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Extruding Film and Sheeting From *Eastapak* APET Polyester

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Contents

Conversions of metric / U.S. customary values may have been rounded off and therefore may not be exact conversions.

Introduction

Eastapak PET polyester is made and marketed by Eastman Chemical Company. Known generically as polyethylene terephthalate, it is available in homopolymer and copolymer compositions. It is extruded into clear and colored film and sheeting for a variety of food and medical packaging uses, and it also finds application in the field of graphic arts.

PET has been used for years in crystalline form suitable for use at elevated temperatures. More recently, the amorphous form of PET (APET) has been used in tough, high-clarity sheet that is thermoformable into a variety of packaging products.

PET pellets, usually supplied in crystalline state, can be converted by various techniques into finished products having crystalline, amorphous, or oriented properties. Accordingly, different technical considerations are required as downstream conversion processes are varied to achieve final product characteristics.

Film and sheeting produced from this material will ordinarily range in thickness from 0.025 to 25.4 mm (1 to 100 mil) and can be wound or cut to length. Copolymer formulations such as *Eastapak* PET 9921 and 9921W polyesters are slower to crystallize than homopolymer PET and thus offer greater latitude in thermoforming thick sheet and deep draws. PET adapts well to in-line extrusion, thermoforming, and trimming operations. PET must be thoroughly dried prior to extrusion.

Material Characteristics

Products made of *Eastapak* APET possess all the desirable features for which PET is so well known:

- Sparkle and clarity
- Toughness
- Good gas barrier
- Good grease and solvent resistance
- FDA compliance
- Good cost / performance ratio

Additives

Denest agents, winding aids, and colorants are sometimes incorporated into PET using additive feeders that are properly equipped with a water-cooling system to allow metering directly into the feed throat. All additives must be thoroughly dried before use with polyesters. Additive feeders have an advantage in that they can be adjusted, as required, while the line is in operation.

A silicone emulsion coating can be applied to either one or both sides of extruded sheeting to retain the excellent optical qualities of polyesters while providing denest properties. Silicone coating cannot always be used when secondary operations such as printing are required.

Process

Eastman has found this extrusion process to be useful under specific conditions at its facilities. Users must decide for themselves which specific conditions will best suit their particular circumstances.

Major elements of the extrusion process include drying the virgin resin and regrind, along with selection of an extruder, screw, extrusion die, gear pump, and chill-roll stack. Process variables will depend on the characteristics desired in the finished product. For example, thermoformed parts that have either amorphous or crystalline characteristics can be produced.

Drying

Since water causes hydrolytic degradation (intrinsic viscosity breakdown), PET must be dried to a moisture level of 0.005% or less before melt extrusion; a significant reduction in intrinsic viscosity, i.e., molecular weight, will result in a reduction in physical properties, particularly impact strength. This can be confirmed by determining the intrinsic viscosity (I.V.) of material following extrusion. High-viscosity polymers require even more thorough drying and control of extrusion parameters to produce extruded sheet of high molecular weight.

PET can be properly dried using a desiccant system that supplies −30° to −40°C (−20° to −40°F) dew point air at a (1 ft^3/min) temperature of 150°C (300°F) and an airflow rate of 0.06 m^3/min times the extruder output rate in kg/h (lb/h) of PET. The hopper is sized to provide a residence time of 5 hours.

The drying system for a specific extrusion line can vary significantly depending on level of regrind, thickness of film or sheeting being extruded, and whether an in-line or off-line thermoforming system is to be used. The level of amorphous regrind that can be safely blended with virgin (crystalline) pellets is relatively low, possibly only up to 30 weight percent for heavy sheeting; however, thin film regrind usually cannot be blended back at any significant level because of low bulk density and particle size.

Crystallization

APET products manufactured from slower crystallizing copolymers almost always require a crystallizer before drying regrind with virgin pellets at 150°C (300°F). A crystallizer is normally required in all operations where significant amounts of thermoforming scrap are reused.

In some instances, the sheet edge trim can be recycled to the extruder hopper immediately after grinding since any surface moisture will be flashed off when it combines with the hot, desiccated air in the dryer. Regrind must be blended uniformly with the dried hopper material to avoid variations in bulk density that will occur with clumping. Clumps and fluff can also cause material conveying and screw feeding problems.

Characteristics of the Extruder

Extruder L / D ratios of 24:1 to 30:1 are suggested for processing *Eastapak* APET polyester. Shorter L / D ratios do not permit optimum output stability and production rate. The extruder drive motor is sized according to the desired output, and a screw designed specifically for PET is suggested. An extruder output of approximately 3.6 to 4.5 kg (8 to 10 lb) per hour per horsepower can be expected from equipment designed for PET. Barrel heaters capable of temperatures ranging from 260° to 315°C (500° to 600°F) are suggested.

