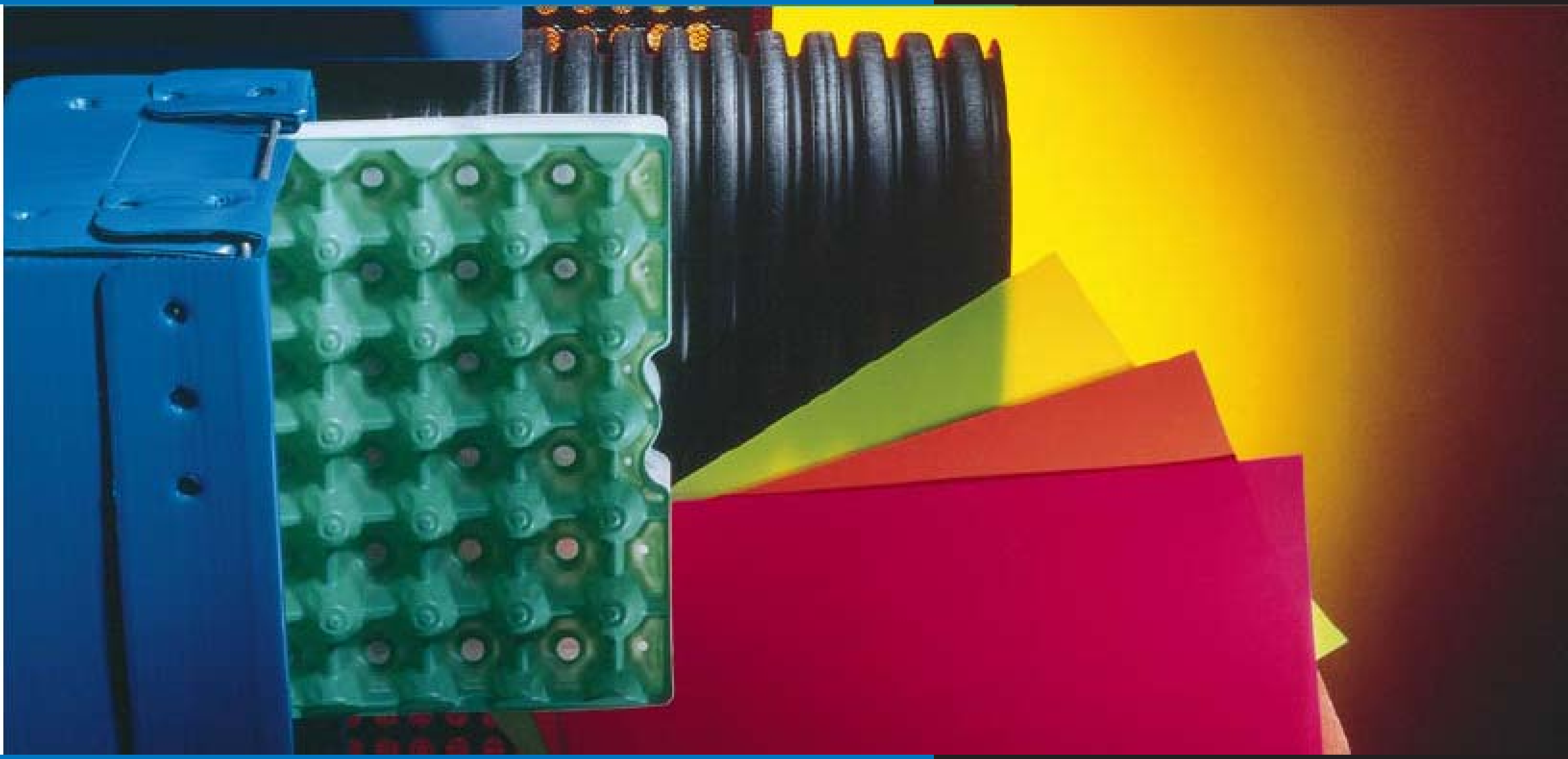
A Guide to Polyolefin Sheet Extrusion



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A Guide to Polyolefin Sheet Extrusion

Introduction

This manual describes the extrusion process and identifies the components of a single-layer sheet extruder. The manual offers guidelines for resin selection, processing and troubleshooting polyethylene and polypropylene. This manual is not intended to replace OEM standard procedures, guidelines or formal training.

The information in this manual is based on practical experience of LyondellBasell's technical service engineers and a collection of abstracts from numerous publications believed to be true.

The extrusion process is a continuous operation of melting and conveying a polymer in a heated screw-and-barrel assembly. The homogenous melt is forced to flow through a screen pack, then a sheet die from which it exits in the desired width and thickness. The die discharge, or extrudate, is wound through a three-chill-roll stack for cooling. The solid sheet is then cooled further on a cooling conveyor while the edges are trimmed to final sheet width. The sheet is either rolled or sheared for later use.

