A Guide to Sheet Extrusion Processing of Polypropylene

Introduction

Current technology produces high performance polypropylene designed for extrusion/thermoforming applications. Resin selection, equipment selection and operating conditions are important considerations. The processing history during sheet extrusion is critical to the thermoforming operation.

Material Selection

When selecting a particular grade of polypropylene, consider the resin's end use performance requirements and the processing characteristics. The "processability" of polypropylene in sheet extrusion and thermoforming is a strong function of the melt properties of the polymer. Polypropylene for melt phase thermoforming requires high molecular weight and high melt strength. High molecular weight grades tend to exhibit high shear viscosity in extrusion. This factor necessitates higher power per pound of output than is normally required for lower molecular weight polypropylenes.

A variety of polypropylene grades, specifically designed for extrusion, and consisting of homopolymers and copolymers are used for melt phase and solid phase thermoforming.

Generally, lower melt flow rate polymers are required for melt phase thermoforming and higher melt flow rate polymers (1 to 3 dg/min, ASTM D 1238, I_2 @ 230°C) are used for solid phase forming. Homopolymers are chosen for their stiffness, and economy, whereas copolymers are required for cold temperature use of the final thermoformed parts. For clarity special clarified random copolymers are used.

In melt phase thermoforming, melt strength is obtained through the use of "high melt strength" polypropylenes, which are designed with low melt flow rates (high molecular weight). Melt strength reduces sheet sag in the thermoforming oven. "A Guide to Thermoform Processing for Polypropylene" is available for a more complete discussion of this process.

Although some extruded-in stress is permissible in sheet for solid phase thermoforming, it is unacceptable for melt phase thermoforming. The nature of the solid phase forming process imparts orientation into the final part. In solid phase pressure forming, orientation is an advantage in the thermoforming and extrusion processes. It increases stiffness and tensile strength for parts that will not be exposed to high heat in use. If the final part will be exposed to heat (greater than 210°F or 100°C), orientation can cause distortion.

Equipment Selection

Commercial extruders are typically 2-1/2 to 6 in. (60 to 150 mm) in diameter. Output is predominantly a function of extruder diameter (See Table 1). The design of the extruder screw is important, since it controls the melting, mixing and conveying of the polymer in preparation for sheeting.

Typical Power and Output of Polypropylene* Extruders

Table 1

Extruder size		Average drive	Output		Barrel heater
(in.)	(mm)	(h.p.)	(lb/h)	(kg/h)	(kW)
1-1/2	38.1	12-18	50-75	23-34	7.5
2-1/2	63.5	25-38	120-160	54-73	21
3-1/2	88.9	50-90	250-400	113-181	45
4-1/2	114.3	95-150	400-700	181-318	75
6	152.4	165-255	800-1,200	363-544	140
8	203.2	350-600	1,500-2,000	680-907	225

*Sheet Extrusion/Thermoforming High Molecular Weight Grades

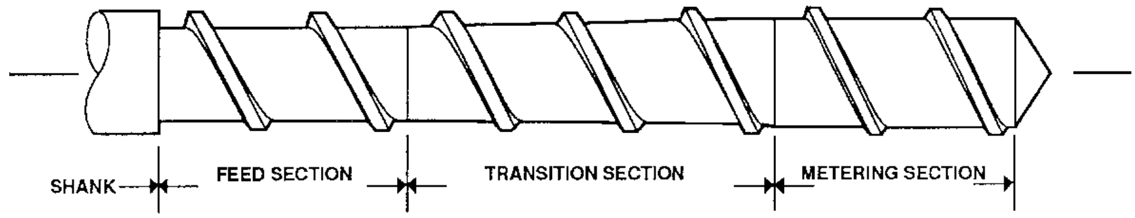
Natural (unfilled) grades of polypropylene can be successfully extruded using a single screw extruder. Mineral filled polypropylene (greater than 20%) usually requires a two stage, single screw with venting to remove moisture or volatiles. Recommendations for actual screw design vary throughout the industry. Guidelines for polypropylene screws are as follows: 1. A compression ratio of 2.5 to 3.5 is recommended; and 2. Typical Length to Diameter (L/D) Ratios should be between 28:1 and 32:1. Low L/D ratio (<24:1) does not provide adequate melting and mixing. Output is proportional to L/D ratio; longer extruders provide higher output, better mixing and improved extrusion stability. Extruders with high L/D ratio (>36:1) have excessive residence time which can cause polymer degradation.

The highly viscous polypropylene grades used for sheet extrusion/thermoforming tend to extrude at high melt temperature due to frictional heating. Conventional, single flighted, square pitched screw designs are usually adequate for polypropylene, however, barrier screws have also become popular because they separate the melt pool from the solid bed (See Figure 1). The solid bed decreases in volume down the length of the screw and the molten pool increases in volume. This provides better melt quality and melt efficiency, and it significantly reduces melt temperature.