Screw Design Considerations

Single flight, square-pitch extrusion screws, both single and double stage, are moderately successful with PET; barrier screws that have been designed specifically for polyesters are often used, particularly when there is emphasis on high output. The barrier screw is characterized by a double-flighted section that provides separate channels for unmelted pellets and molten material.

The segregation of unmelted and melted phases helps maintain the shear mechanism longer during the melting process and will increase output for a given extruder. The output rate for an 89-mm (3.5-in.), 24:1 L / D extruder equipped with a barrier screw and operating at 95 rpm is normally at least 320 kg (700 lb) per hour, but the drive horsepower requirement is usually less than 75. Machine direction gauge variation will be approximately 4% for film extruded from virgin material.

Cooling along the entire length of a screw will decrease output and is usually not suggested. To prevent bridging, a slight flow of ambient temperature water should be used to cool the first 4 flights of the screw feed section.

Single flight, square-pitch, general-purpose screws are sometimes used on an interim basis, but they may be characterized by a high-horsepower requirement and melt temperature overrun. A typical 89-mm (3.5-in.), 24:1 L / D polyolefin screw might be described as:

Feed flights: 9 at 10.69 mm (0.421 in.)

Transition flights: 3

Metering flights: 12 at 2.69 mm (0.11 in.)

Output: 155 kg (340 lb) per hour at 75 rpm

Since two-stage, polystyrene-type screws are quite often used with PET, some extruder screw manufacturing companies have designed and are suggesting two-stage screws. Rheological information and complete physical properties are available for all *Eastman* PET formulations on request.

Gear Pump

Experimental work conducted at Eastman Technical Service and Development Laboratory has shown that a properly designed barrier screw that is 89 mm (3.5 in.) or larger in diameter will perform satisfactorily when processing blends containing up to approximately 30% regrind if the flakes are at least 0.25 mm (10 mil) thick. The machine direction (M.D.) gauge variation with virgin / regrind blends was approximately ±6% when all conditions were kept constant; however, when the percentage or thickness of the regrind was changed, additional time was required for equilibration / steady-stating unless a gear pump was in use.

A gear pump is a positive displacement metering device that operates at a constant speed and has a pressure sensor on each side of the pump to control the system. The suction pressure (between the extruder and pump) can be preset and automatically maintained by changes in the extruder screw speed to provide constant output.

Gauge variation for a sheet extrusion system controlled by a gear pump will usually run approximately ±4%. This control system automatically compensates for changes in the extruder output rate, and it minimizes any effect that changes in the size and amount of regrind would otherwise have on film gauge. If a gear pump is to be used, the metering section can be shorter. This will call for increased emphasis on the design of the feeding and melting sections of the screw.

Screen Pack and Screen Changer

The following screen pack is typical for extruding APET sheeting.

Mesh Size	Number of Screens
24 × 24	1
60 × 60	1
24 × 24	1

Thinner films usually require up to 100 × 100 mesh screens to prevent metal, grit, and other particulate material from damaging the polishing rolls. A hydraulic-powered, automatic screen changer is always suggested on a modern extrusion line.

Die Design

A flexible-lip film extrusion die having a two-piece body is suggested for extruding film from *Eastapak* APET polyester. A flexible-lip die with a streamlined restrictor bar, assuming a restrictor bar die is used, is suggested for sheeting. Film under 0.25 mm (10 mil) requires a land length of 25 to 32 mm (1.0 to 1.2 in.); sheet over 0.25 mm (10 mil) requires a land length of 32 to 50 mm (1.2 to 2.0 in.); sheet over 2.0 mm (80 mil) may require a land length of up to 89 mm (3.5 in.). A die orifice of 1.01 to 1.27 mm (40 to 50 mil) (maximum, before adjustment) is satisfactory for film, but an orifice at least 25% greater than the desired thickness is suggested for sheet.

The face of the die is tapered to permit a short die-to-roll gap, and it has a good surface finish [0.05 to 0.10 microns (2 to 4 microinches)] on all flow surfaces, streamlined flow channels, and a scratch-free die lip. PET rheological data is used to design the flow channel for film / sheeting dies. When thicker sheeting is to be produced from low-viscosity PET, the traditional tapered die may be replaced with a “scalloped” die, especially when polishing roll diameters are 40.6 cm (16 in.) or more.

The die is equipped with heaters having a watt density capable of heating all surfaces to at least 315°C (600°F) to properly purge and clean the die. It should be noted that a restrictor bar die with fluorocarbon bushings may not be suitable at 315°C (600°F). When possible, sheeting dies without restrictor bars are used.

When deckles are required in PET extrusion, they are machined from hard copper to required dimensions and installed internally in the die lips. If deckles are not properly streamlined, the material will hang up and degradation will occur.

Sheet Line

APET film / sheet is normally extruded horizontally from the die to the chill roll. A three-roll stack arrangement is used to calender or polish heavy film or sheeting, and a two-roll, S-wrap arrangement is used for thinner films.

