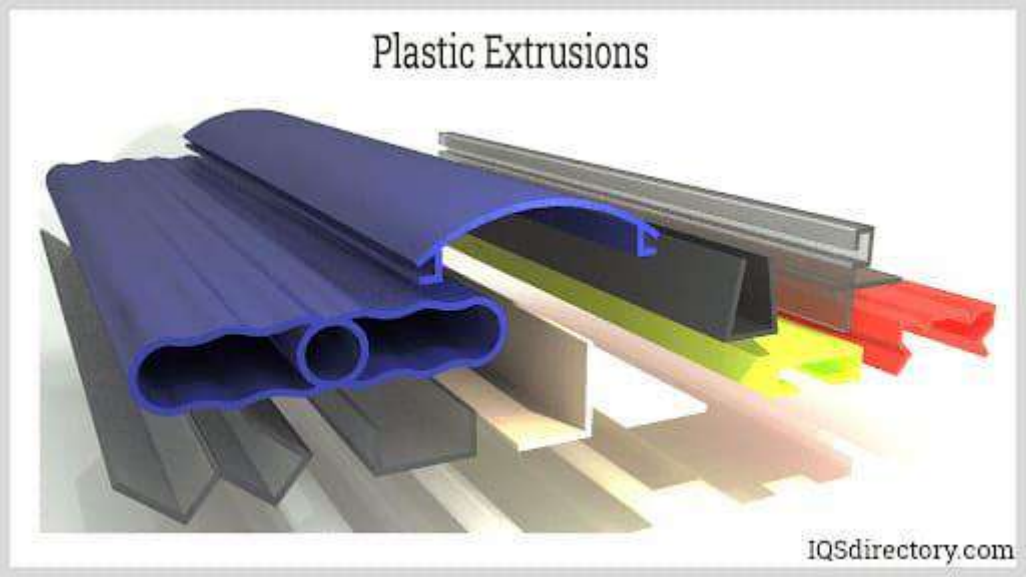
Plastic Extrusion

Introduction

This page provides you all the basic information about plastic extrusion. As you go through the article, you will learn more about:

- Overview of Plastic Extrusion
- Basic Screw Extrusion Process
- Types of Extruders
- Parts of Single Screw Extruder
- Different Types of Dies
- Applications of Plastic Extrusion
- And much more...



Chapter One – What is Plastic Extrusion?

Plastic extrusion, also known as plasticizing extrusion, is a continuous high volume manufacturing process in which a thermoplastic material -- in a form of powder, pellets or granulates -- is homogeneously melted and then forced out of the shaping die by means of pressure. In screw extrusion, the pressure comes from the screw rotation against the barrel wall. As the plastic melt passes through the die, it acquires the die hole shape and leaves the extruder. The extruded product is called extrudate.

A typical extruder consists of four zones:

Feed Zone

In this zone, the flight depth is constant. The distance between the major diameter at the top of the flight and minor diameter of the screw at the bottom of the flight is the flight depth.

Transition Zone or Compression Zone

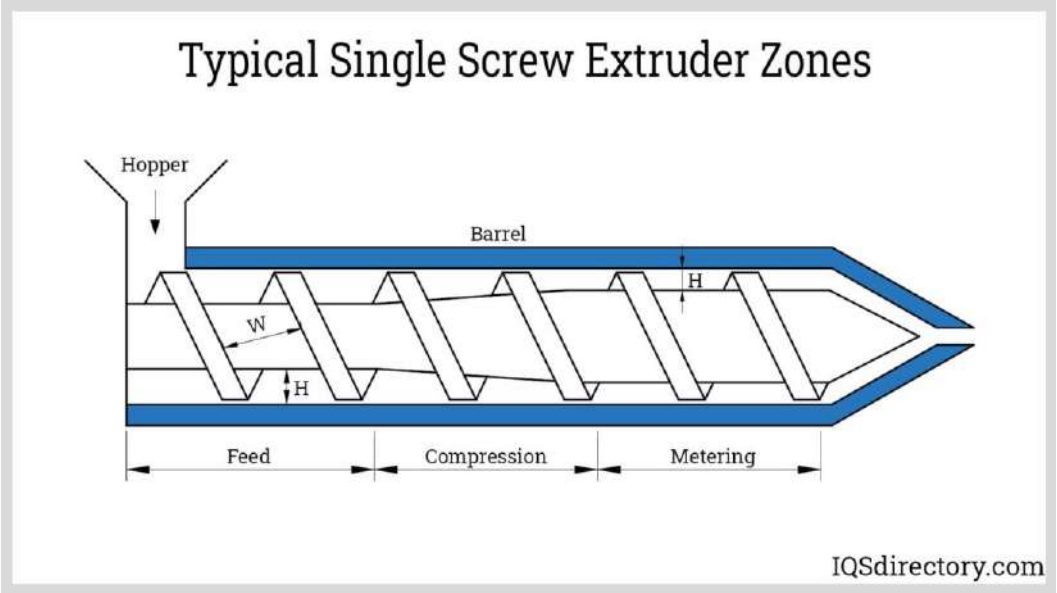
The flight depth starts to decrease in this zone. In effect, the thermoplastic material is compressed and begins to plasticize.

