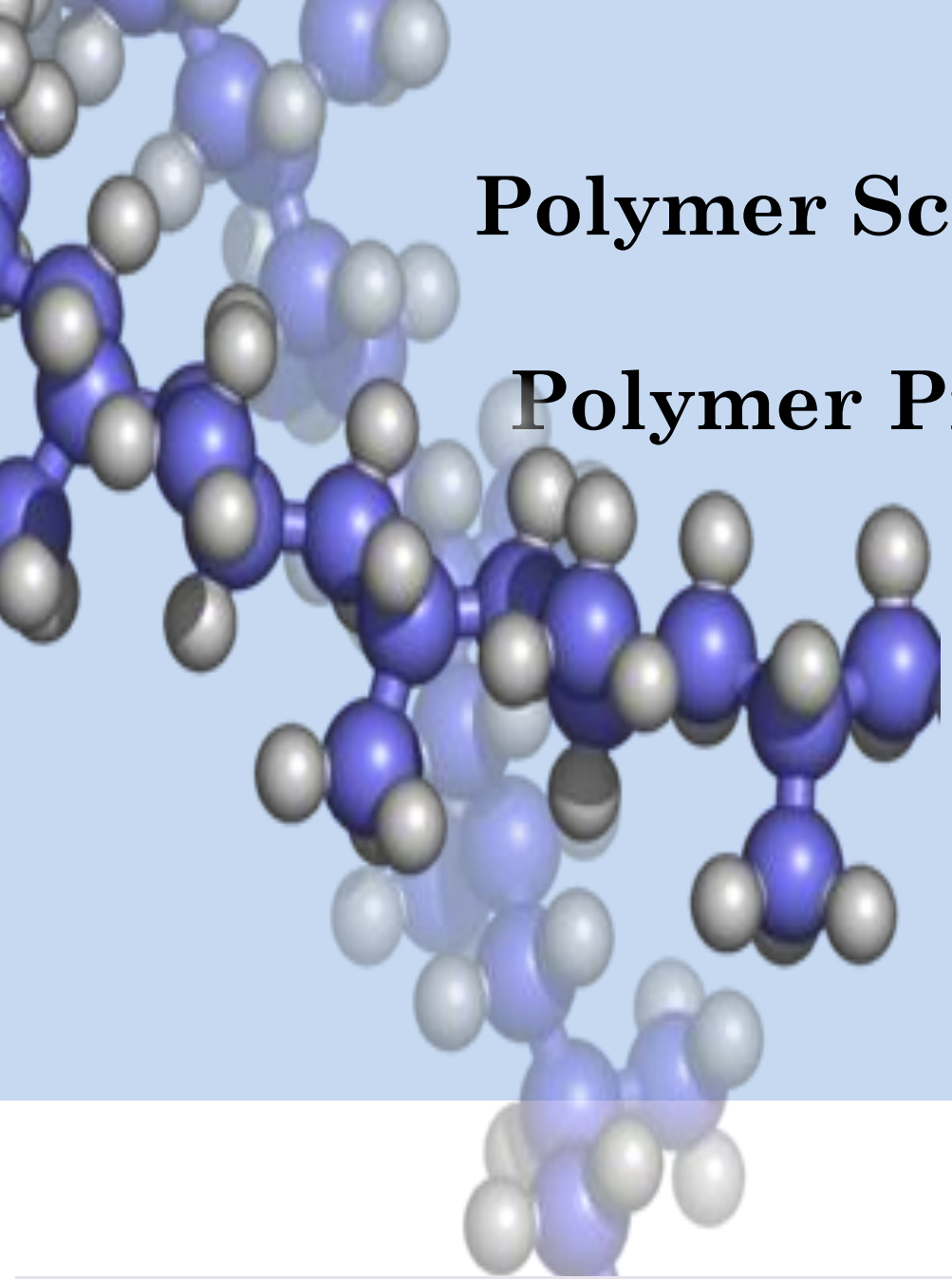


Polymer Science & Engineering

Polymer Processing: Extrusion

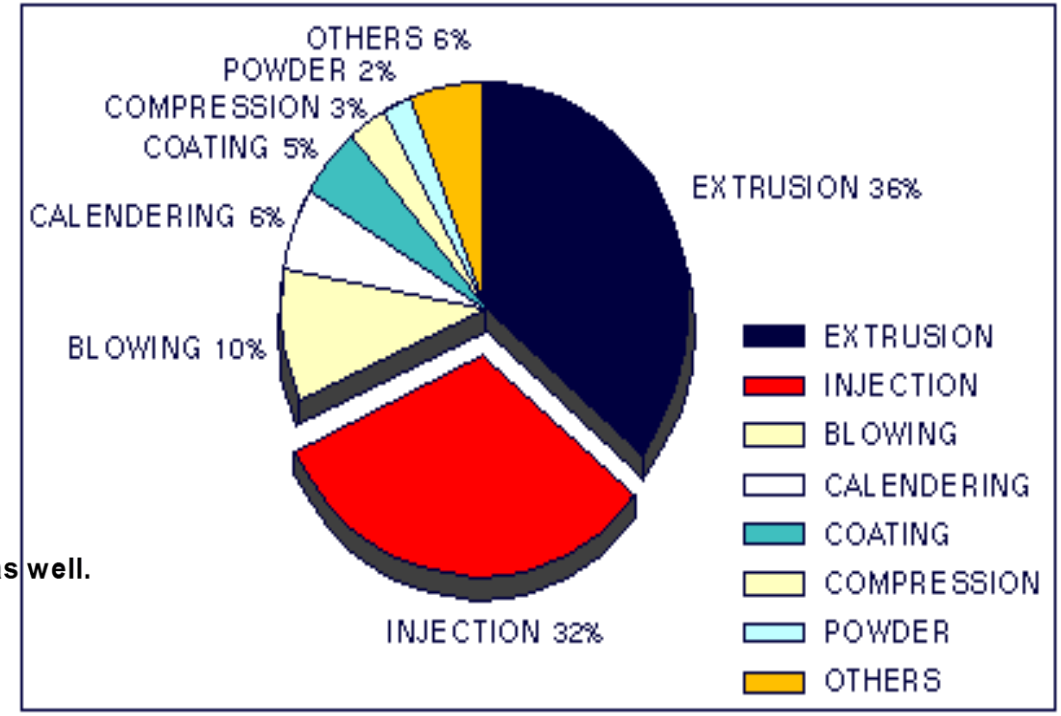
Dr. Motasem Saidan

m.saidan@gmail.com

Polymer Industry

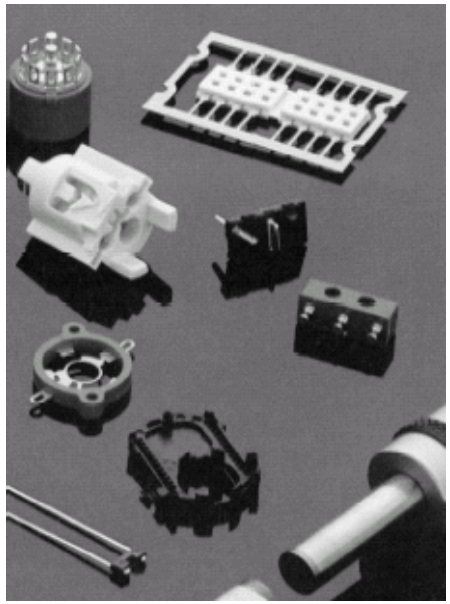
Polymer Family Tree

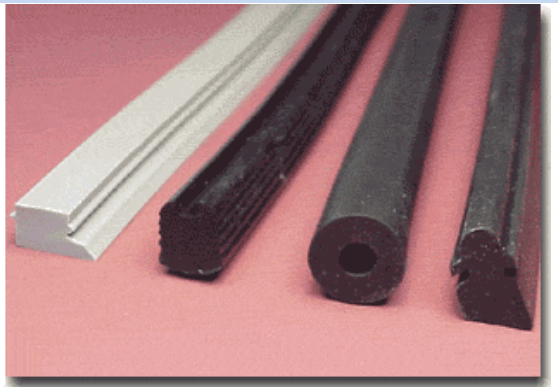
- **Thermoplastics** — Will reform when melted
  - **Not Cross-Linked** — 90% of market
    - Polyethylene 33%
    - Vinyls 16%
    - Polypropylene 15%
    - PMMA
    - ABS
    - Nylon
    - Polycarbonate
    - Saturated Polyester
    - PEEK
    - Polyurethane
      Some are thermosets as well.
    - PVC
- **Thermosets/Elastomers** — Will not reform
  - **Cross-linked** — 10% of market
    - Epoxy
    - Melamine Formaldehyde
    - Phenolic
    - Polyester (unsaturated)
    - Polyimide
    - Polyurethane
      Some are thermoplastic as well.
    - Silicone
    - Urea Formaldehyde