Several options are available to improve extrusion efficiency and melt quality. Mixing sections within the metering zone of the screw are used to obtain a more homogeneous melt, providing good mixing and sheet quality. Mixing devices that are commonly used are categorized as distributive and dispersive. Distributive mixing is the repeated rearrangement of the polymer to reduce nonuniformities. Dispersive mixing is the break-up of materials that have a cohesive nature such as pigments (carbon black) in a polymer melt. Dispersive types such as Maddock/Union Carbide and Egan are shown in Figure 2, Distributive type mixing sections such as pins and pineapple are shown in Figure 3.

Figure 1

CONVENTIONAL SINGLE STAGE SCREW (CONSTANT "SQUARE" PITCH)



BARRIER TYPE EXTRUDER SCREW

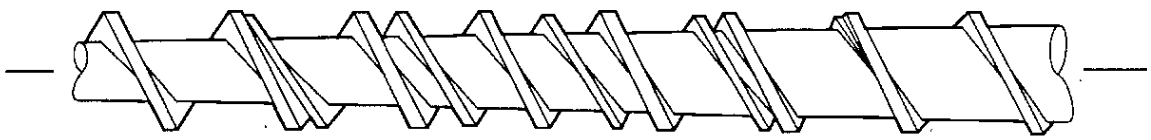
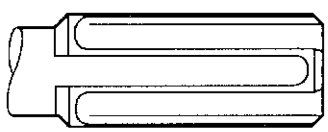
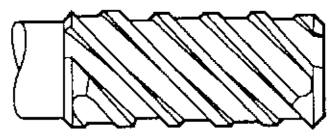


Figure 2

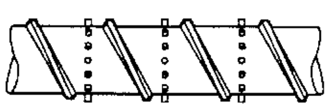


UC Mixing Section

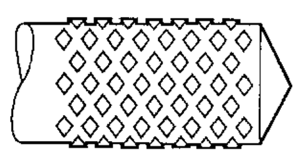


Egan Mixing Section

Figure 3



Pin Mixing Section



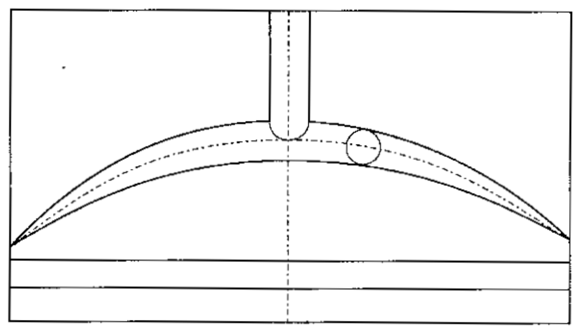
Pineapple Mixing Section

Additional mixing outside of the extruder is accomplished with static mixing sections downstream of the extruder adapter. These consist of mixing vanes/flights that mechanically separate and recombine the molten polymer to homogenize the melt. The advantage of static mixing elements is its mixing capability at low shear rate. However, static mixers cause higher pressure drop (pressure loss) and, therefore, cause higher melt temperature.

Melt pumps or gear pumps are widely used in sheet extrusion to maintain steady output and better sheet quality. Although the stability of the system can be improved by use of a melt pump, it should not be used to compensate for inefficiencies in the screw design.

Once melting and mixing of the polymer is complete, the polymer must flow into the die for sheeting. Several types of dies are used, depending upon the thickness of the sheet, volume of output and width of the sheet. The primary function of the die is to direct an even flow of the molten polymer into the proper sheet dimensions. The coathanger design is recommended for polypropylene because it provides uniform distribution of viscous polymers across the width of the die (See Figure 4).

Figure 4: Coathanger Die



There are several ways to improve flow of polymer through the die. A choker bar aids the flow of high viscosity polymer to the outer edges of the die by restricting flow from the center of the die. Conversely, by restricting flow from the edges of the die, the choker bar enables flow of low viscosity polymers in the center of the die. A flex lip, the most common form of hardware available for fine tuning polymer flow, controls the thickness of the extrudate by adjustment of several bolts along the opening of the die. If the die is not equipped for flow control, minor adjustments can be made by controlling the temperature profile across the die.

The extrudate flowing from the die is quenched and polished by use of a three roll, vertical chrome roll stack. The temperature of each roll is controlled independently to accomplish proper polishing of the plastic sheet. If the roll stack is fed from the top down, the top roll acts as a contact roll and is normally the coolest of the three roll temperatures. The middle and bottom rolls will polish the bottom and top of the sheet respectively. Rapid sheet quenching is undesirable; quenching should occur over the complete contact surface of the three rolls. However, if the roll stack is fed from the bottom up, the bottom roll becomes the cooler contact roll and the top and middle rolls become the polishing rolls.

Extrusion Process Parameters

The extruder barrel temperatures can be set for an increasing, flat or reverse profile. Depending upon screw design, the temperature profile will affect the melt temperature. A reverse profile often reduces the melt temperature. In general, the barrel zones should range from 400 to 470°F (200 to 245°C), but must be optimized for the specific extruder and screw design.

Adapter and die temperatures are normally set to maintain the melt temperature exiting the extruder. The melt temperature should be measured with a thermocouple which extends 0.25 to 0.5 channel diameters into the melt stream of the adapter zone. The recommended melt temperature range for polypropylene is 425 to 475°F (215 to 245°C) however, the higher viscosity polymers may reach 500°F (260°C). Melt temperatures above 500°F (260°C) can be used, but generally increase polymer degradation and make use of regrind more difficult.