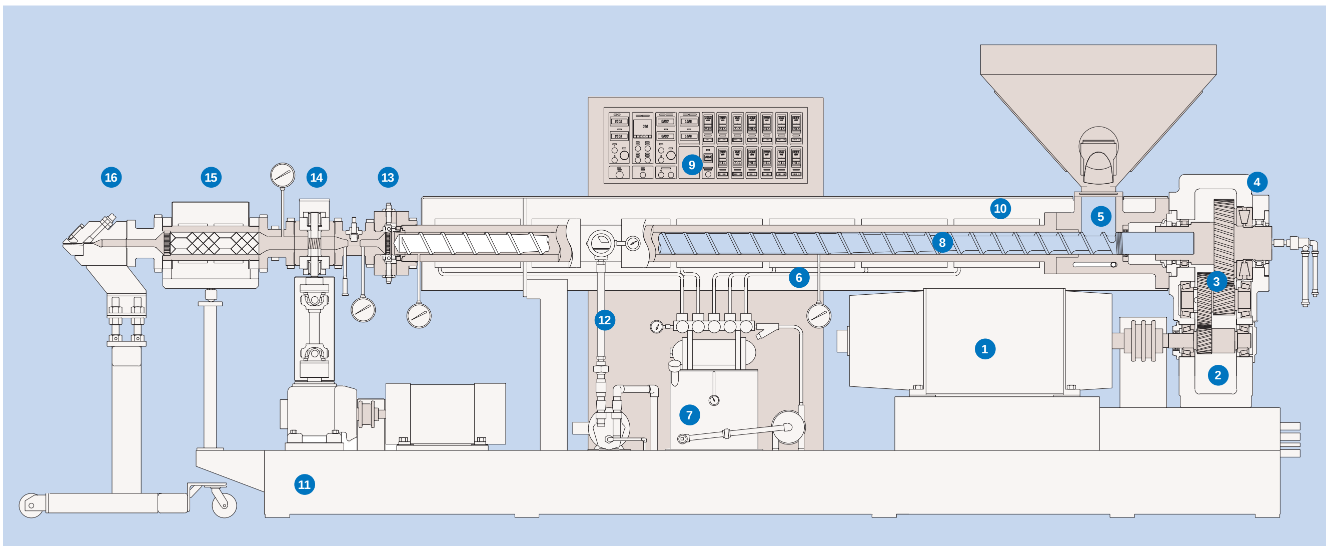
The Extruder

The Screw and Barrel

An extruder screw is a long steel shaft with increasing root diameter and helical flights of constant pitch wrapped around it. A polyethylene and polypropylene screw extruder has typically a 3:1 compression ratio and a minimum 24:1 length-over-diameter (L/D). Such a screw may be a single-stage or two-stage screw depending on the desired production output and mixing requirements. The extruder barrel is a hollow cylinder that houses the screw. The clearance between the screw flights and the inside wall of the barrel is small, 0.005 inch, but constant throughout the length of the barrel. The barrel has an opening immediately above the first flight of the screw in the feed zone that serves as the inlet to free-flowing pellets from a hopper above.

Figure 1. Schematic Diagram of a Sheet Extruder Line (Courtesy of Welex Incorporated)

1 – The Drive Motor
2 – The Gear Drive
3 – High Efficiency Gear
4 – Thrust Bearing
5 – Feed Opening
6 – Heating Elements
7 – Cooling
8 – High Performance Screw
9 – Piping & Wiring
10 – Fully Insulated Guard
11 – Base
12 – Venting
13 – Screen Changer
14 – Gear Pump
15 – Static Mixer
16 – Die



The Compression Ratio

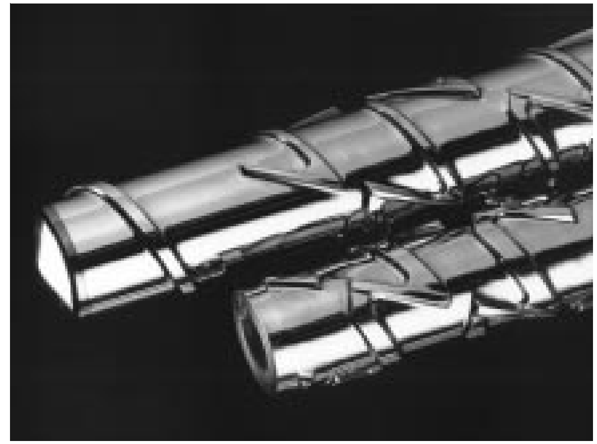
The volume of the first flight in the feed section to the last flight in the metering section is known as the compression ratio (CR). A typical polyethylene screw has a compression ratio of 3:1. A higher CR causes excess shearing and resin degradation. A lower CR provides inadequate shear and poor intermixing of the molten polymer.

The Length/Diameter Ratio

Simply known as L/D, this ratio is desired at 24:1 or greater. This means the screw length is 24 times the diameter of the screw. These dimensions ensure adequate residence time for the polymer to melt and mix.

The extruder screw is designed with three main zones or sections: feed, compression and metering sections.

Figure 2. Extrusion screw (Courtesy of Spirex)



The Feed Zone

The feed zone of the screw has a constant pitch and channel depth. The feed zone heats and softens the plastic pellets by conduction from the heaters, which are placed around the barrel and, to a lesser degree, from friction. The feed zone has the deepest channels of any of the screw sections. The feed zone is often operated at a temperature cooler than the rest of the extruder by circulating water inside the screw shaft to maximize the difference between its temperature and that of the barrel. The temperature gradient between the barrel and screw surfaces allows the polymer to stick to the barrel surface, slip on the screw surface and maximize its forward progress as the screw rotates. Should the screw surface temperature approach that of the barrel, then the melt sticks to the screw and rides around the screw shaft and becomes stationary. This condition is known as “bridging” and results in a low output and ultimately loss of output. Sometimes grooves in the barrel help increase the feeding rate.