Cooling and Polishing Rolls for Thin Film

A chill-roll casting unit will normally be equipped with 250- to 610-mm (10- to 24-in.) diameter rolls, depending on the production rate desired. Chill rolls are chromeplated with a finish of 0.05 to 0.10 microns (2 to 4 microinches) for a superior film finish. When higher production rates are required for film that is to be thermoformed, a roll surface having good release properties may be more desirable.

Ordinarily, two casting rolls plus idlers, trimmers, and a nip are required in a casting setup. The two casting rolls are normally equal in diameter but can be different as in the case of a small “stripper” roll used in conjunction with an extra large chrome casting roll. A schematic diagram of the extrusion line used in Eastman’s Technical Service and Development Laboratory for producing thin APET film is shown in Figure 1.

Figure 1
Chill-Roll Extrusion Line

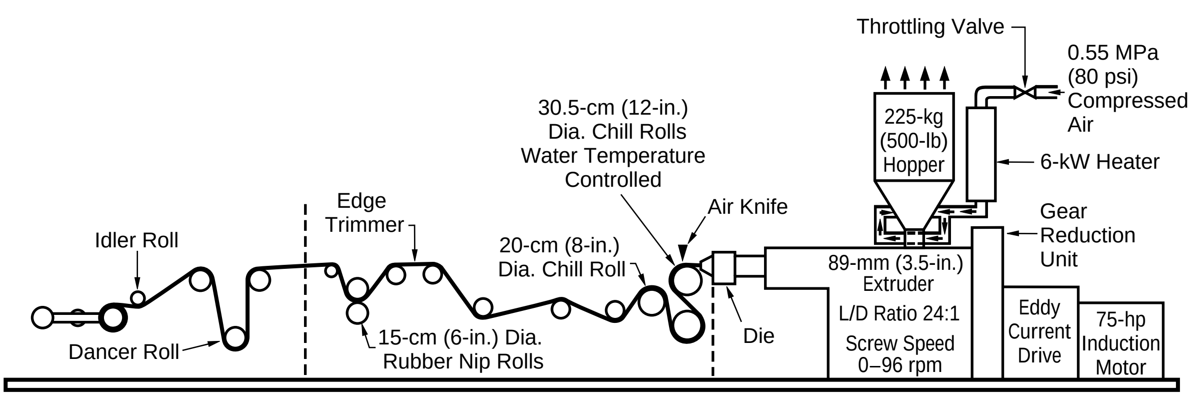
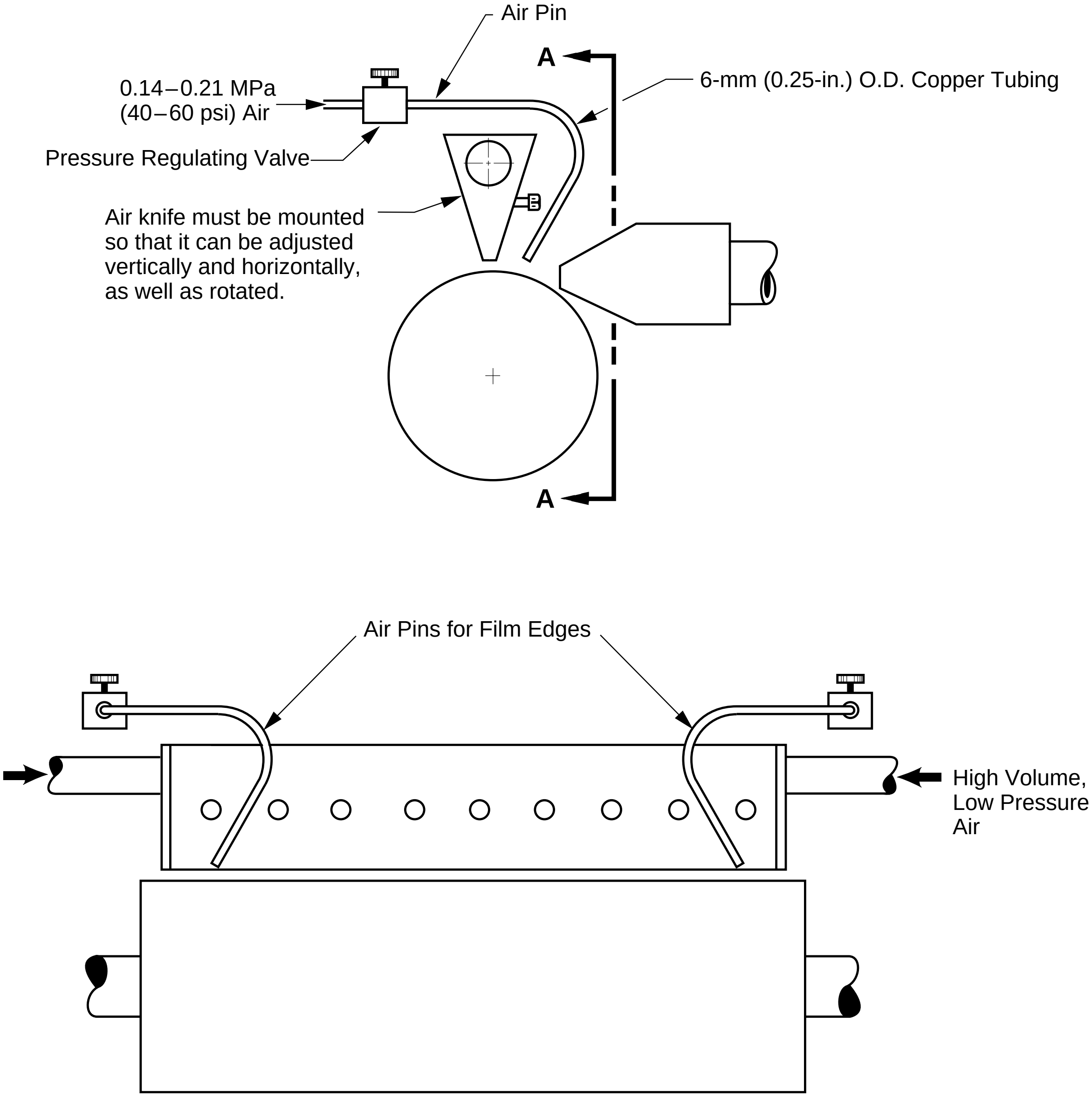


