Introduction to Extrusion

SINGLE SCREW EXTRUSION

Extrusion may be defined as a process for making a product (an extrudate) by forcing a material through an orifice or die to form a shape, or alternatively, the production of finished, or semi-finished products, using an extruder.

Scope of the Handbook

This book will be mainly concerned with the extrusion of thermoplastic products because of their importance in extrusion processes. Thermoplastics are by far the largest group of plastic materials extruded; approximately 65% of all plastics pass through an extruder. As the most popular type of extruder is the single screw machine, this book will mainly concentrate on processes based on that type of machine. Single screw machines are the most popular because they are relatively simple, cheap and easily give a continuous output.

Extrusion and Thermoplastics

In extrusion of a thermoplastic, heating first softens the material so that it can be shaped. The extrusion machine, or extruder does this process. This heat softening is called by various names, such as 'plastication', 'plasticization' or 'thermal softening'. Most extruders are single screw machines. It is the screw which forces the material towards, and then through, the die. Shape is imparted by the die, and/or by post-extrusion forming, and then the product is set to shape by cooling it while maintaining its shape. The equipment that does this is called the post extrusion equipment, while the whole system is called an extrusion line.

Extruder Classification

Extruders may be classified by three figures, for example, 1-60-24. The first number states how many screws the machine has, the second number specifies the screw diameter in millimeters (mm) and, the third number specifies the effective screw length as a multiple of the screw diameter. In the example given therefore, a single screw machine is being described that has a screw of diameter 60 mm and a length of 24 screw diameters (that is, a L/D ratio of 24/1).

Machine Construction

A cut-away drawing of a simple single screw machine is shown in Figure 1. This shows the arrangement of the different parts of the machine. The screw and barrel are the two units that interact to convey the plastic material, melt the material and then force it through the die. The electric motor drive unit and gearbox rotate the screw at a predetermined speed. Temperature controllers are connected to heating/cooling elements on the barrel to hold the temperature at the set-point temperatures. The ability of the screw and barrel assembly to extrude a given material is dependent on the characteristics of the plastics material, the characteristics, or construction, of the screw and barrel, and the conditions under which the system is operated.

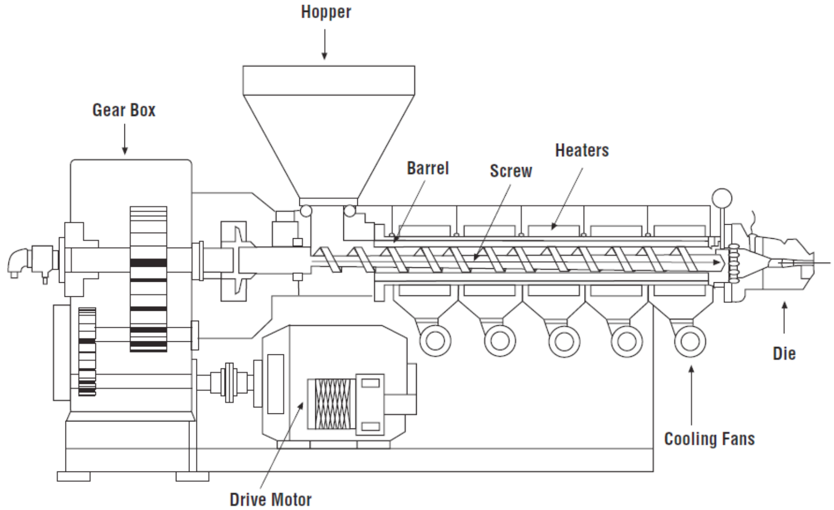


Figure 1. Single Screw Extruder *(courtesy of Dr. Harold Giles)*

Post Extrusion Equipment

Once the extrudate leaves the die it can either be set to the shape to be produced or have its shape altered and then set to shape. The equipment that does this is called the 'post extrusion equipment' or the 'haul off' and in terms of size it is usually far larger than the extruder. One reason is that plastics take a long time to cool. This cooling process often determines how fast the line will operate.

