The Plastic Extrusion Process for Tube, Hose, Pipe, and Rod

Paul Hendess

Introduction

The process through which a polymer is extruded to create tubing, hoses or pipes is a specialized type of extrusion which requires an understanding of the raw material, the extruder, the tooling, the take off equipment and the interactions between all of these variables. The raw material is usually plastic pellets or powder. The conversion takes place by forming a homogeneous melt in the extruder and then pumping it through an extrusion die designed to produce a continuous, hollow tube with a defined cross section. The formed material, or extrudate, is cooled and drawn away from the die exit at a controlled rate. The extrudate can then be wound on a spool, cut to a specified length, or directed into another inline process. Figure 1 shows a representative pipe extrusion line, including the extruder, vacuum tank, belt puller, and cutoff saw.

By contrast, with injection molding or blow molding, which are cyclic processes, extrusion is a continuous or steady-state process. This steady-state characteristic produces some unique benefits and challenges as a manufacturing process. Extruded products are generally long and have a cross section that is usually constant with respect to the machine direction. Injection-molded products are discrete items with varying cross sections in each axis. The fact that tube, hose and pipe extrusion is a steady-state process will be discussed several times.

The terminology used for describing tube, hose and pipe varies from industry to industry. For this discussion, both tube and hose products are flexible. They differ from one another only in the diameter of the final product. Tubing has an outer diameter that is one inch or less while the hoses have an outer diameter greater than one inch. Examples of tubing include medical catheters, intravenous fluid tubing and flexible pneumatic tubing. Garden and irrigation hoses are good examples of hose products. Pipe products are generally rigid and can be any diameter. The range of outer diameters commonly seen in manufacturing is from $^{1}/_{4}$" diameter water pipe made from cPVC, up to 60" diameter corrugated drainage pipe made from HDPE.

Materials

Extrusion techniques can be used to process most thermoplastics and some thermoset plastics. The resins most commonly extruded for tube, hose and pipe products include:

- High- and low-density polyethylene
- Polypropylene
- Polyurethane
- Polystyrene
- Fluoropolymers

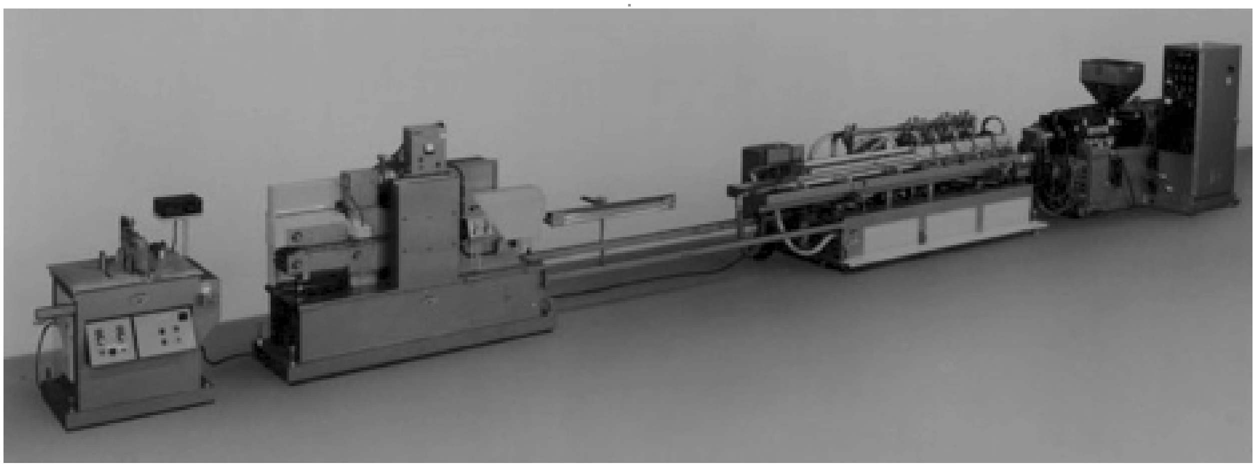

Figure 1. Representative pipe extrusion line. (Courtesy Davis-Standard)

- Nylon
- Polyester
- ABS
- Flexible and rigid PVC.

A characteristic that often differentiates extruded resins from injection-molded resins is the melt viscosity at normal processing temperatures. Extruded plastics often have a higher melt viscosity, which allows the extrudate to retain the shape imparted to it by the die while the extrudate is in the quenching stages.

Combinations of various resins can be used to gain special physical, biological, or chemical properties. Many additives can be used during the extrusion process to enhance the polymer processing characteristics or alter product properties. Such additives include:

- Lubricants
- Thermal stabilizers
- Antioxidants
- Opacifying agents
- Colorants.

EQUIPMENT

The major components of a tube, hose, or pipe extrusion system are often divided into three parts: the upstream components, the extruder itself, and the downstream equipment. Upstream components include:

- Resin handling equipment for conveying the raw materials to the extruder
- Resin conditioning equipment such as dryers.

The downstream components include

- Molten resin filter or screen changers
- The extrusion die assembly
- The quench or vacuum sizing tank
- The product measurement instruments
- The belt puller or nip roll set
- The product cut-off device and/or the winding equipment.

