch/15 feet
- Influenced/controlled by bubble symmetry (flare)
- Potential problems in end use
  - Side weld bag manufacturing
  - Printing (register)
  - Laminating (nonuniform tension)
  - Tracking on bundling machines

Summary

- Polyethylene film properties are strongly affected by resin parameters
  - Molecular weight
  - Density
  - Molecular weight distribution
  - Comonomer (short chain branch type)
  - Long chain branching
  - Polymer type (LDPE vs LLDPE)
- Processing conditions also have a significant effect on film properties, primarily affecting molecular orientation
  - Melt temperature
  - Blow up ratio
  - Draw down ratio
  - Frostline height

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