Products of Extrusion

The products of extrusion include:

• **Feedstock for Other Plastics Processes:** Extruders are widely used as compounders, or mixers. The output from an extruder compounder is granulated or chopped to form the feed for another process, such as, injection molding or extrusion
• **Plastic Film:** This is usually used for packaging or sealed into bags
• **Plastic Pipe:** Used for gas, water, drains, etc.
• **Plastic Tubing:** Used for hose and tubing for automobiles, laboratories, etc.
• **Plastic Insulated Wire and Cable:** Used in the home and industry
for appliances, for electric power distribution, communications etc.
• **Profile:** Used for tracks, windows, doors, home siding, gaskets, etc.
• **Filaments:** Used for brushes, ropes, twine, etc.
• **Sheet:** Used for signs, lighting, glazing, etc.
• **Nets:** Used for packaging, soil stabilization, etc.
• **Plastic Coated Paper and Metal:** Used for packaging

Co-Extrusion

Co-extrusion is a process where two, or more, melt streams are combined in a die to produce an extrudate formed from two, or more, materials. The process is now associated with thermoplastics materials although it was first practiced with rubbery polymers to produce an extrudate with different colored layers. With thermoplastics, the layers of materials are commonly combined in the die. The simplest example combines just two layers, for example a colored layer on a natural core, which saves on colorant costs. In the packaging industry, films based on three or more layers are now common. Laminating two or more layers of different polymers together can produce a product that has barrier properties far superior to those obtained when only one polymer is used. Frequently, one of the polymers used is a gas or moisture barrier layer based on polyvinyl alcohol (PVAL). To produce three layered structures, two or three extruders are usually used. In the blow-molding process it is possible to combine co-extrusion with bi-axial orientation to produce strong, lightweight bottles which give a long storage life to the products. Layered co-extrusion is not the only type of co-extrusion. By arranging for the materials to be combined one after the other, a sequential co-extrudate may be produced. This may consist of a hard thermoplastic material joined to a soft thermoplastic material. Alternatively, two materials may be extruded side-by-side, such as a clear material alongside an opaque material, to produce sheet to make thermoformed trays.

Vented Extrusion

A vented extruder is an extruder that contains a vent, which is used to extract volatiles from a plastic material during the extrusion process. The water (moisture) and volatiles content in a plastic material may be reduced to acceptable levels by the use of a vented machine. Part of the way along the extrusion barrel the melt is decompressed by reducing the screw root diameter. A vent, through which the vapor escapes, is located at this point in the barrel (the vent may be plugged and not used when venting is not required). The vapor-free melt is then conveyed towards the die and re-compressed by increasing the screw root diameter. To ensure that melt does not escape through the vent, a dam or torpedo section is incorporated on the screw just before the vent. Because of the way that vented machines are constructed (a high L/D ratio and a variable screw geometry) and operated, it has been found that they produce very good mixing. It should be remembered, however, that pre-drying of the polymer may be more appropriate, since heating some plastics in contact with water may cause their decomposition, or degradation.

TWIN SCREW EXTRUSION

Twin screw extrusion machines or, twin screw extruders, are the simplest example of multi-screw machines (Figure 2.). The two screws may rotate in the same direction (co-rotation) or they may rotate in opposite directions (counter or, contra-rotation). The flights of the screws may intermesh or they may not intermesh. As intermeshing, or partially intermeshing, types of machines are the most popular the discussion which follows is restricted to this type of machine.

Uses of Twin-Screw Extruders

Twin-screw machines have always been popular for certain processes, for example, where there is a need for a compounding step as well as an extrusion step. This is particularly true for un-plasticized polyvinyl chloride (UPVC). This material is often stabilized against heat degradation by the use of heavy metal compounds (like organic tins, or lead) and such stabilizers are expensive. Thus, for economic reasons, the amount of these heat stabilizers must be kept as low as possible. One way of doing this is to compound and extrude in one step. This saves a further heating stage (if the material is first compounded, cooled and then re-extruded). Twin screw machines are widely used to make UPVC pipe and profiles. Today they are often used to compound other plastics, or resins, with additives to make compounds for use in other extrusion or injection molding operations.

