MKR1153
Polymer Technology II

CH2 EXTRUSION OF PLASTICS

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PROCESSES FOR SHAPING PLASTICS

1. Properties of Polymer Melts
2. Extrusion
3. Production of Sheet, Film, and Filaments
4. Coating Processes
5. Injection Molding
6. Other Molding Processes
7. Thermoforming
8. Casting
9. Polymer Foam Processing and Forming
10. Product Design Considerations

Plastic Products

- Plastics can be shaped into a wide variety of products:
  - Molded parts
  - Extruded sections
  - Films
  - Sheets
  - Insulation coatings on electrical wires
  - Fibers for textiles

More Plastic Products

- In addition, plastics are often the principal ingredient in other materials, such as
  - Paints and varnishes
  - Adhesives
  - Various polymer matrix composites
- Many plastic shaping processes can be adapted to produce items made of rubbers and polymer matrix composites

Trends in Polymer Processing

- Applications of plastics have increased at a much faster rate than either metals or ceramics during the last 50 years
  - Many parts previously made of metals are now being made of plastics
  - Plastic containers have been largely substituted for glass bottles and jars
- Total volume of polymers (plastics and rubbers) now exceeds that of metals

Plastic Shaping Processes are Important

- Almost unlimited variety of part geometries
- Plastic molding is a *net shape* process
  - Further shaping is not needed
- Less energy is required than for metals due to much lower processing temperatures
  - Handling of product is simplified during production because of lower temperatures
- Painting or plating is usually not required

Two Types of Plastics

1. Thermoplastics
   - Chemical structure remains unchanged during heating and shaping
   - More important commercially, comprising more than 70% of total plastics tonnage
2. Thermosets
   - Undergo a curing process during heating and shaping, causing a permanent change (*cross-linking*) in molecular structure
   - Once cured, they cannot be remelted

Polymer Melts

- To shape a thermoplastic polymer it must be heated so that it softens to the consistency of a liquid
- In this form, it is called a *polymer melt*
- Important properties of polymer melts:
  - Viscosity
  - Viscoelasticity

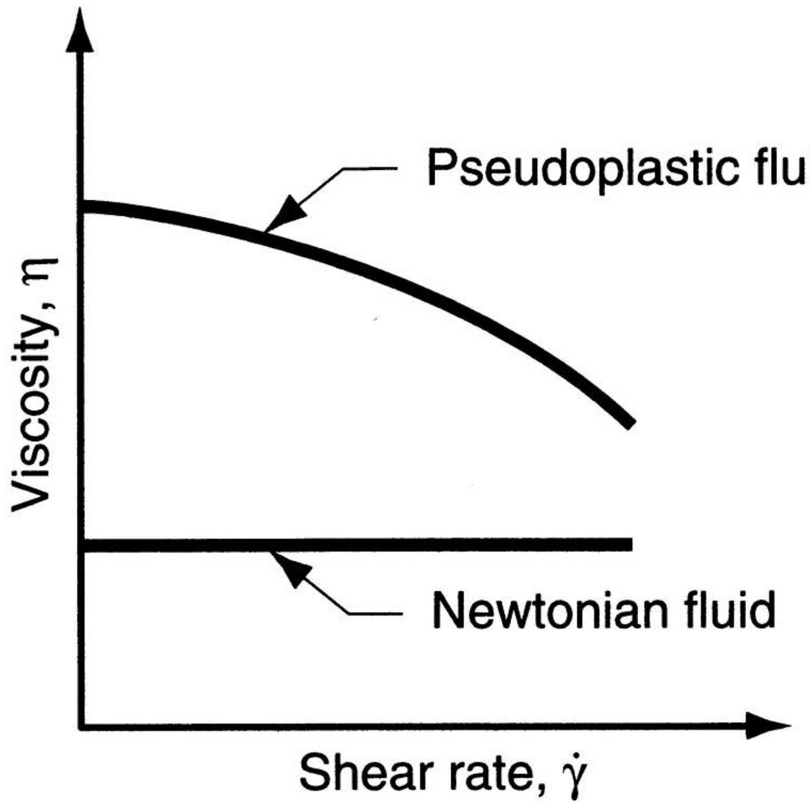
Viscosity of Polymer Melts

Fluid property that relates shear stress to shear rate during flow

- Due to its high molecular weight, a polymer melt is a fluid with high viscosity
- Most polymer shaping processes involve flow through small channels or die openings
  - Flow rates are often large, leading to high shear rates and shear stresses, so significant pressures are required to accomplish the processes

Viscosity and Shear Rate

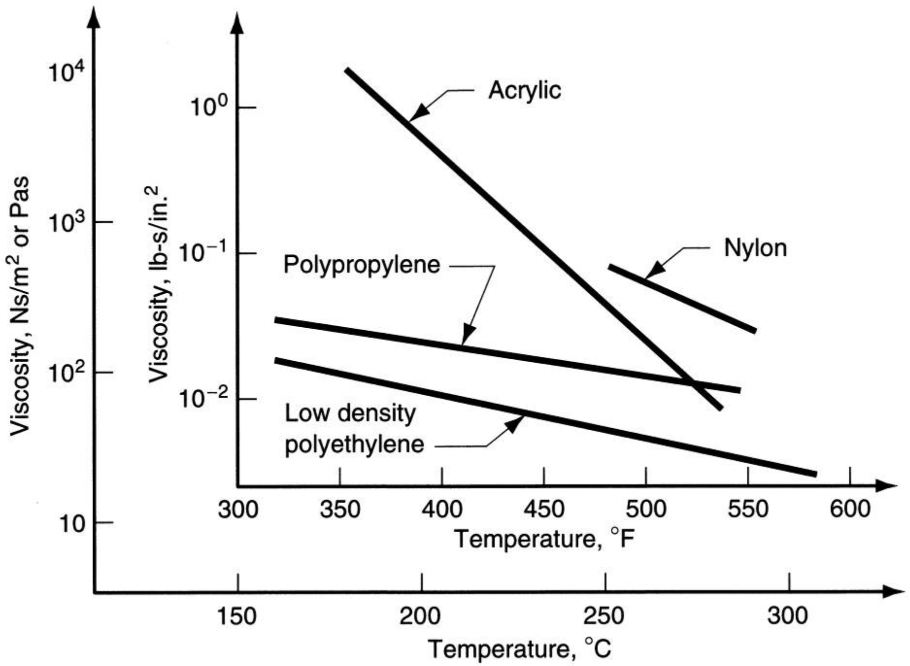
Viscosity of a polymer melt decreases with shear rate, thus the fluid becomes thinner at higher shear rates



Viscosity relationships for Newtonian fluid and typical polymer melt.

Viscosity and Temperature

Viscosity decreases with temperature, thus the fluid becomes thinner at higher temperatures



Viscosity as a function of temperature for selected polymers at a shear rate of 10^3 s^{-1}.

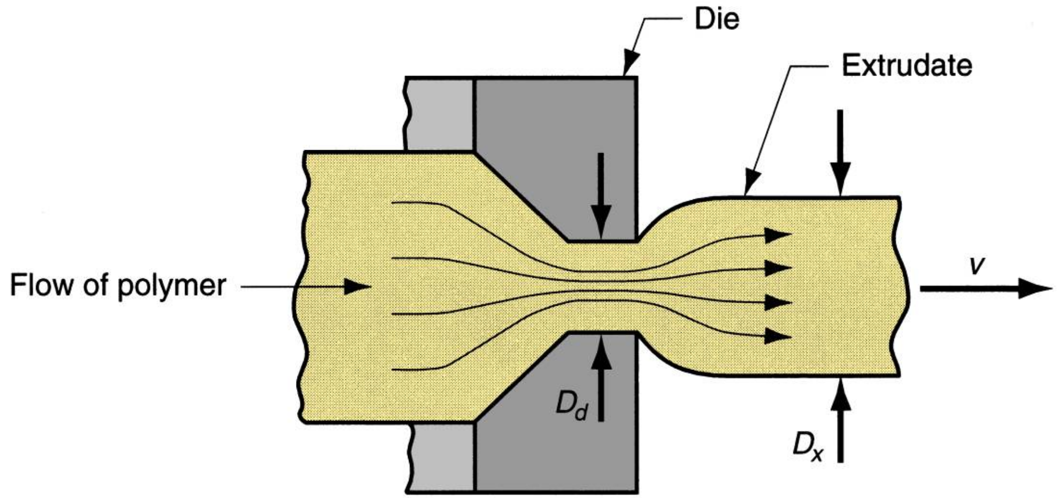
Viscoelasticity

Combination of viscosity and elasticity

- Possessed by both polymer solids and polymer melts
- Example: die swell in extrusion, in which the hot plastic expands when exiting the die opening

Die Swell

Extruded polymer "remembers" its previous shape when in the larger cross section of the extruder, tries to return to it after leaving the die orifice



Die swell, a manifestation of viscoelasticity in polymer melts, as depicted here on exiting an extrusion die.

Extrusion

What is extrusion?

- The word extrusion comes from Greek roots- means ‘push out’
- Continuous process
- Process which forcing a molten materials (plastic) through a shaped die by means of pressure- e.g. melting of plastic resin + adding mixing fillers
- In this process, screws are used to progress the polymer in the molten or rubbery state along the barrel of the machine
- Single screw extruder is widely used, however twin screw extruder are also used where superior mixing is needed

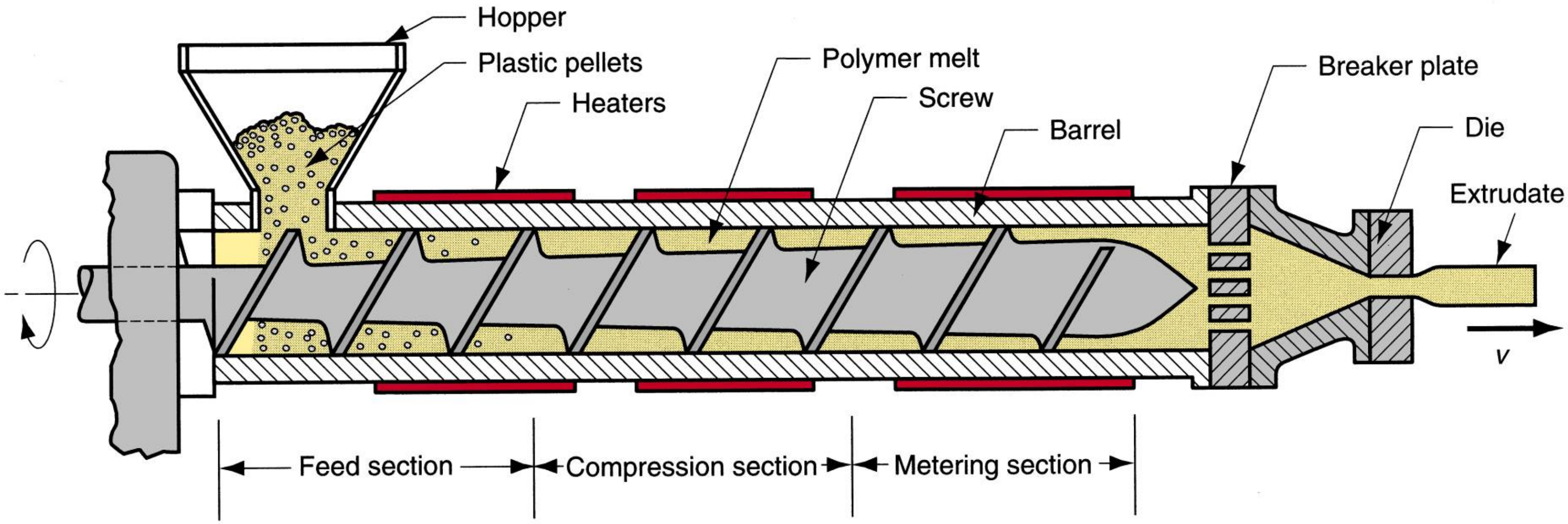
Extrusion

Compression process in which material is forced to flow through a die orifice to provide long continuous product whose cross-sectional shape is determined by the shape of the orifice

- Widely used for thermoplastics and elastomers to mass produce items such as tubing, pipes, hose, structural shapes, sheet and film, continuous filaments, and coated electrical wire
- Carried out as a continuous process; *extrudate* is then cut into desired lengths

Extruder

Figure shows components and features of a (single-screw) extruder for plastics and elastomers

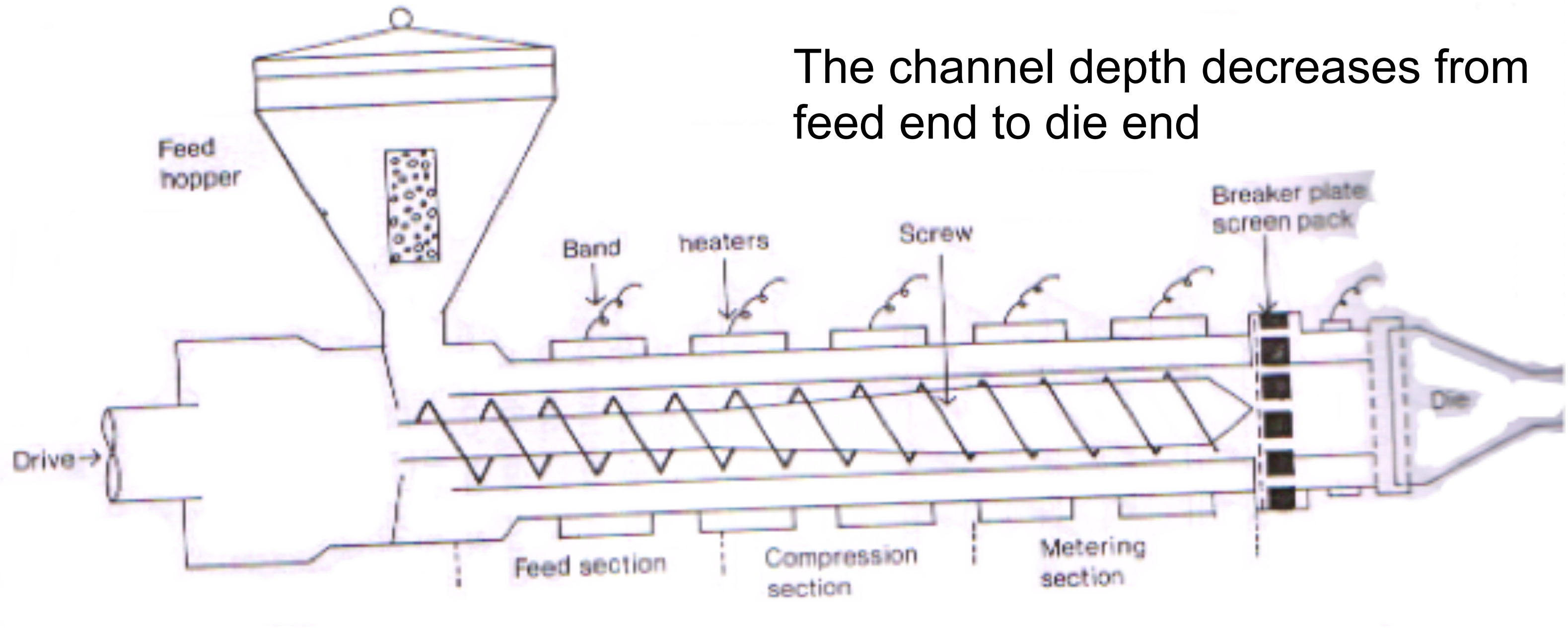


Extruder Screw

- Divided into sections to serve several functions:
  - Feed section - feedstock is moved from hopper and preheated
  - Compression section - polymer is transformed into fluid, air mixed with pellets is extracted from melt, and material is compressed
  - Metering section - melt is homogenized and sufficient pressure developed to pump it through die opening