Mixing Zone

In this zone, the flight depth is again constant. To ensure the material is completely melted and homogeneously mixed, a special mixing element may be in place.

Metering Zone

This zone has a smaller flight depth than in the mixing zone but remains constant. Also, the pressure pushes the melt through the shaping die in this zone.



On another note, the melting of the polymer mixture is caused by three major factors:

Heat Transfer

Heat transfer is the energy transferred from the extruder motor to the extruder shaft. Also, the polymer melting is affected by the screw profile and residence time.

Friction

This is brought by the internal friction of the powder, screw profile, screw speed, and feed rate.

Extruder Barrel

Three or more independent temperature controllers are used to maintain the temperature of the barrels.

Chapter Two – Basic Screw Extrusion Process

Prior to the main extrusion process, the stored polymeric feed is mixed with various additives such as stabilizers (for heat, oxidative stability, UV stability, etc.), color pigments, flame retardants, fillers, lubricants, reinforcements, etc. to improve the product quality and processability. Mixing polymer with additives also help achieve the target property profile specifications.

For some resin systems, an additional drying process to prevent the degradation of polymer due to moisture is usually employed. On the other hand, for those which do not typically require drying prior to use, it might still have to undergo drying especially when these were stored in cold rooms and suddenly placed in a warmer environment thereby initiating moisture condensation on the surface of the material.

After the polymer and additives have been mixed and dried, the mixture is gravity fed into the feed hopper and through the extruder throat.

One common problem when handling solid materials like polymer powder is its flowability. For some cases, material bridging inside the hopper can occur. Thus, special measures like intermittent injection of nitrogen or any inert gas can be employed to disturb any polymer build up on the surface of the feed hopper thereby ensuring a good flow of the material.

The material flows down into the annular space between the screw and the barrel. The material is also bounded by the screw channel. As the screw rotates, the polymer is conveyed forward, and frictional forces act on it.

The barrels are normally heated with a gradually increasing temperature profile. As the polymer mixture travels from the feed zone up to the metering zone, the frictional forces and barrel heating cause the material to be plasticized, homogeneously mixed, and kneaded together.

Lastly, as the melt approaches the end of the extruder, it passes first through a screen pack. The screen pack is used to filter any foreign materials in the thermoplastic melt. It also protects the die plate hole from clogging. The melt is then forced out of the die to acquire the die shape. It is immediately cooled and pulled away from the extruder at a constant velocity.

Further processes like flame treatment, printing, cutting, annealing, deodorization, etc. can be done after cooling. The extrudate will then undergo inspection and proceed to packaging and shipping if all product specifications are met.

Chapter Three – Types of Extruders

There are various designs of extruders available in the market today. These can be divided into two types depending on the mode of operation:

1. Continuous extruders
2. Discontinuous extruders
   Generally, the distinction between the two is the part which moves the material. Continuous extruders have rotating parts while discontinuous extruders have reciprocating components.

Continuous extruders can be further divided into two groups:

1. Screw extruders
2. Disk or drum extruders

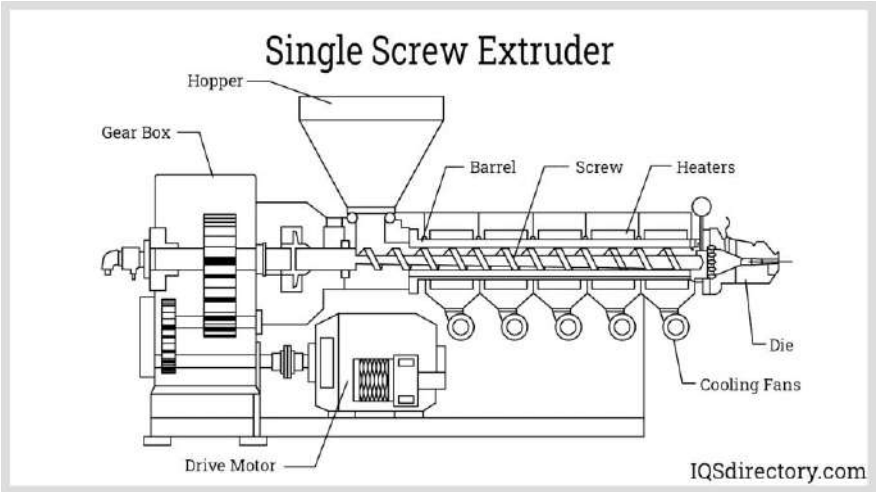
Single Screw Extruders

In the polymer extrusion industry, single screw extruders are the most common continuous extruders due to their various advantages like low cost, simple design, toughness, reliability, and high performance/cost ratio.

A standard single screw extruder has three geometrically varying zones:

1. Feed Zone
2. Transition or Compression Zone
3. Metering Zone

The three zones are created by the constant pitch but varying channel depth of the screw. The depth of the screw channel decreases linearly from the feed zone towards the metering zone which causes the compression phenomena. For screw geometries with only one compression section, it is commonly called a single stage. Zone length, as well as the maximum and minimum channel depths, may vary for the same screw length and diameter. Hence, different screw profiles are possible.