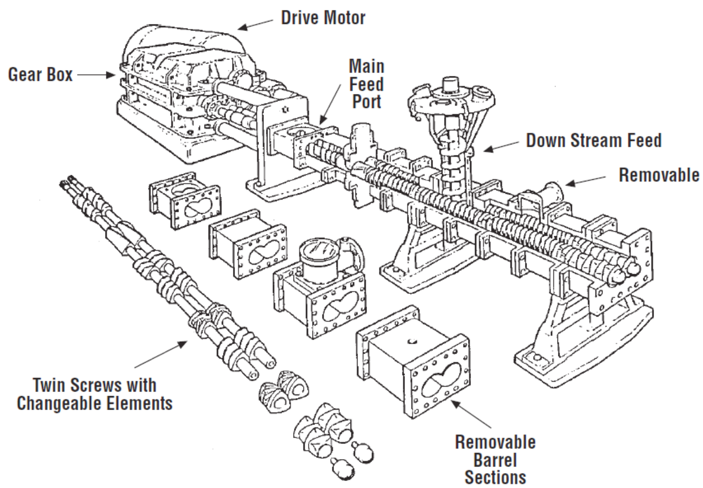


Figure 2. Twin Screw Extruder *(courtesy of Krupp Werner & Pfleiderer)*

Operation and Characteristics

With a single screw extruder the hopper is filled and the screw takes in the material at the rate it wants. Such a scheme, called flood feeding, is often not possible with twin screw machines. This is because the very positive feeding characteristics of twin screw machines may result in very high forces being generated. These forces may be so high that thrust-bearing failure is a real danger. Twin-screw extruders are therefore often starve fed, resulting in a through-put independent of screw speed. The average residence time is inversely proportional to the screw speed and feed rate and, therefore, decreases with increasing output. The Specific Energy Consumption, or the energy input per unit mass of material, also decreases with increasing throughput. The output is often virtually independent of the size of die used. Because of the mixing action, twin screw machines can achieve more melting, mixing and conveying in a shorter machine length than a single screw machine. They are, however, much more expensive.

Co-Rotating or Counter-Rotating Machines

Both types of twin screw extruders have distinct advantages that lead to their use in specific applications. Counter-rotating machines are used for the extrusion of UPVC and co-rotating machines are used for compounding applications. The counter-rotating machine has very positive material feed and conveying characteristics. The residence time and material temperature control in the machine are also uniform. However, air entrapment, generation of high pressure, low maximum screw speed and output are disadvantages usually encountered. The advantages of the co-rotating machine are that the screws wipe each other clean (self-wiping), high screw speeds and high outputs are possible, particularly for materials which are not very shear, or heat, sensitive (such as PE). Less screw and barrel wear are also found. The output is, however, dependent on die-head pressure and at high pressures the material residence time distribution becomes broader (the clearances between the flanks of the screws are usually greater for this type of machine). At the high shear rates possible in this type of machine, this non-uniform residence time can result in decomposition of heat sensitive materials. However, the greater interchannel flow results in better mixing or compounding.

Tapered Machines

Because of the very positive feeding characteristics of counter-rotating twin screw machines, very high forces may be generated. These forces can be so high that thrust-bearing failure is a real danger. Such machines therefore often have to be starve fed and/or run at low screw speeds. This is because it is difficult to incorporate adequate thrust bearings in the small space available. Tapering the screw diameter from the feed section to the die can increase the space available. Thus the screws have a larger diameter at the feed end and larger thrust bearings can then be incorporated, permitting higher outputs. The shear seen at the screw tips is also reduced.

Compounding Extruder

The mixing efficiency of a twin screw extruder can be increased by incorporating mixing elements along the screws. These and other elements may be slotted onto a central shaft to build up the screw section required. On some machines the length, number, and form of the elements used may be easily changed. The elements may take various forms such as reversed screw flights, kneading discs, pins, etc. Thus, in the process, the material may be heat-softened in an extrusion section, passed into the mixing section, and then conveyed into another section. This process may be repeated several times, for example in devolatilizing extruders or machines used to carry out chemical reactions.

Cascade Extruder

The simplest type of cascade extruder consists of two single screw extruders (two screw and barrel assemblies, one mounted above the other) where the output (melt) from the first machine feeds the second. A passageway that may be vented for devolatization connects the two screw assemblies. This type of machine may also be classified as a vented extruder. It offers the advantage that each screw may be driven at a separate speed, so their output can be matched. Valves may be also used to optimize the output from each stage.

Gear Pump

A gear pump is a very simple twin-screw extruder that moves a fluid material through the action of two intermeshing gears (Figure 3.). A gear pump extruder may be used to produce fibers from polymers that have low viscosities at their processing temperatures. Examples of this type of polymer are polyamides, polypropylenes, or PET. A gear pump fitted between the end of the barrel and the die of a single-screw extruder will produce a steady high pressure and a more consistent and higher output from the die. Thus, a gear pump can make the output of an extruder virtually independent of back-pressure and, within reason, of screw wear. As the accuracy of output is improved, significant down gauging of the extrudate is possible (approximately 10%). Since the gear pump is used to build up pressure in the die (>70 MPa/10,000 psi), the screw is not required to develop high pressures. This usually results in a reduction in melt temperatures (approximately 10˚C/18˚F). The combination of down gauging and melt temperature reduction results in material savings and a higher output, as cooling rate often limits output **(See Breaker Plates, Screen Packs and Gear Pumps in Section 4).**