Main features of a single screw extruder

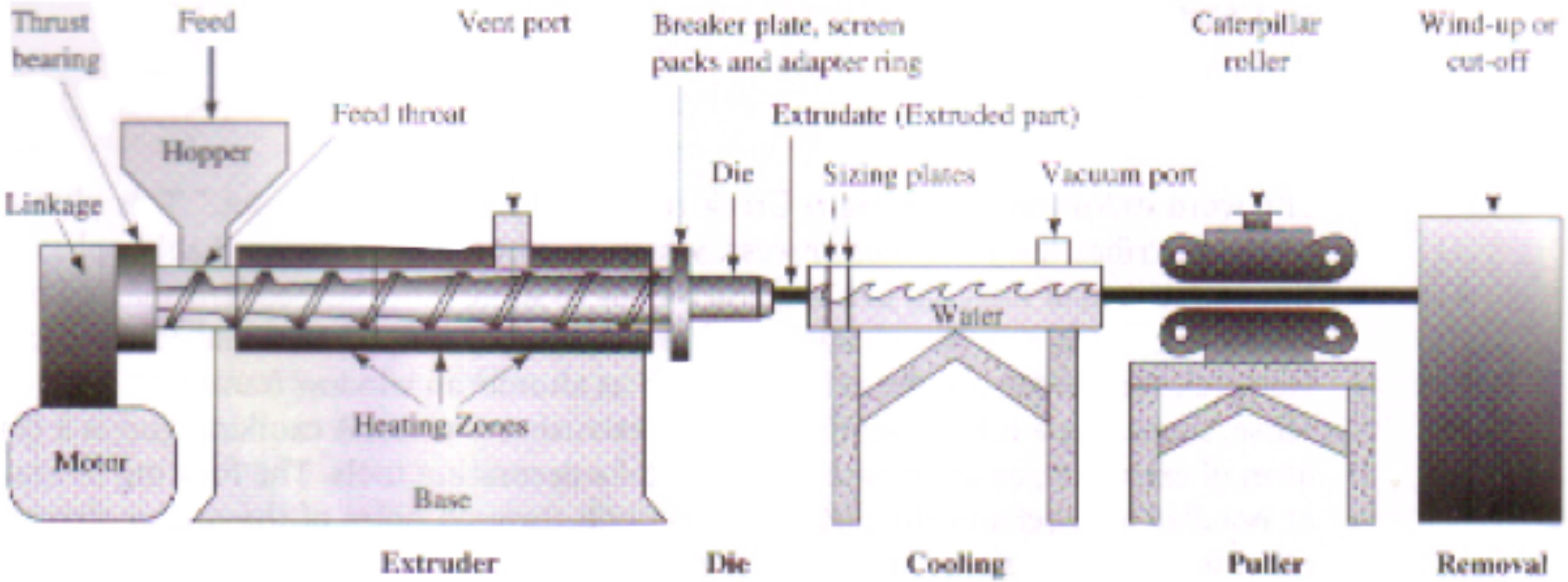
The channel depth decreases from feed end to die end



Solid polymer is fed in at one end, inside the polymer melts and Homogenizes and molten extrudate emerges from the other

There are 3 zones; feed zone, compression zone and metering zone

Typical extrusion line showing major equipment



Materials fed into hopper, falls through a hole in the top the extruder (feed throat) onto the screw. The screw moves the molten plastic forward until the end of the extruder barrel to which die has been attached. Die gives shape to molten plastics, Cooled in water tank

Equipment of Extruder

- Drive motor- turns the screw, provides power for the operation of the extruder to push out the plastic materials
  - The required extruder power increases when;
    - Output increases
    - Barrel diameter increases
    - Screw length increases
    - High output is required at high temperature
  - Power requirement is a function of resin type and mold design

Equipment of Extruder

- A large thrust bearing- mounted on the screw. Prevent the screw from moving backwards
- Barrel- is the chamber in which the screw turns and the resin flows (made of hardened steel.
  - The inside diameter of barrel indicates the capacity & size of extruder.
  - Outside of barrel is jacketed with electrical heating element
  - Heating elements are divided into different controlled zones

Equipment of Extruder

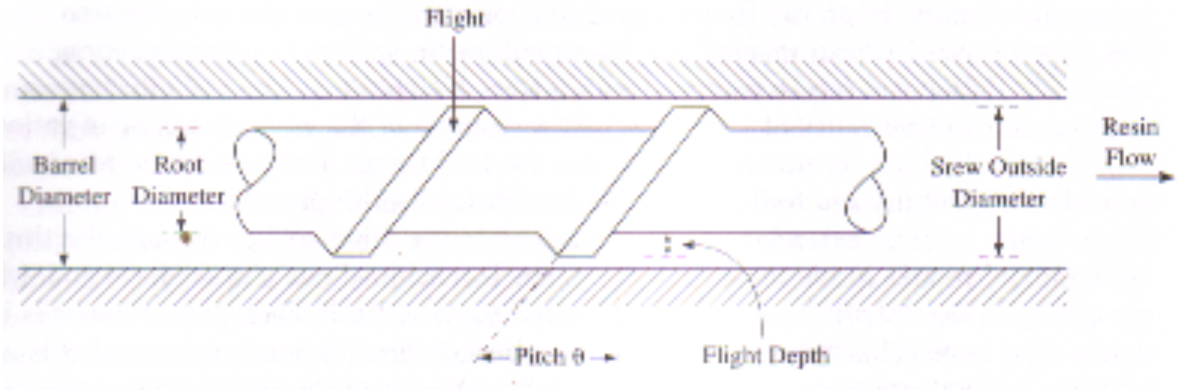
- Feed throat- opening in the top of the barrel, just beyond the thrust bearing (Inlet for the resin)
- Hopper- mounted over the feed throat
- Extruder screw- attached to the drive linkage through the thrust bearing and rotates inside the barrel

Functions of Extruder Screw

- To convey the resin through the extruder
- To mix the ingredient together
- To build pressure in the extruder (so that resin will be pushed through the die)
- To impart mechanical energy as part of the melting process

Extruder screw

The screw is machined out of a solid rod.
Like a shaft with helical screw on it,
each turn of the helix is called a flight.

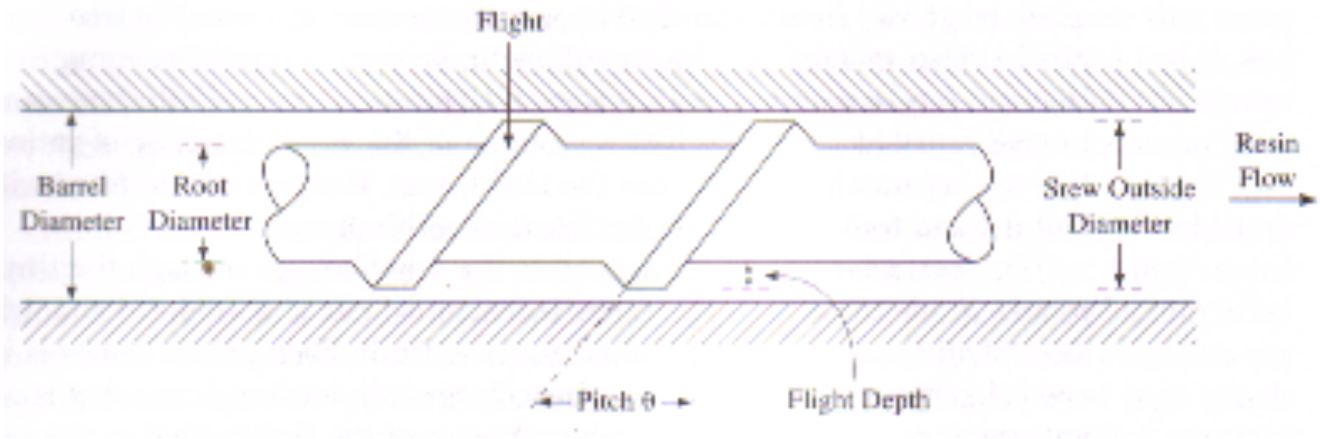


Important parameter= L/D of the screw (length of the flighted portion of the screw/ inside diameter of the barrel)

L/D measures the capability of the screw to mix materials and ability of the screw to melt hard-to-melt material. Typical L/D ratios are 16:1 to 32:1

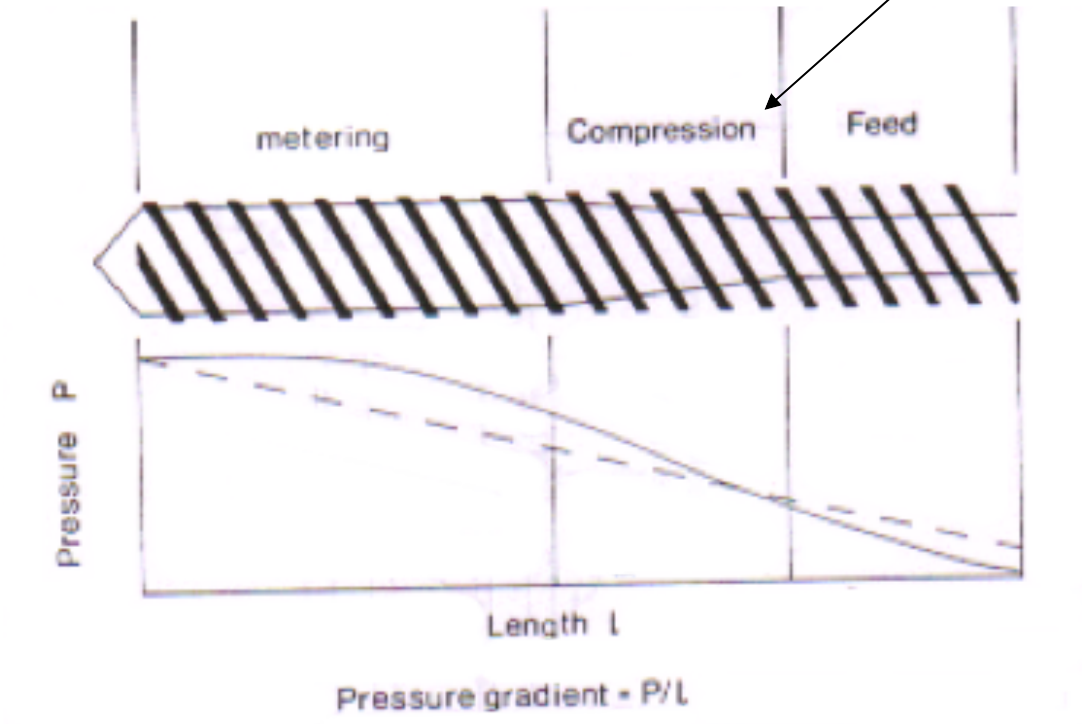
Extruder screw

- Barrel diameter is constant over the entire length of the extruder
- The root is the measure of the diameter of the shaft of the screw (the root diameter can vary along the length of screw)
- The flight rise above the shaft creating a flight depth (difference between top of the flight and the root diameter)
- As the root diameter changes, the flight depth will correspondingly change (if the root diameter is small, the flight depth are large and vice versa



Zones in a single screw extruder

The channel depth decreases from feed end to die end



Decreasing in channel depth results in increasing pressure along the extruder

Feed Zone

- Purpose; Preheat the polymer, and convey it to subsequent zones
- Pulls the polymer pellets from the hopper
- The screw depth is constant
- The feed section has a small, constant root diameter that results in large, constant-depth flight to accommodate the bulky dry solid resins and other additives

Compression Zone

- The second zone- decreasing channel depth
- Usually called as ‘compression’ and ‘transition’ zone
- Compresses the material conveys from the feed zone and plasticates it
- Can be identified as by the gradual increase in the diameter of the root along the length of the section

Compression Zone

- root diameter increase means the flight depth gradually decrease throughout the compression section, compressing the resin and forcing the air/volatiles out of the resin melt
- The volatiles escape by flowing backward through the vent port or gap between screw and barrel
- Removal of these volatiles is important in making pore/void- free product

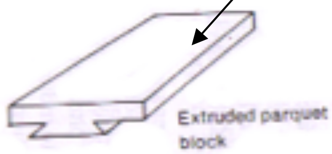
The Die Zone

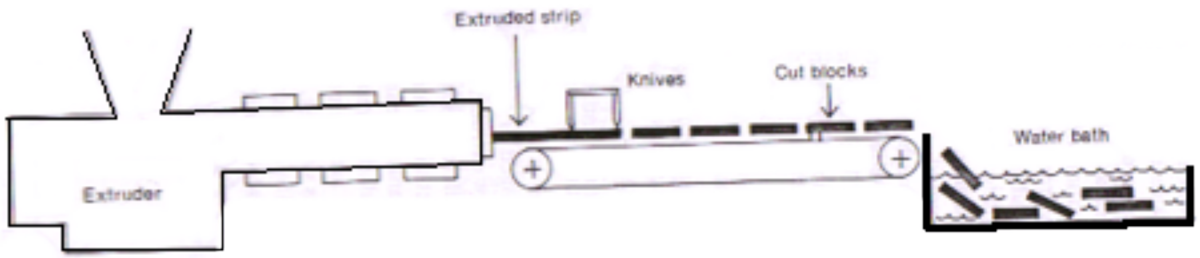
- Located in this region is the screen pack (comprises a perforated steel plate called breaker plate and sieve pack)
- The breaker plate-screen pack has three functions;
  - To sieve out/remove unwanted particles, e.g. dirt, foreign bodies (dies are expansive and difficult to repair)
  - To develop a head pressure that provides the driving force for the die
  - To remove 'turning memory along the spiral screw' from the melt (Polymers are made up of long chain molecules, coiled, etc. , they have tendency towards elastic recovery)

An example of ‘turning memory’

- New design of flooring block; highly-filled PVC compound (PVC + plasticiser + CaCO3, heat stabilizer + pigment)
- After the tiles were removed from the cooling bath, they were all twisted (result from turning memory from the screw).
- The breaker plates is introduced in the extruder to break up the plug of polymer containing the aligned ‘memory’

New design of flooring block





Manufacturing of parquet flooring blocks

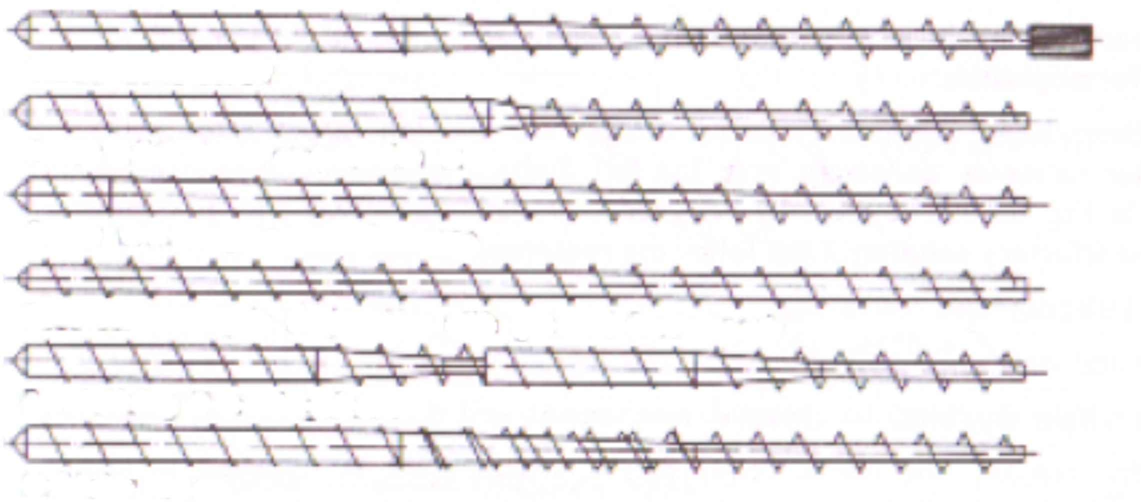
Metering zone

- Constant screw depth and very shallow flight depth
- The function is to homogenize the melt and supply to die region (give final mixing)
- Shallow flight depth ensure that high shear is added to the resin to accomplish any melting of the residual solids.
- High shear also builds pressure on the melted resin and push out of the end of the extruder

Important extrusion parameter; Compression Ratio (measures of the work that is Expanded on the resin)
Compression Ratio = flight depth in the feed section / flight depth in metering section
(as low as 1.1/1 and as high as 5:1, typically 2.25:1)

Screw Design

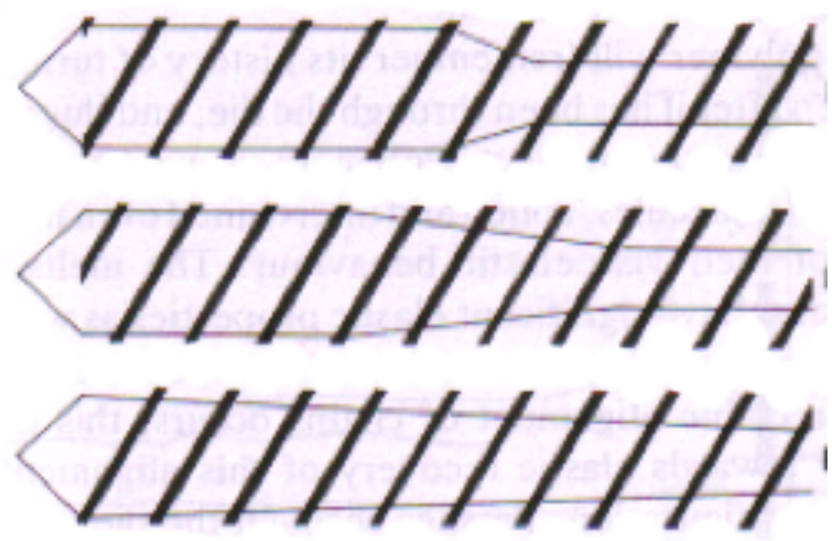
- The screw is the heart of an extruder
- The geometry of the screw changes along the length



