Profiles extrusion with Eastman Provista™ NXT copolymer

Applications

Eastman Provista™ NXT is the latest in a line of Eastman copolyesters (Provista™, Provista™ GP) well-suited for profiles extrusion applications. Provista™ NXT generation offers remarkably fast processing speeds, high resistance to melt fracture, better melt strength, lower processing temperatures and increased compatibility with the PET recycle stream (resin identification code of 1). Provista™ NXT copolymer combines sparkling clarity with excellent toughness and chemical resistance, making it appropriate for a variety of applications. Shapes and profiles extruded from the resin exhibit excellent transparency, clarity and physical properties appropriate for pricing channels, signage, trim, P-O-P structures, electronic packaging, tubes, medical and various other applications. The processing characteristics of Provista™ NXT copolymer are similar to those of many other thermoplastics.

Description

Eastman Provista™ NXT copolymer is a clear, amorphous polymer developed by Eastman Chemical Company for the extruded profiles industry. It is modified to combine the traditional benefits of copolyesters with good melt strength and resistance to melt fracture. Plasticizers or stabilizers are not required or used in this polymer.

Provista™ NXT copolymer can crystallize under some circumstances during processing. As a result, following the usage guidelines outlined in this document is critical to both safety and efficiency of operation.

Drying

For successful extrusion of Eastman Provista™ NXT copolymer, the pellets must be dried before processing. It is suggested that dry air be used to transfer pellets to eliminate air leakage from or into the closed loop dryer system. As in the case of all thermoplastic polyesters, Provista™ NXT copolymer is subject to hydrolysis when it is in the molten state during processing. This hydrolysis results in a decrease in molecular weight that is reflected by a lowering of physical properties. To prevent hydrolysis during the extrusion process, Provista™ NXT copolymer must be thoroughly dried. The moisture level should be 0.04% or less.

Drying the material in a dehumidifying dryer at a temperature of 65°C (150°F) to reduce the moisture content to a level (0.04% maximum) that will prevent significant hydrolysis in processing equipment operating at 195–275°C (380–525°F). Normally four hours drying time is sufficient; however, extended drying times may be required in humid areas or when using less-than-optimal drying equipment. Dryer temperature should not exceed 65°C (150°F) to prevent pellets from softening and sticking together in the hopper.

Type of dryer

The most practical production system for drying pellets is a hopper-dryer system. Modern dryers use a molecular sieve desiccant material in small bead form. The desiccant is placed in the return air (or intake) stream of the dryer in 2 or more beds or canisters. One bed is onstream removing moisture from the return process air while the second bed is being regenerated (dried) at high temperatures by secondary heaters. A number of companies supply dryers to the plastics industry.

It is important that the dryer purchased have the correct design requirements for the plastic material being processed. Provista™ NXT copolymer should be dried at a maximum temperature of 65°C (150°F). Care should be taken to select a dryer that can be accurately controlled to deliver air at that temperature as some dryers can produce undesirable temperature spikes. An inlet temperature gauge is a useful addition to the drying hopper.

Dry air provides significantly more efficient drying than ambient air, particularly during humid summer months. Consequently, a desiccant-type dryer is recommended. This type of dryer provides drying air with a dew point of –40°C (–40°F) or lower. Dew point is an absolute measure of air moisture and is independent of air temperature. Dew point, not relative humidity, should always be specified regarding air dryness. It is worth the small additional cost to incorporate a dew point monitor, which is an option available on many dryers.

The drying hopper should be large enough to allow adequate drying time for the pellets. For example, if the typical throughput of the extruder is 45 kg (100 lb) per hour, a 278-kg (600-lb) capacity hopper is used for a 6-hour drying time. A good drying hopper has a screen and cone system in the bottom to assure uniform airflow through the pellet bed. It is also designed to provide an even flow of pellets from top to bottom (plug flow) as well as an air-lock loading system. Insulated hoppers should be used to maintain the pellet bed at the inlet air temperature.

Vacuum loaders should be used to feed the regrind and pellets from the loader/blender to the drying hopper and then to the extruder hopper. Another approach is to use a central dryer/blender system to serve several extruders. The material from a central system can be transferred automatically to the hoppers of several machines or the dried material may be loaded into clean drums and moved to individual machines.