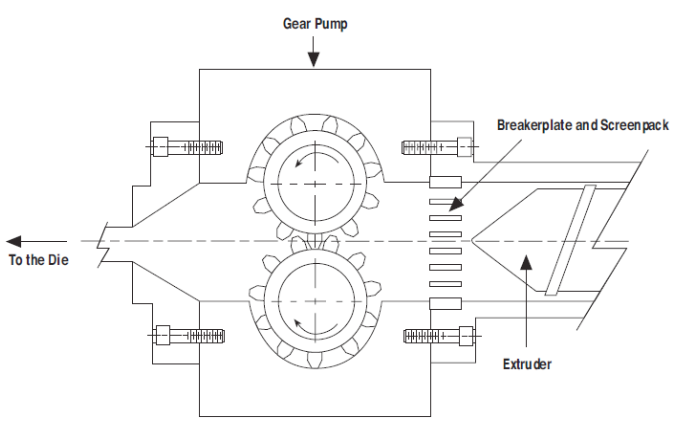


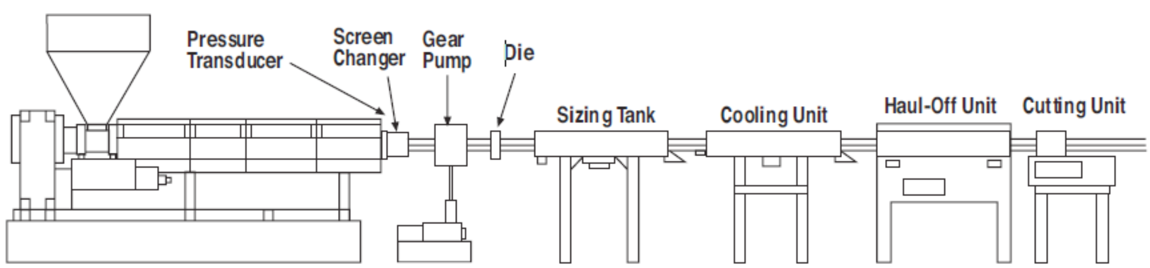
Figure 3. Gear Pump

EXTRUSION PROCESSES

Although a single screw or a twin screw extruder may be used to produce the products described in this section, most commonly single screw machines are used as they are simpler and cheaper. For un-plasticized polyvinyl chloride (UPVC), however, twin screw machines are widely used as they can both compound and then shape the material.

Tube or Pipe

Tube or pipe is extruded from an annular die, usually mounted as an in-line extension (Figure 4.). Within this extension is a mandrel which forms the inner surface of the tube. Low air pressure is usually applied through the mandrel. The tube is held to shape by this internal air pressure as it leaves the die. The molten tube proceeds to a sizing arrangement that sets its dimensions and then to a water-bath or a series of air-cooling rings that fix its dimensions. The sizing equipment, used to control the external diameter of the tube, is normally a water-cooled cylinder (that is, a "sizing die"), which is positioned close to the extruder die. For small-diameter tube or pipe an arrangement of sizing plates or rings, located in the cooling bath, are used instead. Internal air pressure forces the molten tube outward against the inner surface of the sizing die, plates or rings. With larger tubes or pipes the circular profile can be maintained by applying a partial vacuum through fine holes in the inner surface of the sizing die. For optimal control of OD and roundness vacuum sizing tanks are often used, which combine accurate sizing with controlled product cooling. After passing through the cooling bath, the tube goes to a haul-off, a unit based on rubber caterpillar bands or a system of moving clamps, and then to winding equipment or to a cutting device.



Blown Film

Film can be extruded either as a thin-walled tube, cooled by air, or as flat sheet cast onto chilled rolls or into water. In the blown film process (Figure 5.) the melt is extruded through an annular die to produce a tube of controlled diameter and wall thickness. Vertical extrusion, where the die is mounted in a rightangle cross-head, is generally used. The extruded melt is partially cooled in the vicinity of the die, often by passing the tube through a carefully controlled stream of air from a cooling ring. The tube of film is then inflated to a bubble of the required diameter, by low-pressure air introduced through the mandrel in the annular die. The film is hauled off between a pair of nip rolls, located 1 to 10+ meters (3 to 30+ feet) from the die. Thus, the inflation air is trapped within the bubble formed between the nip rolls and the die. After passage through the nip rolls, the cold film is reeled up under constant tension.