The thermochemical environments inside the extruder may also vary depending on the below factors:

1. Screw profile
2. Set temperature
3. Screw speed

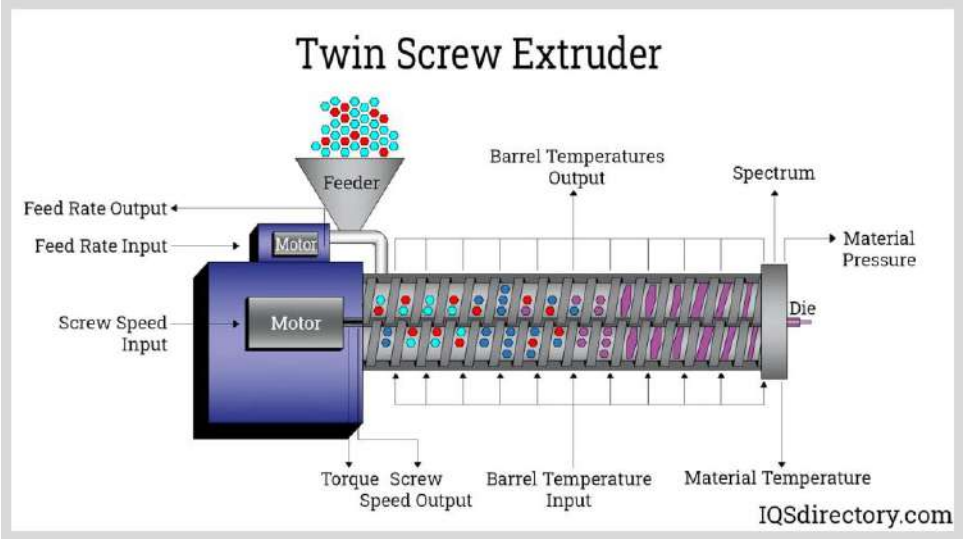
These factors affect the local heat conduction, heat dissipation, velocity profile, and residence time inside the extruder.

The common layout of single screw extruders consists of:

1. Heating elements – used to set the axial temperature profile of the barrel
2. Feed hopper and entry -placed upstream of the extruder
3. Die –placed at the other end of the extruder

Twin Screw Extruders

Generally, twin screw extruders can be classified under continuous multiple screw extruders. These types of extruders have two Archimedean screws in their design hence the name. Twin screw extruders have a lot of classifications because in twin screw extrusion, there are more design parameters such as rotational direction, degree of intermeshing, etc. which can be varied.

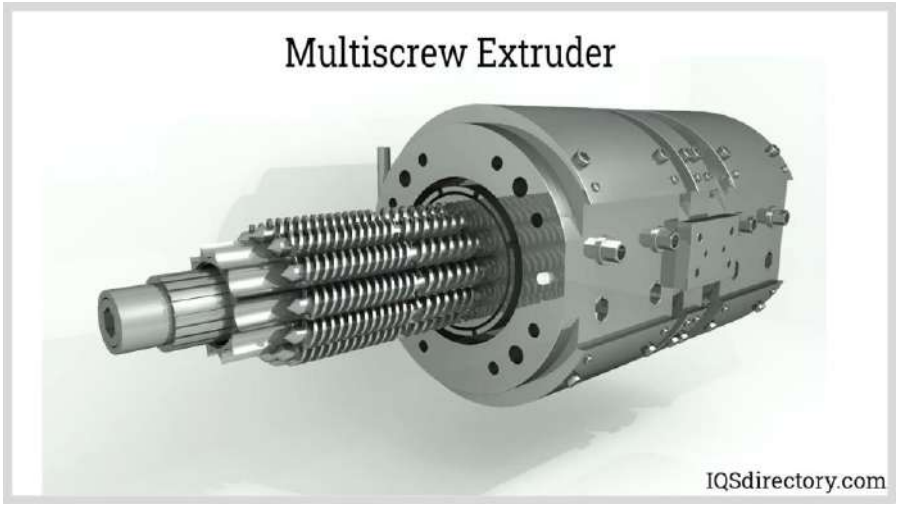


Twin screw extruders can be divided into two and can be further subdivided:

1. Intermeshing extruders
- Co-rotating extruders
- Counter-rotating extruders
2. Non-intermeshing extruders
- Counter-rotating extruders
- Co-rotating extruders
- Co-axial extruders

Multi screw Extruder with More Than Two Screws

One common example of an extruder with more than two screws is a planetary roller extruder. This extruder has similarities with a single screw extruder particularly in the feed section. However, the difference starts in the mixing section. In the planetary roller section, there are six or more evenly spaced planetary screws which revolve around the main screw, commonly known as the sun screw. The planetary screws intermesh with the sun screw and the barrel. Hence, this section of the barrel is designed to have helical grooves to accommodate the helical flights of the planetary screws. Planetary roller section is often connected to the feed section by a flange-type connection.



Planetary roller extruders are capable of intensive mixing due to the rolling action between the planetary screws, sun screw, and the barrel. One advantage of this extruder is that it can

process heat-sensitive compounds with only minimal degradation. Rigid or plasticized PVC extrusion is a common application of planetary roller extruder. It can also be integrated to regular extruders to improve their mixing performance.