There are additional extrusion process methods that will take the extruded product directly into another inline process for the addition of a reinforcement braiding or for the addition of other coatings or resin layers.

PROCESSING PARAMETERS

Resin temperature, resin pressure, resin moisture content, screw speed, and screw motor amperage are usually controlled or monitored to provide a homogeneous melt and a controlled volumetric flow rate. Quenching temperature and the rate at which the extrudate is drawn are controlled or monitored to provide a controlled product size. The extrudate dimensions can be measured using a variety of gauging methods in line. In contrast to injection molding, extrusion can vary the final product size without changing the die tooling. Common extrusion production tolerances or process consistency are held to within 1% of the nominal measured value. As these manufacturing processes involve steady state conditions, any action that can stabilize any parameter or condition is beneficial to the process.

Upstream Components

Incoming raw material inspection

Because the extrusion of pipe, tube and hose are made by steady-state process the resin consistency and its processing properties are critical to the manufacturing process stability and consistency. Changing from one resin batch to another can be like completely changing the polymer altogether. Even within a resin batch, there can be significant characteristic changes that will alter the process steady-state nature.

Therefore, it is beneficial to be able to measure and verify your resin's physical and processing characteristics on a regular basis. Knowing the resin properties allows you to make sure that the extrusion line control parameters are set to the correct values so that you can continue to produce the desired product. Resin characteristics that you may wish to monitor include resin density, resin moisture content, melt index, shear rate versus viscosity data, and tensile strength. Another important test involves pressing out of thin films of your resin on a heated, hydraulic press and looking for imperfections in this sample. This allows you to determine the resin's clarity or color, the presence and amount of gels, unmelts, or particulate contamination in the incoming resin batch.

Resin handling for moisture content and temperature

Some resins are hygroscopic, that is, they absorb water from the surrounding air. Other resins may be hydrophobic, resisting water absorption, but water can still condense on the surface of the pellets. In both cases, moisture that will adversely affect the extrusion process and final product quality. Many companies provide resin drying, heating and conveying equipment. Contact and work with them as necessary to develop the best resin handling arrangement for your extrusion process.

Most hygroscopic resins should be dried to a moisture content of 0.04% by weight or less. Common hygroscopic resins include nylon, polyurethane, and PET. There are others. It is also unfortunately possible to "over-dry" the resin. For some resins, some moisture is necessary for efficient processing as the moisture acts as a plasticizing agent. By "over-drying" the resin, a condition can be created where the resin will not melt, and the processing viscosity will be extraordinarily high, making the resin unprocessable.

Another way to improve the consistency and stability of the extrusion process is to feed the extruder with resin that has been preheated. By preheating the resin, the extruder is able to more consistently heat, melt and mix your resin during processing.

Gravimetric resin feeding

When resin is fed into the extruder, you will use one of two methods: flood or starve feeding. Flood feeding is the easiest and most commonly used method. With flood feeding, the resin is added to the extruder hopper until the hopper is nearly filled, and the resin falls to the feedscrew by gravity to be conveyed down the extruder barrel. The resin pellets or powder will fill the flights of the feedscrew as it can. With trickle, or starve feeding, the resin pellets or powder is administered to the hopper, and then to the feedscrew at a controlled rate usually defined by the weight delivered in a given time period. Equipment known as gravimetric feeders are used to control the rate at which the resin is delivered to the feedscrew. Gravimetric feeders are often used in processes that make multi-layer products, especially where the layers of resin are particularly thin and difficult to measure after the product has been extruded.

The Extruder

Selection criteria

The extruder performance requirements are being successfully met when the desired outputs are being attained, with adequate resin melting and melt homogeneity, at a constant discharge pressure and melt temperature. When an extruder is selected for a process, the following extruder parameters need to be considered:

- Extruder diameter
- L/D ratio
- Feedscrew design
- Feedscrew RPM range and interchangeability
- Available torque and horsepower
- Gearbox design and thrust capacity
- The distribution of barrel heating zones
- The type of barrel cooling
- The need for venting the barrel
- The need for feedscrew cooling
- The design of the feedscrew and the hardfacing of the barrel liner
- The control instrumentation arrangement.

The extruder is discussed in other areas of this book in more detail. Suffice it to say that the extruder's job in manufacturing tube, hose and pipe, is to deliver a homogeneous melt material, at a uniform rate, head pressure, and melt temperature. It is easier stated than accomplished. Many variables act together in this system and as they interact, they will cause process variations that will manifest themselves in the extruded product quality.

Controlled and monitored parameters

There are only a few control parameters involving the extruder in the extrusion of tube, hose and pipe. There are also only a few monitored parameters. The controlled parameters usually consist of the temperature control zones for the feed section, the extruder barrel zones, and the extruder clamp area. The other controlled parameter is the screw speed in rpm. These two parameters must be held as constant as possible to achieve that ever-elusive steady-state condition. The monitored, or resultant extruder parameters include the extruder motor amperage, the exit melt temperature, and the head melt pressure.