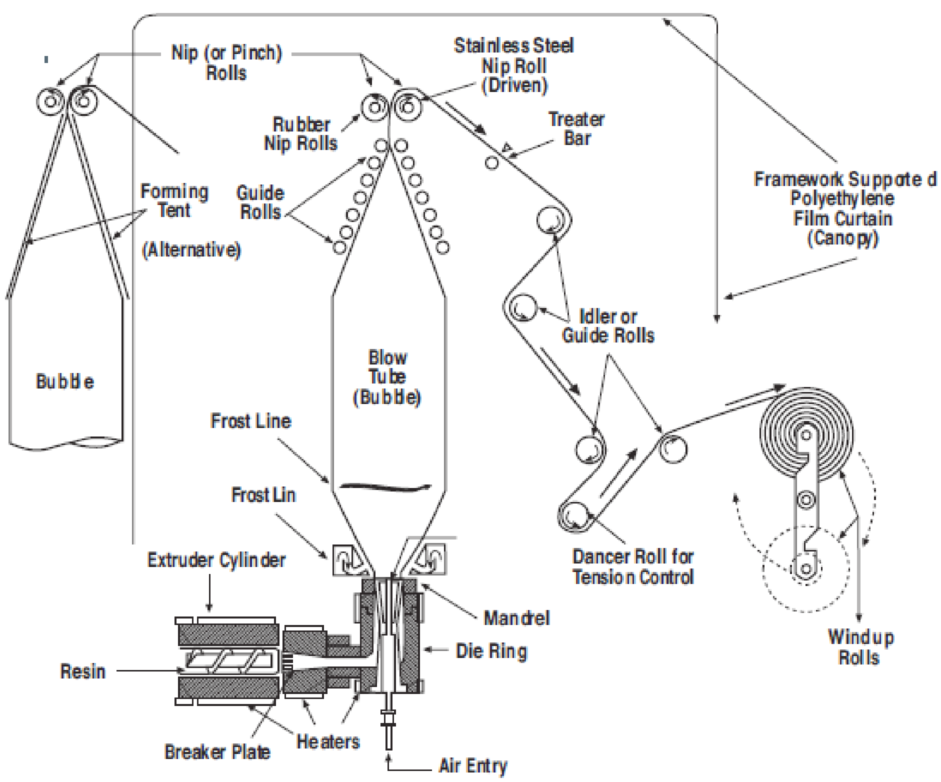


Figure 5. Blown Film Extrusion

It is important to maintain a steady bubble that feeds to a constant position in the nip rolls. The diameter of the bubble and hence the width of the flattened tube (the "lay-flat" width) is determined by the amount of inflation. The thickness of the film depends on the output from the extruder, the bubble blow ratio (diameter of bubble: diameter of die) and the film haul-off rate. Thus, by varying the blow ratio and the haul-off rate, a range of lay-flat widths and thickness can be produced from the same die. Changing the extrusion conditions may also vary the optical and mechanical properties of film produced from a given polymer. "Blocking" during the manufacture of tubular film is one of the most serious limitations to high-speed production. "Blocking" is the tendency of opposite faces of films to adhere to each other, thus making separation difficult. If sufficient air-cooling time is not allowed before the tube of film is closed at the nip rolls, then blocking will result. Blocking additives in the polymer such as erucamide or TiO2 can also be used to alleviate this problem.

Flat Film

In the extrusion of flat film the melt is extruded from a straight slit die and cooled either by quenching in water or by casting onto highly polished watercooled chill rolls (Figure 6.). Both systems involve a rapid cooling of the film, after which it is wound up on take-off rolls. In the casting process, high temperatures may be used because of the fast cooling possible with chill rolls. Therefore, much higher output rates can be achieved than in the tubular process. The slit die, which is usually center-fed, is fitted with heaters along its length. When a water-bath is used for cooling, carry-over of water can be a problem. Hence, the chill-roll process, which involves no direct water contact with the film, is usually preferred. The chill rolls must be highly polished because the film surface is an exact reproduction of the roll surface.

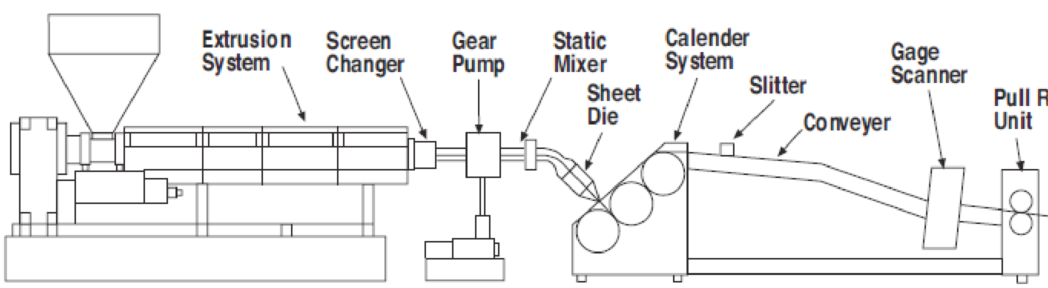


Figure 6. Sheet and Film Extrusion

Extrusion Lamination

The application of polymers such as polyethylene or polypropylene to paper, fabrics, metal foils and various other flexible substrates by the extrusion-lamination process is a rapid and economical method of producing laminates for packaging. The thermoplastic material is extruded in the form of a flat film through a slit die. As the very hot film leaves the die lips, it is cast into a niproll assembly formed by a water-cooled steel casting roll and a rubber-covered pressure roll. The substrate to be coated is fed continuously over the rubber pressure roll into the nip, which presses the molten film on-to and into the substrate to form a laminate. As the laminate runs around the steel roll the plastic layer is cooled and the laminate is taken off by wind-up mechanisms. The extruder output rate and the speed of the substrate control the thickness of the applied coating.