Disk Extruders

Disk extruders are classified as continuous extruders, but they do not utilize screws to convey the material. Instead, they use disks or drums to facilitate the extrusion process. In some cases, disk extruders are also called screwless extruders. Most disk extruders are operated based on viscous drag transport.

Unlike the screw extruders, disk extruders are now less common in the industry.

Stepped Disk Extruder

Stepped disk extruder, also known as slider pad extruder, has a stepped disk placed a small distance from a flat disk. Pressure is generated at the transition of one gap size to another when one of the disks is rotated with a melt in the axial gap.

Stepped disk extruders can be used in a continuous process if there is a provision for exit channels in the step disk. One major drawback of this extruder is maintainability. The intricate design of the flow channels makes it hard to clean.

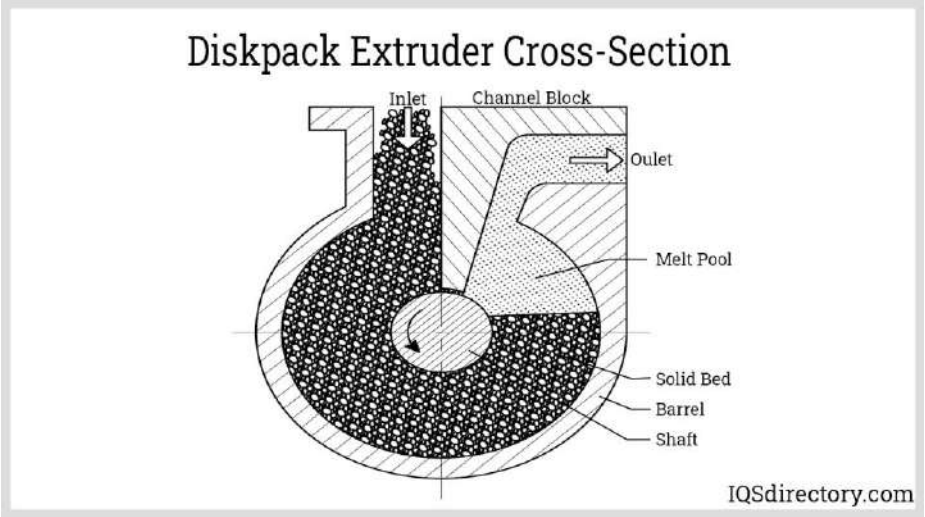
Drum Extruder

Drum extruder utilizes a rotating drum and barrel to perform the extrusion process. The polymeric material is fed into the annular space between the drum and the barrel. The material is carried along the circumference of the barrel as the drum rotates. Before the end of one full rotation, there is a wiper bar that scrapes the melt from the drum and directs the flow to the exit and then to the extruder die.

Disk pack Extruder

Disk pack extruder is capable of basic polymer-processing operations that is as efficient as existing machineries. It has similar features like the single screw extruder and drum extruder. Disk pack extruders can be treated as single screw extruders with zero helix angle and very deep flights.

The material is fed in the axial gap between thin disks on the rotating shaft. The melt moves with the disks and before one complete rotation, a channel block closes off the space between the disks. Like the wiper bar in drum extruders, this channel directs the flow to the outlet channel.



Mixing blocks and spreading dams can be integrated into the diskpack extruders.

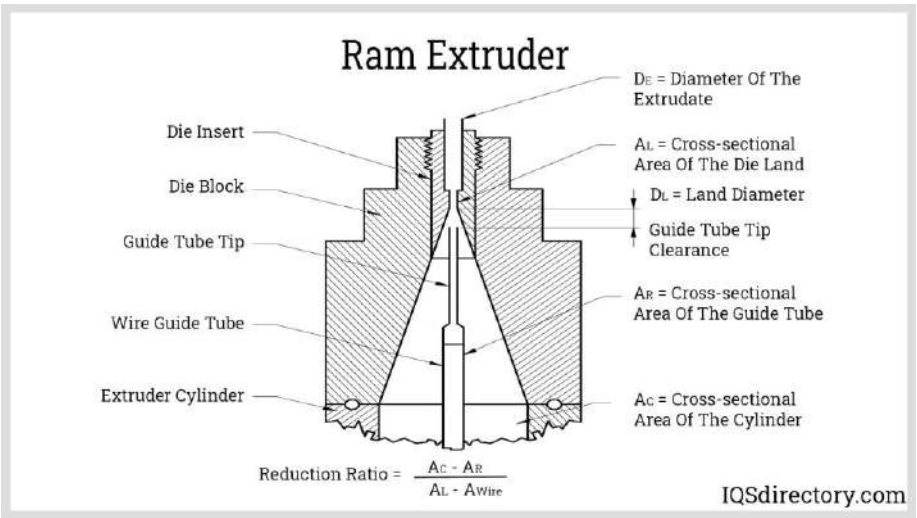
Elastic Melt Extruder

Unlike other disk extruders which operate based on viscous drag transport, elastic melt extruders make use of the elastic properties of polymer melt to move the material and build the required die head pressure.