Common screw geometry, with three-zone screw is the most common

Variation in Screw Design

- PE, e.g. LDPE melts gradually- screw with overall length evenly divided between three zones (PE screw)
- If the polymer melts sharply, very short compression zone is needed (nylon screw)
- PVC, its melting is more gradually than PE (difficult to extrude)- use a screw with one long compression zone along its entire length

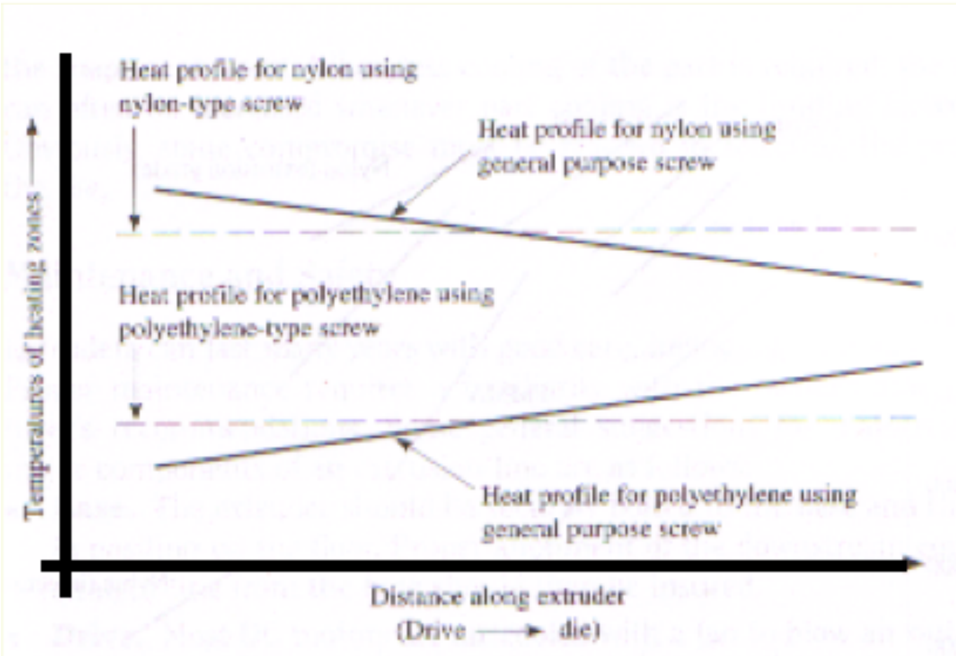


From top: Nylon, PE and PVC screw

Special Screw Design

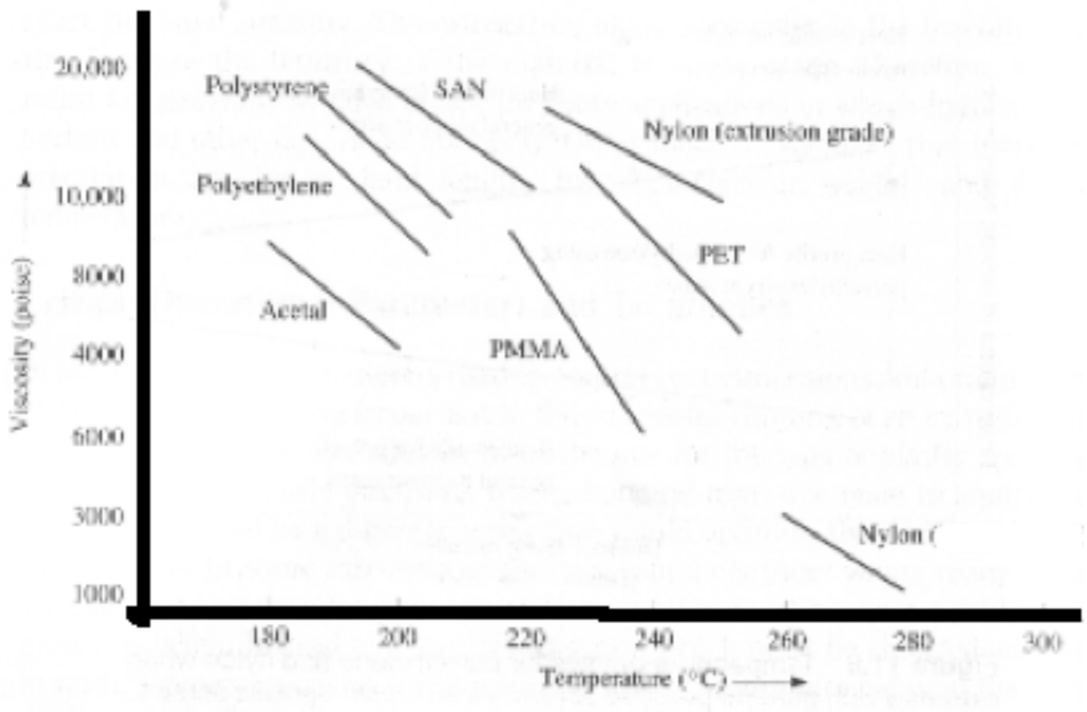
- Modification of the screw basic design is needed to obtain good distribution of filler
- However changing screw design is a difficult task, thus general purpose screw is used
- The performance of these general purpose screw can be modified by changes in operational setting such as temperature, screw speed, etc

- General purpose screw- the performance of this extruder can be modified by changes in setting; temperature, screw speed, etc.



Temperature profiles for PE and nylon when extruded with general- purpose screws versus resin-specific screws

- Mixing of two or more resins are strongly dependent upon viscosities (materials are mixed more efficient when viscosities are similar, e.g. temperature mixing for PMMA and PE is at 218C)

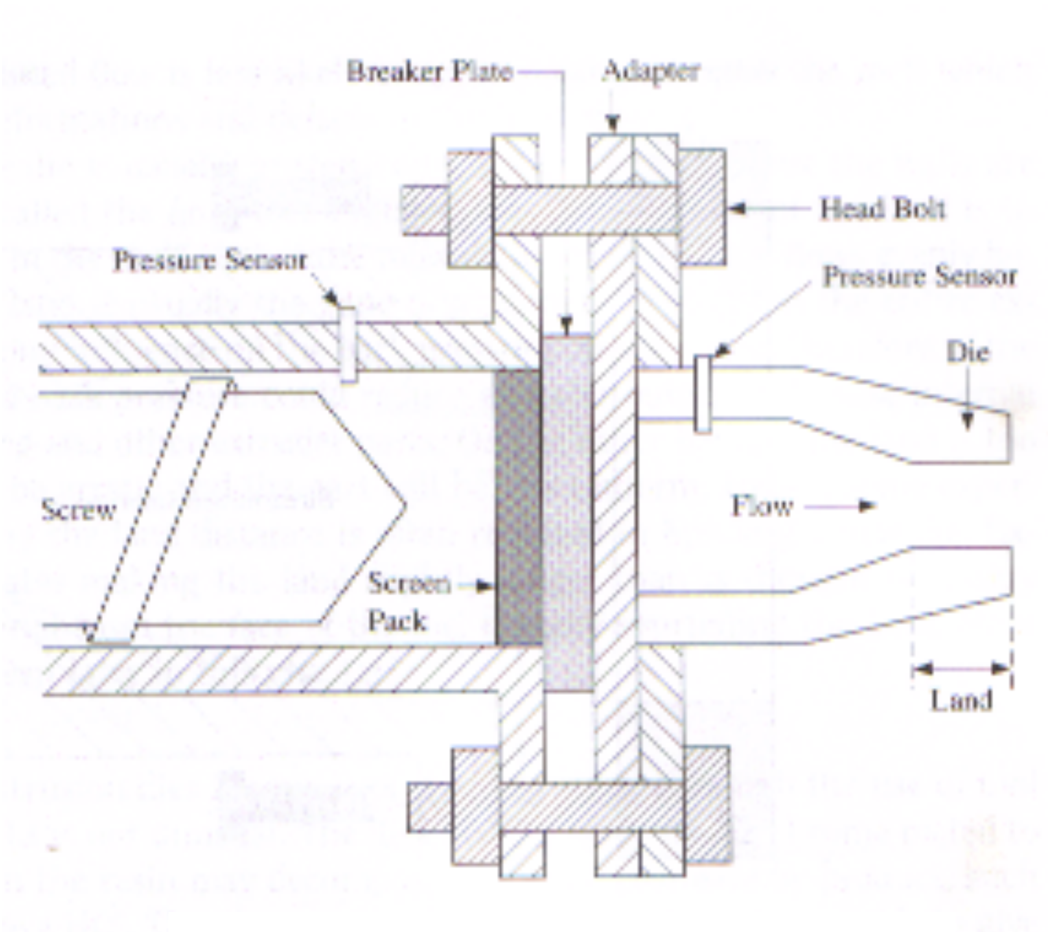


Plot of viscosities of common resins as a function of temperature

Head Zone

- Portion of extruder follows the end of screw
- After leaving the end of screw, plastic flow through screen pack then through breaker plate (disc of sturdy metal with many holes drilled through it)
- Screen pack – collection of wire screen (usually in different mesh), to filter out unmelted resin or contaminants
- Screen pack will become clogged with filtered materials and must be changed (at this point, is said to be blinded). It is noted by an increase in the back pressure in the extruder

Head Zone



Head zone and typical die

Die

- The shaping tool that is mounted on the end of extruder; onto a ring called adapter
- Purpose; to give shape to the melt
- Most extrusion dies made of stainless steel

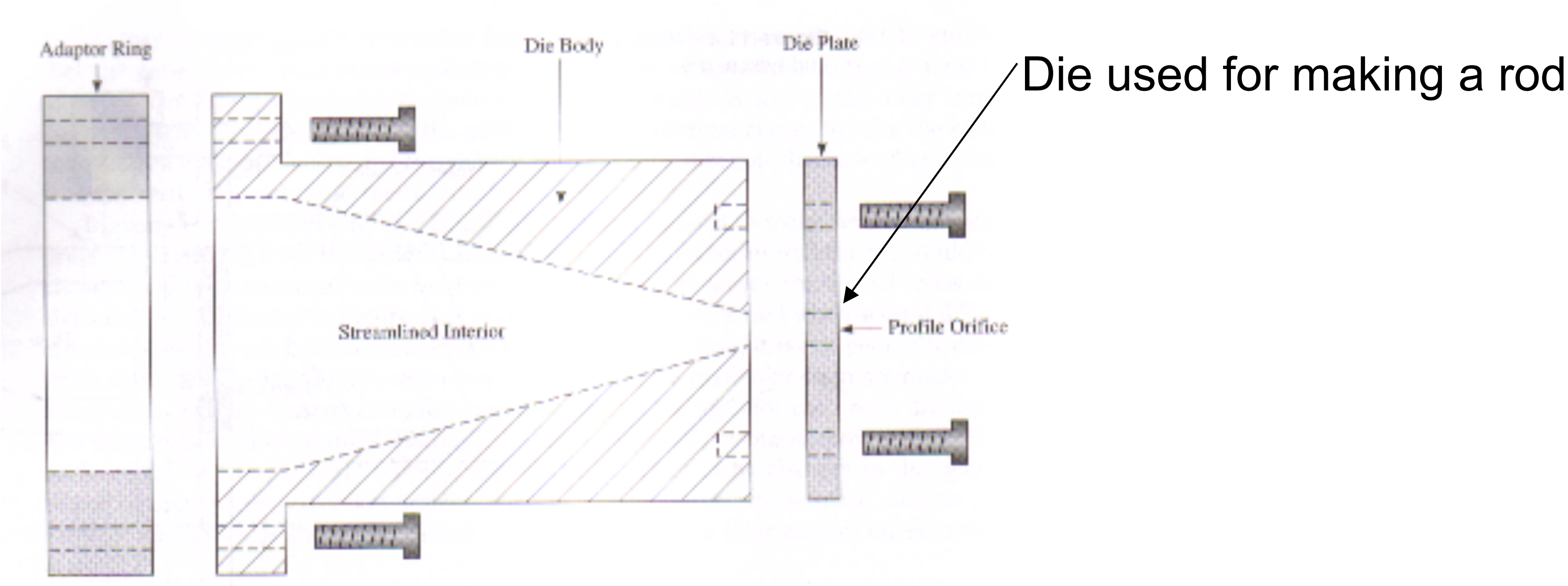


Figure 11.5 Extrusion die parts.

Cooling

- Upon exiting the die, the extrudate must be cooled to retain its shape
- The extrudate is introduce into a cooling bath, extrudate can passes through sizing plate (plates of rings with holes of the proper size)

Extrusion vs. other processes

Advantage	Disadvantage
Continuous	Limited complexity of parts
High Production volumes	Uniform cross-section shape only
Low cost per weight	
Efficient melting	
Many types of raw materials	
Good mixing (compounding)	

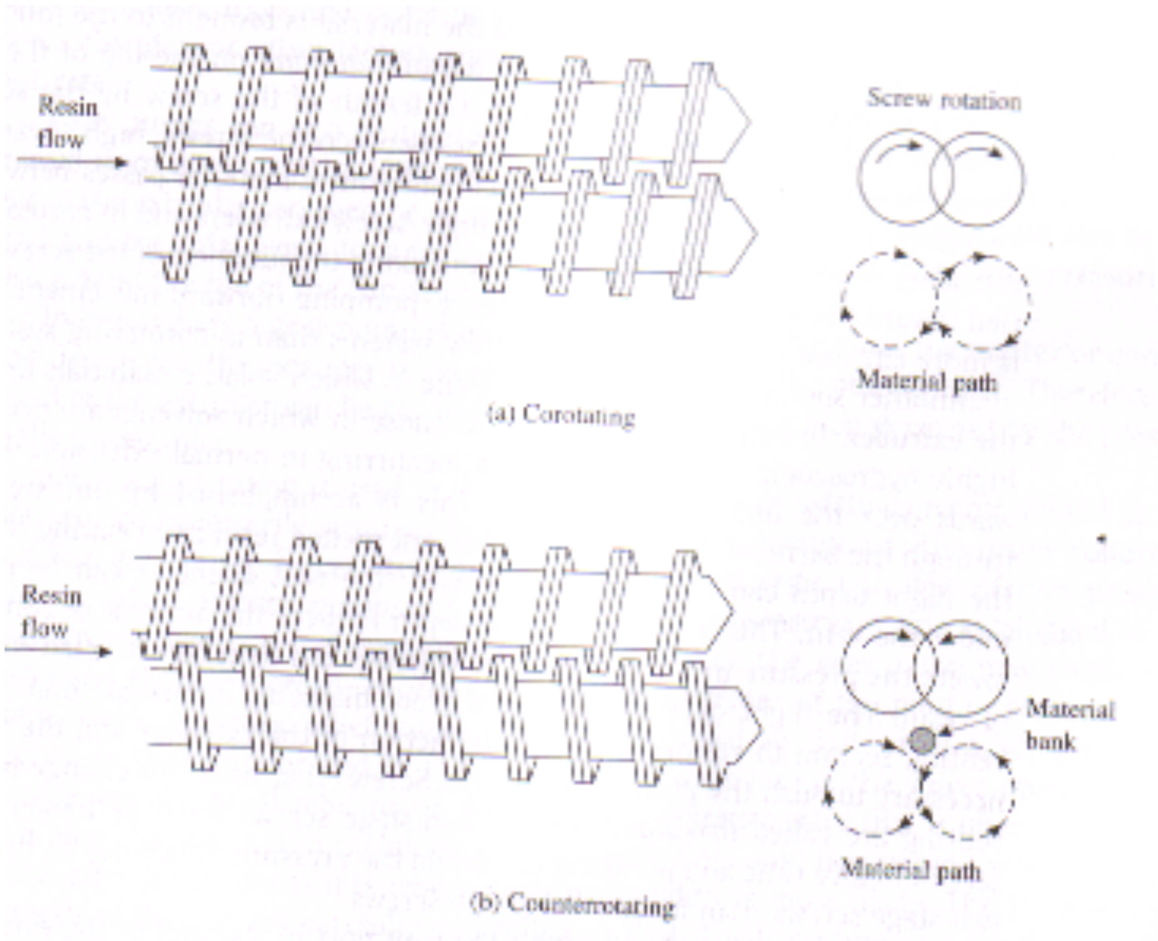
Puller

- After the part has been cooled, it will retain its shape under moderate tension and radial compression force, then enter a puller
- Puller is required to draw the materials away from the extruder

Twin-Screw Extruder

- Can be divided into co-rotating and counter-rotating types
- Twin-screw extruder is a relatively expensive machine;
  - Difficult to accommodate bearings (dimensions limited)
  - Complicated gear boxes
  - Two screws

Twin-Screw Extruder



The screw rotate in the same direction

The screw rotate counter To each other

Twin-Screw Extruder
Co-rotating

- Co-rotating – the material is passed from one screw to another and follows a path over and under a screw
- The path ensures that most of the resin will be subjected to the same amount of shear as it passes between screw and barrel

Twin-Screw Extruder
Counter rotating

- Material is brought to the junction of the two screws and material bank is build up on top of the junction
- This build up of the material is conveyed along the length of the screw by the screw flights
- Total shear is lower than in single-screw and co-rotating twin screw

Co-rotating vs Counter-rotating

Which of these methods produce better mixing?

