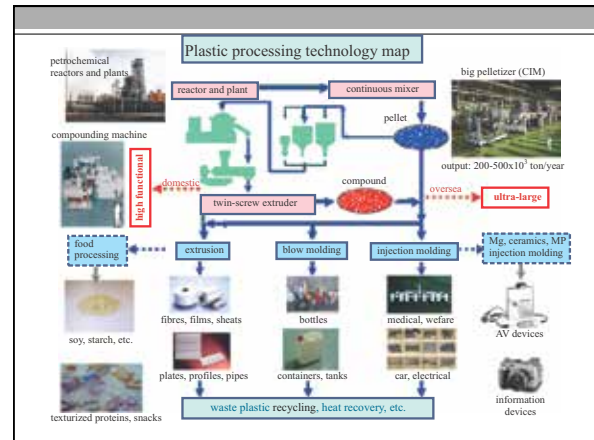
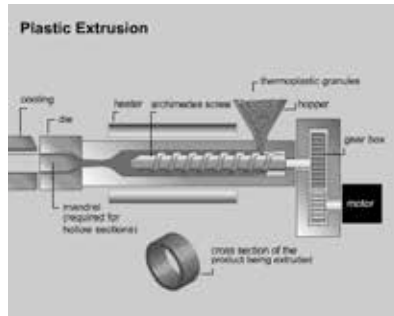


EXTRUSION



Extrusion

- The extruder is the most important piece of machinery in the polymer processing industry.

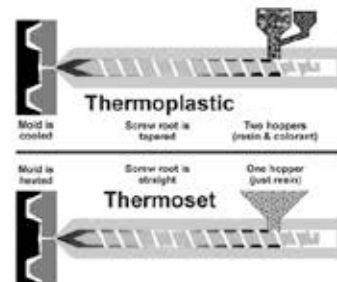


Extrusion

- To extrude means to push or to force out.
- Material is extruded when it is pushed through an opening.
- The part of the machine containing the opening through which the material is forced is referred to as the extruder die.
- As material passes through the die, the material acquires the shape of the die opening.
- The extruded product is referred to as the extrudate.

Polymer Types

- Polymers can be divided into three main groups: thermoplastics, thermosets, and elastomers.



Feed Type

- Materials can be extruded in the
 - molten state or
 - solid state
- **Melt fed extrusion:** the extruder acts purely as a pump, developing the pressure necessary to force the polymer melt through the die.
- **Plasticating extrusion:** If the polymer is fed to the extruder in the solid state and the material is melted as it is conveyed by the extruder screw from the feed port to the die.

Extruder Types

- There are two basic types of extruders:
 - continuous and
 - discontinuous or batch type
- **Continuous extruders:**
 - capable of developing a steady, continuous flow of material.
 - rotating member for transport of the material.
- **Batch extruders:**
 - operate in a cyclic fashion
 - reciprocating member to cause transport of the material.

History of Polymer Extrusion

- The first machine for extrusion of thermoplastic materials was built around 1935 by Paul Troester in Germany.
- Before this, extruders were primarily used for extrusion of rubber.
- Rubber extruders were steam-heated ram extruders and screw extruders (with very small L/D ratios, about 3 to 5).
- After 1935, extruders evolved into electrically heated screw extruders with increased length.
- Around this time, the basic principle of twin screw extruders for thermoplastics was conceived in Italy by Roberto Colombo of LMP.

Main Functions of an Extruder

- The main functions are
 - solids conveying,
 - plasticating or melting,
 - melt conveying or pumping,
 - devolatilization,
 - mixing, and
 - die forming.

Different Types of Extruders

- Extruders in the polymer industry come in many different designs.
- Mode of operation: continuous or discontinuous
- Discontinuous mode is ideally suited for batch type processes, such as
 - injection molding
 - blow molding

Different Types of Extruders

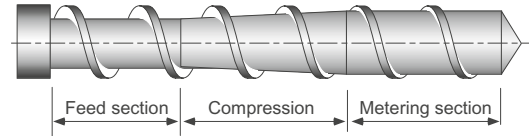
- Screw extruders are divided into single screw and multi screw extruders

Screw extruders (continuous)	Single screw extruders	Melt fed Plasticating Single stage Multi stage Compounding
	Multi screw extruders	Twin screw extruders Gear pumps Planetary gear extruders Multi (>2) screw extruders

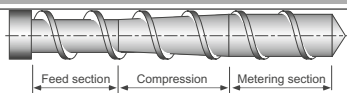
The Single Screw Extruder

- The single screw extruder is the most important type of extruder used in the polymer industry.
- Its key advantages are
 - relatively low cost,
 - straightforward design,
 - ruggedness and reliability, and
 - a favorable performance/cost ratio.