Polymer Processing: Major Processes

- Extrusion
- Injection Molding
- Blow Molding
- Thermoforming

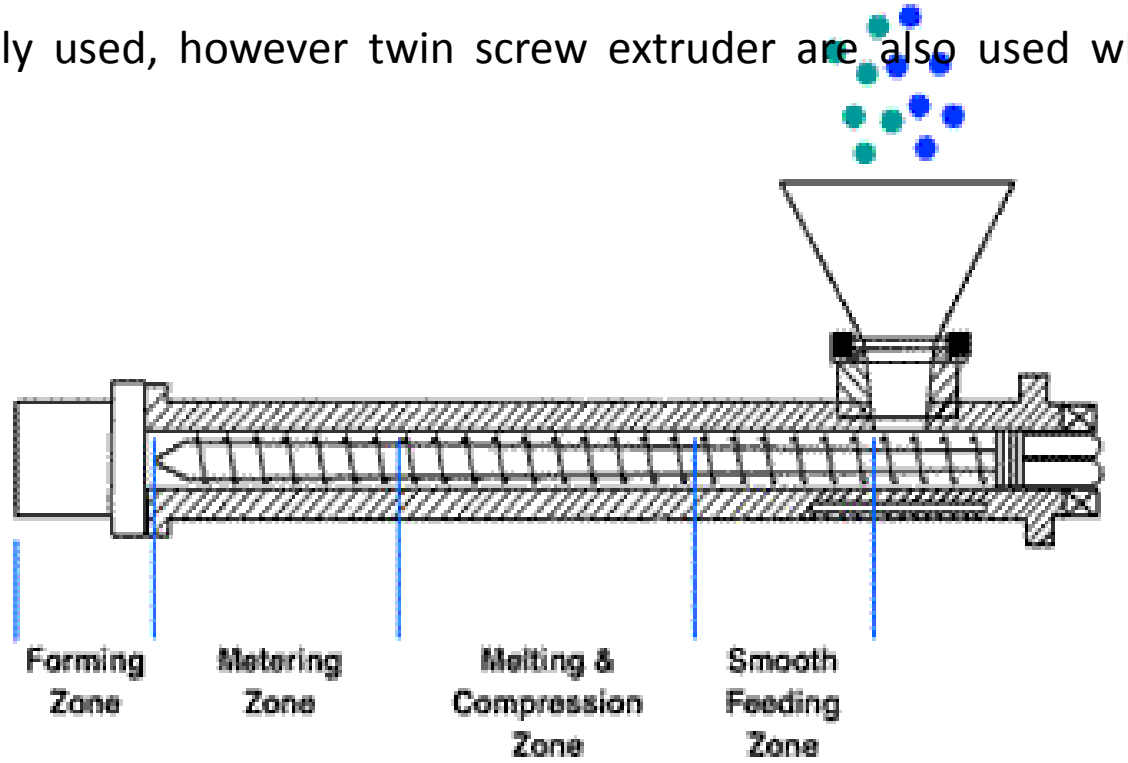




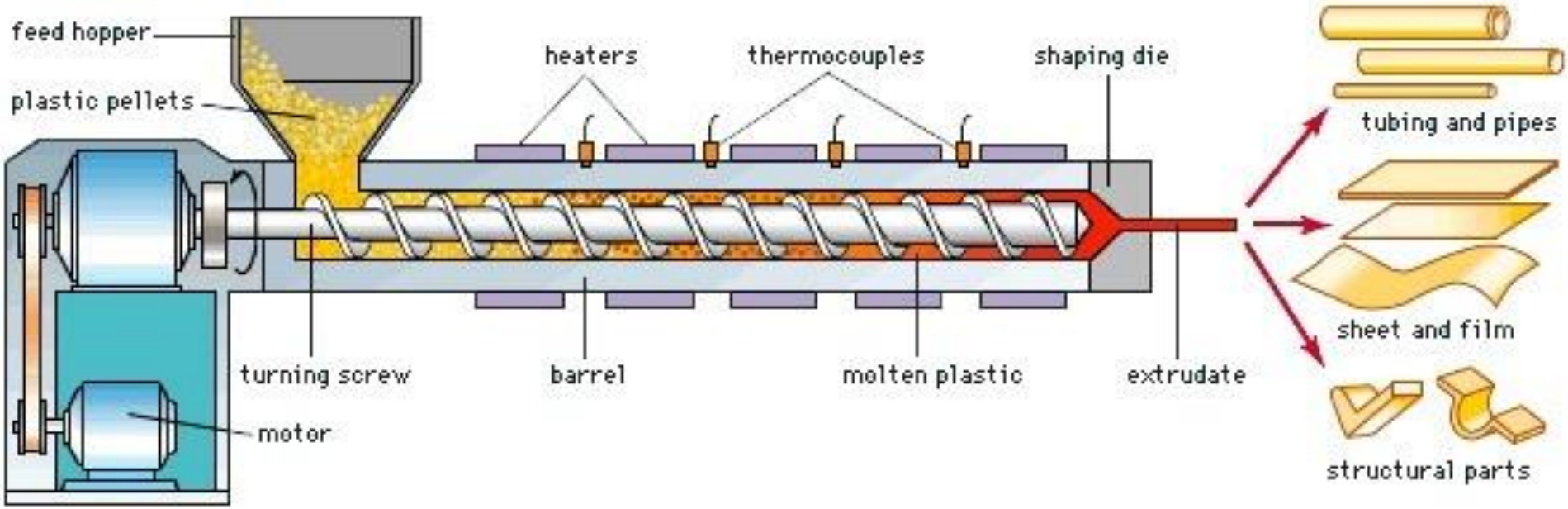
Extrusion System

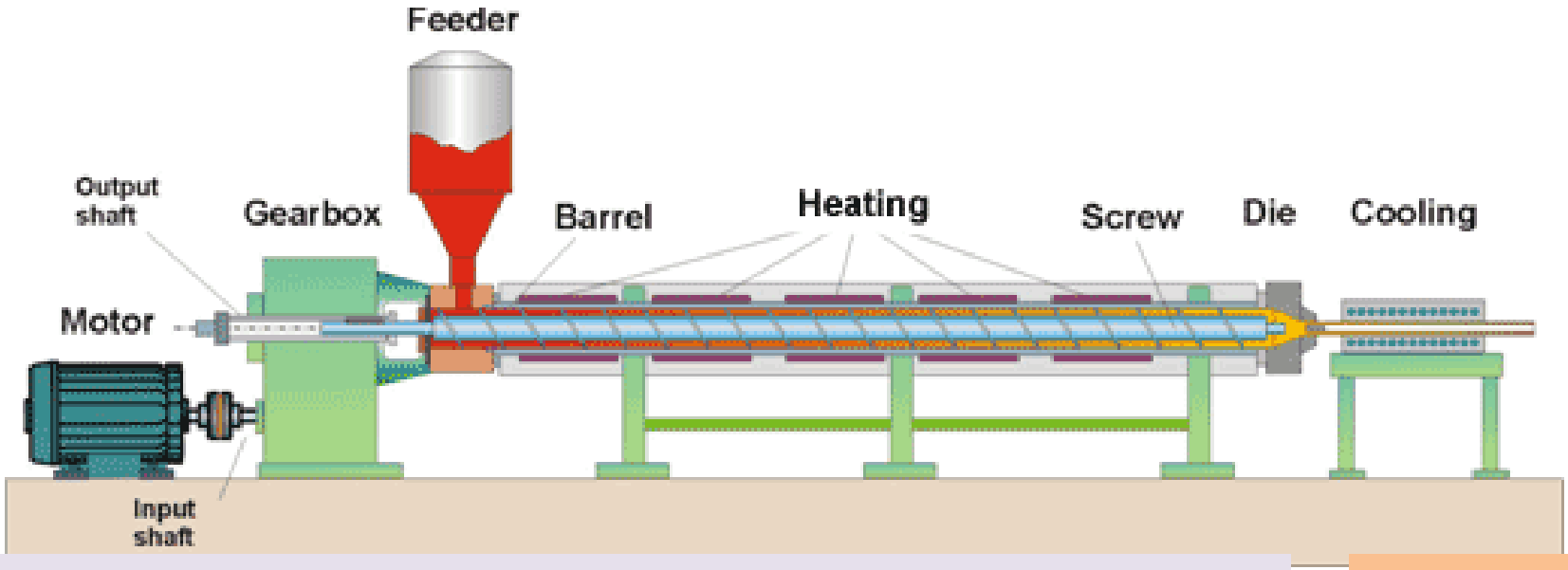
- The extrusion machine forms the basis of nearly all other polymer processes.
- The word extrusion comes from Greek roots-means ‘push out’
- Continuous process
- Basically involves melting polymer pellets and extruding them out through a two dimensional die- e.g. melting of plastic resin + adding mixing 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
- Produces long, thin products