Dryers are specified according to their blower capacity in cubic meters (m^3) [cubic feet (ft^3)] per minute [m^3/min (cfm)] of air delivery. A good dryer design criterion allows 0.062 (m^3/min)/kg/h (1.0 cfm per lb/h) of material to be extruded. For example, if 45 kg/h (100 lb/h) of material is to be extruded, a minimum blower capacity of 2.8 m^3/min (100 cfm) is used. A dryer with a blower capacity of 2.8 m^3/min (100 cfm) should be considered the smallest size for any user. Smaller capacity dryers should not be used because they may not provide sufficient airflow to prevent excessive heat losses.

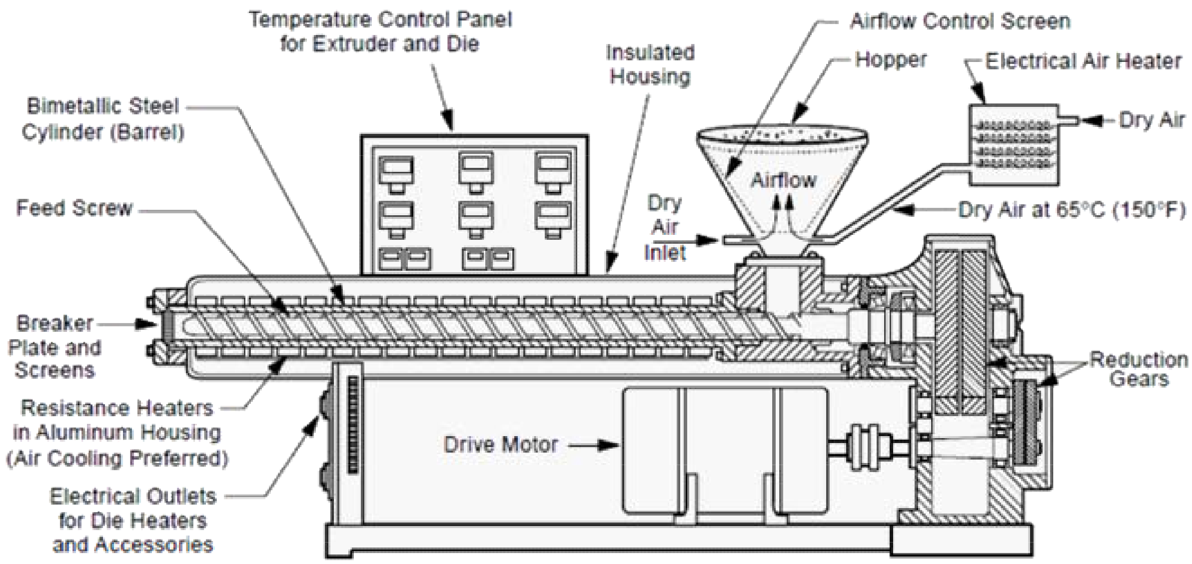
Dryer requirements can be summarized as:

- Type of dryer: automatic, desiccant
- Air dryness: dew point of –40°C (–40°F) or lower
- Air temperature: maximum 65°C (150°F) at the hopper inlet
- Circulation: 0.062 (m^3/min)/kg/h (1.0 cfm per lb/h) of plastic to be dried and not less than 2.8 m^3/min (100 ft^3/min) per unit
- Monitors: (a) hopper inlet thermometer, (b) dew point monitor
- Hopper size: 6–10 times the hourly poundage to be dried. (Hold-up capacity depends on average incoming pellet moisture content.)
- Hopper shape: for good air and pellet flow, a tall, slender hopper should be used versus a short, large diameter design.

Extruder

Eastman Provista™ NXT copolymer requires the same feeding, melting, compression and metering processes as those required by other thermoplastics. The screw at the entry point (Zone 1) should be heated to at least 165°C (330°F). Care must be taken to prevent overheating in the feed zone because premature melting and screw "roping" may occur. Feed throat cooling is recommended, and occasionally, internal screw cooling of the first 3 or 4 flights may be necessary. As the pellets are conveyed down the extruder barrel by the screw, additional heating and compression occur followed by a metering zone. A typical extruder is shown in Figure 1.