Wire Coating

In the wire coating process wire or a bunched cable core passes through a mandrel, mounted in a cross-head, which directs the conductor centrally into the die orifice. Here the conductor comes into contact and is coated with softened plastic. The wire is drawn away from the die under conditions that produce a predetermined insulation thickness (Figure 7.). The position of the tip of the mandrel relative to the die parallel is very important for most materials, because it controls the tightness of the covering of the wire. Some machines use a vacuum system to control the tightness of this covering. The insulated conductor then passes through one or more cooling baths to a haul-off, or capstan, maintained at constant speed, and from there to a wind-up drum. Generally, an accumulator is inserted between the capstan and the wind-up arrangements to allow c ompleted reels to be changed without interfering with the extrusion operation. Cooling must be gradual, for if the insulation is cooled too rapidly the outer layers will freeze and contract, resulting in voids between the insulation and the conductor. Foamed coatings can be extruded directly onto wire using a compound containing a blowing agent; a chemical compound that will liberate nitrogen or some other inert gas on heating. Extrusion conditions should be such that the blowing agent decomposes on the last few flights of the screw. The melt issuing from the die is then in an un-blown state and expands to its final dimensions as it leaves the die. Premature expansion leads to a product with a rough external finish.

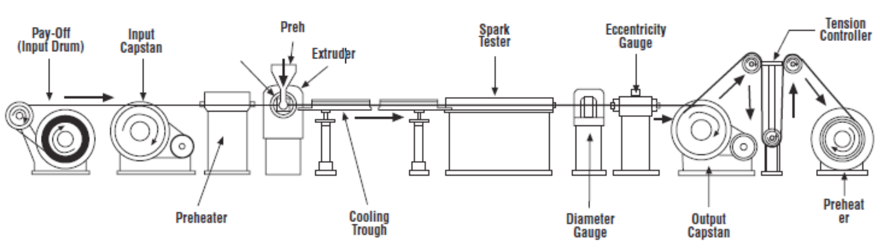


Figure 7. Wire Coating

Sheet

Sheet is extruded through a slit die (See Figure 6.). After leaving the die it is cooled gradually by passing it over a serpentine of water-cooled rolls. With some materials, for example, polypropylene and polystyrene, it is desirable to use a series of polishing rolls to achieve sheet with a good surface finish. The haul-off equipment is designed to prevent distortion of the sheet during cooling and to minimize draw-down. Sheet is generally cut to length with a travelling circular saw or shear. Incorporating a corrugation unit in the haul-off produces corrugated sheet, with transverse corrugations. A system is also available for forming longitudinal corrugations by using water-cooled forming dies. Embossed sheet, such as embossed acrylic sheet for lighting fittings, is produced by passing the extruded sheet between a pair of embossing rolls mounted close to the die. The sheet is air cooled as it leaves the die in order to retain a sharp impression.

Profile

Profiles of open or hollow cross section can be extruded from specially designed dies. Each shape presents its own problems of die design and postextrusion handling. Profile dies are frequently intricate and thus difficult and expensive to make. Unless CAE is used, a lengthy process of trial and error is required to establish both die design and extrusion conditions (A case in point, is to prevent preferential flow in the thicker sections). Such dies can be used for small sections, but a simpler technique is desirable for larger profiles (for example, for diffusers for fluorescent lighting fittings). One technique involves post-forming sections extruded from tube dies. Compared with profile dies, these large tube dies can be made at low cost and their symmetry facilitates uniform flow. The inner lip of the die can have a reeded surface that imparts a pattern to the extrudate. A knife mounted in the die face, slits the emerging reeded tube and the tube passes to a shaping and cooling jig. Alternate inner and outer formers do the shaping with polished forming surfaces. Cooling is accomplished by internal and external perforated copper rings through which is directed a gentle flow of air. The haul-off may be the rubber caterpillar-band type, and an on-demand knife cutter can cut off sections. Trial and error will again be necessary to establish conditions and former design, but adjustments to formers are made more quickly and cheaply than changes to a profile die.