Figure 2 illustrates the casting roll arrangement equipped with small air jets to hold the film edges in contact with the chill roll. This is done to minimize neck-in and to eliminate edge weave. The air jets can be fabricated from 6-mm (0.25-in.) O.D. copper tubing. In addition, an air knife is used to force the hot, extruded web into intimate contact with the chill roll across its entire width.

Figure 2

Chill-Roll Extrusion—Air Knife and Air Pin Positioning



View "A-A"

The low melt strength of PET makes it essential that the die-to-chill-roll distance be minimized. Too large an air gap will allow the web to drag over the lower die lip creating lines in the sheet. The vertical position of the chill roll is adjustable so that the top is approximately 6 to 12 mm (0.25 to 0.50 in.) above the center line of the die (see Figure 3). When using a three-roll stack, the nip point is at or slightly below the center line of the die, as shown in Figure 4.

Figure 3

Chill Roll Positioning

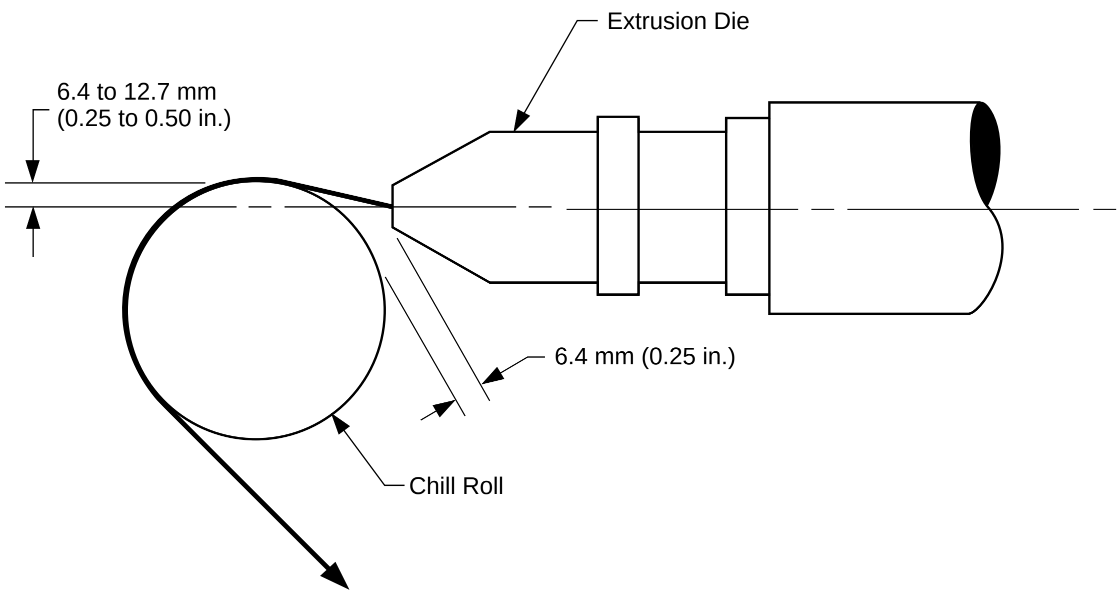
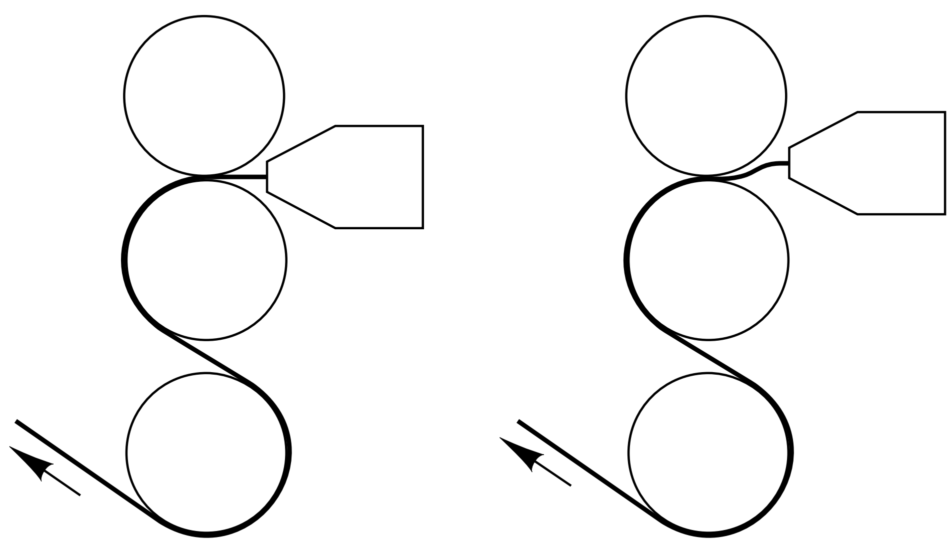