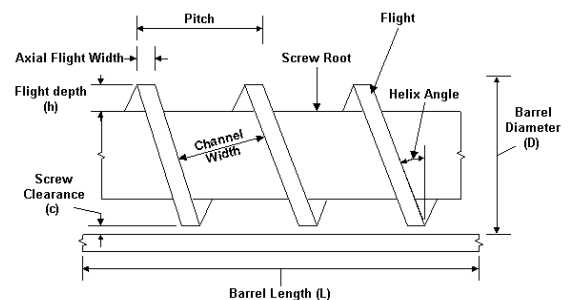
Geometry of conventional extruder screw



- This geometry is also referred to as a "single stage."
- The screw has only one compression section, even though the screw has three distinct geometrical sections!
- The depth of the screw channel (or the height of the screw flight) reduces in a linear fashion → is essential to the proper functioning of the extruder.



- The first section (closest to the feed opening) generally has deep flights. The material in this section will be mostly in the solid state. This section is referred to as the feed section of the screw.
- The last section (closest to the die) usually has shallow flights. The material in this section will be mostly in the molten state. This screw section is referred to as the metering section or pump section.
- The third screw section connects the feed section and the metering section. This section is called the transition section or compression section.



- In Europe, the standard extruder sizes are 20, 25, 30, 35, 40, 50, 60, 90, 120, 150, 200, 250, 300, 350, 400, 450, 500, and 600 millimeters.
- Most extruders range in size from 25 to 150 mm.
- Length to diameter (L / D) ratio:
 - Typical L / D ratios range from 20 to 30, with 24 being very common.
 - Extruders used for extraction of volatiles can have an L/D ratio as high as 35 or 40 and sometimes even higher.

Basic Operation

- The basic operation of a single screw extruder is rather straightforward.
- Material enters from the feed hopper.
- As material falls down into the extruder barrel (the barrel is stationary and the screw is rotating) frictional forces will act on the material.
- These frictional forces are responsible for the forward transport of the material, at least as long as the material is in the solid state (below its melting point).

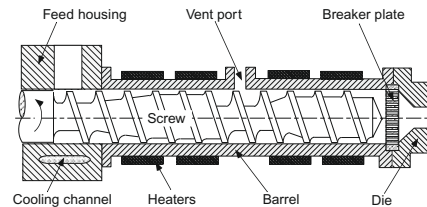
- As the material moves forward, it will heat up as a result of frictional heat generation and because of heat conducted from the barrel heaters.
- When the temperature of the material exceeds the melting point, solids conveying zone ends and the plasticating zone starts.
- The boundaries of the functional zones will depend on
 - polymer properties,
 - machine geometry, and
 - operating conditions.
- The functional zones can change as operating conditions change. However, the geometrical sections of the screw are determined by the design and will not change with operating conditions.

- When all solid polymer has disappeared, the end of the plasticating zone has been reached and the melt conveying zone starts.
- In the melt-conveying zone, the polymer melt is simply pumped to the die.
- As the polymer flows through the die, it adopts the shape of the flow channel of the die.
- Since the die exerts a resistance to flow, a pressure is required to force the material through the die.
- This is generally referred to as the diehead pressure.

- The diehead pressure is determined by
 - the shape of the die (particularly the flow channel),
 - the temperature of the polymer melt,
 - the flow rate through the die, and
 - the rheological properties of the polymer melt.
- It is important to understand that the diehead pressure is caused by the die, and not by the extruder!

Vented Extruders

- Vented extruders are significantly different from non-vented extruders in design and in functional capabilities.
- A vented extruder is equipped with one or more openings (vent ports) in the extruder barrel, through which volatiles can escape.



- The design of the extruder screw is very critical to the proper functioning of the vented extruder.
- The development of the two-stage extruder screw, especially designed for devolatilizing extrusion.
- Vented extruders are used for the removal of monomers and oligomers, reaction products, moisture, solvents, etc.

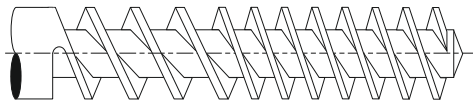
- The devolatilization capability of single screw extruders of conventional design is limited
- No more than 5% volatiles!! → they are sometimes equipped with two or more vent ports
- L / D ratio of 40 to 50 → mechanical problems
- Twin screw extruders can handle solvent contents of 50% and higher, using a multiple-stage extraction system, and solvent content of up to 15% using singlestage extraction.