Why?

Start-up

- The extruder should be preheated before attempting to turn the screw (heating zones and die)
- When some resins are used in extrusion (especially those likely to decompose with prolong heating), the resins are removed from the extruder by running another resin through the extruder before shutdown- this process is called purging
- Purging resin should be easy to melt, have sufficient density to sweep the prior resin, be known to present no start-up problem

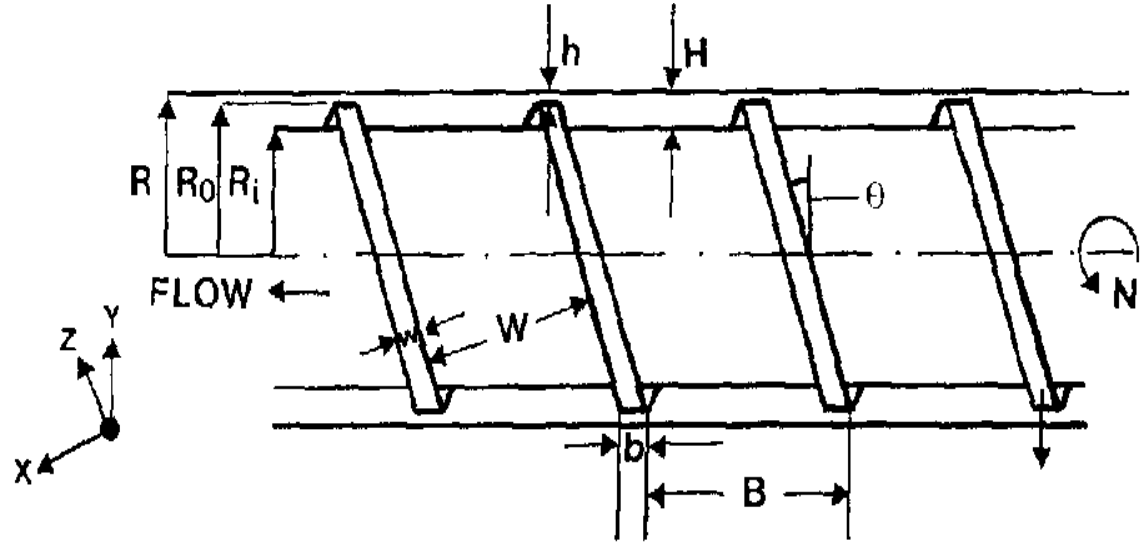
Capacity

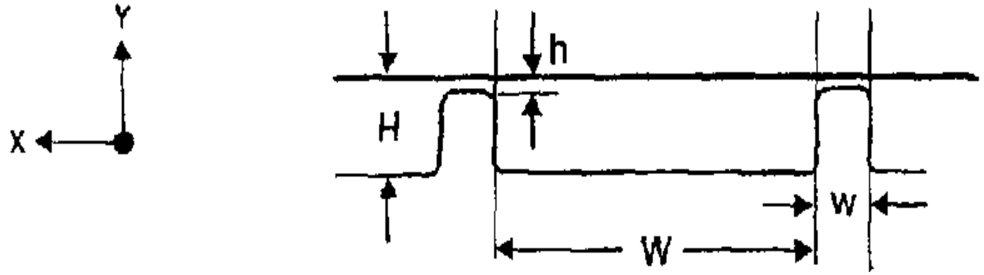
- The single most important parameter that determine extruder capacity is the size of screw
- Total flow of the extruder (total amount of extruder that passes through the extruder)
- Total flow = drag flow – pressure flow – leakage flow

Capacity

- Drag flow = measure of the amount of material that is dragged through the extruder by friction action by the barrel and the screw
- Pressure flow = flow that is caused by the back pressure inside the extruder
- Leakage flow = the amount of materials that leaks past the screw in the small space between the screw and the barrel

Single Screw Extruder



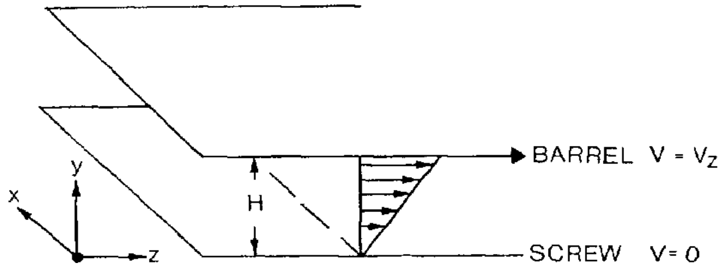


Barrel Diameter $D = 2R$
Screw Helix Angle θ
Screw Pitch $B + b$
Screw Rotation Speed N (RPM)

Channel Depth $H = R - R_i$
Screw Clearance $h = R - R_o$
Channel Width W
Flight Width w

Drag Flow

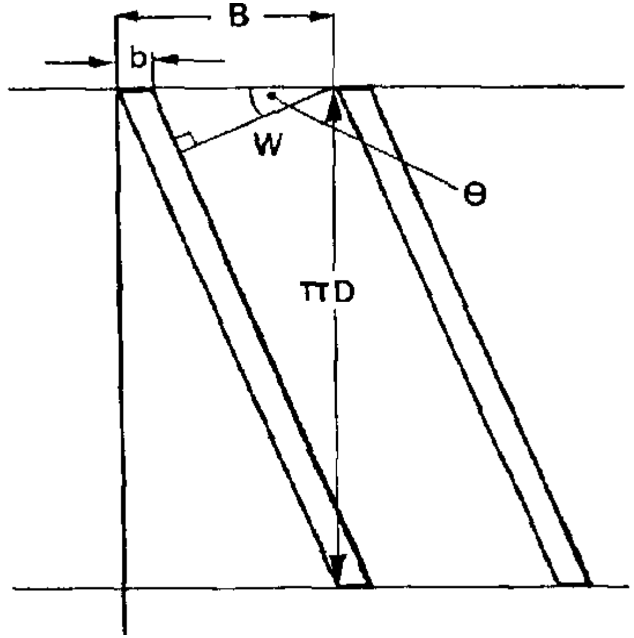
- Determined by a consideration of flow between parallel plate in a classical analysis of Newtonian fluid flow



- Down channel (z-dir) velocity $V_z = V cos\theta$
- Drag Volumetric Flow rate $Q_D = W \int_0^H v(y)dy$
- Velocity profile $v(y) = V_z \frac{y}{H}$

$$Q_D = \frac{WV_z}{H}\int_0^H ydy = \frac{WV_z}{H}\frac{H^2}{2} = \frac{WV_zH}{2}$$

Tangential velocity at barrel surface is determined from the rotation speed of the screw



- Down channel Velocity

$$V = \pi D N$$

$$V_z = \pi D N \cos\theta$$

- The Drag Flow rate

$$Q_D = \frac{\pi}{2} W H D N \cos\theta \equiv \alpha N$$

- The drag flow effectively pumps the polymer through the extruder. Q_D is proportional to rotation speed N.
- Proportionality constant a only depends on screw geometry

Pressure Flow

- Can also be found by classical Newtonian flow analysis
- Pressure Flow $$Q_P = -\frac{WH^3}{12\mu}\frac{\Delta P}{L} \equiv -\frac{\beta}{\mu}\Delta P$$

Total Flow = Q_D + Q_P

$$= \frac{\pi}{2}WHDN\cos\theta - \frac{WH^3}{12\mu}\frac{\Delta P}{L}$$

$$= \alpha N - \frac{\beta}{\mu}\Delta P$$

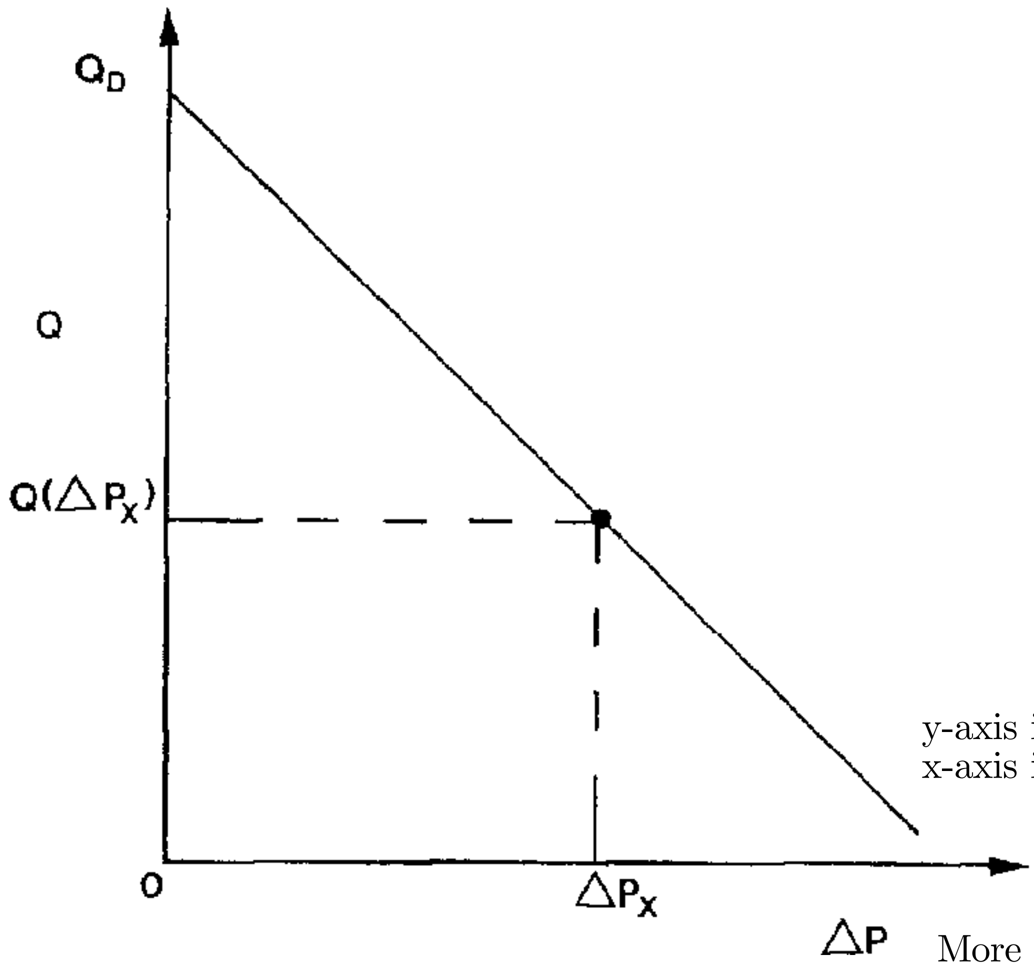
Total Flow

- Screw dimensional parameter; D, H, θ, L and the other constant are combined into two constant, α and β
- Total Flow = αN – (βP/η)

$$Q = \alpha N - \frac{\beta}{\mu}\Delta P$$

  - Increasing in the speed of extruder (N) will increase the output of a particular screw
  - Output of extruder will decreased by increase in the back pressure (P)
  - Back pressure will increase significantly as the screen pack become contaminated
  - If the viscosity decreases, as it would when the temperature is increased, the second term of equation will increase, and decrease the output

Extruder Characteristic



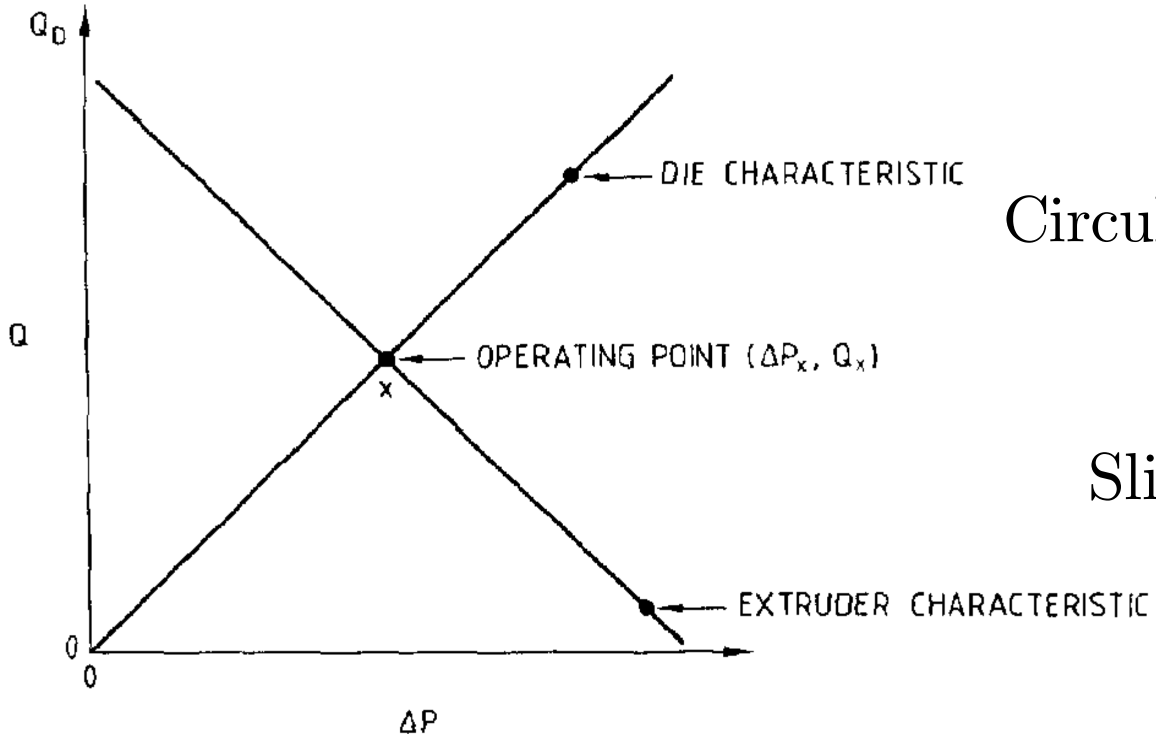
$$Q = \alpha N - \frac{\beta}{\mu} \Delta P$$

Extruder characteristic for a Newtonian Fluid is a linear relation between Q and delta P

y-axis intercept $\Rightarrow$ OPEN DISCHARGE ($\Delta P = 0$)
x-axis intercept $\Rightarrow$ CLOSED DISCHARGE ($Q = 0$)

More Flow Restriction $\Rightarrow$
Larger Pressure (larger ΔP) $\Rightarrow$
Smaller Throughput (lower Q)

Die Characteristic



$$Q = K\frac{\Delta P}{\mu}$$

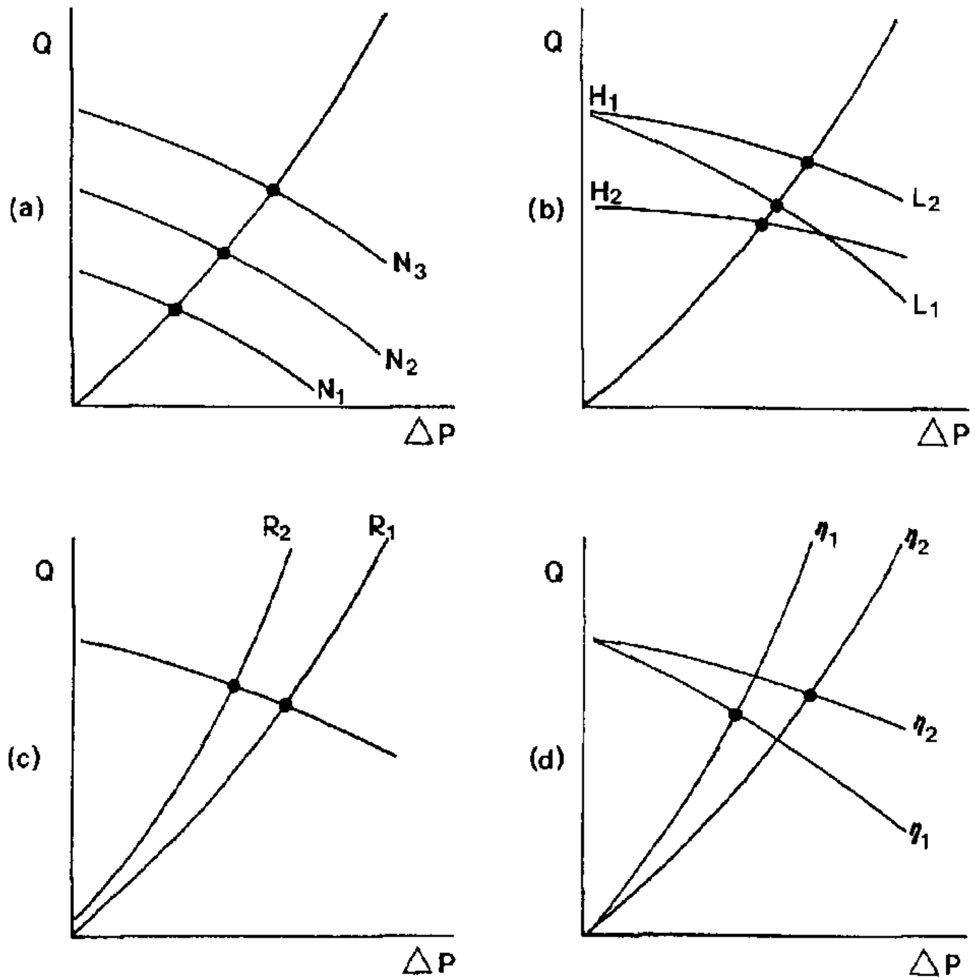
Circular Die: $$K = \frac{\pi R^4}{8L}$$