Figure 1 Typical extruder



It is suggested that an extruder be selected with a length-to-diameter ratio of at least 24:1. Since the diameter of the extruder barrel determines the available heating area and material output of the extruder, large machines 6.35 cm (2.5 in.) and up are typically used in production situations. A nominal screen pack is used when extruding shapes and profiles from Eastman Provista™ NXT copolymer; i.e., one 40-mesh, one 60-mesh, and one 80-mesh screen. The use of a finer mesh, denser screen pack can be used, but caution should be exercised such that the appropriate melt temperatures of the material and pressure limitations of the machine are not exceeded. It should be mentioned that Provista™ NXT can run successfully without screen packs, as long as final part appearance and size are acceptable to the end-user.

Screw design

Eastman Provista™ NXT copolymer can be successfully extruded by using either a single-stage square pitch or barrier screw design. For example, experimental work on profile and tubing extrusions in Eastman's laboratory has been done on a 6.35-cm (2.5-in.) extruder with a 24:1 L/D ratio using the following barrier screw design:

- 5 feed flights 12.2 mm (0.480 in.) deep
- 4 transition flights
- 13.5 metering flights 2.5 mm (0.098 in.) deep
- Overall compression ratio of 2.5:1

Note: The term "overall compression ratio" only applies to a barrier screw and is calculated using the metering and feed zone flight depths. In reality, the true compression ratio is unknown due to the variable degree of compression the melt experiences in the barrier section.

While the use of an existing screw may be possible, the degree of success depends on the required melt temperature, output rate, and product quality. Surging, poor homogenization, excessive load on the drive motor, and extrudate voids may be caused by screws with excessively high compression ratios, excessively deep feed zones, overly shallow metering sections, or possibly too many transition flights. Limited evaluations may often be conducted under less-than-optimum conditions by using internal screw cooling, reverse temperature profiles or starve-feeding.

Temperature profile

The preeminent feature of Eastman Provista™ NXT is its ability to run at very high processing rates without melt fracture. This capability also implies that running cooler melt temperatures and maintaining suitable melt strength is more feasible than with other material alternatives. In short, controlling the polymer melt temperature to 210–230°C (410–445°F) (hand probe measurement of the melt stream) should be a sufficient target for providing the melt strength necessary to extrude most profile shapes.

The following "hum" profile may be useful as a starting point to achieve reasonable melt temperatures (210–230°C):

- Feed Section (Zone 1): 190–210°C (375–410°F)
- Transition Section (Zone 2): 210–235°C (410–455°F)
- Metering Section (Zone 3+): 190–210°C (375–410°F)

An example temperature profile for Eastman Provista™ NXT run on an Eastman laboratory extruder is provided here as a starting point. Adjustments may be necessary in specific instances to produce acceptable results.

- Extruder: 6.35 cm (2.5 in.), 24:1 L/D, 3 barrel zones, 1 clamp, 1 die zone
- Zone 1: 205°C (400°F)
- Zone 2: 230°C (445°F)
- Zone 3: 200°C (390°F)
- Clamp: 200°C (390°F)
- Die: 205°C (400°F)
- Melt Temperature (taken at the die with hand-held probe at 30 RPM): 220°C (430°F)
- Pressure: 1,000 psi
- Throughput: 55 kg/h (120 lb/h) at 30 RPM

Other temperature control issues

Another point to consider in obtaining a suitable melt temperature is the fact that increased screw RPM will correspondingly cause the melt temperature to rise, due to viscous heating from shear on the screw. Calculations have determined that if the shear rate in the metering section of the screw exceeds 35 s^{-1} [given by the equation below, where D is screw diameter (m), N is screw speed (rotations/sec), and H is the flight depth (m) of the screw in the metering section] then the melt temperature will likely exceed 245°C (475°F). Melt strength at excessive temperatures are likely to make profile shape control difficult.

$$\text{Shear rate} = \frac{(3.14)\,DN}{H}$$

In the event that melt strength does become an issue at the desired extruder output (RPM), screw and barrel design may need to be reconsidered. If gels or unmelts appear, temperatures in the transition zone (Zone 2) may be raised to help produce a clear extrudate. In addition, it may also be helpful to lower the feed zone (Zone 1) setting. This increases solids conveying by preventing the pellets from sticking on the screw. Gels and unmelts may appear or be more numerous when running regrind Eastman Provista™ NXT with virgin material. If available, screw cooling may be useful in such circumstances.