During shearing deformation of the material between a stationary and rotating plates, uneven distribution of normal stresses will develop in the melt in all directions. These stresses cause a centripetal pumping action which drives the continuous extrusion of material through a central opening. Due to this mechanism, elastic melt extruders are also commonly referred to as normal stress extruders.

Single Ram Extruder

Ram extruders, also known as plunger extruders, are used in a discontinuous operation. They are simple and tough positive displacement devices which can generate very high pressure.



Ram extruders are advantageous in batch operations like injection molding and blow molding. However, this type of extruder also has two major drawbacks such as its limited melting capacity and poor equal temperature distribution of the melt.

One type of ram extruder is the single ram extruder, which is used for general purpose molding. In addition, this is used in extruding ultrahigh molecular weight polyethylene (UHMWPE) or polytetrafluoroethylene (PTPE).

Multi Ram Extruder

Multi ram extruders are designed to operate in a continuous manner. Some designs have four plunger-cylinders –two for plasticating and two for pumping which are connected by an intricate shuttle valve. Some multi ram extruders, on hand, are designed as twin ram extruders with cylinders in a V-shape.

Chapter Four – Single Screw Extruder Parts

The major functions of different components of a single screw extruder will be discussed in this chapter. These include:

Extruder Drive

The extruder drive is responsible for the screw rotation. It supplies the required torque to the extruder screw shank. There are three main drive systems:

1. AC motor drive systems
2. DC motor drive systems
3. Hydraulic drives

Thrust Bearing Assembly

Thrust bearing assembly resists the axial forces acting on the screw which is brought by the die head pressure. Hence, the actual force is determined by the die head pressure. The load is calculated by multiplying the screw‘s cross-sectional area with the die head pressure.

The assembly is normally placed at the connection of the screw shank and the output shaft of the drive.

There are various types of thrust bearings like ball thrust bearings, cylindrical roller thrust bearings, spherical roller thrust bearings, tapered roller thrust bearings, etc. Each type has its own advantages and disadvantages.

Barrel and Feed Throat

Some extruders have a barrel and feed throat which are connected. Basically, the barrel is the part that encloses the screw while the feed throat is where the material enters.

For extruders with this design, the feed throat is usually designed with a water-cooling system to avoid premature melting of the polymer at the feed entry. This is also to prevent further problems like melt sticking on the surface and material flow restriction.

In designing the feed section of the extruder, the following should be considered:

1. Efficient cooling capability
2. Good thermal barrier between the feed entry and barrel
3. Large pressure capability

Feed Hopper

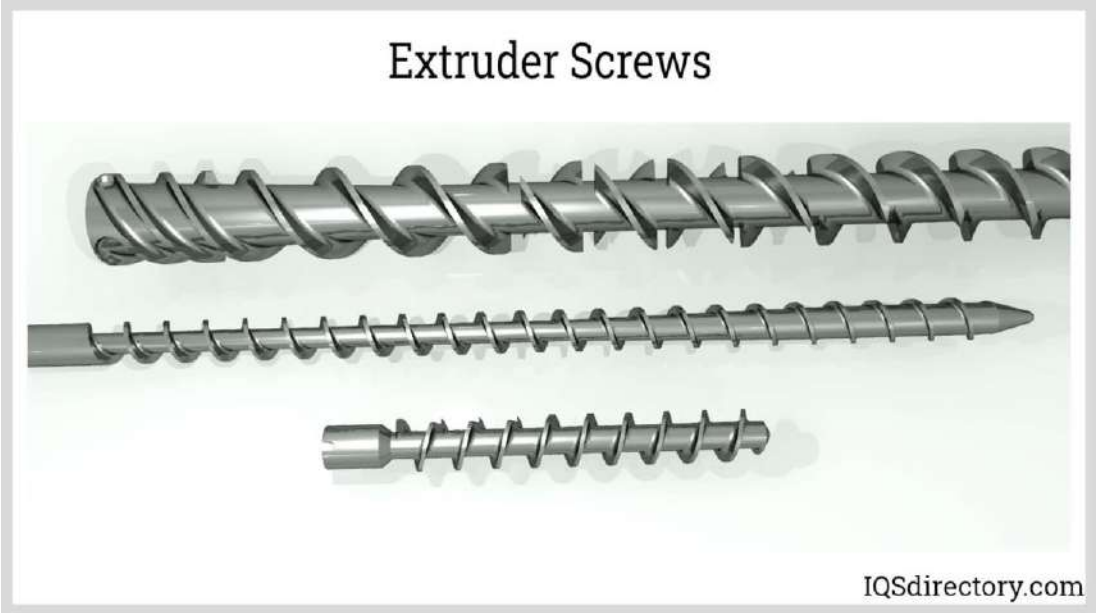
The feed hopper is used to feed the material into the extruder. The feeding is usually done by gravity flow. However, some materials do not easily flow and if not aided with additional devices, it may cause bridging inside the hopper. Additional devices like vibrating pads and stirrers are incorporated in the feed hopper to ensure good flow of material.