Figure 4

Three-Roll Stack Positioning



Normal position of die relative to nip point when sagging of the molten extrudate is not a problem.

Roll stack lowered relative to the die to overcome extrudate sag, minimizing air entrapment and random unpolished areas.

Cooling and Polishing Rolls for Thick Film and Sheeting

A three-roll stack is usually suggested for heavy film and sheeting [0.25 to 6.35 mm (10 to 250 mil)]. With this particular setup, nip-polishing (sometimes called kiss-polishing or calendering) will produce film or sheet having superior appearance characteristics compared with those associated with the two-roll, S-wrap technique.

When PET film or sheet is properly nip-polished, practically all die and flow lines are eliminated. It should be noted, however, that nip-polishing is more difficult than two-roll casting and that very good transverse direction thickness control at the die is essential, particularly with thinner gauges.

The die is adjusted prior to bringing the polishing roll into position to ensure uniform strain across the web. Roll pressure [kg / cm (lb / in.)] is inversely proportional to film gauge, and consequently, pressure can range from approximately 18 kg / cm (100 lb / lin. in.) for heavy sheet up to 62.5 kg / cm (350 lb / lin. in.) for thinner gauges. Due to the high applied force, chill-roll diameters are at least 305 mm (12 in.), with 406 and 450 mm (16 and 18 in.) diameters being more typical in production situations. Roll surfaces are hardened to approximately 48–50 Rockwell C before chromeplating to prevent worm-tracking and grooving.

Additional roll design factors:

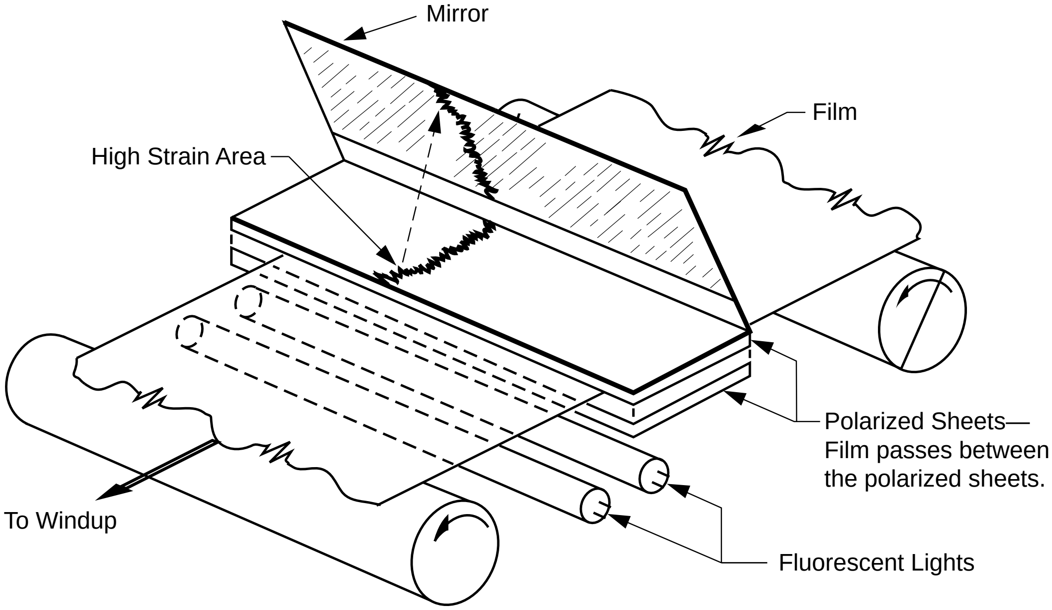
1. The roll surface has a 0.074-mm (0.003-in.) thick chromeplating with a finish of 0.05 to 0.10 microns (2 to 4 microinches) for graphic arts and custom sheet / film production. Thicker sheeting, which is usually extruded at higher production rates for thermoforming, may require a better surface finish to prevent sticking.
2. Roll diameters match each other to within ±0.074 mm (±3 mil) for an accurate nip-polish.
3. The total indicated run-out or roll straightness and concentricity is not to exceed 0.025 mm (1 mil). If very thin film [<0.13 mm (<5 mil)] is to be produced, roll finish match and run-out are even more critical.