Rubber Extruders

- Industrial machines for rubber extrusion were built as early as the second half of the nineteenth century.
- The advantages of cold feed extruders are thought to be:
 - Less capital equipment cost
 - Better control of stock temperature
 - Reduced labor cost
 - Capable of handling a wider variety of compounds

- Hot feed rubber extruders are usually very short, about 5D
- Cold feed extruders range from 15 to 20D.
- Cold feed rubber extruders do not differ too much from thermoplastic extruders.
- Some of the differences are:
 - Reduced length
 - Heating and cooling
 - Feed section
 - Screw design

- The extruder screw for rubber has constant depth and variable decreasing pitch (VDP). Screws for thermoplastics usually have a decreasing depth and constant pitch.



Typical screw geometry for rubber extrusion

- Plastiscrew manufactured by NRM

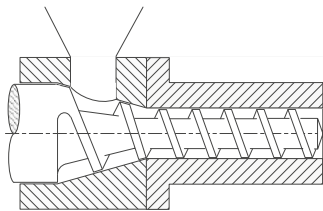
Another difference with the rubber extruder screw is that the channel depth is usually considerably larger than with a plastic extruder screw. The larger depth is used to reduce the shearing of the rubber and the resulting viscous heat generation.



- Pirelli rubber extruder screw

This design uses a feed section of large diameter, reducing quickly to the much smaller diameter of the pumping section.

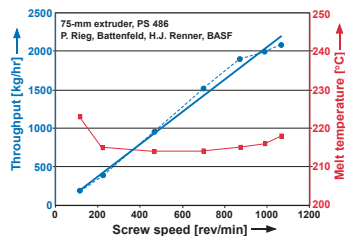
Large amount of leakage over the flight and improves the batch-mixing capability of the extruder.



High-Speed Extrusion

- Single screw extruders (SSE) usually operate at screw speeds between 50 to 150 rpm.
- Twin screw extruders (TSE) used in compounding typically run at screw speeds ranging from 200 to 500 rpm.
- High-speed single screw extruders (HS-SSE)
- Battenfeld supplies a high speed 75-mm SSE that can run at screw speeds up to 1,500 rpm. This machine can achieve throughputs up to 2,200 kg / hr.

- One of the interesting characteristics of the HS-SSE is that the **melt temperature remains more or less constant** over a broad range of screw speed.



- the residence time of the polymer melt is reduced
- the volume of the molten polymer reduces as the melting length becomes longer

Important advantages of high-speed SSE

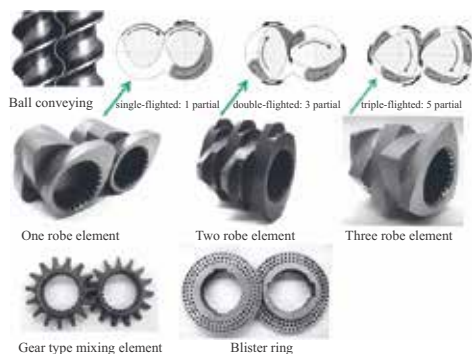
- Extruders without Gear Reducer
- Energy Consumption
- Change-over Resin Consumption
- Change-over Time and Residence Time

The Twin Screw Extruders

- A twin screw extruder is a machine with two Archimedean screws.
- There is a tremendous variety of twin screw extruders, with vast differences in design, principle of operation, and field of application.
- Therefore, difficult to make general comments about twin screw extruders.

Classification of Twin Screw Extruders

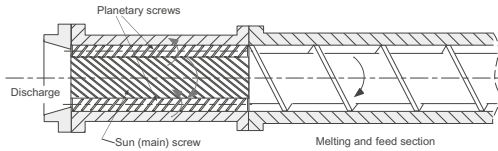
Intermeshing extruders	Co-rotating extruders	Low speed extruders for profile extrusion High speed extruders for compounding
	Counter-rotating extruders	Conical extruders for profile extrusion Parallel extruders for profile extrusion High speed extruders for compounding
Non-intermeshing extruders	Counter-rotating extruders	Equal screw length Unequal screw length
	Co-rotating extruders	Not used in practice
	Co-axial extruders	Inner melt transport forward Inner melt transport rearward Inner solids transport rearward Inner plasticating with rearward transport



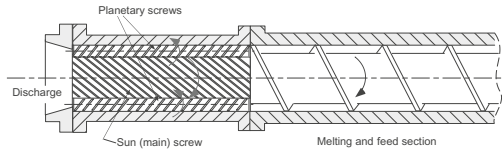
Single-screw	Twin-screw
Fair feeding	good feeding
Flood feeding	starve feeding
Fair melting	good melting
Fair mixing (distributive mixing)	good distributive and dispersive mixing
Non-self wiping	self wiping
Non-modular design	modular design (flexible)
Fair degassing	good degassing
Good pressurization	limited pressurization

The Multiscrew Extruder With More Than Two Screws

- This extruder looks similar to a single screw extruder.
- The feed section is, the same as on a standard single screw extruder.
- However, the mixing section of the extruder looks considerably different.