The Compression Zone

The compression zone, also known as the transition zone, has a cone shaped root and a reduced channel depth. This section compresses the soft pellets into a melt and squeezes out entrapped air. As the melt undergoes compression, additional heat is generated from the high friction between the polymer on one side and the flight and barrel surfaces on the other. This heat is known as frictional heat and is combined with external heat from electrical heaters. The compression zone is commonly about 50 percent of the screw length. The compression zone may be either tapered or step design.

The Metering Zone

The metering zone of the screw begins at the end of the compression section and ends at the screw tip. The metering zone has a constant cross section and smaller channel depth than either the feed and compression sections. Because of these dimensions, the polymer in the metering zone is subjected to intensive shear and mixing, which are essential steps to homogenize the polymer physically and thermally. The temperature gradient within the polymer can vary between 10°F and 50°F from the surface of the screw to the surface of the barrel. A uniform polymer temperature is critical to avoid delaminating, warping and other imperfections in the finished product. The metering section may have a mixing device such as a Maddock mixer or mixing pins (Figures 3 and 4) to provide additional mixing of the polymer.

Figure 3. Maddock mixer

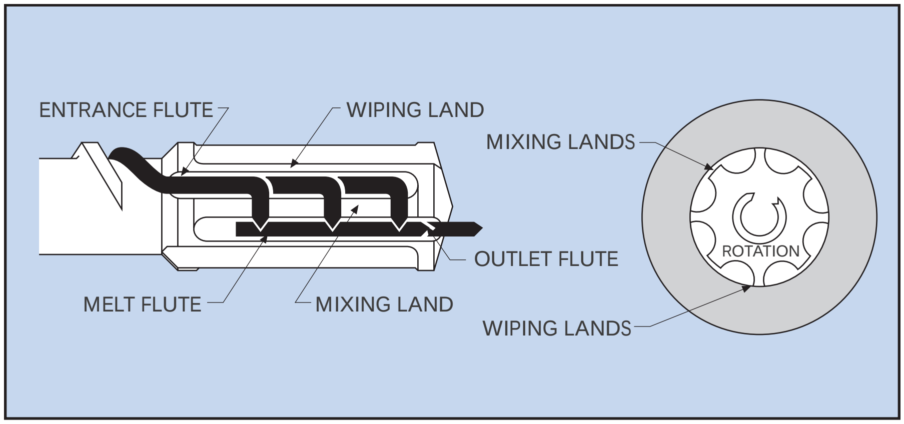
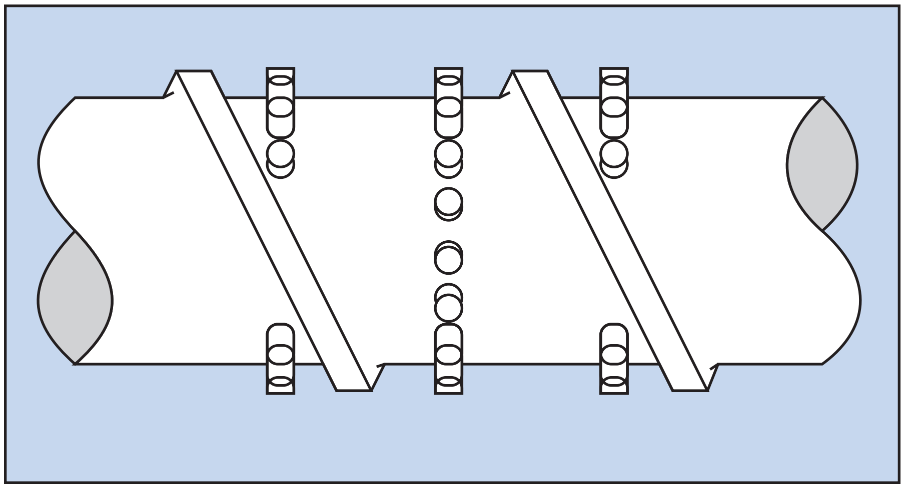


Figure 4. Mixing pins



Head Zone

The head zone assembly of an extruder system is positioned between the discharge end of the screw and barrel and the die entrance. The head zone assembly normally consists of one or a combination of several of the following:

- A static mixer, such as a Kenics or Koch, that provides distributive mixing and promotes homogeneous temperature of the polymer (Figure 5).
- A melt pump, often called a gear pump, a rotary-gear device intended to boost the system pressure and meter the polymer to the die inlet at a stable, surge-free rate (Figure 6). The pump allows the extruder to operate as an efficient melting device independent of its pumping function.