Hagen-Poiseuille Law

Slit Die: $$K = \frac{WH^3}{12L}$$

The operating point is the Intersection of the Extruder Characteristic and the Die Characteristic

Effect of Process Variables



(a) Effect of Screw Speed ($N_3 > N_2 > N_1$)

(b) Effect of Screw Channel Depth ($H_1 > H_2$) and Metering Section Length ($L_2 > L_1$)

(c) Effect of Die Radius ($R_2 > R_1$)

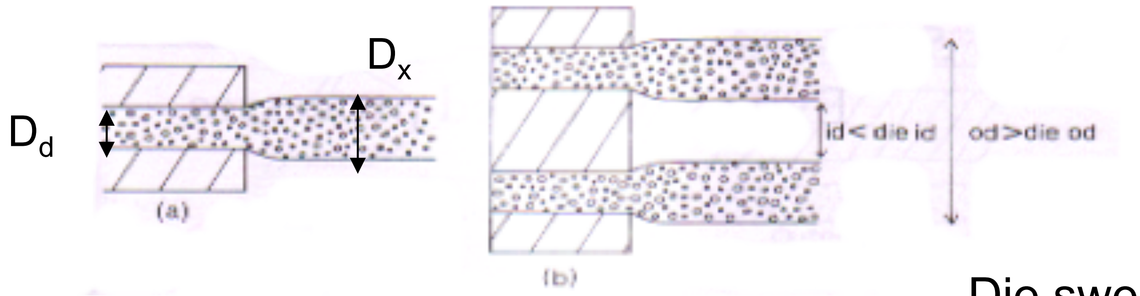
(d) Effect of Viscosity ($\eta_2 > \eta_1$)

Part Dimension Control

- The geometry of the die is the major influence on setting the part size and shape
- Important phenomena that occurs in this region is the swelling of the size (cross section) of the extrudate as it exits the die
- The swelling is called 'die swell'
- The die swell is measured as the ratio of the diameter of the extrudate to the die orifice diameter (D_x/D_d) after exiting the die

Die Swell

- The effect in which the polymer swells as it leaves the die
- The result is an extrudate which differs in its dimensions from those of the die orifice
- Die well results from recovery of the elastic deformation as the extrudate leaves the die channel before it freezes



Die swell in (a) rod and (b) pipes

Die Swell

- Is caused by the viscoelastic nature of the polymer melt (also has been called as 'plastic memory' -as it restore the shape previously held)
- Die swell can be reduced by;
  - Extending the land
  - Increasing temperature- impart the energy needed to disentangled the molecules
  - Shortened the distance between the die and the water tank

Defects - Melt Fracture

- Melt fracture- Skin rupture usually occurs only on the outside surface of the film when stretching and cooling occur too fast and cause micro tears.
- Melt fracture caused by skin rupture occurs when the surface of the film is stretched too quickly on leaving the die.
- the extrudate has a rough surface, with short cracks that are oriented at the machine direction or helically around the the extrudate.
- Occur due to low temperature of the melt, high molecular weight, die is not properly streamlined, etc
- Solve by; streamlined the die, raising the melt temperature, selecting resin with low molecular weight, etc.

Defects - Melt Fracture

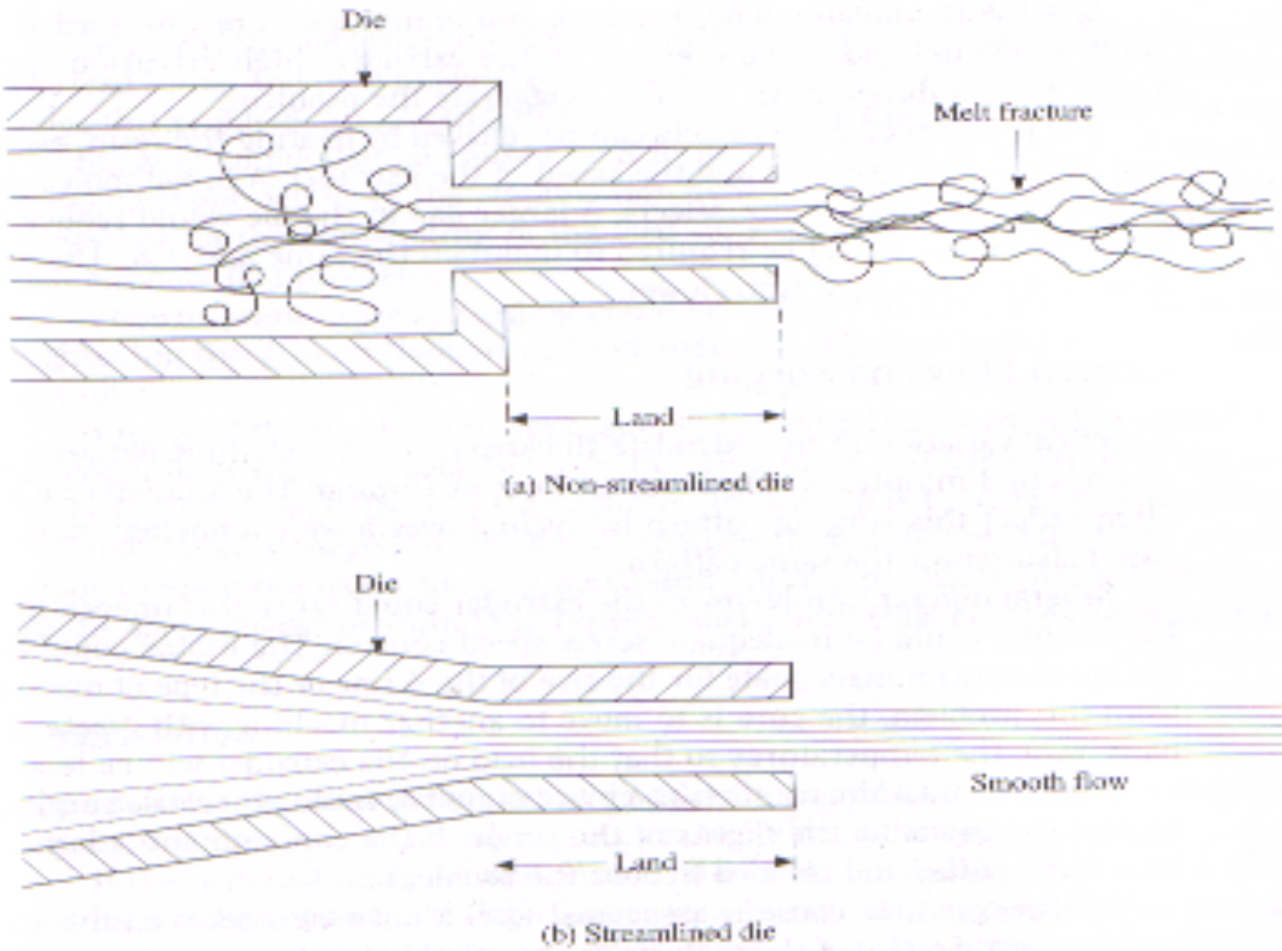
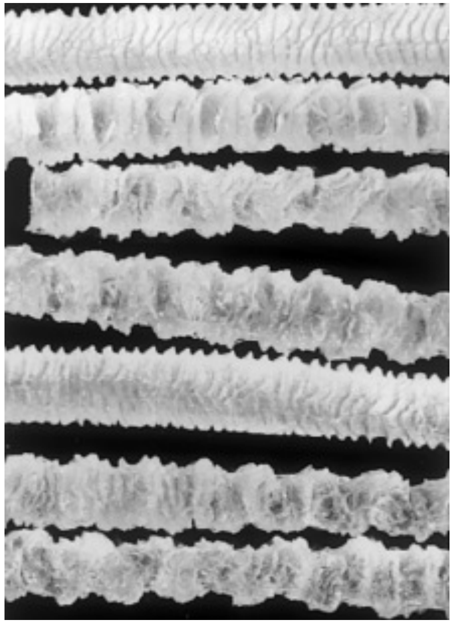


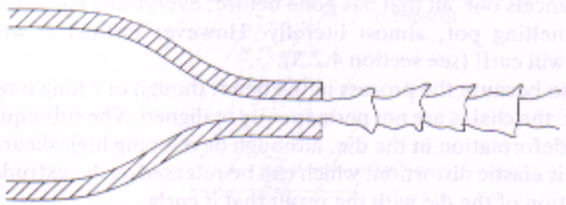
Figure 11.10 The effect of streamlining in a die to prevent melt fracture.

Effect of streamlined in a die to prevent melt fracture

Defects

- Die exit instability
  - shark skin– the outer surface of the part is rough with line running perpendicular to the flow direction (a tearing of the outer surface- usually associated with stresses in the extrudate from sticking to the die wall)
  - orange peel- defect in a surface of an extrudate in which a small dimple are formed
  - Bambooing- defect in a surface of an extrudate that resembles bamboo





Defects - Degradation

- Detected by discolorations and lower physical and mechanical properties
- Caused by; too high heat for the speed of the extrusion, past resin that not fully purged, etc
- Solved by; good combination of heat and extrusion speed, better purging materials/ procedures, etc.

Defects - Contamination

- Detected by spots (small dimples) in the extrudate- sometimes called ‘eye-fish’
- Caused by; contamination (dust, other resin) fall into the hopper or other parts of resin conveying system
- Solved by; keep hopper covered, inspecting the incoming materials, etc

Defects - Bubbles in the Extrudate

- Excessive moisture/volatiles can be absorbed by resin and then vaporized when the melt exits the die- resulting bubbling in the extrudate
- Solved by; dry the resin before fed into the hopper, store the resin in low humidity location, etc.

Main Features of a single screw extruder

The Breaker Plate and Screen Pack

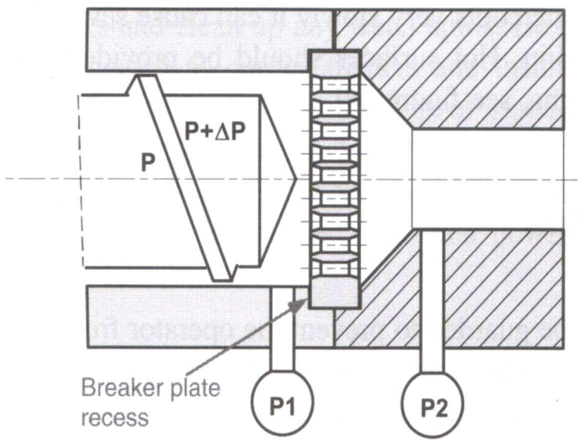


Figure 6.8 The breaker plate recess

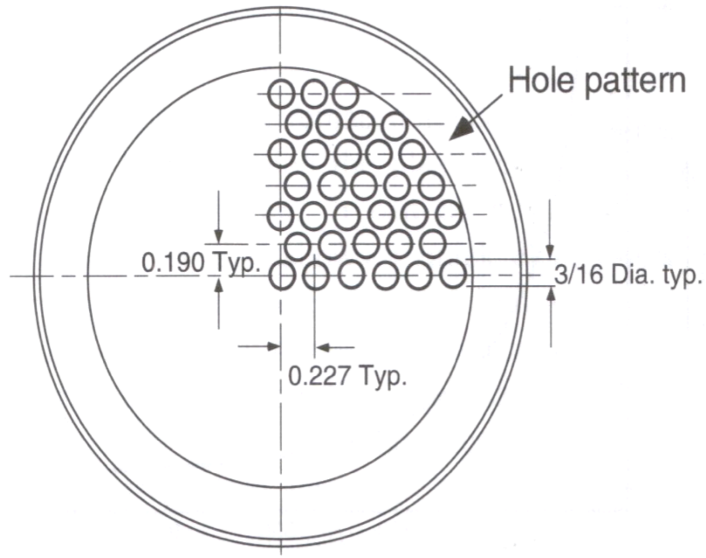
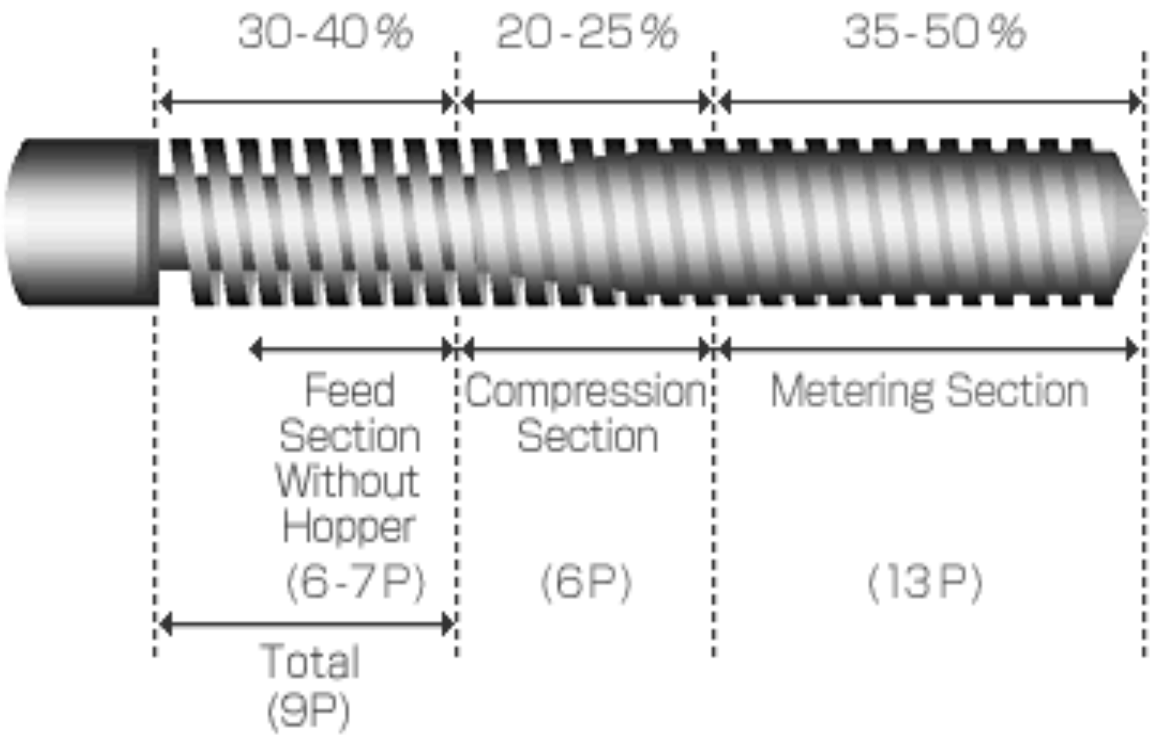


Figure 1.13 Example of a breaker plate

Main Features of a single screw extruder

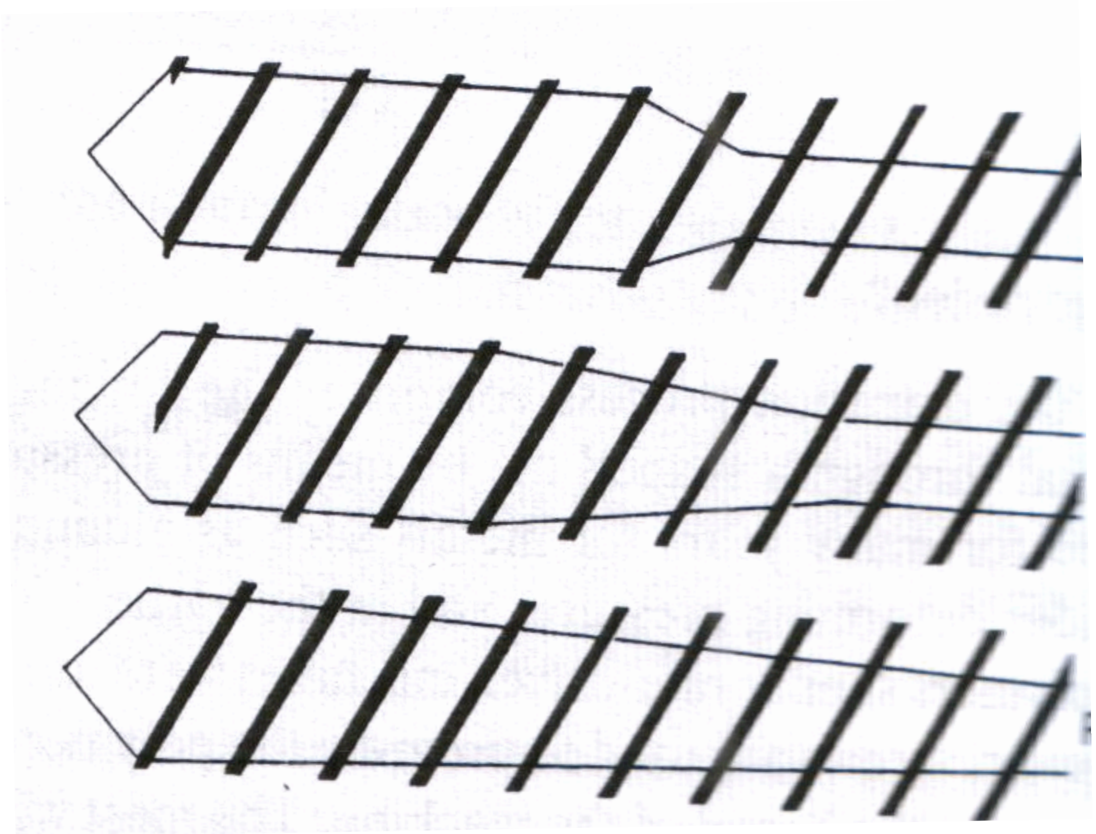
Extruder Zones and Their Functions



- Main Characteristic?
- Functions?