The metering section (Zone 3) and die/clamp temperature settings may be used to lower the final melt temperature. Typically, motor load or pressure constraints limit the ability to reduce temperatures beyond the recommended range. However, in cases where equipment allows, it is useful to continue maximizing melt strength by carefully lowering temperature settings in these zones.

Start-up and shut-down procedures

The following protocols should be used when starting-up and shutting-down the extruder with Eastman Provista™ NXT. It is important to emphasize that NXT is a material that can crystallize in the screw barrel as well as in the die, making important the adherence to these procedures, written to protect both equipment and personnel.

Shut-down procedure

1. Shut-down for tooling (line) adjustments:

   - Continue to run Eastman Provista™ NXT slowly out of the die at 5–10 RPM. Slowing the screw below 5 RPM may allow crystallization of the material both in the die/clamp and on the screw ("roping"). If this occurs (evidenced by total loss of material flow) immediately raise all machine temperatures to 230°C (445°F) or higher. Carefully monitor motor load and pressure as feed is reestablished.

2. Shut-down requiring stoppage of the screw for >15 min but with machine temperatures maintained:

   - Close feed hopper and empty barrel of all Eastman Provista™ NXT. Preferably purge the barrel at process RPMs or higher.
   - Increase temperature of die/clamp to at least 230°C (445°F). Also, make sure all barrel zones are maintained at 210°C (410°F) or higher.
   - Cut extruder RPM to zero.

3. Total shut-down of extruder:

   - Close feed hopper. Empty barrel of all Eastman Provista™ NXT. Preferably purge the barrel at process RPMs or higher.
   - Stop screw drive motor and power off heaters.

Start-up procedure

1. Start-up following shut-down scenario 2 or 3 (above):

   - Set extruder temperatures on the barrel zones and die/head to at least 230°C (445°F).
   - Allow a cold machine at least 1 hour of soak time once temperature settings are reached.
   - Fill extruder feed hopper with fully dried Eastman Provista™ NXT.
   - Following all neccessary safety precautions, slowly increase screw speed to 5–10 RPM. Carefully monitor load current (amps) and melt pressure to assure proper functioning as the screw begins rotating. **BECAUSE OF THE DANGER FROM CONTACT WITH MOLTEN PLASTIC RELEASED UNDER PRESSURE, USERS SHOULD TAKE ALL NECESSARY SAFETY PRECAUTIONS TO PREVENT INJURY INCLUDING MAINTAINING A SAFE DISTANCE FROM THE DIE.**
   - Once pressure and load have stabilized and a clear melt stream is produced, lower temperatures and adjust RPM settings to process conditions.

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Additional information

As an alternative to raising extruder temperatures, as described in shut-down procedure 2 and start-up procedure 1, the user may purge the machine with a fully amorphous Eastman copolymer such as Eastman Provista™, Provista™ GP, or Provista™ ST prior to shut-down. This can be done at processing conditions and with undried material. Once the amorphous material has purged the extruder, the barrel should be emptied. Subsequent start-up with Provista™ NXT can be accomplished at normal temperature and RPM settings.

If unmelted crystalline polymer (typically white particles) appears in the melt during start-up, or load current and melt pressure are excessive, the machine temperatures should be increased to 245°C (475°F) and additional time should be waited before raising speed above 5 RPM.

Black specks may appear after transitioning from another material or after an extended period of time at high temperatures. If this becomes excessive, it is recommended that a full removal and cleaning of the screw and die be performed. Additionally, it may be helpful to purge or blanket the pellet hopper and other vent areas on the screw with an inert gas such as nitrogen. This helps prevent oxidative degradation of the molten polymer during lengthy heat-up and cool-down periods.