Instrument calibration

It cannot be emphasized enough that the temperature, pressure, rpm, and amperage instrumentation needs to be calibrated on a regular basis. Instruments tend to drift over time. If the instruments are not calibrated regularly, you cannot believe what they are telling you and any process documentation that you may have recorded is worthless. You certainly cannot base a steady-state process on them. Most extrusion facilities have the measurement and control instruments calibrated twice per year.

Downstream Components

Resin filter or screen changer

At the end of the extruder barrel is the breaker plate or restrictor bushing, depending on the viscosity and thermal sensitivity of the resin being extruded. Process that extrude resins that are less viscous and more thermally stable will use a breaker plate, otherwise, a restrictor bushing. The breaker plate is a disk with a large number of holes. The breaker plate serves several purposes. It acts as:

- A seal between the extruder flange and the downstream adaptor flange
- A source of back pressure to the feedscrew
- Also serves as a place to install filtering screen disks called a screen pack.

A restrictor bushing, usually for extruding unplasticized polyvinylchloride pipe, provides a free-flowing, controlled-size orifice that produces a fixed back-pressure, or resistance to the feedscrew without causing potential areas of melt degradation or stagnation in the melt flow channel.

There are extrusion processes that can be described as short-run processes in one extreme, and then there are long-term processes on the opposing extreme. Short-run processes, for example, may produce medical tubing, are generally less than 12 hours long. In cases like this, product will be produced during one shift, then torn down for cleaning the next day, and then reassembled for another manufacturing run on the third day. In long-term processes, for example, producing rigid PVC pipe, the extrusion manufacturing operates for 24 hours a day and 7 days per week until the production goals have been reached. Long-term processes provide the best efficiencies as they will usually allow a steady-state condition to be more readily achieved.

Short run processes will use melt filtering in the form of screen packs in the breaker plate. Because of the limited duration of the manufacturing run, a screen pack will provide enough filtering capability to allow the manufacturing run to be completed without changing the screen pack before the line is torn down for cleaning. In the case of the long-term process, especially if the resin quality allows larger amounts of particulates into the resin, some kind of continuous or cyclic melt filter will be installed. Many companies provide these kinds of melt filters, and work closely together with the extruder manufacturers to insure physical compatibility.

Figure 2 shows a rotary-type, continuous screen changer assembly that would bolt to the discharge end of the extruder.

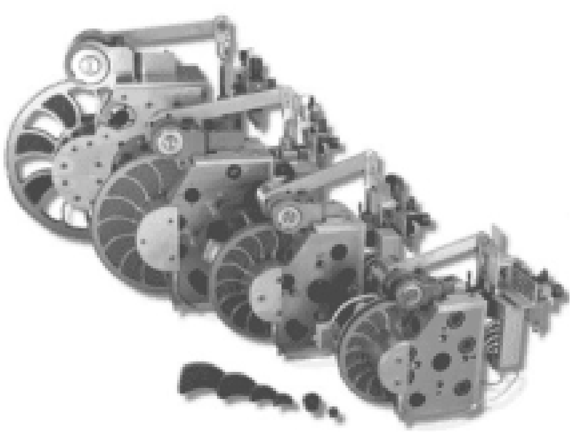

Figure 2. Rotary-style continuous screen changer. (Courtesy of Patt Filtration)

When considering cyclic or continuous melt filtration systems, there are many companies that have the capability of providing either type, therefore they are able to match the filter type to the process. Cyclic screen changes are usually less expensive, and will contribute less to a steady-state process condition as the filter media will fill with particulates and change the melt pressure over time. Also, when the slide plate of the screen changer is activated, there may be a momentary melt flow interruption as the new filter media volume is filled. Continuous melt filter systems are usually more expensive, but will contribute more to a steady-state process condition. The goals with any melt filtering system will include:

- A steady melt pressure contribution, a steady melt temperature
- Little or no area for melt stagnation and melt degradation
- Minimal additional melt volume in the melt flow path
- A simple and reliable mechanism for the melt filter exchange.

Melt gear pump

Many extrusion processes for tube, hose and pipe will incorporate a melt pump or gear pump in the melt flow path to improve the melt flow stability. The decision for using a melt pump system will usually reside with the variety of resins that will be processed, and the required accuracy in the final product. If a few resins are to be extruded, or ideally, if only one resin is to be processed, the feedscrew design that is used may be optimized to the point where the feedscrew will provide an extrusion rate accuracy and repeatability that will equal the benefits provided by a melt pump system. In the attempt to keep any extrusion manufacturing system as simple as possible, with as few process variables as possible, it is preferable to try to achieve the required melt delivery accuracy and repeatability without the use of a melt pump system.

Figure 3 shows a melt gear pump mounted on top of a frame holding the precision motor drive, with an electrical box for temperature control zones.

If many resin types will be used, and it is not efficient to change feedscrews with each resin type change, and high volumetric accuracies are needed, a melt pump may provide a workable solution. Melt pumps substantially increase the:

- Mechanical system complexity
- Melt flow paths
- Control system in any extrusion process.