Compression or transition zone

- The length of the compression zone depends on the material to be extruded. These variations are shown below:



Die End of Extruder

- Progress of polymer melt through barrel leads ultimately to the die zone
- Before reaching die, the melt passes through a *screen pack* - series of wire meshes supported by a stiff plate containing small axial holes
- Functions of screen pack:
  – Filter out contaminants and hard lumps
  – Build pressure in metering section
  – Straighten flow of polymer melt and remove its "memory" of circular motion from screw

Die Configurations and Extruded Products

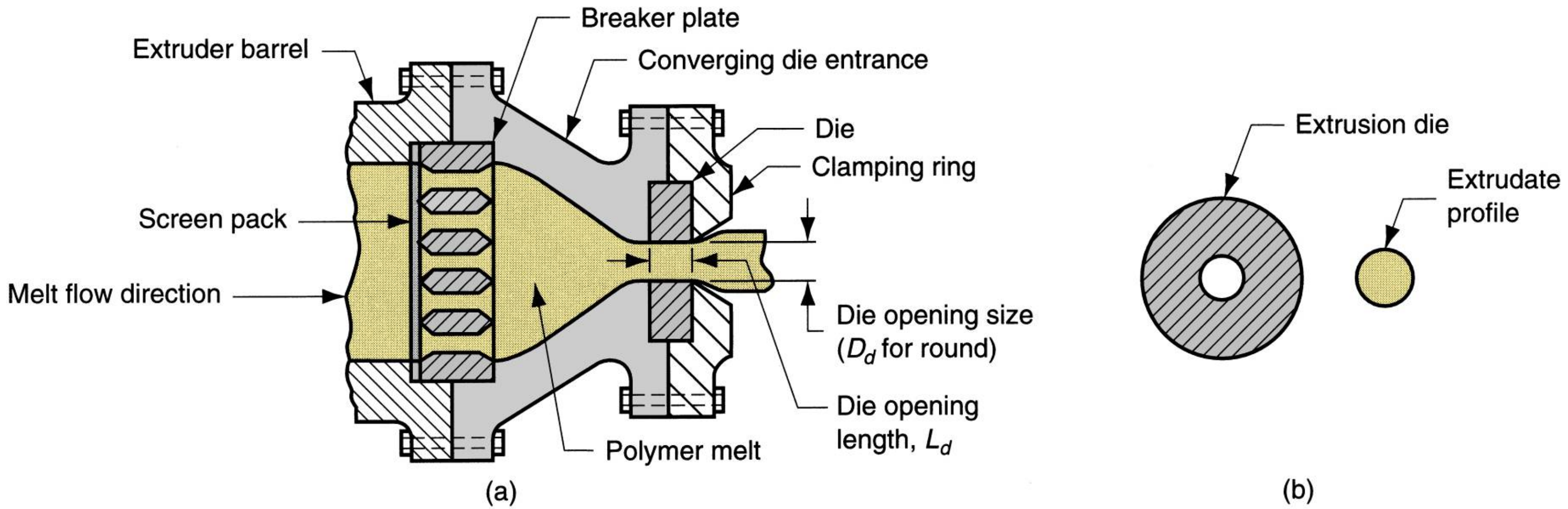
- The shape of the die orifice determines the cross-sectional shape of the extrudate
- Common die profiles and corresponding extruded shapes:
  - Solid profiles
  - Hollow profiles, such as tubes
  - Wire and cable coating
  - Sheet and film
  - Filaments

Extrusion of Solid Profiles

- Regular shapes such as
  - Rounds
  - Squares
- Irregular cross sections such as
  - Structural shapes
  - Door and window moldings
  - Automobile trim
  - House siding

Extrusion Die for Solid Cross Section

Figure below shows (a) Side view cross-section of an extrusion die for solid regular shapes, such as round stock; (b) front view of die, with profile of extrudate. Die swell is evident in both views.

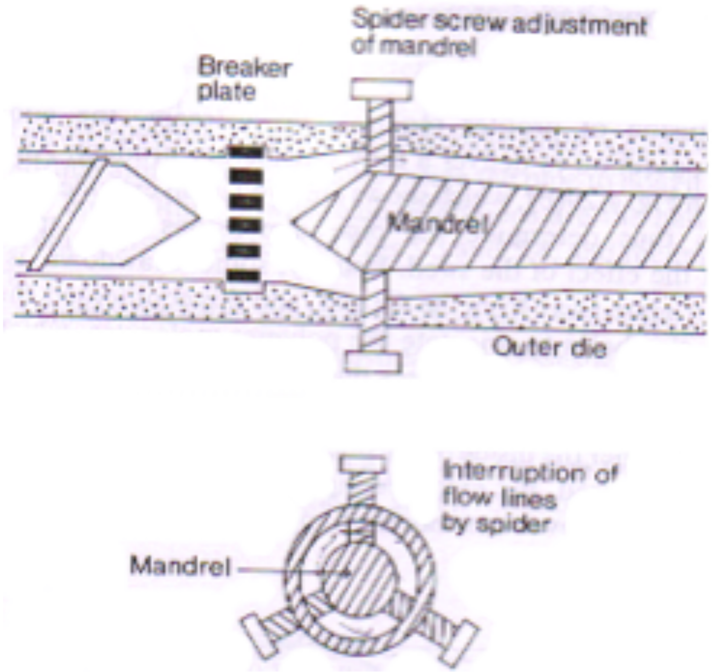


Profile Extrusion

- Solid parts that have shapes other than simple round rods of flat sheets are called profile shapes/profiles
- Is a direct manufacture of product from the extruder die
- These products are continuous lengths, the cross-sectional profile is determined by the die shape
- Examples; PE gas piping, PVC water and drainage pipes, garden hose, etc

Profiles and Die

- Design of dies- difficult process
- Example in producing pipe, mandrel is used to an annulus through which the pipe will emerge. Screw adjuster need to be used to centralized the mandrel
- The presence of screw will interrupt the melt flow



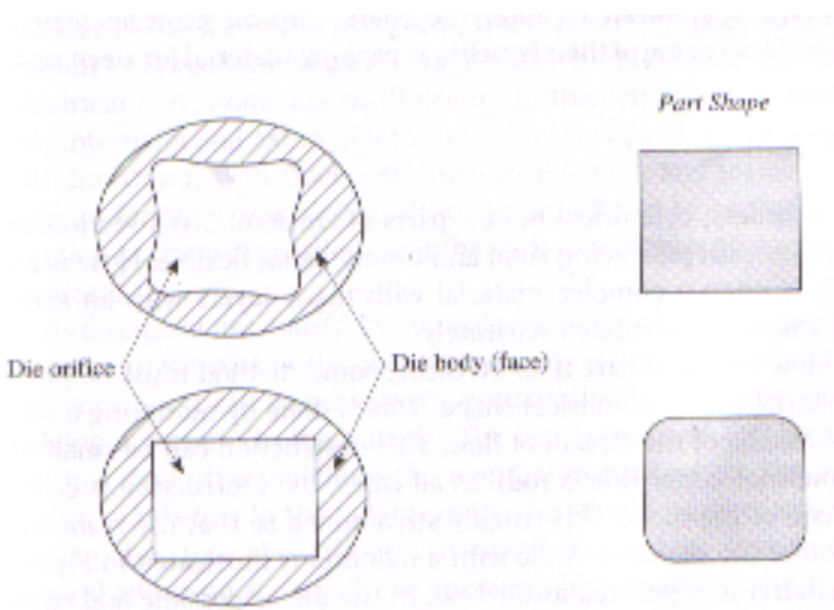
Schematic diagram of pipe die

Profiles and Die

- Shape of the exit orifice might be slightly different the shape of the final part
- This is due to the tendency of molten plastics to flow more in the larger parts of the die (i.e. at the center), swell as it exits the die, shrink when it cooled
- Die swell (the swelling process) distorts the shape of the extrudate
- Therefore the shape of the die opening must compensate the die swell and the distortion phenomena

Profiles and Die

- If the die has a sharp corners, the flow will be less in the location, and sharpness of the corner will be round
- If the sharp angle is desired in the final product, the die should have a slight excess of material in the region between the points of the sharp angle

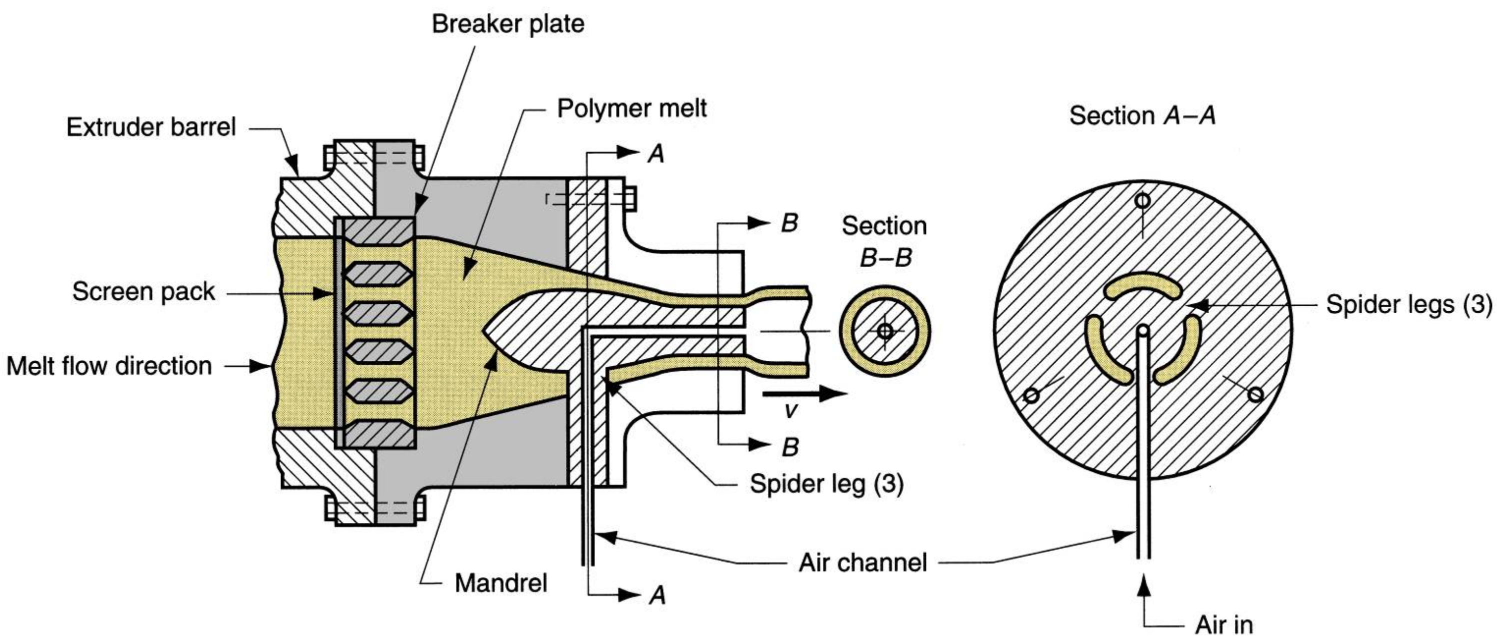


Hollow Profiles

- Examples: tubes, pipes, hoses, and other cross-sections containing holes
- Hollow profiles require mandrel to form the shape
- Mandrel held in place using a spider
  - Polymer melt flows around legs supporting the mandrel to reunite into a monolithic tube wall
- Mandrel often includes an air channel through which air is blown to maintain hollow form of extrudate during hardening

Extrusion Die for Hollow Shapes

Figure shows side view cross-section of extrusion die for shaping hollow cross-sections such as tubes and pipes; Section A-A is a front view cross-section showing how the mandrel is held in place; Section B-B shows the tubular cross-section just prior to exiting the die; die swell causes an enlargement of the diameter.



Wire and Cable Coating

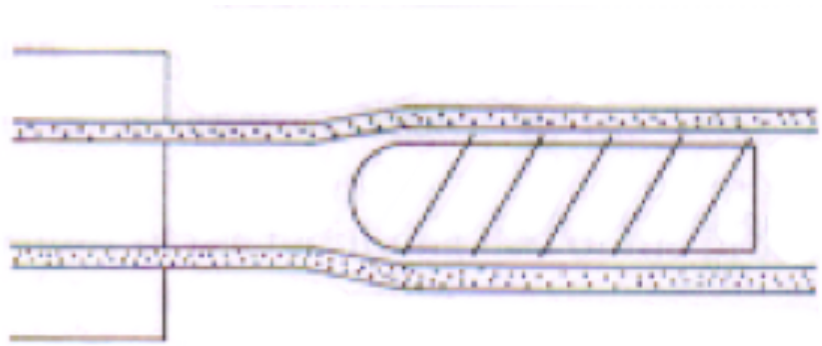
- Polymer melt is applied to bare wire as it is pulled at high speed through a die
  - A slight vacuum is drawn between wire and polymer to promote adhesion of coating
- Wire provides rigidity during cooling - usually aided by passing coated wire through a water trough
- Product is wound onto large spools at speeds up to 50 m/s (10,000 ft/min)

Downstream Operations

- Often extrusion of profiles requires downstream (the addition of a secondary operation to deliver a fully satisfactory product)
- e.g.the die swell in an extruded pipe. The die dimension is only an approximation
- The ‘drawdown’ is applied to pull the extrudate away from the die exit, this counteracts the swell

Downstream Operations

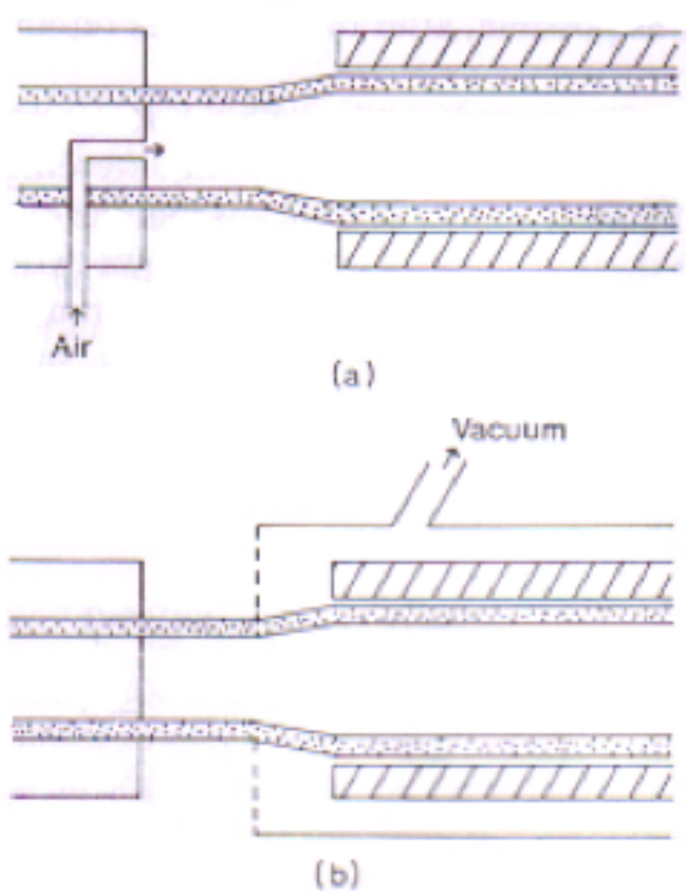
- If exact internal diameter is required, internal sizing size is used
- The extruded pipe, while still hot and soft from the extruder, is passed over a mandrel of appropriate size