There are two common problems which may be encountered when using a feed hopper:

1. Fast Compression – For materials with wide particle size distribution, square feed hoppers may cause conveying problems due to fast compression of materials. For materials like these, it is best to use a hopper with a circular cross section. Square feed hoppers are more suitable for materials with uniform size.
2. Air Entrapment – Some materials have a low bulk density which may cause air entrapment inside the hopper. If this air will not be vented, it will enter the extruder and eventually exit at the die. In effect, it will damage the quality of the extrudate. In some instances, a small explosion can also occur when the air leaves the die. To address this, a vacuum feed hopper is recommended.

Extruder Screw

The extruder screw is the most important component of the extruder. Basically, a screw is a cylindrical rod with changing diameter and helical flights around it. This component is responsible for the conveying, heating, and mixing of the material.

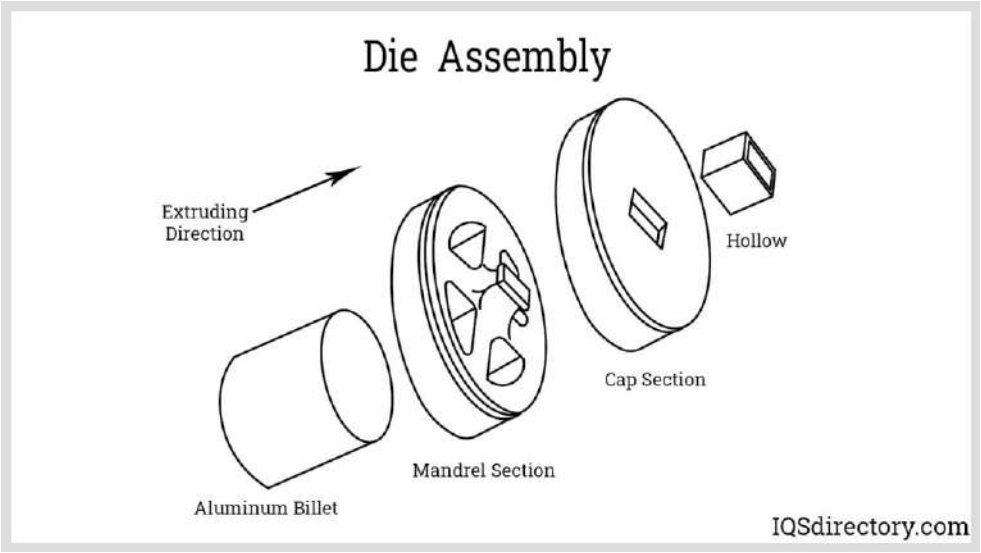


In most extruders, the outside diameter of the screw, from flight-to-flight tip, is constant. The radial clearance to screw diameter ratio is 0.001 in general, ranging from 0.0005 to 0.0020.

Medium carbon steels are the most common material used in screws. Other materials include low carbon steel, stainless steel, tool steel, nickel-based materials, and hardfacing materials.

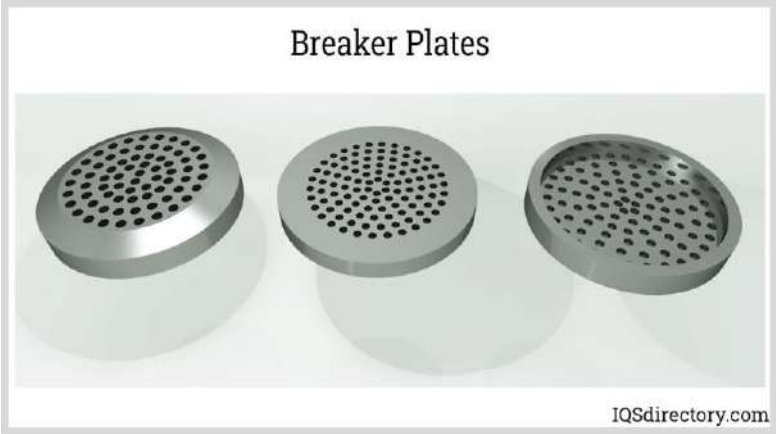
Die Assembly

The die is also a critical part of the extruder because this is where the shaping of the material takes place. In some cases when the exit opening of the extruder barrel is not compatible with the entry exit of the die, an adapter to connect the two is required. But for a die which is designed to fit a specific extruder, an adaptor is not needed anymore.



Breaker Plate

A breaker plate is used to stop the spiraling motion of the melt and initiates its straight-line flow instead. If the spiraling is not stopped, this may stretch up to the die exit thereby causing distortions in the extrudate. Aside from this, breakers plates are used to support filter screens.



Screens and Screen Changers

The major purpose of screens in an extruder assembly is to remove any foreign materials out of the melt. To improve the homogenization of the melt inside the extruder, screens can also be used to increase the die-head pressure. Breaker plates usually support the coarsest screen followed by the finer screens.

There are four filter media commonly used as screens for extruders:

1. Square weave wire mesh
2. Dutch twill wire mesh
3. Sintered powder
4. Random metal fiber

For melt with high amounts of contaminants, screens are easily clogged, and they are replaced frequently. Automatic side-plate screen changers are commonly used for cases like this to avoid shutting down the extruder. The change of screens can be done while the extruder is online.