  - ✓ Coating for electrical wire
  - ✓ Tubes, etc.
  - ✓ Pipes

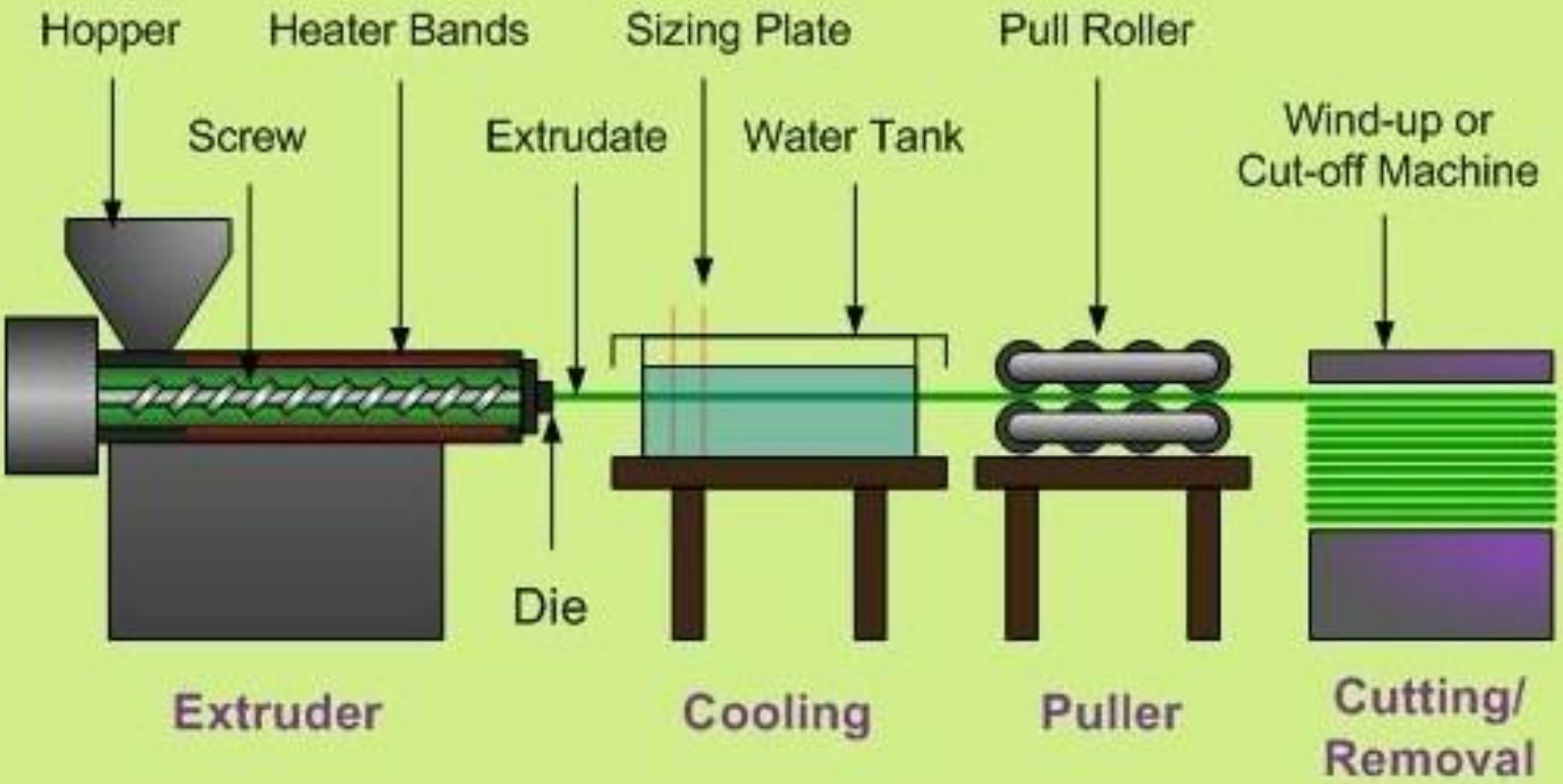


Extrusion machine


feed hopper
plastic pellets
heaters
thermocouples
shaping die
tubing and pipes
sheet and film
structural parts
turning screw
barrel
molten plastic
extrudate
motor