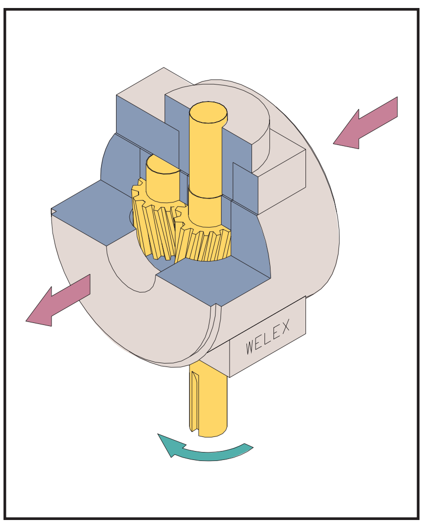


Figure 6. Melt pump (Courtesy of Welex Incorporated)

- A breaker plate that holds the screen pack. A typical 20/40/60/80-mesh screen pack is recommended for polyethylene and polypropylene processing. Higher gauge (finer mesh size) may be used to increase back-pressure and mixing; however, it may limit extrusion output and raise melt temperature, causing degradation (Figure 7).

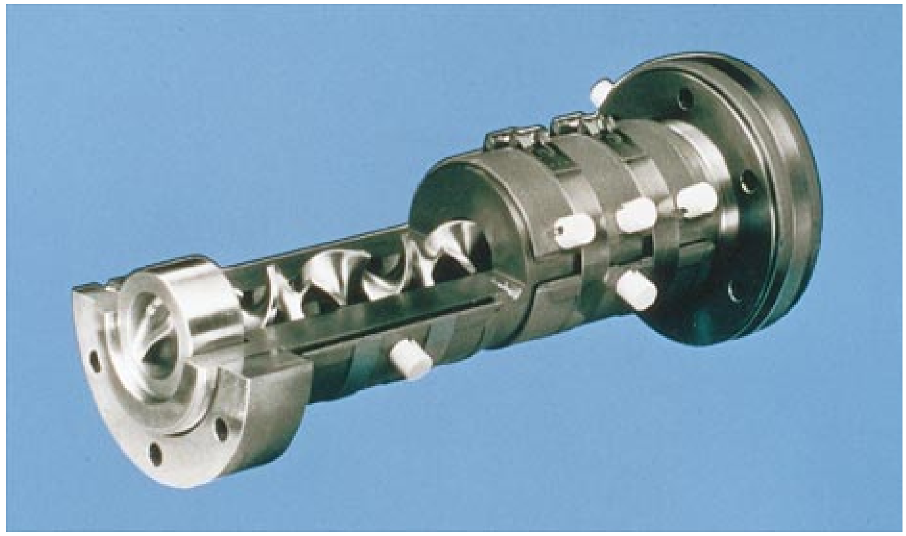


Figure 5. Static mixing sections (Courtesy of Chemineer-Kenics)

Figure 7. Breaker plate (Courtesy of Dynisco)

Sheet Die

A sheet die serves to spread the molten polymer to a predetermined width and uniform thickness. A balanced die is essential for uniform sheet thickness. A typical polyethylene, monolayer, sheet die has a standard, coat hanger-type, manifold design. This die has a streamlined manifold with a teardrop-shape profile and chrome-plated flow passage with a mirror finish. Such a die has an internal adjustable choker bar to distribute polymer flow uniformly across the full width of the die and a flexible upper lip and fixed lower lip for fine tuning of the final sheet thickness (Figures 8 and 9).

To properly design a sheet die, a die manufacturer requires the following information:

- Rheological data such as viscosity versus shear rate of the polymer (Figure 10).
- Thickness range of final product.
- Sheet width.
- Throughput rate.

Manifold Section

The primary manifold is designed to distribute the melt from the center to each end of the die at a uniform flow rate and pressure. The manifold cross section is usually teardrop or half-teardrop in shape, which allows for gradual transition from the manifold height to the pre-land section. The manifold cross-section area is usually reduced in a linear fashion from the center to the ends of the die, which ensures minimal polymer residence time and reduces the possibility of resin stagnation and degradation.

Figure 8. Multiflow I – standard coat hanger-type die (Courtesy of EDI)

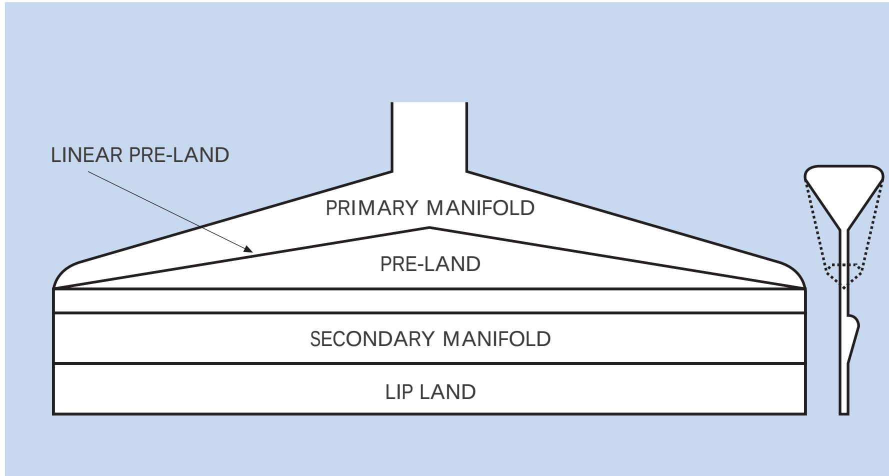


Figure 9. Sheet die with internal deckles (Courtesy of EDI)

Pre-Land Section

The pre-land shape is linear and distributes the melt from the center to the outside edge of the die.