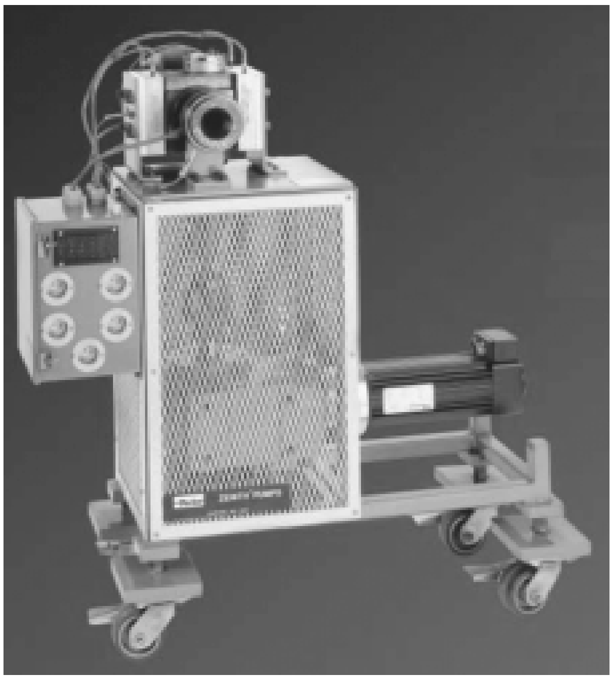

Figure 3. Melt pump assembly with motor drive. (Courtesy of Zenith Pumps)

Even through the melt pump will provide a uniform volumetric delivery for each turn of the pump, the melt pump drive system accuracy will be critical. The additional temperature control zones will also add their variability to the extrusion system. Also, the melt pressure delivery to the melt pump from the extruder will need to become a closed-loop, pressure control system. When incorporating a melt pump into an extrusion system, the primary feedscrew speed control will change from a constant rpm control to a melt pressure feedback control where the inlet melt pressure to the melt pump will be the controlled parameter, no longer the feedscrew rpm. There will usually be the addition of another melt pressure transducer into the process that will be used solely for the melt pressure feedback control system.

As with the melt filtration systems, there are many companies that specialize in the design and manufacture of melt pump systems which can be added to just about any tube, hose, and pipe extrusion line. There are few, if any companies that design and manufacture the equipment for the entire extrusion line. The degree of focus and development on each aspect of the extrusion line and extrusion process has become so concentrated over the years to the point where it has evolved into an industry where no single extrusion equipment company can be the expert in all phases and areas of the extrusion process. The extrusion line owner-operator is guided into the situation of working with many companies to assemble a complete extrusion line. There are some cases where one extrusion equipment company will take the supervisory lead and become responsible for the entire manufacturing line, and then coordinate the activity of the various equipment manufacturers to assemble the entire line for the end user.

Extrusion die assembly

Many extrusion die designs are used in tube, hose and pipe product manufacturing that are divided into several main categories. These categories include the primary division of crosshead extrusion dies and inline extrusion dies or extrusion heads. From this point the extrusion die type further divides into sub-categories depending on how many resins are involved in the process (co-extrusion), the final extruded product shape, if the extrudate will be used as a coating over a substrate or not, and the nature of the resins and how their nature applies to the end product.

The purpose of the extrusion die or extrusion head is to form the molten resin into its final or near-final shape prior to quenching. Extrusion dies have very few moving parts and therefore are comparatively simple machined-metal, electrically-heated assemblies that fasten to the discharge end of the extruder, or the screen-changer, or the melt pump. This simplicity of the extrusion die assembly is made in comparison with the mechanical complexity of equipment like the extruder. The extent of moving parts in an extrusion die is mostly limited to the wall centering adjustment mechanisms.

An inline extrusion die has an operational centerline that is collinear with the extruder screw axis. A crosshead extrusion die has an operational centerline that is 90° to the extruder screw axis. Both inline and crosshead extrusion dies can be mounted to an extruder in a number of other ways using various adapter and connection types depending on the requirements of the product manufacturing operation.

Figure 4 shows an inline, spiral manifold extrusion die assembly for making small diameter hose and tubing, with adjustable wall centering.

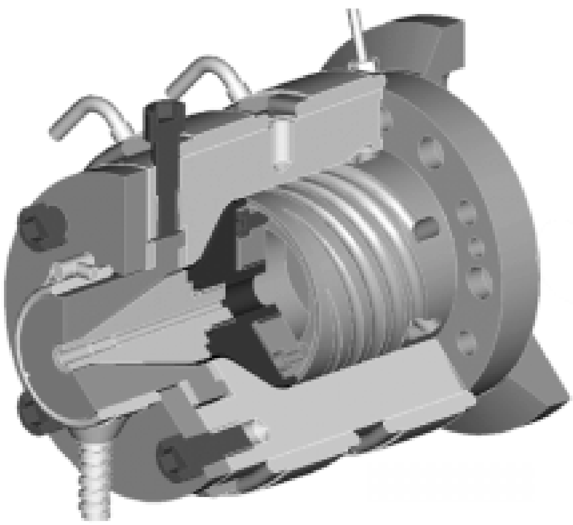

Figure 4. Inline spiral tube extrusion die. (Courtesy of StreamLine Extrusion)

The importance and involvement of the extrusion die in the extrusion process is as great as every other piece of equipment that contributes to the process. The extrusion die can be compared to the injection mold in the injection molding process, or the blow mold in the blow molding process, in that the extrusion die is responsible for imparting the product size and shape. The extrusion die or the tooling set in the extrusion die can be readily changed in order to make different product types or sizes. A significant difference between the extrusion die and the injection mold is that the injection mold can make only one part shape, where the extrusion dies and tool sets are capable of making various product sizes with one tool set.