Pipe extrusion; internal sizing mandrel

Downstream Operations

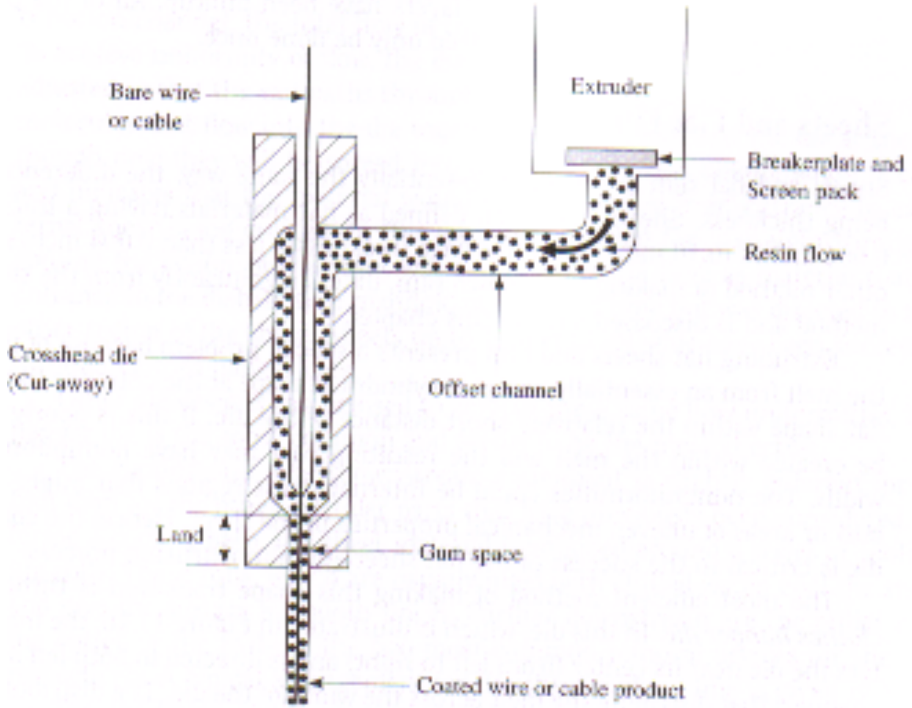
- If exact internal diameter is required, external sizing device is required
  - Pipe is pressurized against internal mandrel by an air injection
  - A vacuum outside the mandrel allows the normal atmospheric pressure inside the pipe to hold it against the mandrel



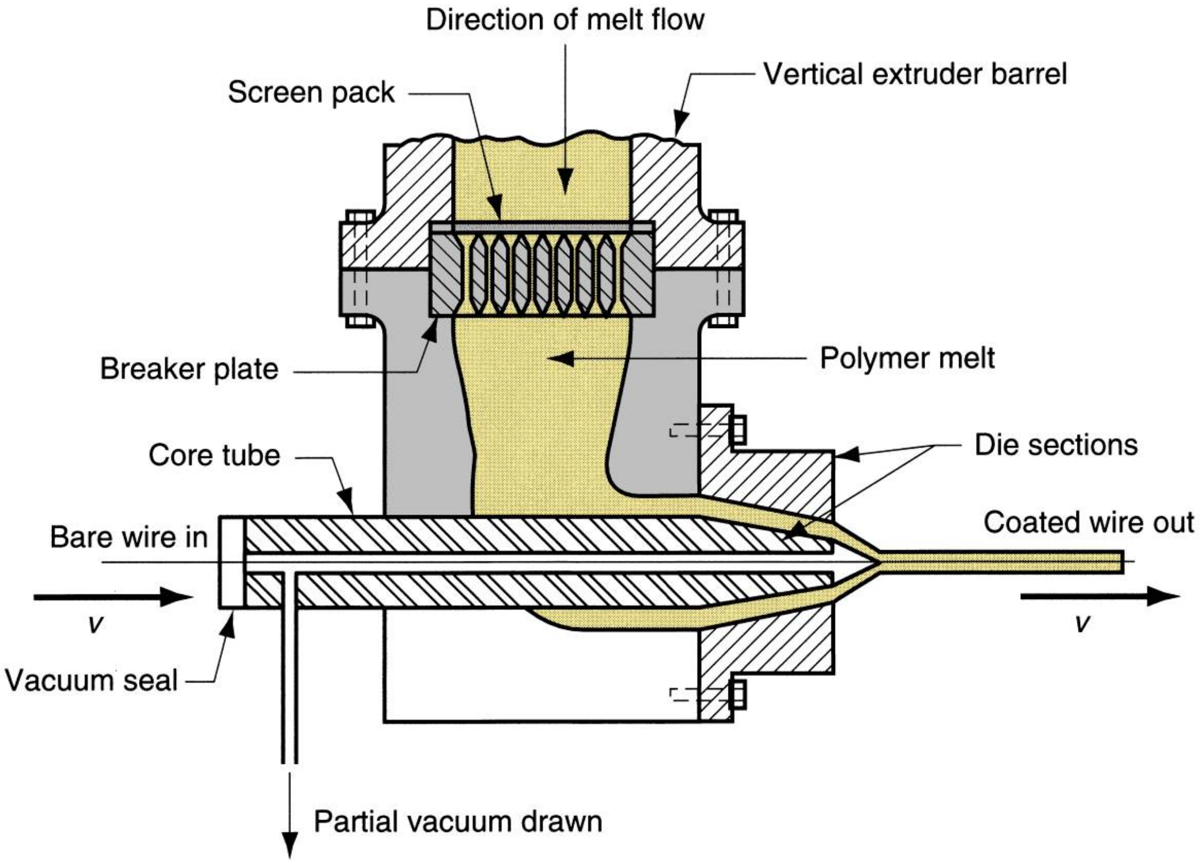
Pipe extrusion; external sizing
(a) Pressure sizing
(b) Vacuum sizing

Coating of Wire and Cable

- The biggest sector of the industry is the electrical cable manufacture
- In this process, the flow of the resin is directed to the side of the extruder through an offset die (tube attached to the end of the extruder with a right angle turn to move the molten resin to the side of the extruder)
- The offset channel then merges into the crosshead die.
- Fire hose is also produced by this technique



Extrusion Die for Coating Wire



Side view cross-section of die for coating of electrical wire by extrusion.

Orientation in Pipes and Hoses

- Orientation of chain occur in the machine direction
- Thus the properties of extruded product are anisotropic

If an extruded pipe is tested by pressurizing it until it burst,
Where the failure will occur????

Polymer Sheet and Film

- Film - thickness below 0.5 mm (0.020 in.)
  - Packaging - product wrapping material, grocery bags, and garbage bags
  - Stock for photographic film
  - Pool covers and liners for irrigation ditches
- Sheet - thickness from 0.5 mm (0.020 in.) to about 12.5 mm (0.5 in.)
  - Flat window glazing
  - Thermoforming stock

Sheet and Film Production Processes

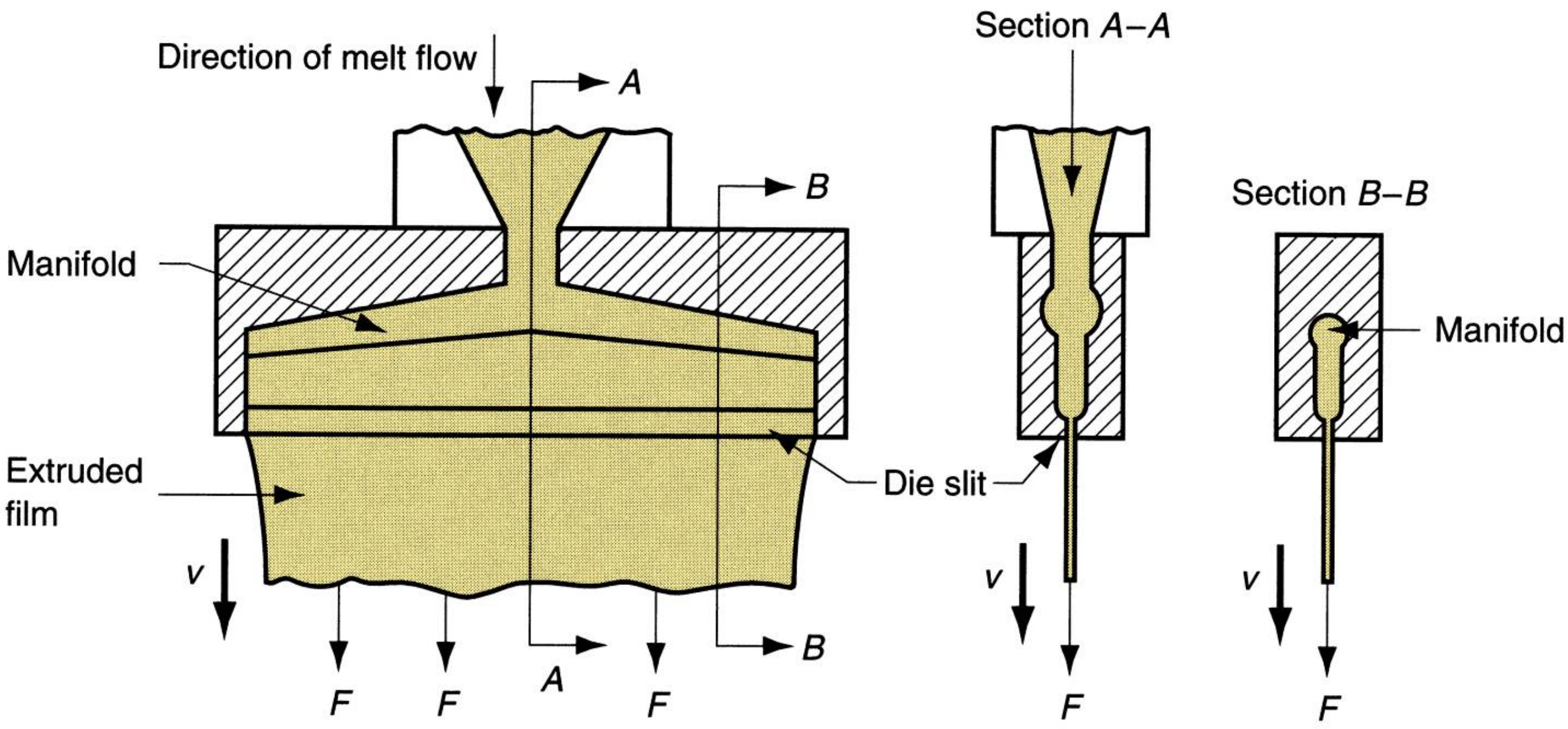
- Most widely used processes are continuous, high production operations
- Processes include:
  - Slit-Die Extrusion of Sheet and Film
  - Blown-Film Extrusion Process
  - Calendering

Slit-Die Extrusion of Sheet and Film

Production of sheet and film by conventional extrusion, using a narrow slit as the die opening

- Slit may be up to 3 m (10 ft) wide and as narrow as around 0.4 mm (0.015 in)
- A problem is uniformity of thickness throughout width of stock, due to drastic shape change of polymer melt as it flows through die
- Edges of film usually must be trimmed because of thickening at edges

Slit Die Extrusion



One of several die configurations for extruding sheet and film.

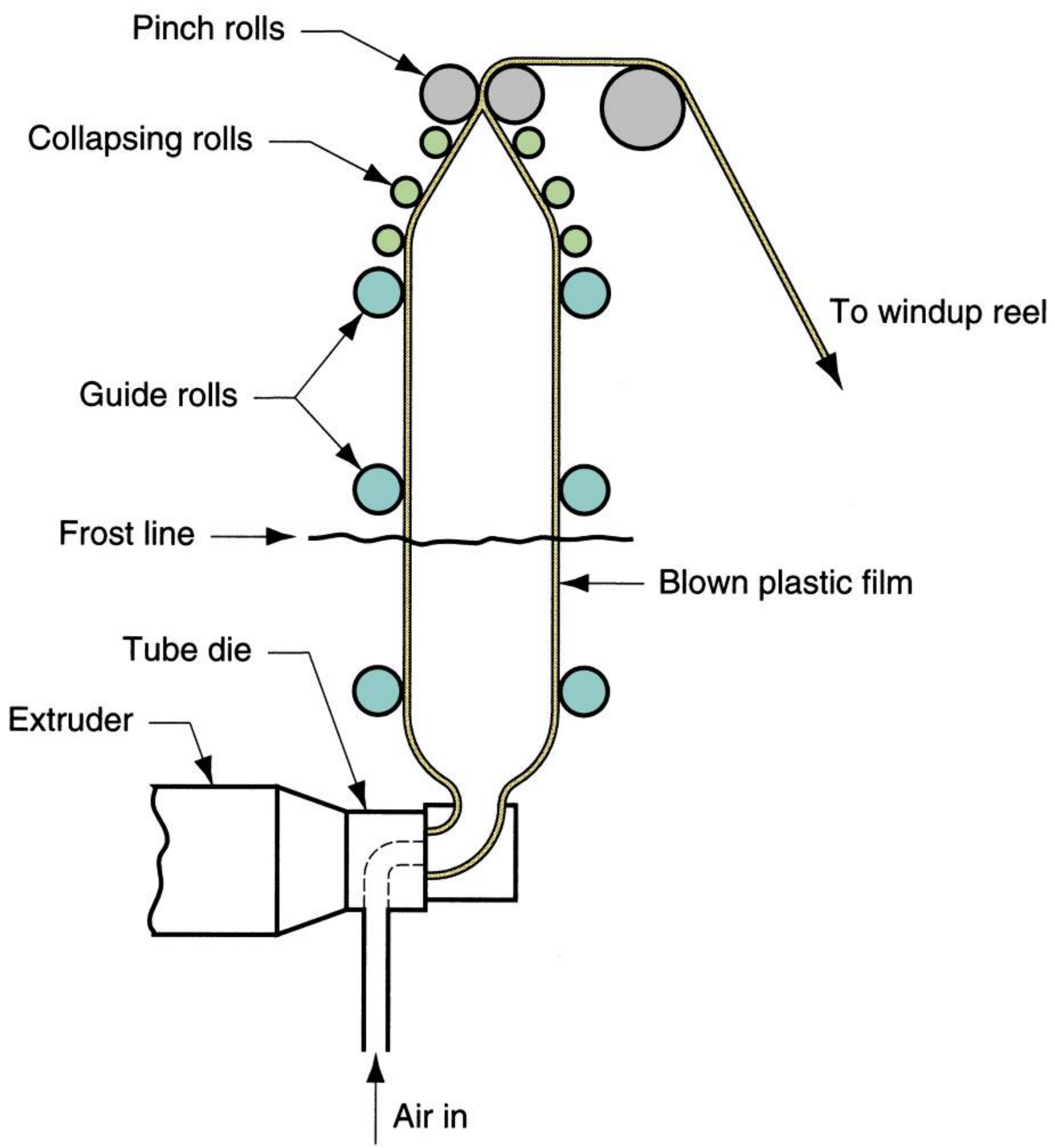
Blown-Film Extrusion Process

Combines extrusion and blowing to produce thin-film tubes, plastic bags

- Process sequence:
  - Extrusion of tube
  - Tube is drawn upward while still molten and simultaneously expanded by air inflated into it through die
    - Air is blown into tube to maintain uniform film thickness and tube diameter

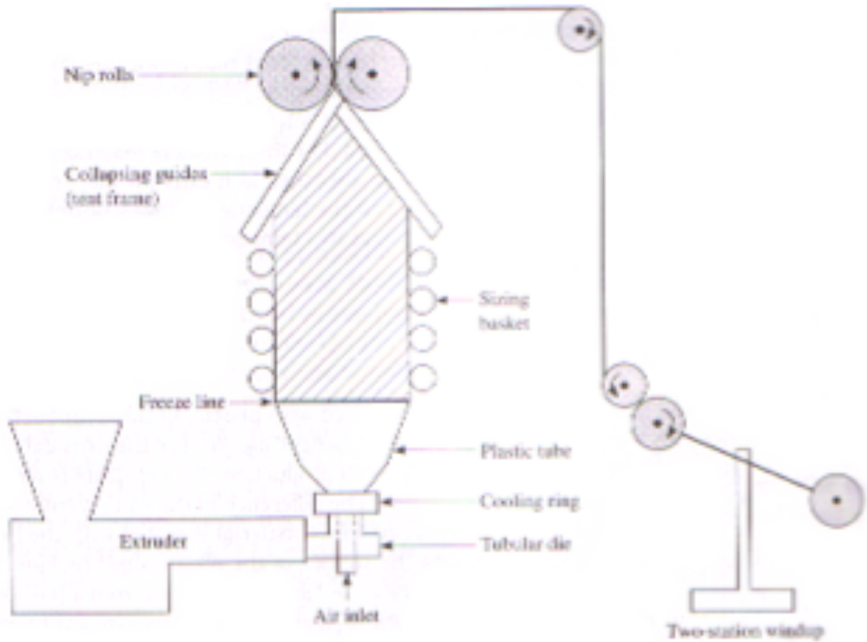
Blown-film Process

Blown-film process for high production of thin tubular film.