Die design and drawdown ratio

Because of its good melt strength and excellent resistance to melt fracture, Eastman Provista™ NXT offers a combination of high line speed with excellent compatibility with a wide array of die designs and drawdown ratios. Drawdown is the ratio of the size of the extrudate as it leaves the die to the size of the finished product. Provista™ NXT sets a new standard for copolyester drawdown ratios, giving added flexibility for sizing and cooling profiles. For example, Provista™ NXT parts have been successfully run in test labs using close to 2:1 drawdown ratios with air table cooling, as well as with nearly 1:1 ratios with water cooled sizing blocks, demonstrating the tremendous versatility of the NXT grade resin. Once an appropriate cooling setup and drawdown has been chosen, a "rule of thumb" for sizing the die gaps is to maintain the thickness draw at approximately 1/2 the overall drawdown ratio. However, actual wall thicknesses should be opened or closed as necessary, since drawdown ratio is not a precisely estimated figure. Minor reworking of the die opening is often necessary before consistent production of quality parts. It is important to remember that too much drawdown should be avoided, as it can cause excessive internal stress in the finished product. For asymmetrical shapes, problems may be encountered in producing the desired width-to-thickness ratio because of distortion. Simple profiles, such as T-edging, angle or channel sections are relatively easy to produce. However, heavy sections with randomly spaced projections may cause difficulty. Therefore, it is suggested that profiles be designed with uniform thicknesses wherever possible.

Vacuum sizing and quenching

The most commonly used method of sizing plastic tubing and pipe is probably vacuum sizing. In vacuum sizing, the extrudate is cooled in a water bath that is under vacuum. The vacuum chamber, usually called the vacuum box, is a long water bath with an airtight lid. The molten extrudate forms the seal around the sizing plate or sleeve at the entrance to the vacuum box, and a rubber gasket that fits around the cooled pipe or tube forms the seal at the exit. Figure 2 shows a typical extrusion line utilizing the vacuum box method of sizing. There are a number of suppliers of vacuum-sizing equipment.

When vacuum box sizing is used to extrude tubing and hollow profiles from Eastman Provista™ NXT copolymer, the sizing device should be fabricated from thin [1.0–1.3 mm (0.04–0.05 in.)] brass, bronze or stainless steel having an interior finish of about 25 RMS. The length of the sizing sleeve should be approximately 1 to 1.25 times the diameter

Figure 2 **Tubing extrusion line using vacuum sizing**

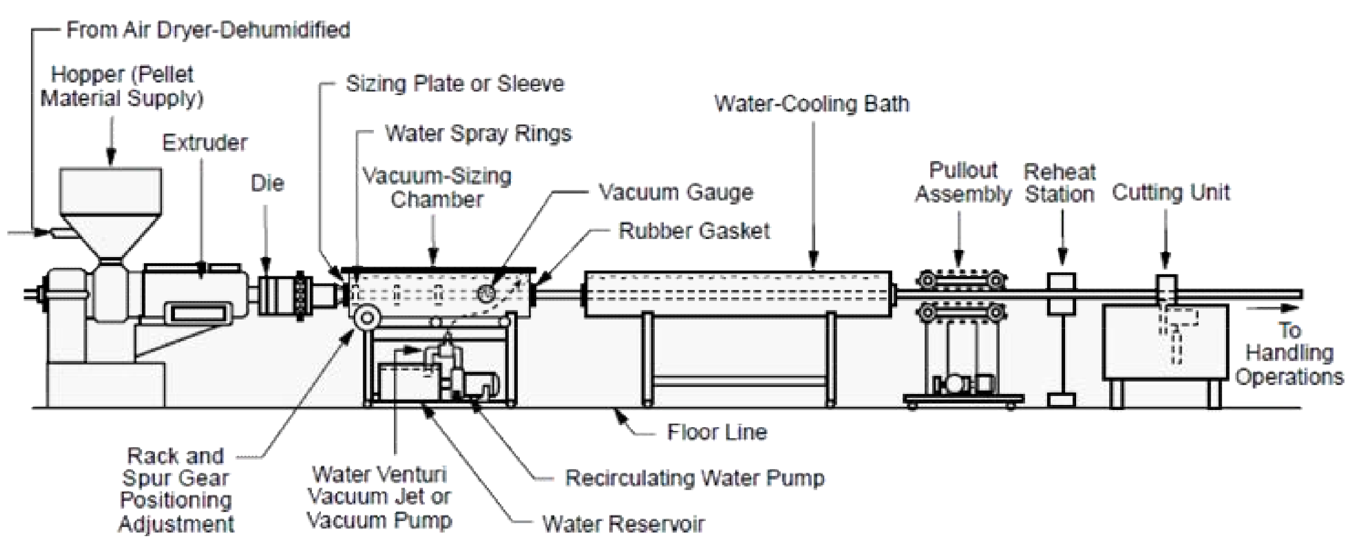
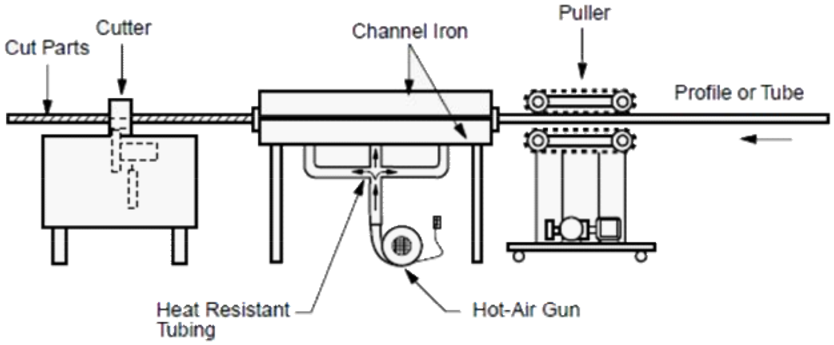