Secondary Manifold

Any stress in the melt not relieved in the pre-land section is provided here before the melt exits the die.

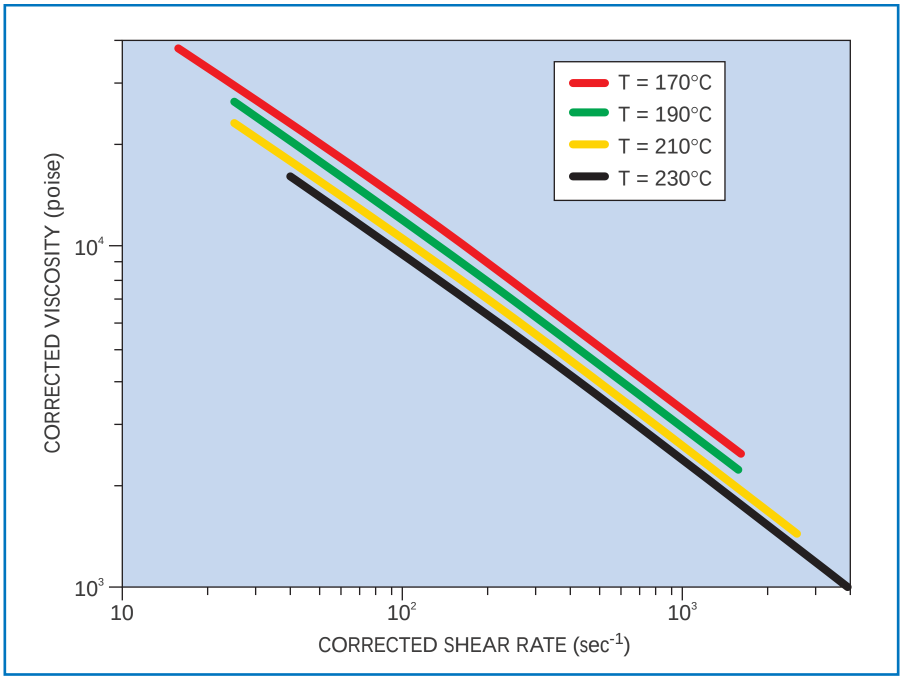
Lip-Land Section

This section is designed for tuning pressure for a specific opening range allowing fine tuning of the final sheet thickness.

Deckles

Deckles produce a sheet narrower than the die width by blocking the extremities of the die lip, either externally or internally, with metal pieces called deckles. The deckles force the resin to exit the die from the unblocked, but narrower die width. Deckles may promote resin stagnation that leads to degradation of the polymer. Deckles should not reduce the width of the melt more than 25 percent.

Figure 10. Viscosity vs. shear rate of Petrothene® LB 8320



Viscosity as a function of shear-rate and temperature

SHEAR RATE	VISCOSITY, POISE			
1/sec	338.0°F	374.0°F	410.0°F	446.0°F
1/sec	170.0°C	190.0°C	210.0°C	230.0°C
1.585E+01	3.86E+04	—	—	—
2.512E+01	3.00E+04	2.61E+04	2.30E+04	—
3.981E+01	2.31E+04	2.02E+04	1.78E+04	1.59E+04
6.310E+01	1.78E+04	1.56E+04	1.38E+04	1.23E+04
1.000E+02	1.36E+04	1.19E+04	1.06E+04	9.48E+03
1.585E+02	1.03E+04	9.12E+03	8.11E+03	7.27E+03
2.512E+02	7.83E+03	6.93E+03	6.18E+03	5.56E+03
3.981E+02	5.90E+03	5.24E+03	4.69E+03	4.23E+03
6.310E+02	4.43E+03	3.94E+03	3.54E+03	3.20E+03
1.000E+03	3.31E+03	2.95E+03	2.66E+03	2.41E+03
1.585E+03	2.46E+03	2.20E+03	1.99E+03	1.81E+03
2.512E+03	—	—	1.48E+03	1.35E+03
3.981E+03	—	—	—	1.00E+03

Sheet Cooling

Polishing Roll Stack

This unit is three, highly polished, chrome-plated rolls. The rolls have carefully designed cooling passages to maximize heat transfer and minimize side-to-side temperature gradients. Each roll has its own fluid (antifreeze), temperature control unit and pump. Cooling fluid must circulate at a volume sufficient to cool the sheet and give it a smooth finish. Rolls must have very precise flatness and perfect roundness to produce a flat sheet. Roll gaps must be precisely set to desired sheet thickness. Textured rolls produce an embossed sheet (Figure 11).

Cooling Conveyor

The conveyor is normally 10 to 20 feet long. Unforced ambient air cools the sheet and allows it to lay flat, minimizing warping during the final cooling stage. Optionally, blowers may be added either on the top or bottom or both sides of the sheet to maximize the cooling rate. Near the end of the cooling stage and ahead of the pull rolls, the edges of the sheet are trimmed and cut to the desired final width.