Blown Film

- The extruded materials flow through a tubular die
- The melt flow around a mandrel and exits the die as a tube
- A cooling ring is placed at the exit of the die to give the tube some dimensional stability
- Air is introduced through the back of the die and flow upwards inside the middle of the tube of materials



Blown Film

- The tube or bubble, continues to expand, cool and crystallize until the radial (tensile) strength of the plastics equals the pressure of the air inside.
- The bubble is then forced into a flat sheet by the collapsing guides, and moved into the nips rolls
- Then it travels down over some rollers and it was sealed

Blown Film

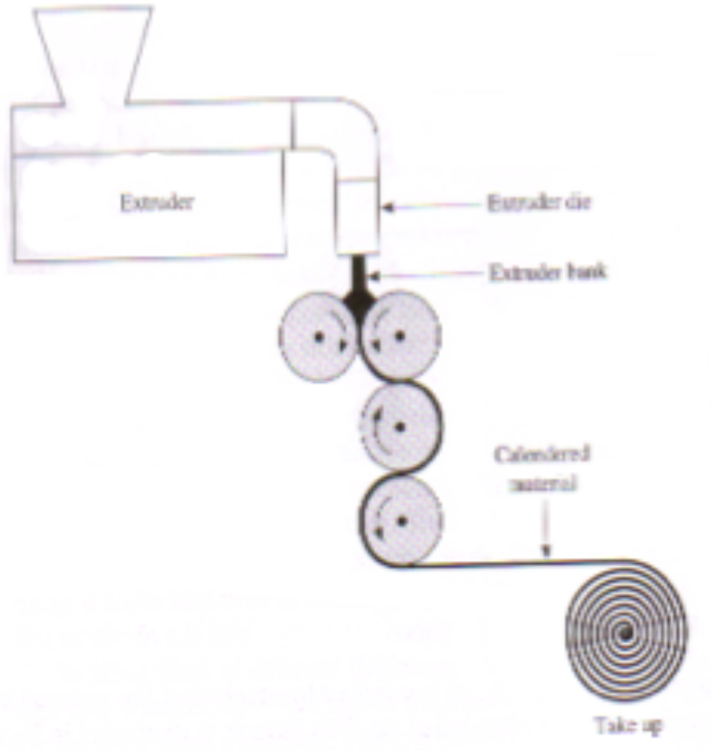
- The stretching and cooling of the tubes causes the molecules to be oriented
- Push of the internal air orients the molecules in radial direction
- Nip rolls orients the molecules in the machine direction
- Blown film are therefore are biaxially oriented
- The orientation causes some crystallization in the film

Blown Film

- The amount of expansion of the bubble is important in controlling the process & predicting mechanical properties
- Parameter blow-up ratio (ratio of the final tube diameter after blow-up to the diameter of the orifice of the die) is important, ratio of 3:1 is common
- Most mechanical properties are increased as the blow-up ratio increases because orientation increases
- Materials are amorphous when exit the die, as it cools and stretches the molecules become more oriented, then become less transparent

Calendaring

- Alternate method for making sheets or flat film
- In this process, the extrudate is extruded directly into the nip area between two rolls.
- The roles have small gap between them, and plastics is forced through this gaps by the counterrotating of the rolls.

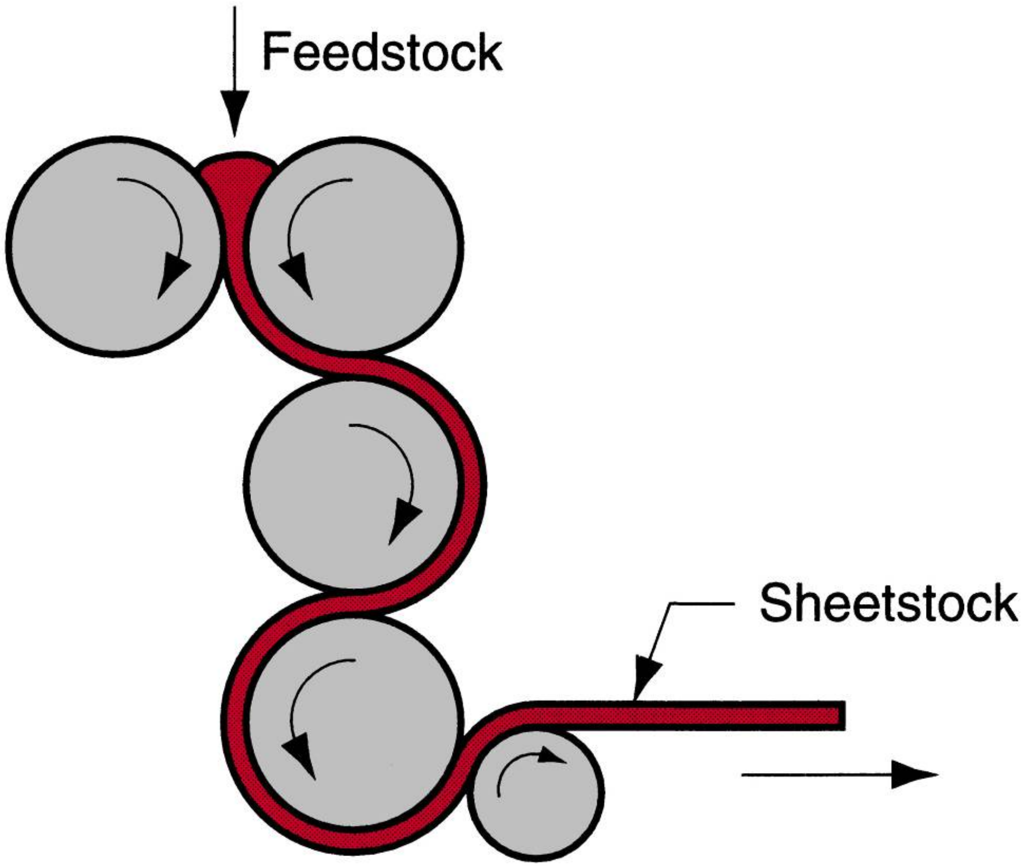


Calendqring

Feedstock is passed through a series of rolls to reduce thickness to desired gage

- Expensive equipment, high production rates
- Process is noted for good surface finish and high gage accuracy
- Typical materials: rubber or rubbery thermoplastics such as plasticized PVC
- Products: PVC floor covering, shower curtains, vinyl table cloths, pool liners, and inflatable boats and toys

Calendaring

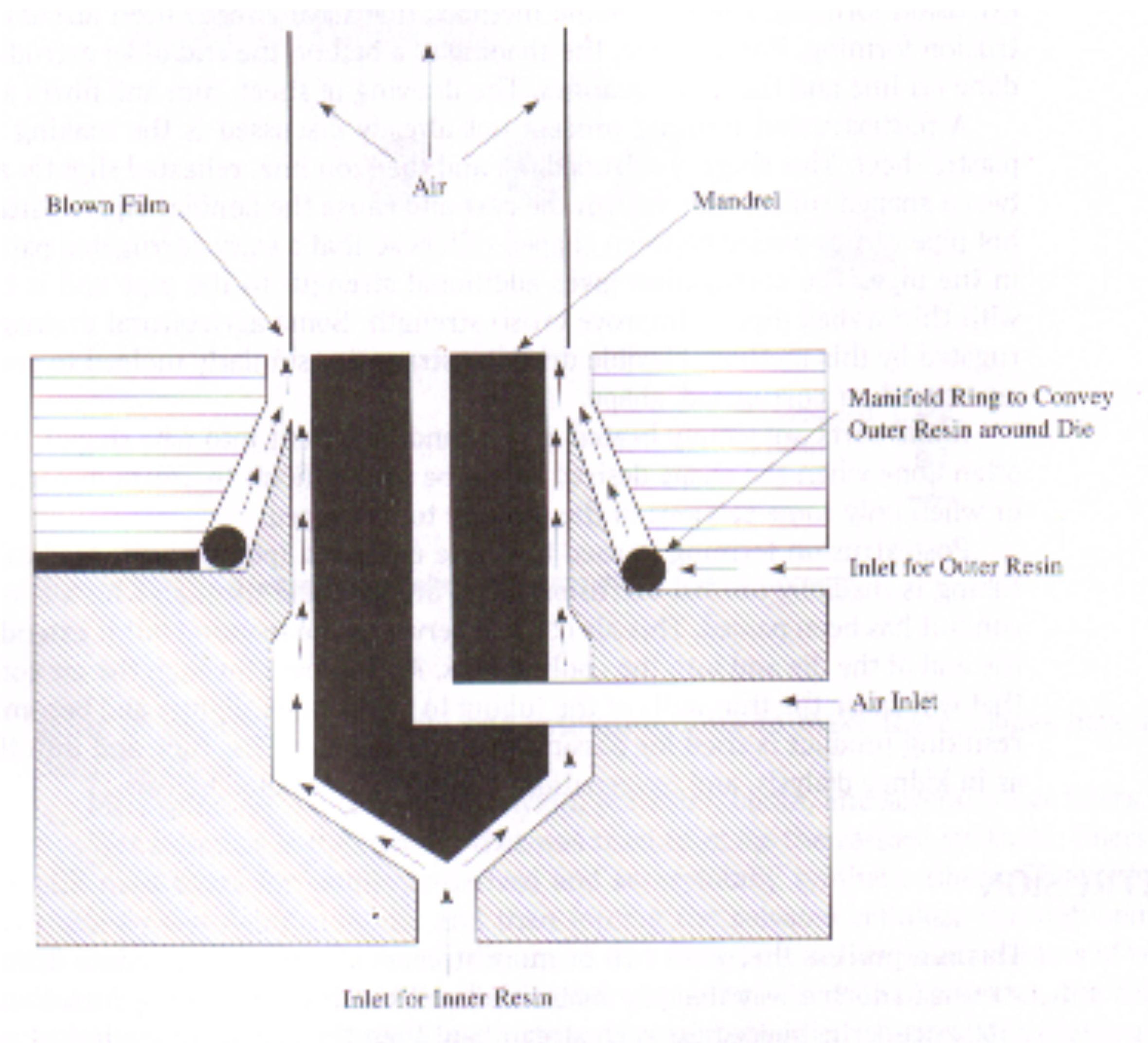


A typical roll configuration in calendaring

Co-Extrusion

- Extrusion of more than one type of polymer at once to give a laminated product
- This technique allows product to have different properties on each side
- Example, the inner containers of breakfast cereals are mode from blown HDPE film with the inner layer of lower softening temp.

Co-extrusion Die for Blown Film



Fiber and Filament Products

- Definitions:
  - *Fiber* - a long, thin strand whose length is at least 100 times its cross-section
  - *Filament* - a fiber of continuous length
- Applications:
  - Fibers and filaments for textiles
    - Most important application
  - Reinforcing materials in polymer composites
    - Growing application, but still small compared to textiles

Materials for Fibers and Filaments

Fibers can be natural or synthetic

- Natural fibers constitute ~ 25% of total market
  - Cotton is by far the most important staple
  - Wool production is significantly less than cotton
- Synthetic fibers constitute ~ 75% of total fiber market
  - Polyester is the most important
  - Others: nylon, acrylics, and rayon

Fiber and Filament Production - Spinning

For synthetic fibers, *spinning* = extrusion of polymer melt or solution through a *spinneret*, then drawing and winding onto a *bobbin*

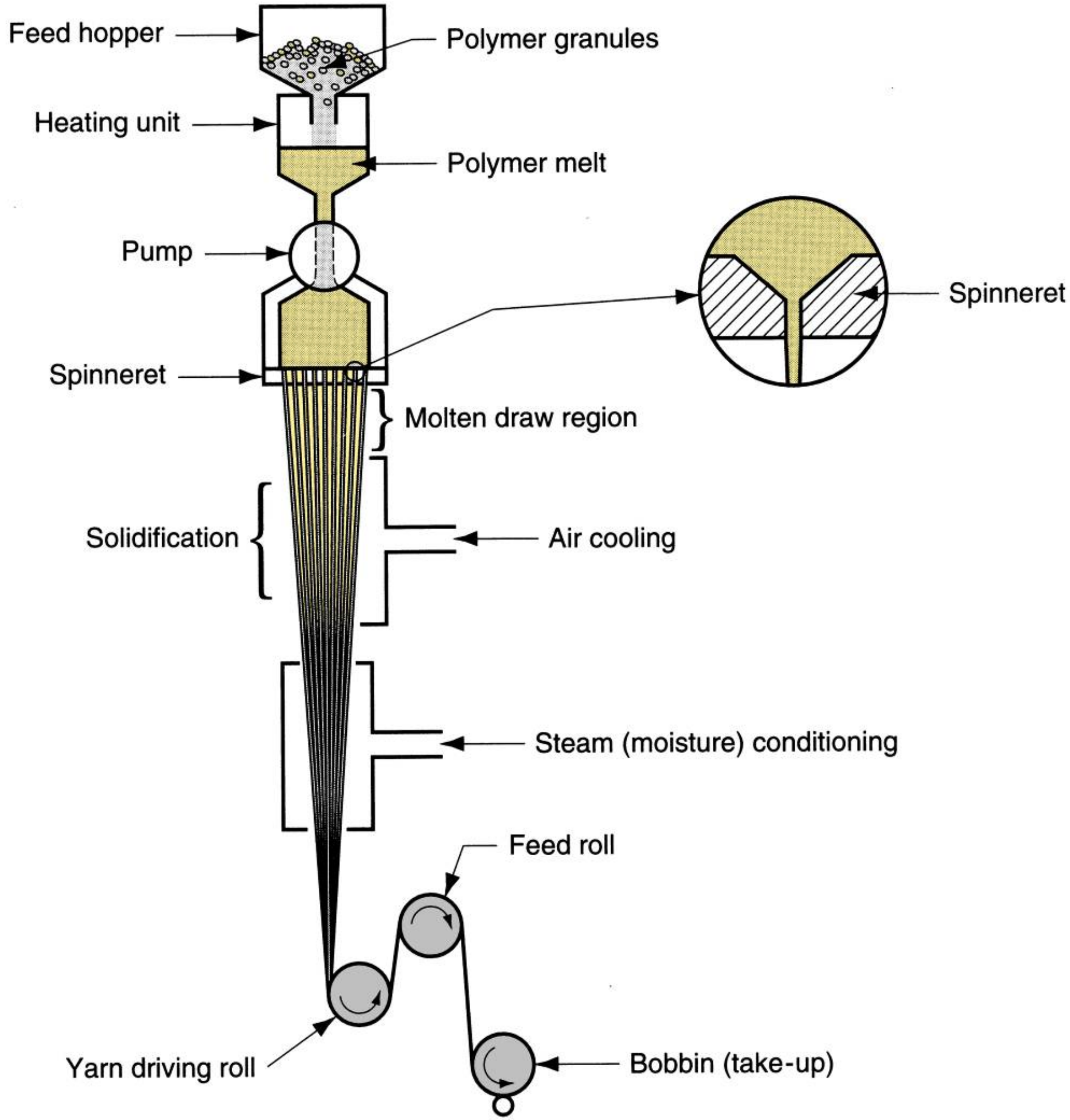
- Spinneret = die with multiple small holes
- The term is a holdover from methods used to draw and twist natural fibers into yarn or thread

Melt Spinning

Starting polymer is heated to molten state and pumped through spinneret

- Typical spinneret is 6 mm (0.25 in) thick and contains approximately 50 holes of diameter 0.25 mm (0.010 in)
- Filaments are drawn and air cooled before being spooled onto bobbin
- Significant extension and thinning of filaments occur while polymer is still molten, so final diameter wound onto bobbin may be only 1/10 of extruded size
- Used for polyester and nylon filaments

Melt Spinning



Melt spinning of

continuous filaments