Figure 3 **Hot-air oven for improved cutting**



of the desired finished profile. A forward-spraying cooling water ring should be located around the sleeve and should be capable of impinging water at the juncture of the sleeve and vacuum box. Some extrudate lubrication such as a detergent/water mixture is helpful during start-up but is usually not required once the process is fully operational. Chilled water [5–10°C (45–50°F)] will allow more efficient cooling of the tubing or profile with less agitation; however, 20–25°C (65–75°F) water works satisfactorily with a properly located spray ring. The vacuum in the vacuum box should be sufficient to achieve proper dimensioning yet low enough to prevent drag and chatter marks from forming on the extrudate. A typical vacuum level for sizing 25-mm (1-in.) diameter tubing with a 0.38-mm (0.015-in.) thick wall would be 380–510 mm (15–20 in.) of water. Provista™ NXT copolymer exhibits good melt strength, which allows the material to run on an air table sizing system. However, water-cooled sizing blocks and/or plates have been used successfully to allow much greater throughput. Tubing and profiles of Provista™ NXT copolymer are usually cooled adequately for cutoff or sawing when exiting the vacuum box or plate-sizing tank. If the finished part shrinks or distorts as it leaves the cooling tank, it will probably be necessary to insert an extra cooling tank prior to pullout.

Cutting/fabrication

Profiles and tubing extruded from Eastman Provista™ NXT copolymer may require close control with respect to cutting and sawing. The material may show a tendency to split, shatter or possibly leave chips and fragments attached to the severed edge. If this occurs, a combination of part reheating and cutter-blade lubrication can significantly improve the quality of the cut. Reheating the part may be accomplished with either heated water or air. Water heating can be accomplished with immersion heaters. Temperatures of approximately 50°C (120°F) not only help provide a cleaner cut but can also help reduce residual stresses which can cause distortion of the extruded part. Heating with hot air just prior to cutting can be done simply by hot-air oven or hot-air gun as shown in Figure 3. More elaborate oven-type setups may include ceramic or IR heaters in place of the channel in Figure 3.

A marked improvement in chip and fragment elimination has been accomplished by using a lubricating device in the cutting mandrel. An atomized water generator was evaluated in Eastman's laboratory that sprays a light atomized mist of water, water plus silicone, or water plus liquid detergent into the cutter. Water alone was found to be as effective as the other 2 coolants and less troublesome to use.

In summary, cutting or fabrication problems may vary among different section thicknesses, line speeds and profiles. However, Eastman Provista™ NXT copolymer can be successfully cut by observing the guidelines presented here.

Regrind

The excellent thermal stability of Eastman Provista™ NXT copolymer permits reuse of clean regrind. However, care must be taken to prevent contamination of the regrind by other plastics in the scrap-handling equipment; otherwise, clarity and toughness of extruded items could be affected. Purging compounds should not be reused.

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