Film that is produced by nip-polishing has excellent optical quality. Nip-polished film can be examined for strain uniformity by using polarized light as illustrated in Figure 5.

Output rates for APET film and sheeting are normally limited by cooling rate. Thin roll-shells, chilled water, and independent temperature controls should provide good cooling efficiency. The cooling rate becomes more limiting for thicker extrudates and can call for chill rolls of different design from those used for thinner films.

Figure 5

Setup for Checking Strain Uniformity in Nip-Polished Film



Note: If it is not possible to install such a setup in line, a similar setup could be located near the extruder for use in checking individual pieces at regular intervals.

Winding Equipment

Precise tension control is an important design consideration for APET film winding equipment. Sudden changes in tension or uneven tension will produce wrinkles in the film. Minimum winding tension is used with APET film to reduce blocking tendencies, and a silicone coating or incorporation of an internal denest additive can reduce the tendency to wrinkle. A small idler roll positioned within 13 mm (0.5 in.) of the wind-up roll is a helpful aid in wrinkle control. It is suggested that long spans between the wind-up roll and the upstream idler rolls be avoided.

Simple hydraulic winders are quite adequate for heavier sheeting, but turret winders are required for thinner films. If gauge bands are particularly critical, a secondary slitting / winding operation is normally required.

APET film has a very high gloss, and the resulting high coefficient of friction makes denesting of formed blisters difficult. Consequently, an external silicone coating or internal denest concentrate is suggested. Information on the use of these products can be obtained from Eastman.

Static Control

It is suggested that equipment for controlling static be located downstream from the nip rolls and just before wind-up to minimize dust pickup, electric shock, film clinging, and blocking.

Extrusion Conditions

Conditions shown in Table 1 are suggested as a starting point for extruding 0.51-mm (20-mil) sheet from PET on an 89-mm (3.5-in.), 24:1 extruder. The die temperature is set approximately 5°C (10°F) lower than the stock temperature. It is generally suggested that stock temperature not exceed 280°C (540°F); however, heavier sheet can require melt temperatures as low as 250°C (480°F).

Table 1 also gives suggested starting temperatures for nip-polishing with a three-roll stack. These temperatures need to be adjusted for best results. In the majority of cases, the rolls are operated at temperatures just below the point at which sticking would occur. When down stack casting is used, the top roll is set approximately 8° to 10°C (15° to 18°F) cooler than the middle roll so that the film will follow the middle roll and release easily from the top roll. With a two-roll, S-wrap setup, the first roll is operated as hot as possible without film sticking, and the second roll is adjusted to obtain the desired film flatness.

Table 1

Typical Extrusion Conditions for *Eastapak* PET [Nip-Polishing 0.51 mm (20-mil) Sheeting on a Three-Roll Stack]

Extruder: 8.9-cm (3.5-in.), 24:1 L/D Barrier Screw
Screen Pack: 24-60-24 Mesh Arrangement

	°C	**(°F)**
Barrel Zone No.		
1	270	(520)
2	295	(560)
3	295	(560)
4	275	(530)
5	270	(520)
Gate	270	(520)
Adapter	270	(520)
Die Zone No.		
1	270	(520)
2	270	(520)
3	270	(520)
Stock Temperature	270	(520)
Chill-Roll Temperature No.		
1	40	(100)
2[a]	50	(120)
3	65	(150)

[a] *The temperature of No. 2 roll is maintained at 3° to 5°C (5° to 10°F) below that at which sticking would occur.*

Start-Up and Line-Out Procedures

When processing PET into film and sheeting, it is suggested that extended runs be made and that frequent stops and restarts be avoided. Even though interruptions in production can be tolerated without degradation becoming a problem, they are to be avoided as much as possible to minimize the presence of die lines in the finished product.

The extruder and die are thoroughly cleaned prior to extrusion of APET film and sheeting. Any nicks or scratches on the die flow surfaces are polished, and the surfaces of the chill rolls are thoroughly cleaned.

PET can remain in the extruder barrel if the system can be reheated to approximately 315°C (600°F), which is 30°C (50°F) higher than normal production temperatures. Sufficient time must be allowed in all channels of the extruder / neck / die to heat the PET until it is completely melted.