The quality of the sheet is crucial for good thermoformability; most sheet imperfections from extrusion become magnified downstream in thermoforming. Sheet quality is affected by the use of regrind. In thermoforming, regrind levels of 50 or 60% and higher are not uncommon.

Although polypropylene producers have formulated extrusion/thermoforming polymers with maximum melt stability, the polymer integrity can be further protected by extrusion in an inert environment. This is easily achieved at a low cost by injecting nitrogen at the base of the feed hopper. The inert atmosphere retards the thermal degradation process to minimize melt flow rate increase per pass. In addition, yellowing is greatly reduced.

Extruder pressure normally ranges from 1,500 to 3,000 psi (100 to 205 bars) upstream of the breaker plate, although some extruders maintain pressures to 4,000 psi (275 bars). Such pressure is required to obtain sufficient mixing.

Generally, the high viscosity polypropylenes used for sheet extrusion generate enough pressure and often require course screen packs to keep the melt temperature low. Screen sizes from 20 to 100 mesh (0.84 mm to 0.15 mm opening) are recommended for fractional melt flow rate (polypropylene which is not suspected of contamination). If contamination is a concern, a finer screen pack will be necessary.

The die gap should be 5 to 10% greater than the desired sheet thickness. The roll stack nip also aids in controlling the sheet thickness and gauge uniformity. Thinner sheet, up to an approximate thickness of 0.050 in. (1.25 mm), requires a minimum nip pressure of 150 pounds per linear inch (ph - total psi distributed over the contact area of the nip); for thicker sheet, 100 phi should be sufficient.

The chrome roll stack temperatures should be individually controlled for proper quenching and polishing. The contact roll should be 140 to 170cF (60 to 80°C) and the polish rolls should be 170 to 210°F (80 to 100°C). The rolling bank should be kept at a minimum to lessen the degradation of the polymer and entrapment of air bubbles, and to minimize the formation of an oriented film surface on the sheet.

Improper extrusion or quenching of polypropylene can cause a high degree of orientation in the sheet. Orientation is related to the alignment of the polymer chains in the direction of flow during processing. It is a quantitative measure of the dimensional stability. Polymers such as polypropylene tend to return to an unoriented state during reheating. This results in warpage or deformation when the sheet or final part is reheated. Orientation can be minimized if: the melt temperature of the polymer is maintained in an acceptable range (420 to 480°F or 215 to 250°C); the die gap is not greater than 15% thicker than the final sheet thickness; and the sheet is quenched with minimum tension.

Sheet Extrusion Troubleshooting

Sheet Lines in Machine Direction

Build up or scratches on die lips	Clean die
Large or uneven rolling bank	Adjust die gap for even guage. Remedy extruder surging (screw design, melt pump)
Loss of contact between sheet and rolls	Adjust die gap for even guage.
Uneven, quick quenching of sheet	Adjust roll stack temperatures (increase).
Winder tension too high	Slow winder speed.
Moisture in polymer	Dry the polymer or vent the extruder.
Poor roll surface	Clean or resurface roll.
Polish rolls not concentric	Replace rolls.

Sheet Lines in Transverse Direction

Extruder surging	Remedy extruder surging (screw design, melt pump)
"Chatter" marks	Minimize rolling bank. Operate roll stack within specified torque. Use independent roll drives for thin gauge sheet.
Pull roll chatter	Pull at a slower speed.
Sheet sticking to roll stack	Reduce melt temperature and/or roll stack temperatures.

Parabolic Sheet Lines

Large and/or unstable bank	Adjust die gap, line speed and/or remedy extruder surging.
Poor flow of polymer through the die	Adjust die temperature to direct flow.
Bank forming at second nip point	Increase take-off speed. Increase pull roll tension. Adjust nip gaps. Reduce extruder output.
Contamination	Check polymer, feed and extruder system.

Surface Defects

Low gloss recommended temperatures.	Adjust roll stack temperatures. See guide for
Uneven surface gloss	Supply more polymer to the first nip. Adjust nip gap for even thickness.
Loss of gloss on one side first nip to allow contact at second nip.	Adjust roll contact on unpolished surface; increase
Spotted surface	Eliminate moisture from polymer by pre-drying or venting extruder. Eliminate air entrapment in the melt. Check for polymer contamination. Check polymer degradation. Lower melt temperature. Check temperature uniformity across each roll. Clean fouled chill roll internals.
Rough surface (sharkskin)	Adjust roll stack temperature. Decrease polymer viscosity. Increase melt temperature.
Extruder surging	Check working order of equipment, temperature and pressure sensing devices. Check screw design for polypropylene. Increase back pressure. Cool feed zone to increase polymer feed.

High Sheet Orientation

Sheet thickness draw-down	Lower pull roll and/or winder tension. Adjust die gap to not more than 10% of final sheet thickness. Increase roll stack temperatures to recommended settings. Decrease nip pressure.