Feeder
Output shaft
Gearbox
Barrel
Heating
Screw
Die
Cooling
Motor
Input shaft

Extrusion process



Equipment of Extruder

1) **Drive motor**- turns the screw, provides power for the operation of the extruder to push out the plastic materials

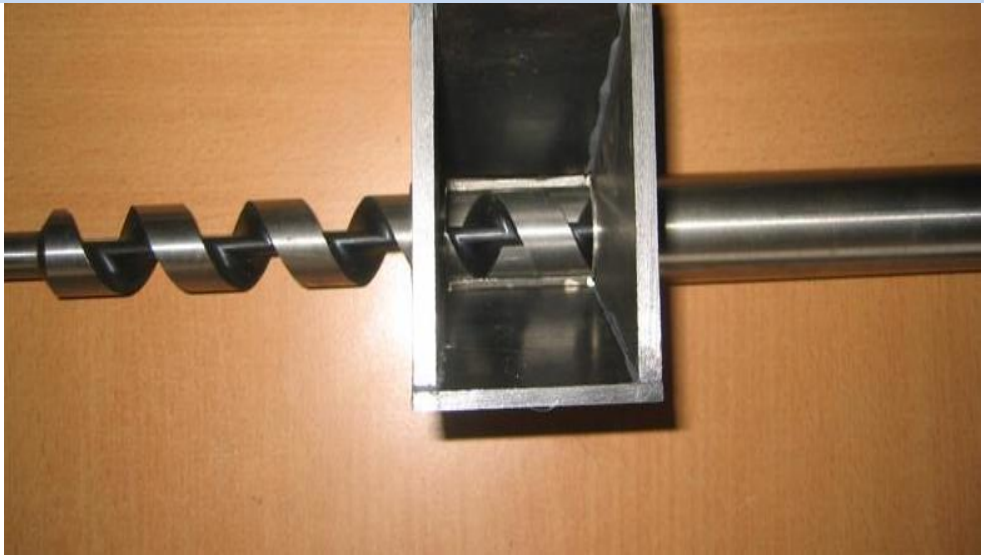
- The required extruder power increases when;
  - ✓ Output increases
  - ✓ Barrel diameter increases
  - ✓ Screw length increases
  - ✓ High output is required at high temperature

A large thrust bearing-mounted on the screw to prevent the screw from moving backwards

Equipment of Extruder

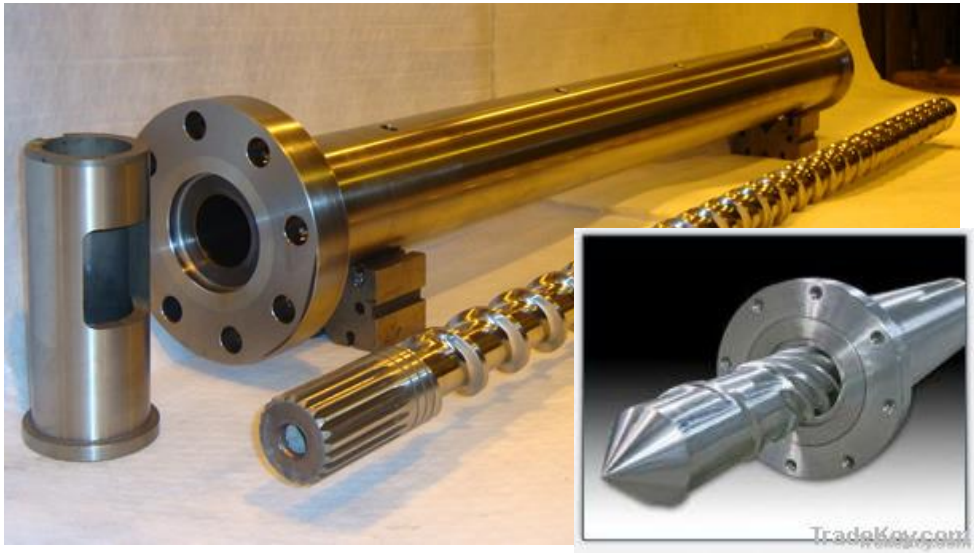
2) Hopper: to feed the extrusion machine with the polymer pellets