Before start-up, polymer drying conditions are reconfirmed. Extruder and die temperatures are checked to see that they are properly adjusted and that heat-up time has been adequate for any residual PET to become molten. When starting the extruder, screw rotation is set at 15–25 rpm with the hopper throat closed. The extruder is then starve-fed to prevent overloading until an extrudate appears at the die. It is not usually necessary to starve-feed the extruder on subsequent runs because PET remains in the barrel from previous use.

To minimize die lines, the screw is stopped after a continuous web is coming from the die, and the die lips are cleaned again. The die lips are cleaned with a brass spatula and then a light abrasive household cleaner; finally, they are wiped with a clean cloth. After thorough cleaning, the die extremities and the orifice are sprayed with a silicone release agent.

When ready to begin operation, the chill-roll takeoff unit is brought into casting position quickly and the extruder restarted. A clean start will prevent molten polymer from drooling on the die, which would otherwise require recleaning. A leader of film or paper can be prethreaded back through the takeoff equipment to aid in start-up and to prevent the extrudate from rolling up on the die lips.

An alternate threading method better suited for thin-gauge cast film follows:

> Back the takeoff unit away from the die slightly and insert a piece of stiff cardboard [the same width as the die and about 30 cm (12 in.) long] against the die lip just under the orifice. When the melt first emerges, it can be caught on the cardboard and carried onto the chill roll. When using a conventional horizontal casting technique, this can prevent melted material from forming a bead and sticking to the die lips. If polymer clinging to the die lips creates die lines, a thin spatula can be used to dislodge the material. A clean start-up is absolutely necessary to minimize die lines in the film, particularly when nip-polishing is not used.

During start-up with a two-roll, S-wrap unit, the first chill roll is set at approximately 45°C (110°F), which is somewhat cooler than normal, to prevent sticking on the freshly cleaned surface. After 10 to 15 minutes, PET plate-out will act as a release agent for the film, and the roll temperature can be increased to approximately 60°C (140°F). If spotty pick-off of the plate-out is noted, the chill-roll temperature can be increased another 10°C (18°F) to remove the excess. After a few minutes, it may be returned to the previous setting.

Film edges may be trimmed with razor slitters utilizing industrial-type blades, securely mounted to prevent chatter. The included cutting angle is minimized to prevent edge buildup on the finished wound roll.

The calendering gap must be set before starting a three-roll stack. If roll alignment is not accurate, use a zero gap for 0.13- to 0.25-mm (5- to 10-mil) film, a 0.13- to 0.25-mm (5- to 10-mil) gap for 0.38- to 0.51-mm (15- to 20-mil) film, and set the gap equal to the gauge for anything greater than 0.64 mm (25 mil). If rolls are well matched, the gap will approach the film gauge even for thinner films.

Gauge uniformity is then checked and die adjustments made, as required, to minimize variation across the web. The film thickness is measured at 5-cm (2-in.) intervals and the readings carefully marked to accurately indicate any adjustments needed. A width of the extruded film, marked for thickness across the web, is held up to the die bolt pattern and is used as a guide to adjust the die bolts, plus or minus, to achieve thickness uniformity. Bolts in heavy areas are tightened, and bolts in thinner areas are loosened repeatedly until the gauge variation across the film width is no more than ±5% except at the edges, which are to be trimmed.

Once the die is properly adjusted, the polishing roll can be brought into position, and only minor adjustments should then be required. Proper line-out procedure will minimize the possibility of producing film with nonuniform strain resulting from thick and thin areas across the web.

A short die-to-chill-roll air gap is required to minimize sagging of the extrudate and thus prevent premature chill-roll contact ahead of the nip point; otherwise, air entrapment and random unpolished areas are likely to result. If air entrapment is still a problem when using a low melt temperature and a short air gap, the chill roll may be lowered to permit direct entry of the extrudate into the nip so that it will be contacted simultaneously by both polishing rolls (see Figure 4).

If a shutdown is necessary to change materials in the extruder, the PET is thoroughly purged from the barrel. Molten PET sticks to metal and is difficult to remove from the screw, but it can be readily purged from an extruder with *Eastar* copolyester. In either case, the hot die can be opened and cleaned.

If the machine is to be restarted on PET, the barrel need not be purged if the system can be reheated to 315°C (600°F). For a shutdown of not more than 1 hour, the barrel heaters need not be readjusted. For an overnight shutdown, a drool pan is mounted under the die and filled with melted polymer to seal the lips and prevent oxidation of the polymer that remains in the die.

Quality Considerations

There are at least three quality control concerns requiring attention during film or sheeting production runs. They include measurement of gauge uniformity, strain level, and I.V. It is suggested that film gauge be controlled to ±5% of the target thickness in both the machine (M.D.) and transverse (T.D.) directions. The strain level is important because it will affect the film's performance during and after thermoforming. Excessive strain can pull the film out of the chains during thermoforming. Too much strain can also cause localized shrinkage of the material during thermoforming that can result in nonuniform gauge and / or wrinkles. Strain level can be determined by checking shrinkage of a heated [120°C (250°F)] sample.