- Heat-sensitive compounds can be processed with a minimum of degradation.
- For this reason, the planetary gear extruder is frequently used for extrusion /compounding of PVC formulations, both rigid and plasticized.



Disk Extruders

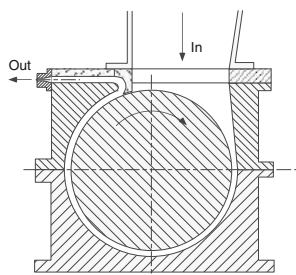
- There are a number of extruders, which do not utilize an Archimedean screw for transport of the material, but still fall in the class of continuous extruders.
- Sometimes these machines are referred to as screwless extruders.
- These machines employ some kind of disk or drum to extrude the material.
- Most of the disk extruders are based on viscous drag transport.

- One can classify the disk extruders according to their conveying mechanism.

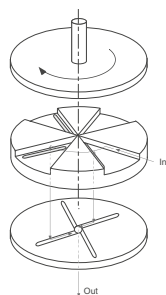
Disk or drum extruders (continuous)	Viscous drag extruders	Spiral disk extruder
		Drum extruder
		Diskpack extruder
	Elastic melt extruders	Stepped disk extruder
		Screwless extruder
		Screw or disk type melt extruder

- The industrial significance of disk extruders is still relatively small compared to screw extruders.

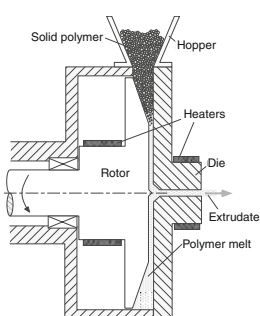
Drum Extruder



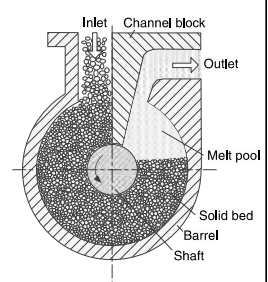
Stepped Disk Extruder



The Elastic Melt Extruder



Diskpack Extruder



Other Types of Extruders

Reciprocating extruders (discontinuous)	Ram extruders	Melt fed extruder Plasticating extruder Capillary rheometer
	Reciprocating single screw extruders	Plasticating unit in injection molding machines Compounding extruders such as the Kneader

Ram Extruders

- Ram or plunger extruders are simple in design, rugged, and discontinuous in their mode of operation.
- Ram extruders are essentially positive displacement devices
- They are able to generate very high pressures.
- Because of the intermittent operation of ram extruders, they are ideally suited for cyclic processes, such as injection molding and blow molding.

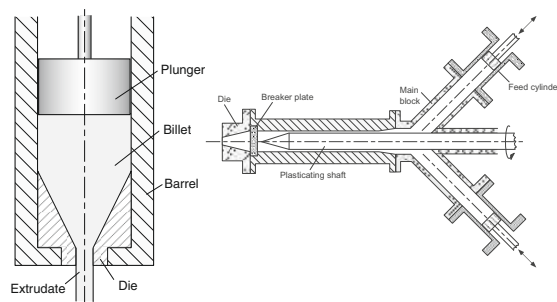
- Early molding machines were almost exclusively equipped with ram extruders to supply the polymer melt to the mold.
- The two main limitations are:
 - Limited melting capacity
 - Poor temperature uniformity of the polymer melt
- There are basically two types of ram extruders: single ram extruders and multi ram extruders.

The single ram extruder is used in small general purpose molding machines, but also in some special polymer processing operations.

- One such operation is the extrusion of intractable polymers, such as
 - ultrahigh molecular weight polyethylene (UHMWPE) or
 - polytetrafluoroethylene (PTFE).
- These polymers are not considered to be melt processable on conventional melt processing equipment.