The pressure drop across the screen is an important parameter that is closely monitored for this system. If the pressure drop exceeds the set point, it triggers the screen change. A hydraulic piston moves the used screens out, and at the same time a new set of screens against the breaker plate is placed. Some systems have filtering units placed downstream if further cleaning is needed.

Heating Systems

Heating and cooling systems set the extruder at the desired temperature during start-ups and normal operations. Electric heating, fluid heating, and steam heating are the most common ways of heating the extruder.

Compared to other methods, electric heating has a lower maintainability, cheap, and efficient. In addition, electric heating can be used in wider temperature ranges. Due to these advantages, electric heating is commonly used in most applications. Each barrel of extruder has its own electrical heater which is controlled independently thereby maintaining a temperature profile along the extruder.

Electrical heaters can be classified into two:

1. Electrical resistance heater -heat generated depends on the conductor resistance and the current which passes through.
2. Induction heater -the extruder barrel is surrounded by a primary coil where an alternating current passes through thereby generating alternating magnetic fields of the same frequency. In effect, an electromotive force is induced, and eddy currents are generated.

Fluid heating is a type of heating system which allows even temperature distribution over the heat transfer area thereby preventing localized heating. However, fluid heating is usually operated at lower temperatures, with only a maximum operating temperature below 250°C. Aside from this, fluid heating systems major drawbacks are:

1. Expensive installation
2. High operating expenses
3. Bulky

Steam has a high specific heat making it a good heating service on extruders. However, raising the temperature to high temperatures is challenging since this also requires high operating pressure. Steam heating is now uncommon for extruder applications because of the following drawbacks:

1. Bulkiness
2. Chance of leakage
3. Corrosion
4. Heat losses

Cooling Systems

In heating the polymer, the action of the screw contributes to 70 to 80% of the total energy. Localized internal heat generation in the melt is probable and might cause the process temperature to get higher than the set point. Cooling systems in the extruder are used to lower the temperature when it tends to exceed the target. Forced-air cooling by blowers are commonly used cooling systems for extruders.

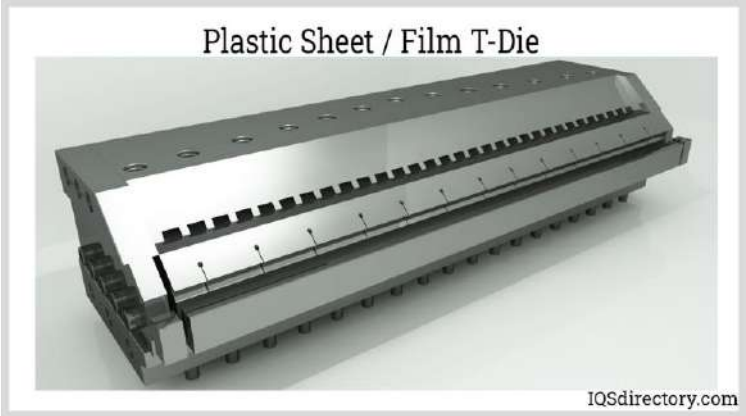
Chapter Five – Die Types

There are various types of die which can be used in film and sheet extrusion, pipe and tubing extrusion, blow film extrusion, profile extrusion, and coextrusion.

Film and Sheet Dies

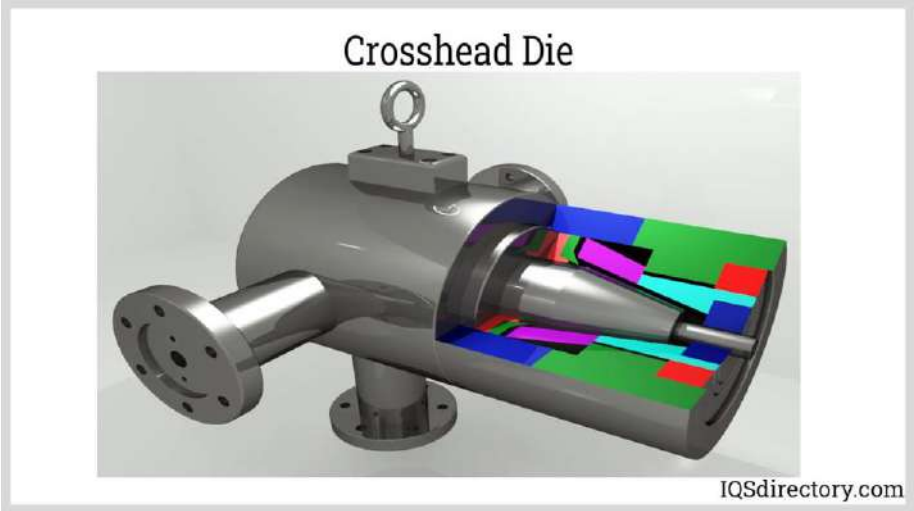
Films and sheets are basically the same. Their only difference is the thickness of the material. Films are thinner with less than 0.5 mm thickness compared to sheets with more than 0.5 mm thickness. In film and sheet extrusion, there are three die types which can be used:

1. T-die
2. Fishtail die
3. Coat hanger die



Pipe and Tubing Dies

Pipes and tubing also differ only in size particularly on the diameter. Tubing has a smaller diameter than a pipe. Tubing diameter is less than 10 mm while pipes have generally larger diameter. In-line dies and crosshead dies are used to extrude annular products.