Pull Roll

Two rolls with a rubber-covered surface provide good traction. The rolls open and close by actuating a piston. The rolls are driven by a separate variable-speed motor at a slightly faster speed than the finishing rolls to provide tension in the sheet and promote intimate contact between the sheet and the polishing rolls. The extruder operator can vary the speed of the rolls to keep tension to a minimum and equal on both sides of the melt.

The finished product is either wound in a roll or if heavy gage, sheared and stacked for later use.

Figure 11. Chill rolls (Courtesy of Welex Incorporated)

Auxiliary Equipment

Continuous Thickness Measurement

A high-accuracy, non-contact, traversing sensor takes continuous measurements across the sheet. The profile data are displayed on a screen that enables the operator to make appropriate thickness corrections. Gauging systems can also automatically control average thickness by adjusting line speed. Profile may also be adjusted by using automatically controllable Autoflex dies to maintain perfect profile in the sheet (Figure 12 and 13).

Static Eliminator

A bar-type static eliminator ionizes the air around it. Positively charged material, passing through ionized air, attracts free negative ions and becomes neutralized. Negatively charged material attracts positive ions and becomes neutralized. The result is a static-free sheet.

Corona Treater

A corona treating system is designed to increase the surface energy of a plastic sheet to improve wetability and adhesion of ink. The treated sheet has improved printing properties.

Figure 12. Scanning gauge and control system (Courtesy of NDC)

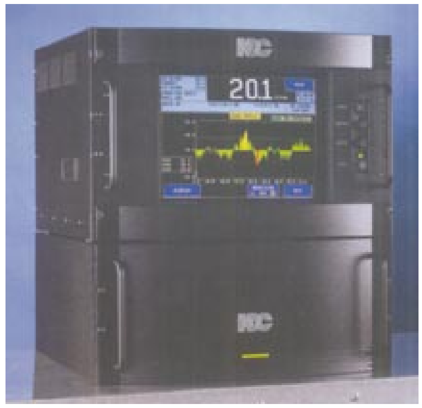


Figure 13. Transverse frame scanner (Courtesy of NDC)

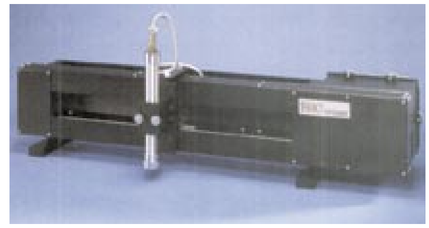


Figure 14. Static eliminator (Courtesy of Simco)

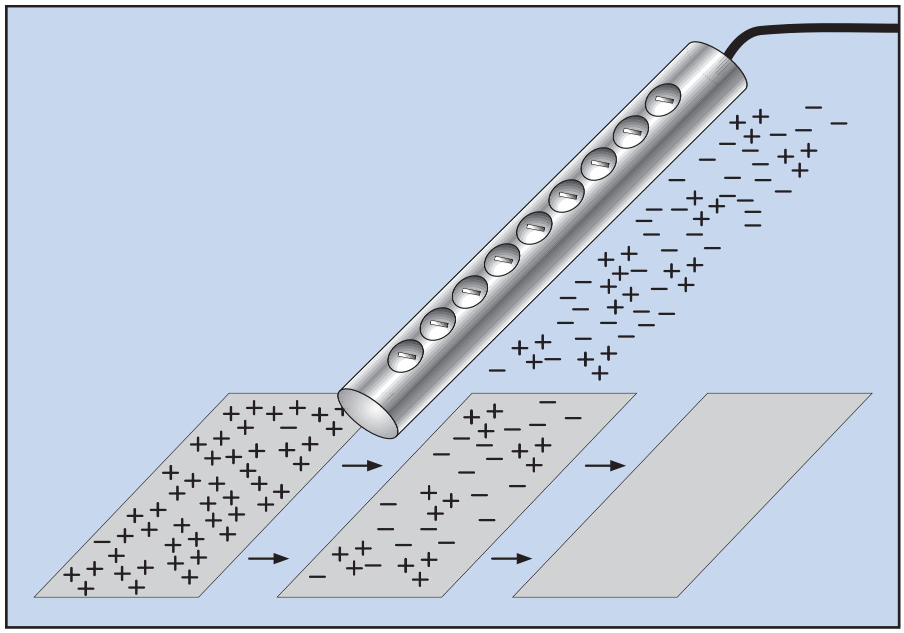


Figure 15. Corona treater (Courtesy of Enercon Industries)

Resin Selection

The preferred resin for sheet extrusion and thermoforming has a high molecular weight (MW) or low, fractional, melt index (MI). These properties ensure the resin has adequate melt strength (or melt stiffness) to produce a uniform gauge thickness, under optimum conditions, and hold its own weight during thermoforming.

Polyethylene (PE) resins are available in a wide range of densities. High density polyethylene (HDPE) homopolymer has the highest density (0.960 g/cc or higher) and, as a result, has the highest stiffness, chemical resistance, moisture resistance and heat deflection temperature (HDT), but the lowest, cold temperature, impact strength of all types of polyethylene. HDPE copolymers, which have densities below 0.960 g/cc, have reverse properties of HDPE homopolymers. In other words, the lower the density of the resin, the higher its impact strength and the lower its stiffness. HDPE copolymers have densities between 0.959 g/cc and 0.940 g/cc. Linear low density polyethylene (LLDPE), with densities between 0.940 g/cc and 0.918 g/cc, and low density polyethylene (LDPE), with densities between 0.935 g/cc and 0.915 g/cc, can be successfully extruded if the grade has the proper melt index.