With extrusion die assembly types, another selection method or decision tree can be constructed as selecting between an inline design or crosshead design, processing one resin or more than one resin, and if you are coating a substrate or not. It is most preferable to extrude product with an inline configuration if possible. The inline method contributes the least disturbance and shear history to the melt flow. Unfortunately, the inline extrusion method is not agreeable with all product manufacturing types.

inline extrusion can be used most often for single layer plain tube, or single layer plain tube with a single surface stripe or single encapsulated stripe. inline extrusion die types include spider-type, spiral-type, or strainer-basket type assemblies. Resins and products that are often extruded with inline extrusion heads include cold water plumbing pipe made from white, rigid PVC or a fluoropolymer medical catheter with a spider-type head; and natural gas pipe or electrical conduit from high-density polyethylene with a spiral-type or strainer-basket type extrusion head.

Crosshead extrusion is most often found in coating applications such as wire-coating (described in detail elsewhere in this Toolbox), multiple-layer tube, hose or pipe coextrusion processes, striping coextrusion processes with either surface stripes or encapsulated stripes, and extruded profiles that have a round outer shape, but contain multiple openings or lumens of specific shape to carry multiple fluids.

Figure 5 shows an extrusion crosshead assembly with a spiral melt flow manifold and adjustable wall centering.

When resin enters the extrusion die from the extruder, screen changer, or melt pump, the melt flow channel is usually in the form circular supply orifice. It is the job of the extrusion die to convert this rod of resin into an annular (tubular) shape to form the tube, hose or pipe. This conversion from a rod to an annulus is done by the manifold, or flow channel type that is designed into the extrusion die.

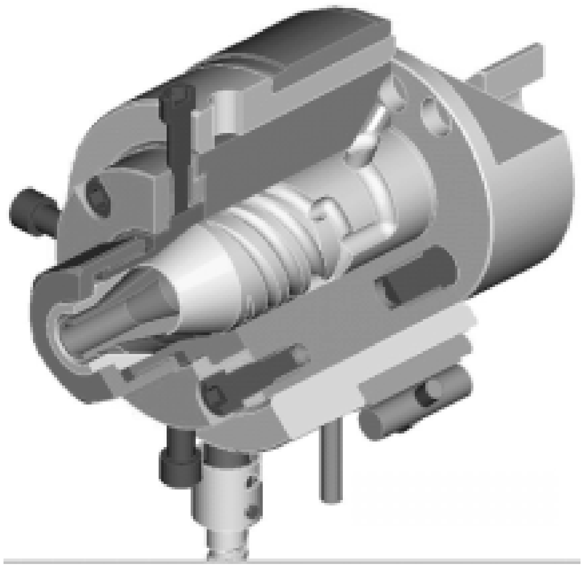

Figure 5. Crosshead extrusion die with spiral manifold. (Courtesy of StreamLine Extrusion)

Some special extrusion die arrangements that have been developed for specific product types include extrusion dies for HDPE corrugated pipe, FPVC/RPVC spiral wound swimming pool hose, and Y-block manifold arrangements that connect more than one extrusion die to one extruder in order to take advantage of extruder output capacity when making smaller diameter products.

Another special tube and hose extrusion process is referred to as tandem extrusion. This coextrusion process involves two or more extruders with as many extrusion dies. There are many cases where coextrusion within one extrusion die assembly is not possible because of resin processing temperature incompatibility, or because a braided reinforcement is placed between hose layers. It is in this case that two extrusion dies will be used together in a single process The extruded product from the first die travels to the other for sequential coating. There are cases where the die-to-die spacing is merely inches in distance. There are other cases, for example the addition of the braided reinforcement, where one resin layer goes through a quench tank and is cooled, before entering the second extrusion die for subsequent coating.

The air gap and quench entry

In between where the extrudate exits the die and where it enters the quench tank is a critical area known simply as the air gap. The extruded resin is first seen by the outside world in this area. There are many processes going on in the air gap, although if correct extrusion processing is taking place, it will be difficult to tell that anything is happening there at all. Some examples of the processes taking place include die swell, melt orientation, melt fracture and draw resonance. In the air gap, the extrudate should appear to the human eye as completely motionless. If you can see or detect any motion in the air gap, your processing is likely not stable. This goes back to the concept of extrusion being a steady-state process.