Blown Film Dies

Blown film extrusion widely utilizes a spiral mandrel die. This type of die is versatile as it can be used with various materials in a broad range of operating conditions. In addition, spiral mandrel dies have good melt distribution and only require low pressure during operation.

Another option is the conventional crosshead die. Compared to spiral mandrel dies, conventional crosshead dies are more likely to develop weld lines.

Profile Extrusion Dies

In the plastic industry, some applications require specific extrudate shapes. Profile dies are generally used for this purpose whenever other extrudate shapes are required aside from typical rectangular or annular products.

Co extrusion Dies

In co extrusion, a single die is used to join two or more polymers which are simultaneously extruded.

There are three different dies which can be used in co extrusion:

1. Feed Block Dies
2. Multi-manifold Internal Combing Dies
3. Multi-manifold External Combing Dies

Calibrators

Calibrator is a sizing die which is used to determine the final pipe dimensions in pipe extrusion. In general, a calibrator contacts the extrudate. The calibrator then cools and strengthens the extrudate freshly coming out of an extrusion die to help maintain its required shape.

To prevent the extrudate from collapsing, vacuum can be applied to ensure close contact of the calibrator with the extrudate. This type of calibrator is often called a vacuum calibrator.

Chapter Six – Plastic Extrusion Applications

Compounding

Pellets produced from compounding extrusion can be used as feedstock for further extrusion processes like injection molding or rotomolding. Compounding polymers with different ingredients like flame retardants, stabilizers, release agents, mineral fillers, colorants etc. has produced new formulations which meet the requirements of specific applications.

Sheets and Cast Films

The construction industry is one of the major consumers of plastic sheets. These are usually used for glazing on doors, windows, bullet proof sheet, and protective sheet.

Aside from this, sheets can also be used as protective covers over walkways and as sound barriers in commercial and industrial applications. Refrigerator liners, food containers, decorative panels, and lamination applications also utilize plastic sheets.

Cast films, on the other hand, are used in the food, agricultural, and packaging industries. Specifically, cast films are used in:

1. Food wrapping
2. Agricultural film for weed control
3. Protective film during shipments

Extrusion Coating and Lamination

Extrusion coating is done by protecting a substrate using a polymer. Coating a material with a polymer improves the product quality including the heat sealability of packaging, tear and crease resistance, appearance, chemical resistance, and printing ability.

Common materials which are coated with plastic are paper, polyester, metal foils, cellophane, paperboard, cloth, and other plastics. Extrusion coating and lamination have a wide range of applications in dairy packaging, juice cartons, carpet coating and backing, frozen food containers, oven-safe paperboard trays, heat seal layers used in general packaging, etc.

Wire and Cable Coating

Plastic extrusion can be employed to coat wires and cables primarily for insulation and protection. Coating wires and cables is done by a crosshead extrusion process.

For this application, the common polymeric materials used are:

1. Polyethylene
2. Polyvinyl chloride
3. Polyamide

4. Polybutylene terephthalate
5. Thermoplastic elastomers
6. Ethylene propylene copolymers
7. Polypropylene
8. Fluoropolymers

Pipe and Tubing

Pipes and tubes are widely used in different industries. Specifically, these plastic extrusion products are utilized as:

1. Water or sewage pipes
2. Drinking straws
3. Vacuum lines
4. Medical tubing
5. Plastic pipettes
6. Circular plastic posts
7. Refrigeration hose
8. Other related applications

Material selection for pipes and tubing depend on its applications. Pipes are normally made from polyethylene, rigid polyvinyl chloride, and nylon. On the other hand, thermoplastic resins are commonly used to produce tubing.

Tubing can be flexible or rigid. Elastomers, cross-linked PE, flexible polyvinyl chloride, and polyurethane are widely used for flexible tubing while commodity resins are used for rigid tubing.

Monofilament Fiber

Sports industry is one of the major users of monofilament fiber. Monofilament is used as tennis, badminton, racquetball, and squash racket strings. Synthetic ropes are also made from monofilament fibers and these are widely used in construction, fences, greenhouses, orchards, etc.

Extrusion Blow Molding

Extrusion blow molding is often employed to create huge, irregularly shaped hollow parts. The automotive industry is a key customer of extrusion blow molding products including parts of bumpers, knee bolsters, air conditioning, side view mirrors, door handles, and so forth.

Stock Solid Shapes

Extrudates are not limited to rectangular or annular shaped products. They can also take the form of a solid shape. Rods, slabs, square rods, square tubes, etc. are some of the common stock solid shapes.

Conclusion

- Plastic extrusion is a continuous high volume manufacturing process in which a thermoplastic material is homogeneously melted and then forced out of the shaping die by means of pressure.
- There are different types of extruder. Generally, extruders can be classified as continuous or discontinuous extruders.
- A single screw extruder has different parts with the screw as the most important component.
- In plastic extrusion, there are various types of die which can be used like T-die, fishtail die, coat hanger die, spiral mandrel die, crosshead die, etc.
- Plastic extrusion has a wide range of applications including sheets, films, coatings, pipe, tubing, etc.