- mounted over the feed throat
- Feed throat- opening in the top of the barrel (Inlet for the resin)



3) 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

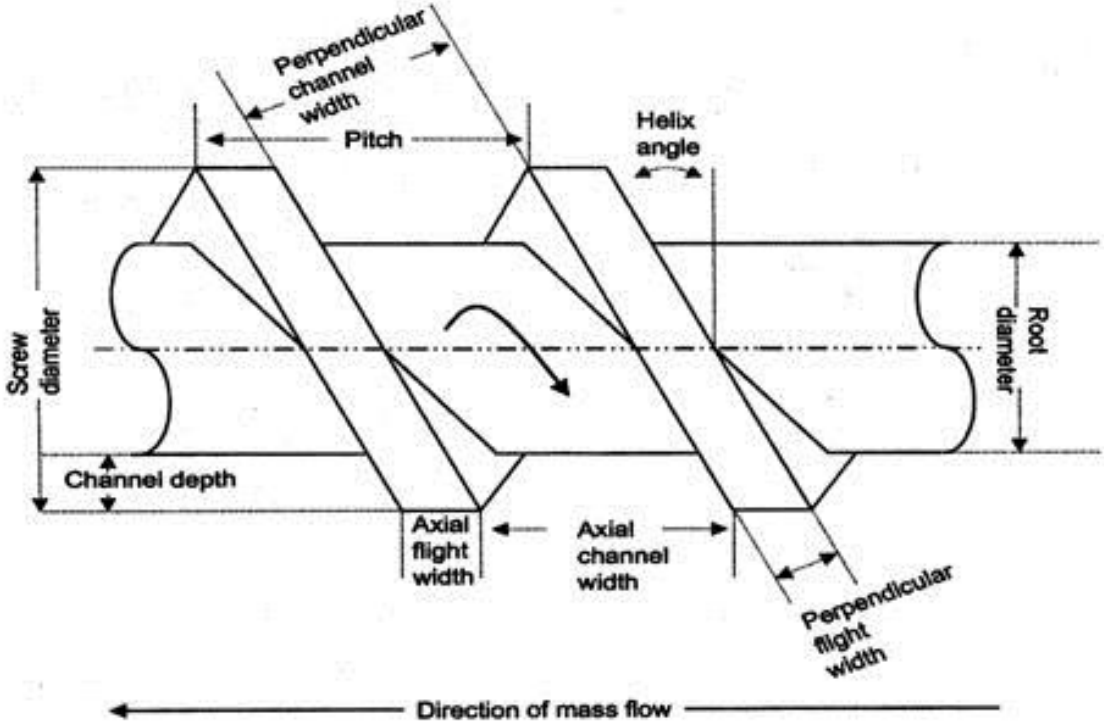
4) **Extruder screw-** attached to the drive linkage through the thrust bearing and rotates inside the barrel

Functions of Extruder Screw:

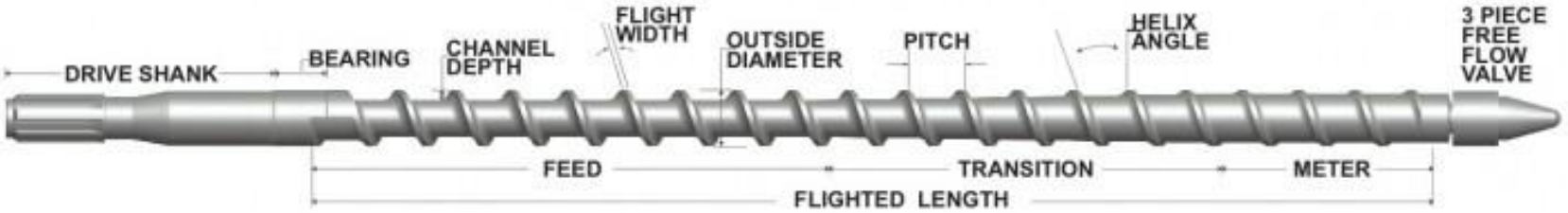
- To convey the resin through the extruder
- To mix the ingredient together
- To build pressure in the extruder (so that resin will be pushed through the die)
- To impart mechanical energy as part of the melting process

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.