For blister-packaging applications, the film M.D. shrinkage is controlled from approximately 8% to 10%. For applications in which the film will be used in its extruded condition and not thermoformed, it is suggested that M.D. shrinkage be held at a maximum of 4% to 5%. The use of polarized light is an excellent nondestructive technique for qualitatively checking extruded film, sheet, or formed parts for the presence and uniformity of strain. A simple polarized light apparatus can be mounted in line with the extruder to monitor strain (see Figure 5). PET is unlike many other polymers in that strain attributable to die draw-down is very low; however, a considerable amount of strain can be produced in the polishing operation.

The toughness of APET film is highly dependent on its I.V. as well as other factors, including strain. I.V. determination is rather complicated and is not usually suggested as a quality control test. Indirect I.V. indicators are related to extruder drive motor load and physical properties of the film / sheet. Some I.V. data can be supplied, as required, by Eastman and independent testing laboratories.

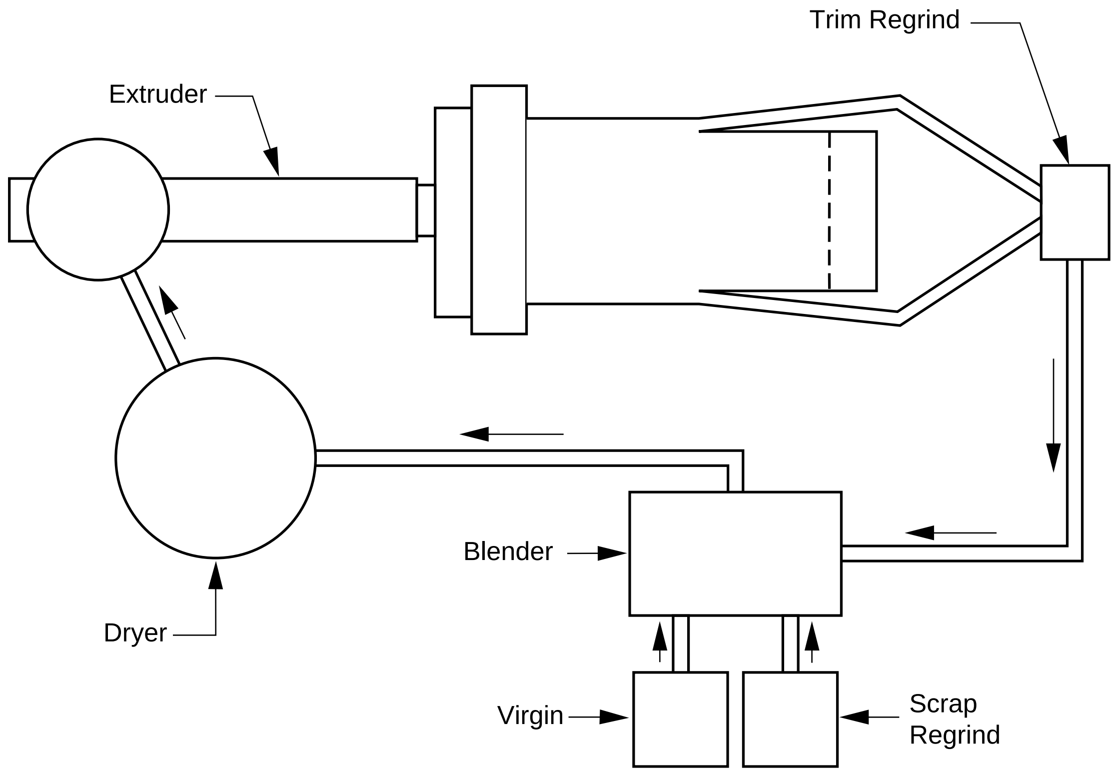
Scrap Reclaim

Both crystalline PET and amorphous PET are recyclable polyester products, either in the existing PET stream or as a regrind / virgin blend in film / sheet extrusion. Complete combustion of these products produces primarily CO_2 and water. Scrap from PET extrusion and thermoforming operations is normally reclaimed. It is suggested that regrind be utilized as a mechanical blend with virgin pellets. The regrind must be kept free from contamination to assure good-quality film; it must also be crystallized before drying. The regrind / virgin pellet blend should then be dried for approximately 4 hours at the same conditions previously suggested for PET pellets.

Figure 6 illustrates an arrangement for reclaiming trim scrap.

Figure 6

Scrap Reclamation System



For additional information on *Eastapak* PET polyester, please contact Eastman at one of the addresses shown on the back cover of this publication.

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Material Safety Data Sheets providing safety precautions that should be observed in handling and storing Eastman products are available online or on request. You should obtain and review the available material safety information before handling any of these products. If any materials mentioned are not Eastman products, appropriate industrial hygiene and other safety precautions recommended by their manufacturers should be observed.

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Publication TRS-106D
May 2001

ECP 6134 A3 (5-01) Printed in U.S.A.