Extrusion Blow Molding

Hollow articles (such as bottles) are produced using the blow molding process. This process normally starts with the extrusion of a short thickwalled tube, or "parison", from a tube die mounted in a cross-head. This tube is extruded vertically downward between the two halves of a split, watercooled mold. The two halves of the mold are closed, sealing the ends of the molten tube. Air is then applied to the interior of the tube, blowing it outward against the inner surface of the mold. Frequently, as one molding is cooling another is made ready to receive a fresh parison. The split molds may be mounted on a turntable below the extruder die. Alternatively, the melt can be delivered to two or more static molds by arranging for melt to be diverted, in turn, to different dies connected to the same extruder. All extrusion-blown moldings involve welds of the open-ended parison which are potential sources of weakness. Thus care must be taken in the design of the mold to ensure the formation of strong, bead-type, welds. In the blow-molding field it is possible to combine co-extrusion with bi-axial orientation and so produce strong, lightweight bottles which give a long storage life to the products.

Fiber from Film

The extrusion process can be used to produce fibers or tapes from film. Such products are usually based on polyethylene or polypropylene and they may be used as string, rope or as a woven product (such as a sack). The polymer may be extruded on a single screw machine into a flat sheet using the chill roll process. The sheet may is then slit into tapes by either stationary or rotating knives. Godet rolls are then used to stretch the tape (mono-axial orientation) while it is heated in a hot air oven or on a hot stretching table. In the
production of film tape, the width of the tape may decrease to 1/3 of its original slit width as a result of this stretching process. This imparts a significant strength to the tape, in the machine direction. Annealing may then be performed on the tape before it is wound into packages suitable for weaving.

Nets

Polymer nets are commonly used in the packaging industry to package fruit. The polymer may be extruded through slots cut in a circular die. By rotating the outside of the die, relative to the center, a circular net may be produced in a wide range of patterns. If the slots are large then heavy gauge nets may be produced which are suitable for landscaping and soil stabilization applications.

Product Identification

In order to ease recycling, the above products or components are frequently marked with a symbol or abbreviated term identifying their component polymers. Legends suitable for the generic identification and marking of plastics products have been suggested by standards organizations such as the International Standards Organization (see ISO 1043). In the simplest case, a series of letters associated with a plastic material (See Table 1. on page 17) are stamped onto a product between inverted (reversed angle) brackets (for example, >ABS<). ISO also suggests how to identify fillers, flame retardants, plasticizers etc. For example, the presence of a flame retardant may be indicated by a molded or printed legend which contains FR as in >PA 66-GF30-FR(52)<. This legend shows that the product is made from a nylon 66 material that contains 30% glass fiber. The FR(52) indicates that the nylon contains also a red phosphorous (code number 52) type flame retardant. Other flame retardants have their own numbers.

SAFETY

This section is written to help an operator, who runs an extruder or an extrusion line, to work in a safe way. It cannot cover all the possible hazards, as it is only a general guide. Safety is the responsibility of everyone. It is very important that everyone who is concerned with an extrusion process fully appreciates the possible hazards. This means that safety education and training are very important.

A New Machine

Before a new extruder is put into service a responsible person must check that the machine is acceptable from a safety point of view and that it conforms to local and national safety codes and practices. This means listening to the advice of the machine supplier, local government officers, etc. A local plastics association, or federation, will offer useful advice in regard to whom should be contacted and what codes of practice should be followed. Any legislation in force should be considered, as the minimum required. It is very important to ensure that all those concerned with extrusion processing develop a common sense, responsible attitude, and are trained to increase their safety awareness.

Materials Handling

It must be emphasized that most thermoplastic materials do not present problems during normal handling as they are usually supplied as granules or pellets. However, to prevent material contamination, the thermoplastic material should not be touched or handled, with the bare hand. Remember, it makes sense not to allow any material to come into contact with the skin or eyes, particularly if the material is dusty (for example, the material may have been dusted with a lubricant or coloring system). If during normal operation, the atmosphere becomes dusty then the operating procedure should be reviewed and modified until the contaminated atmosphere is eliminated. When handling a thermoplastic material, the biggest danger is often one of spilled material. Because of the shape of the pellets, the spilled material makes the floor very slippery and can cause falling injuries. Therefore, any spilled material must be collected immediately and disposed of in an approved way. This usually means sweeping up the spilled material and placing it an appropriately labeled bag for reclamation.

Burns

Some extruders operate at temperatures of as high as 750˚F/400˚C or above. As any temperature above 140˚F/60˚C is unpleasant to touch, burns must be recognized as a common source of accidents in the extrusion processing industry. It is one of the reasons that a cover or guard usually protects the extruder barrel. Like any other guard it should not be needlessly opened, or removed, as it is there for protection of both the operators and the equipment.

At the processing temperatures employed, hot thermoplastic materials (resins) behave like hot melt adhesives and can be very difficult to remove from the skin. These resins are organic materials that have high specific heats and low thermal conductivities. Thus, as the hot melt contains a large amount of heat, severe burns can result. The burning process can be very painful as the hot melt releases the heat it contains very slowly. An instinctive reaction, when hot melt comes into skin contact, is to pull the hot melt away with a bare hand, but this simply transfers the hot, sticky resin to another area. One should quickly scrape off the resin, plunge the covered area into cold water and obtain medical advice.