It is beneficial to keep any random air currents from entering the air gap as these air currents will adversely affect the uniform extrudate cooling. The air gap distance should also be held constant. The air gap distance will determine the elongation rate that the melt cone or extrudate, experiences in the air gap. Usually, the air gap distance will be kept as short as possible to minimize the area where the extrudate can be negatively affected. There are some extrusion processes, like fluoropolymer tubing extrusion, where the air gap is several inches in length, and protected from air drafts. This is because fluoropolymers can be elongated, or drawn down from the extrusion die a great deal. This effect can be as much as 100:1 by cross-sectional area.

As the extrudate is drawn through the air gap, another motionless area is the extrudate entry into the quench tank. This is quite challenging as the quench tank entry has running water. The water is usually under strict control by the use of dams, diaphragms, and weirs to keep the flow rate as constant as possible but this still creates a stress on the incoming extrudate. This area is quite important, as the area where the extrudate first makes contact with water from the quench tank creates an irreversible condition in the product as the outer extruded surface is altered from a high-temperature viscous liquid to a solid.

Extrudate quench and cooling

Tube, hose and pipe extrusion use two main product quench and cooling systems. One is free extrusion, and the other is vacuum sizing. We have already presented a small portion of the quench tank area in the previous paragraph as the extruded product is drawn through the air gap and into the quench tank. Most extrusion processes quench and cool using water as the main heat transfer media. Some processes use controlled air streams when the product is very sensitive to cooling, or needs to be cooled very slowly. Some processes use more aggressive heat transfer media such as liquid nitrogen to move heat more quickly.

Figure 6. 10-foot free extrusion cooling tank. (Courtesy of RDN Manufacturing)

Free extrusion is when the product cooling process takes place at ambient pressure. No vacuum effects are exerted on the product outer diameter to assist in quenching the product and controlling the size. In free extrusion low pressure air may be introduced into the inner diameter of the extruded product. This helps define the inner diameter dimension and assists in the inner diameter cooling. There are no hard and fast rules about which products should be vacuum sized, and which products should be free extruded. Generally speaking, smaller, flexible products, like thin-walled medical catheters are free extruded. Larger, rigid products, like heavy-walled PVC pipe products are quenched with vacuum sizing. In free extrusion, there is usually no tooling at the quench tank entry to control the product size, as there is in vacuum sizing processes.

Figure 6 shows a 10-foot long cooling tank that can be used for free extrusion, and can be adapted to immersion or spray cooling.

In vacuum sizing, the extruded product is drawn through the air gap and into a wall of water to begin drawing heat away from the outer surface, forming a skin, or thin portion of the outer wall as a solid, or near solid surface. The product is further drawn into a chamber that is exposed to a controlled vacuum. This vacuum chamber can be as short as 1 foot or as long as 6 feet in length. This negative-pressure environment causes the extruded product diameter to expand slightly and to make contact with a series or rings or a sleeve that is referred to as the vacuum sizer tooling. There are different vacuum sizer tooling types, styles, and lengths for various products and materials. The vacuum sizer tooling allows the extruded product to be fixed at a controlled outer diameter. The product wall thickness is then controlled and varied by the extruder output. A vacuum sizing tank can also be often used as a free extrusion tank, and a free extrusion tank is always a free extrusion tank.

Figure 7 shows a vacuum sizing tank for small tubing that can be adapted to immersion or spray cooling.

Figure 7. Vacuum sizing and cooling tank. (Courtesy of RDN Manufacturing)

Within the quench tanks, there is usually one of two methods to cause cooling, one is immersion cooling, and the other is spray cooling. In immersion cooling the extruded product is held under water, completely immersed as it is cooled by the water. Rollers or other holding methods are used to keep the tube product under the water surface. The extruded product will float to the water surface in immersion cooling conditions and needs to be controlled. The roller shape or other product holding method should conform to the round shape of the extruded product so that the round shape is not distorted into an oval. If the product is allowed to float to the surface, unbalanced product cooling will occur, where the bottom is cooled by the water, and the upper portion that is exposed to cools much slower.

Also in immersion cooling, the cooling effect will be limited by the laminar effect of the water in the tank. The water that is directly in contact with the extruded product determines the rate of heat flow from the product to the water based on the temperature differential. This water, though, tends to be drawn along with the moving surface. The warmer the water in contact with the product surface, the poorer the cooling efficiency. In order to disrupt the laminar condition of the water that surrounds the product, different wiping methods or walls are used to exchange the water that is in contact with the product outer diameter.

A concept worth remembering is that extruded products, when drawn through a quench tank or a vacuum sizing tank, cool and solidify from the outside wall to the inside wall. For an extruded tube, hose, or pipe to cool completely, all the heat energy stored within the wall must be transferred to the quench tank water on the outside of the product. The thinner the wall, the faster it will cool to room temperature. The heavier the wall, the slower it will transfer heat and cool to a uniform solid state. Also, plastics are poor thermal conductors, that is, they absorb and relinquish heat fairly slowly. The resin thermal conductivity is a fixed, heat will only be conducted to the surface so fast, no matter how cold the water in the quench tank may be.

With spray cooling, the immersion portion of the tank is exchanged for a tank area that houses a set of spray nozzles that will cause water to be sprayed all around the surface of the extruded product. This cooling method is 20–40% more efficient compared to immersion cooling. This is because the laminar effect in the immersion cooling method does not exist, and there is continuous exchange of cooled water applied to the product surface.