Polypropylene (PP), unlike PE, has a uniform density of approximately 0.899 g/cc. However, the mechanical and thermal properties of PP follow the same pattern as PE. A PP homopolymer has higher stiffness and HDT than a PP copolymer.

LyondellBasell offers both PE and PP grades for sheet extrusion. Please ask your LyondellBasell sales or technical service representative for a resin recommendation.

Safety

LyondellBasell actively pro-motes and practices safe operating standards. These standards can make your operation a safe and profitable one as well.

Equipment

Be sure to use:

- Safety Glasses
- Heat-Resistant Gloves
- Ear Plugs
- Steel-Toed Shoes
- Non-Skid Flooring

Warning Signs

Install warning or identification signs where there are:

- Emergency Stops
- Pull Cords to stop certain machine functions
- Pinch Points
- Heaters
- Blades or Cutters

Procedures

Read and understand your OEM safety procedures before operating the equipment. Observe all tags and keep them legible.

Do not stand in front of the die lip; hot plastic may spew out.

The barrel, adapter and heater bands are electrically heated and operate at high temperatures. Do not handle electrical wiring or heater bands without first locking-out power. Do not work with the hot metal without protective hand covering and do not allow bare skin to come in contact with the heater's metal surface.

Keep tools, hands and loose clothing away from the chill rolls and sheet take-up rolls. A safety switch attached to a yellow cord should be located near the chill roll. When the cord is pulled, the roll should open automatically and stop. An Emergency Stop button is also located on the control panel.

When working on the chill rolls, two technicians should be present to assist each other as needed.

Do not allow the extruder barrel pressure to exceed its maximum design rating. Install appropriate pressure alarms and ensure appropriate relief plugs are installed.

Do not allow the extruder barrel or die temperature to exceed 500°F when processing polyethylene. Periodically calibrate the temperature controllers to ensure they are functioning accurately. Body bolts have been torqued tight at 450°F. If higher temperatures are to be used on the die body, bolts must be tightened at that temperature or higher to avoid leakage.

Do not allow the extruder drive motor to develop excessive amperage. As the screw rpm is increased, visually check the pressure gauge and the drive ammeter to be sure you are within the safe range. The drive ammeter must be checked frequently so that if an overload is encountered, the screw drive can immediately be shut off. If the drive unit continues to run, the high torque that develops can break the screw or otherwise damage the extruder or auxiliary equipment.

When handling the die or the bottom lip of the die, handle them slowly and carefully, as they are very heavy. Always use a cart when changing or cleaning the die.

When using a utility knife to cut samples or remove sheet from paperboard cores, cut away from the body and your free hand.

Check or adjust the safety stops on the die cart so the die does not damage the chill rolls as the cooling and polishing unit is rolled closer to the die.

Start-up Procedures

Set-up and calibration

The final sheet thickness is determined by the height of the nip. Adjust the nip between the first and second chill rolls to the desired thickness of the finished sheet. Use copper shims or a feeler gauge to set up the nip dimensions. Be sure the rollers are in the OFF position when gauging the gap.

Adjust the die gap to 1.1 times the desired thickness of the finished sheet to ensure the die output is generous enough not to starve flow through the nip rolls.

Preheat all extruder zones (Table 1) for approximately one hour and thirty minutes. A safe practice is to use mechanical or electro-mechanical devices such as shear pins, clutches or torque limitors on the extruder. These devices prevent damage to the screw or drive motor if the extruder is started and the polymer is inadequately melted.

Preheat the die (Table 1) for approximately one hour and thirty minutes.

Circulate coolant into the chill rolls at the recommended temperature (Table 1) for approximately one hour and thirty minutes. Be sure the rolls are rotating during this warm-up time.

The suggested start-up conditions are only guidelines and may need adjustment up or down after start-up. The age of the extruder, its condition and the efficiency of the heater bands can influence the heating process.

Table 1. Suggested set-up conditions (°F)

PRODUCT	HDPE	LLDPE	LDPE	EVA	PP
Feed Zone	380	350	330	300	400
Compression Zone	400	370	340	310	420
Metering Zone	420	400	350	320	440
Breaker Plate	420	400	350	320	440
Die	400	380	330	300	400
Melt. Temp. Not To Exceed	470	450	400	370	470
1st Roll	180	180	150	120	160
2nd Roll	190	190	160	130	175
3rd Roll	195	195	165	135	140
Final Sheet Temp.	120	120	100	100	120