Resin Decomposition and Fumes

Thermoplastic materials (resins) are organic materials, which, generally, have low thermal stability. At the processing temperatures employed they can easily be degraded to give unpleasant, irritating odors and, if seriously overheated, they can produce a large quantity of noxious gas. Such gases should not be inhaled, and treated as harmful. This means that if, for example, the extruder barrel is stripped for cleaning it should be done in an extremely well ventilated area. Gloves, long sleeved overalls and a facemask should be worn when the barrel and screw are stripped and cleaned. If the gas produced by resin decomposition becomes trapped inside the machine, it can cause serious accidents. It can blow hot resin (plastic or melt) from the nozzle or even through the hopper. In the worst case, it could produce an explosion and cause damage to the machine, such as shearing the bolts holding the die/nozzle. Thus one should be careful and follow the correct operating procedures, particularly at the start up of an extrusion operation.

Rolls

Rolls, such as the rubber covered rolls for pulling and steel rolls for cooling, are widely used in extrusion processing. The gap between them, called the 'nip' or 'bite', is very dangerous, as it is capable of trapping fingers or clothing causing serious injury. Such nips must be guarded, treated with respect, and avoided. Long hair should be kept covered; neckties and other loose clothes should not be worn as they can also become trapped. Be particularly careful if you have to wear gloves as these can become trapped; it is probably best to make the gloves as small as is convenient (for example, slit the backs and remove the cuffs). Learn a start-up technique that avoids the possibility of trapping a hand in the nips. Above all, find out what to do if something, or somebody, does get trapped. This means knowing how to stop the machine in a hurry and how to release or open the nip.

The Screw
Normally the only part of the screw that the operator sees is that which is exposed when the machine runs out of material, that is at the base of the hopper. It looks fairly harmless but it is very dangerous and will easily remove your fingers. So, keep your hands out of the hopper and only put them into this danger area when you are satisfied that it is safe to do so; when the screw is stopped, the power is off and the machine is isolated. Always check that the machine is isolated yourself. To protect the expensive screw, do not put metal tools into the hopper when the screw is turning. There should be a guard between the base of the hopper and the screw (to prevent finger trapping) and ideally, the screw should not turn if the hopper is removed. Do not remove the hopper, and expose the screw, until the extruder is stopped and you have checked that the machine is isolated.

The Die or Nozzle
The die (sometimes called the nozzle) is often the part of the extruder that an operator sees the most during machine operation. Accidents involving the die are a major hazard because of failure to protect the operator against danger from burning or finger trapping. Therefore, do not reach over moving equipment and never remove a guard or, attempt to bypass a guard. When cleaning or stripping the die make sure that the equipment is locked in the non-running mode and that the power (electric) supply is disconnected. Specific cleaning instructions from the die maker should be followed to prevent danger to the operator and damage to the forming surfaces of the die.

Other Equipment
Cutting, grinding, sawing and chopping equipment must, of course, be well guarded. They usually are the most common dangers that arise when a safe working approach is ignored. Do not reach over moving equipment and never remove or attempt to bypass a guard. If you have been specifically authorized to do something like this, then make sure that the equipment is locked in the non-running mode and that all electric power is disconnected.

Work Handling Devices
A work-handling device, also known as a robot, is an item of parts handling equipment (PHE). When guarding a parts handling device, such as a robot, consideration should be given to the area covered by the machine, the speed of operation of the arm, the speed of acceleration /deceleration of the arm, the complexity of the movements involved and the time-scale over which the movements occur. This last point is very important as often an operator can be mislead into believing that the PHE is in-operative as it appears to be switched off when it is standing still. When guarding a parts handling device (or a robot) both the downstream operations and the working area of the PHE must be considered. Special custom-built enclosures must often be built for each application.

Electrical Equipment

Most extrusion equipment is heated by electric resistance elements and driven by electric motors. Machine control cabinets are often kept locked to protect the operator from coming into contact with the main electrical supply. Leave such equipment alone unless you are trained and authorized to inspect, repair or adjust it. Report any damaged, or frayed, wires or cables immediately, and do not disconnect the equipment ground wires. Any damaged plugs or connectors should be reported.

Safety Guards

An extrusion line contains dangerous machinery that must be guarded appropriately. Safety guards cover many mechanical, electrical and heat hazards and these must be kept in place. Remember: the guards are there for your protection. Machine guarding is just one way of making the process safer and should not be relied upon to the extent that inspection, maintenance and training are neglected.