When a wall thickness measurement system is used, the measurement sensors will often be placed in the quench tank water. This will be further covered in the next section on product measurement instrumentation.

After the quench and cooling tank is a short section that houses an air wipe, or water blow-off. This device removes the surface water so that when the product outer diameter is measured, no water droplets will interfere with or distort the optical-based measurement. Also the air wipe confines the water to the quench tank. This keeps the workplace floor dry which improves safety. Air wipes are often selected by compressed air usage, and noise levels.

Product measurement instruments

Most extrusion lines producing tube, hose and pipe products have an on-line gauging system that measures, at least, the product outer diameter with a laser-based scanner. Such laser gauging systems have very high measurement accuracy and a very high scanning rate for measurement averaging. These gauging scanners are usually placed in the extrusion line after the air wipe and before the belt puller or nip roll. When viewing the product as it travels from the quench tank to the gauging scanner, to the belt puller, to the cutter, the product must appear visually stable and motionless. Any sign of motion, bounce, or vibration is indicative of a disruption in the steady-state condition that needs to be rectified.

The next level for laser measurement is a dual-axis scanner system. When using a single axis scanner, the possibility exists for the measurement plane to be in an orientation where the average diameter is not measured due to extruded product ovality. A dual-axis laser measurement scanner uses two laser scanners, with measurement planes that are 90° apart. By having the scanners mounted this way, and by taking the average from the two scanners, any ovality that exists in the extruded product can be taken into account and a measurement that more accurately represents the true product diameter may be displayed.

Figure 8 shows a dual-axis laser scanner for tube and hose. The arrows surrounding the hole are showing the axis that is being measured as the product passes through the scanner. These axis are 90° to one another allowing the scanner to determine if the part is uniformly round.

Figure 8. Dual-axis laser measurement scanner. (Courtesy of Zumbach Electronics)

Another inline inspection parameter is known as flaw detection. This is different than outer diameter or wall measurement parameters because flaw detection looks for short-term variations on the surface of the product, there is no dimensional measurement made. For example, if there is a piece of particulate matter on the outer diameter of the product, the flaw detector will announce or record that a surface flaw has been detected, and collect a count of flaws over time or distance. The limitation here is of the scanning field and the size of the flaw. There are limits to how small of a flaw can be detected, and the coverage of the flaw detection scanner. Sometimes multiple flaw detection scanning beams will be arranged around the product to gain additional detection coverage.

Figure 9 shows a flaw detector assembly with three axes measurement.

A third level is wall thickness measurement. This is most often accomplished with a series of four ultrasonic sensors that are mounted to a frame in the quench tank. The water environment is necessary as it is used to conduct the ultrasonic energy. These four sensors are located at four places, equally spaced around the product diameter. In a simple description, the ultrasonic sensors emit bursts of ultrasonic energy that impinge on, and then penetrate the surface of the extruded product. Two echoes are created, one from the outer surface and the second from the inner surface. By knowing the ultrasonic energy velocity, and by measuring the time between the echoes, a wall thickness value can be obtained. The four sensors provide the product wall thickness in four, 90 degree increments. These wall thickness measurements, combined with a dual-axis outer diameter scan provides a good representation of the extruded product.

Figure 9. Three-axis flaw detection scanner. (Courtesy of Zumbach Electronics)

It is important to remember that with all dimensional measurements taken during the manufacturing process, the final product size may still change from the value measured inline. This is because the product may not have reached equilibrium. Measurements taken when the product is hot will be different than those taken when the product is cooler. Also the orientation or stretching while in the melt state through the air gap can produce a condition where the product will shrink in the axial direction. The axial direction shrinkage will change the diameter and wall dimensions. In some medical product applications, tubing will be cut to length and then attached to a metal frame to fix the tube ends, and then the frame with the fastened tubes will be placed in a hot air oven to allow the product to anneal.

The dimensional measurements can be used to control different extrusion line parameters to maintain a setpoint dimensional value. This is very much like a temperature control zone on the extruder barrel or the extrusion die. One example of closed-loop dimensional control involves tracking the dual-axis measurement of the outer diameter, and then varying the belt puller speed to keep the diameter value at set point. When the belt puller speed increases, the product diameter decreases, and vice versa. In manufacturing rigid pipe, the vacuum level on the vacuum tank can be used as a controlled parameter to increase or decrease slightly the product outer diameter. There are also cases where the extruder speed, or the gear pump speed will be varied up or down slightly to increase or decrease the resin flowing from the extrusion die.