Troubleshooting Guide

PROBLEM/SYMPTOMS	POSSIBLE CAUSE	SOLUTIONS
Extruder surging An unsteady state of extrusion or cyclical melt output. Gauge variation. Fluctuations in the extruder drive ammeter and in back-pressure	Volatiles or moisture in the melt	Dry the resin Minimize the use of regrind
	Wide bulk-density variation of the resin, i.e., pellets and inconsistent regrind	May be too many fines in the regrind
	Wide range of MI within the resin	Increase backpressure Use narrow MI range
	Bridging of resin in feed hopper or throat	Lower temperature at feed throat
	Starving the screw, especially with a two-stage screw	Lower feed-zone temperature
	Insufficient backpressure	Use finer mesh screen pack Check resin MI
Dimples or pock marks on sheet surface	Entrapped volatiles or moisture	Check for excessive level of fines in regrind or moisture on surface of the resin
	Inadequate throughput	Increase rpm or slow haul-off speed Check size of nip gap
	Rapid or excessive sheet cooling	Raise roll surface temperature
Brown and black specks in sheet	Regrind quality	Check heat history of regrind or number of passes through equipment.
	Untimely purging of extruder	Check resin for lower than normal MI A lower MI resin acts as a purge removing degraded (brown and black) polymer from the barrel Check barrel temperature
Lines in machine direction	Contamination (hung-up, degraded resin)	Clean die lip then die interior Check die for damage or deep scratches Check for source of moisture
Lines in transverse direction	Sheet sticking to rolls	Lower roll temperature
	Stuttering roll rotation	Increase roll tension or adjust roll chains
	Large bead (bank) size	Balance extruder output with line speed to reduce bead size
Vent flow	Output of first stage of screw is higher than the second stage	Raise temperature of second stage or lower temperature of the first-stage feed zone
Rough sheet surface	Excessive bead size	Reduce bead size by either increasing line speed or reducing rpm
	Incompatible resin mix	Check MI of regrind.
	Remove all sources of possible contamination	Purge extruder and die Replace screen pack
	Poor mixing in extruder	Increase screen pack Use a static mixer
	Inadequate pressure of roll	Increase roll nip pressure

PROBLEM/SYMPTOMS	POSSIBLE CAUSE	SOLUTIONS
Dull sheet surface	Low gloss	Raise roll temperature
	Uneven gauge	Adjust die gap, roll gap
	Inadequate polishing	Increase roll nip pressure
Sheet curling at center	One side of the sheet is cooling faster than the other	Raise the temperature of the concave side
Sheet curling at edges	Edges are too thick or too thin	Balance the die
Excessive orientation	Excessive bead size	Reduce bead, adjust gauge and die gap
	Melt sag between die lip and nip rolls	Reduce distance between die and rolls
	Processing temperature too low	Raise barrel temperature
	High pull-off tension	Reduce haul-off speed

Metric Conversion Guide

TO CONVERT FROM	TO	MULTIPLY BY
Area		
square inches	square meters	645.16
square millimeters	square inches	0.0016
square inches	square centimeters	6.4516
square centimeters	square inches	0.155
square feet	square meters	0.0929
square meters	square feet	10.7639
Density		
pounds/cubic inch	grams/cubic centimeter	7.68
grams/cubic centimeter	pounds/cubic inch	0.000036
pounds/cubic foot	grams/cubic centimeter	0.016
grams/cubic centimeter	pounds/cubic foot	62.43
Energy		
foot-pounds	Joules	1.3558
Joules	foot-pounds	0.7376
inch-pound	Joules	0.113
Joules	inch-pounds	8.85
foot-pounds/inch	Joules/meter	53.4
Joules/meter	foot-pounds/inch	0.0187
foot-pounds/inch	Joules/centimeter	0.534
Joules/centimeter	foot-pounds/inch	1.87
foot-pounds/square inch	kilo Joules/square meter	2.103
kilo Joules/square meter	foot-pounds/square inch	0.4755
Length		
mil	millimeter	0 0254
millimeter	mil	39.37
inch	millimeter	25.4
millimeter	inch	0.0394
Output		
pounds/minute	grams/second	7 56
grams/second	pounds/minute	0.1323
pounds/hour	kilograms/hour	0.4536
kilograms/hour	pounds/hour	2.2046

TO CONVERT FROM	TO	MULTIPLY BY
Power		
kilowatts horsepower	(metric)	1.3596
horsepower (metric)	kilowatts	0.7376
voltage/mil	millivolts/meter	0.0394
millivolts/meter	voltage/mil	25.4
Pressure		
pounds/square inch (psi)	kilopascals (kPa)	6.8948
kilopascals (kPa)	pounds/square inch (psi)	0.145
pounds/square inch (psi)	bar	0.0689
bar	pounds/square inch (psi)	14.51
Temperature		
°F	°C	(°F-32)/(1.8)
°C	°F	1.8°C+32
inches/inch	F meters/meter, C	1.8
meters/meter,C	inches/inch, F	0.556
Thermal conductivity		
Btu-in/h., sq.ft.,°F	w/(m-°K)	0.1442
W/(m-°K)	Btu-in/hr,sq.ft.,°F	6.933
Thermal expansion		
inches/inch,°F	meters/meter,°C	1.8
meters/meter,°C	inches/inch,°F	0.556
Viscosity		
poise	Pa-sec.	0.1
Pa-sec	poise	10
Volume		
cubic inch	cubic centimeter	16.3871
cubic centimeter	cubic inch	0.061
cubic foot	cubic decimeter	23.3169
cubic decimeter	cubic foot	0.0353
Weight		
ounce	gram	28.3495
kilogram	ounce	0.03527
pound	kilogram	0.4536
kilogram	pound	2.2046
ton (US)	ton (metric)	0.972
ton (metric)	ton (US)	1.1023

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9531/0715