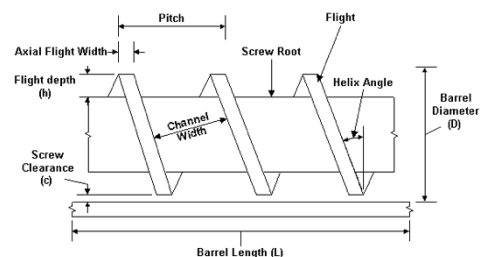
The single ram extruder

The multi ram extruder

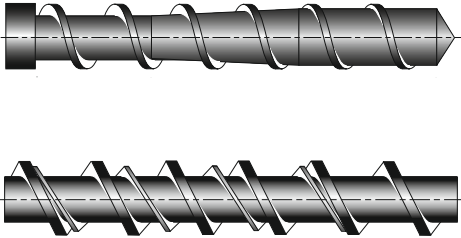


Screw Design

The single most important mechanical element of a screw extruder is the screw

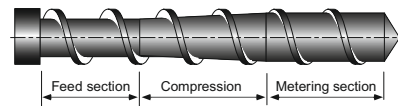


Single flight / Double flight

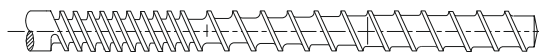


General characteristics of the standard extruder

- Total length 20–30 D
- Length of feed section 4–8 D
- Length of metering section 6–10 D
- Number of parallel flights 1
- Flight pitch 1 D (helix angle 17.66°)
- Flight width 0.1 D
- Channel depth in feed section 0.15–0.20 D
- Channel depth ratio 2–4



Modifications of the Standard Extruder Screw



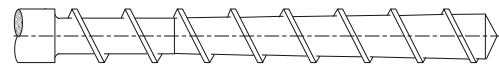
Standard screw with additional flight in the feed section



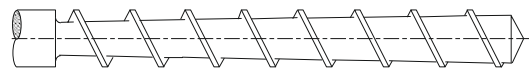
Variable pitch extruder screw with reducing pitch



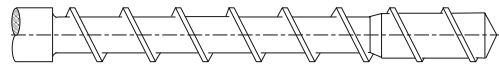
Variable pitch extruder screw with increasing pitch



Zero-meter extruder screw



Zero-feed zero-meter extruder screw



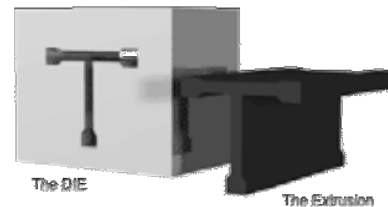
Rapid compression screw

Die Design

- The objective of an extrusion die:

"To distribute the polymer melt in the flow channel such that the material exits from the die with a uniform velocity."

- The actual distribution will be determined by
 - the flow properties of the polymer,
 - the flow channel geometry,
 - the flow rate through the die, and
 - the temperature field in the die.



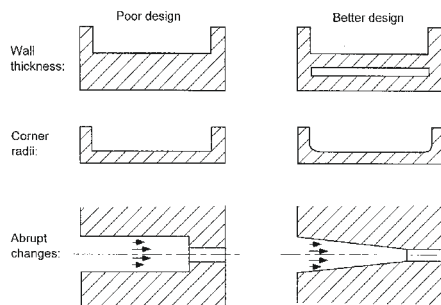
Some general rules that are useful in die design

- No dead spots in the flow channel
- Steady increase in velocity along the flow channel
- Assembly and disassembly should be easy
- Avoid abrupt changes in flow channel geometry
- Use small approach angles

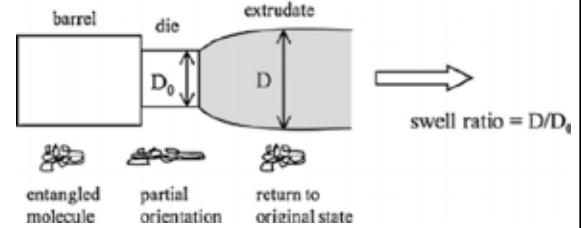
Basic guidelines in profile design to minimize extrusion problems

- Use generous internal and external radii on all corners; the smallest possible radius is about 0.5 mm
- Maintain uniform wall thickness (important!)
- Avoid very thick walls
- Make interior walls thinner than exterior walls for cooling
- Minimize the use of hollow sections

Basic guidelines in profile design to minimize extrusion problems



Die Swell



Die Swell

- Die swell is a common phenomenon in polymer extrusion.
- When a viscoelastic fluid flows out of a die, the extrudate diameter is usually greater than the channel size.
- The degree of extrudate swell is usually expressed by the die-swell ratio (B) of extrudate diameter versus die diameter.
- A better understanding of such flow behavior will be beneficial for the optimization of processing parameters and the design of extrusion equipment, both of which affect product quality and production cost.