The next step in product dimensional measurement and control involves the ultrasonic wall thickness measurement, and using this information to vary and control the wall thickness or wall centering of the extruded product. The ultrasonic information is used in a control algorithm that will be directed to a mechanically driven adjustment system at the extrusion die. Newer extrusion die designs can be adjusted for wall centering while in operation and can be driven by the ultrasonic sensor information to produce a product that has a wall thickness consistency that is only limited by the measurement sensor accuracy and the repeatability. Extrusion dies that are controlled for wall centering with ultrasonic sensors have actually been in use for about 20 years. They had been limited to very large extrusion dies that make larger diameter pipe products. Sheet and film flat dies have been using heated bolts to vary the die gap and the control the product thickness in the transverse direction for many years. The most recent developments have been accomplished in the areas of smaller extruded products. For example medical tubing, automotive fuel hose, or high-speed wire coating processes. Prior limitations in extrusion die design have been overcome and now the closed-loop wall-centering of extruded products has been coupled with the dual-axis diameter measurement and control.

Line speed controller in the form of a belt puller or nip roll set.

The governing extrusion line speed parameter is either a belt puller or a nip roll device. The goal is to provide a constant, controlled draw away from the extrusion die, and to do so without damaging the product by crushing, distorting, or causing any aesthetic defects. The primary difference between belt pullers and nip rolls is the contact with the product through which the pulling and frictional force can be applied. Nip rolls will have a very small contact area with the product and so are limited in the product size they can control without damage. They are also limited to the pulling force that can be applied to the product to draw it downstream from the extrusion die. Belt pullers have a much greater contact length by using pairs of belts held apart by motor-driven rollers. Between the rollers are plates that create and maintain contact of the belt to the product.

Figure 10 shows a 2-belt product puller, or catapuller for medium size tube and hose products.

A wide variety of materials are used to cover or coat nip rolls and puller belts. The material has to have sufficient grip and surface friction to prevent slipping, and sufficient hardness/softness to prevent damage to the product. Again there are many companies that specialize in this equipment and the materials coating the belts or rolls. Belt and roll covers can range from hard, solid urethane materials which have very high surface friction, to extremely soft, foamed neoprene materials, and everything in between. The belt puller or nip roll must be able to overcome any frictional forces that may be applied to the extruded product beginning at the extrusion die exit, and through the quench tanks. For example, in products that are vacuum sized, the sizing sleeve friction and any rubber seals in the vacuum system must be overcome, in addition, the melt draw resistance due to resin melt viscosity in the melt cone must be overcome. Usually the free extrusion process will have much less friction for the belt puller or the nip roller to overcome.

Figure 10. Belt puller assembly. (Courtesy of Conair)

Highly accurate motor drives and mechanical drive systems control the belt or roll speed to provide a steady state process. The machine mechanical stability also receives a lot of attention so as to avoid mechanical vibration, and to provide a reliable, firm platform for pulling the product downstream.

Product cut-off device or winding equipment

When the extruded tube, hose or pipe is brought to this stage of production a decision needs to be made whether to cut the product to a specific length, or to wind it up on a spool or reel. Of course, with rigid pipe products, the process is often limited to a cut-off device in the form of a fly-knife cutter for smaller products, or a traveling saw for larger products. If the product is too rigid to be wound on a spool or coiled, it must be cut to length. If the product is flexible, there can then be a choice of cutting or winding.

When winding products one must consider if the product taking a set, or curve of the spool during winding and subsequent storage is a quality problem. Many extruded products can be wound on a spool where either the curvature imparted to the product is of no consequence, or the product resists taking a curvature set enough so as not to create a quality problem. Spools for winding can be quite small, for example for medical tubing, or quite large, for example for corrugated drainage pipe. Winders can be as simple as a single motor-driven shaft with a removable spool, or as complex as having multiple shafts with automatic product cutting and transfer from spool to spool. Product tension control also can come into play with flexible products and smaller diameter products so that the product is not accidentally stretched and distorted while on the spool.

Figure 11 shows a fly-knife cutter for flexible tube products where high length accuracy is required.

Figure 11. Fly-knife cutter. (Courtesy of Conair)

Figure 12. Top-cut traveling cut-off saw. (Courtesy of RDN Manufacturing)

Figure 12 shows a cut-off saw assembly for rigid pipe products.

When cutting products to length, the length is normally determined by either an encoder that is connected to the belt puller or nip roller to define the length, or by an optical sensor that actuates the cutter when activated by the product. Accuracy of the cut length can vary from fractional inches to thousandths of an inch. Here is another case where the accuracy and repeatability of the cut length are strongly dependent upon the continuing axial shrinkage of the product after extrusion.

A tremendous amount of time and effort has gone into the design and process development for cutting extruded products. The design of fly-knife cutting blades and the blade drive mechanisms have seen great changes over the recent years. The intention is to create the perfect cut, where there are no particulates created during cutting, and where there is no distortion of the product diameter on either side of the cut. Many lubricants and lubricant delivery systems have been incorporated into tubing and pipe cutters to assist the cutting process and to increase blade longevity.

Conclusion

The extrusion of tube, hose and pipe is one of the simpler plastics forming processes when compared to injection molding, blow molding, or blown film processing. The key to successful, efficient extrusion processing is found in taking every parameter that can affect the manufacturing system, identifying it, and controlling it, or monitoring it. There is no such thing as insignificant parameters in the extrusion process. Remember that the extrusion of tube, hose or pipe is a steady-state process. Anything that happens that alters the steady-state condition will disrupt the steady-state condition and create variation in the product quality.