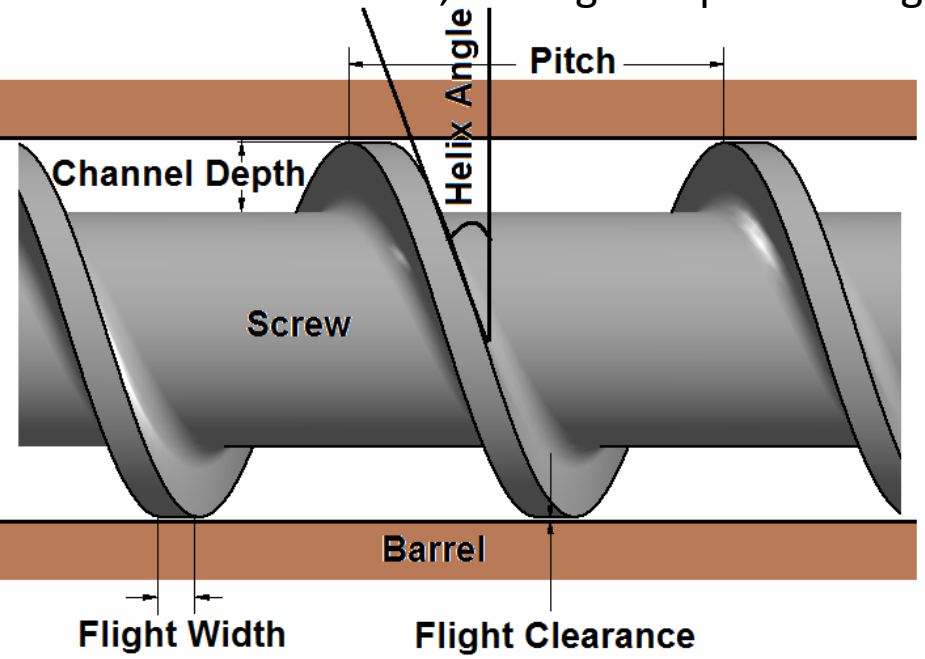
$$L/D = \frac{\text{Screw flighted length}}{\text{Screw outside diameter}}$$

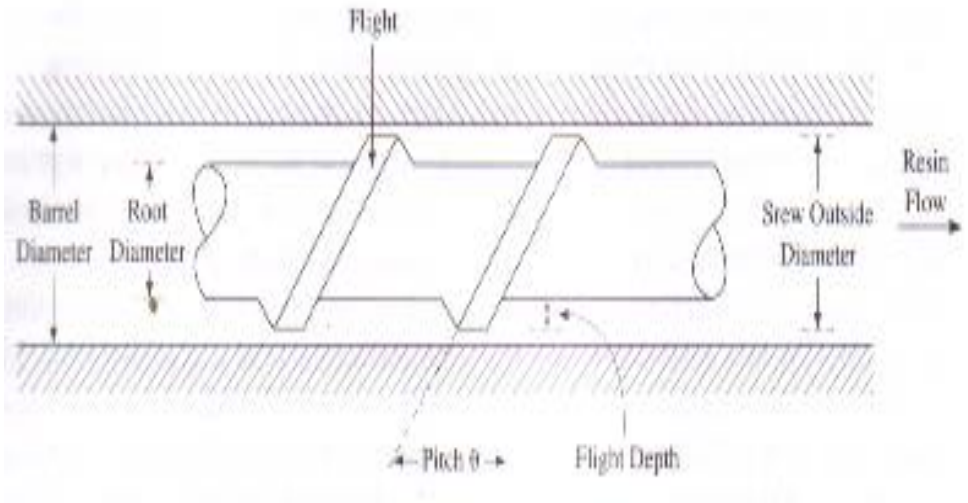


- Important parameter= L/D of the screw (length of the flighted portion of the screw/ inside diameter of the barrel)
- L/D measures the capability of the screw to mix materials and ability of the screw to melt hard-to-melt material. Typical L/D ratios are 16:1 to 32:1

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)

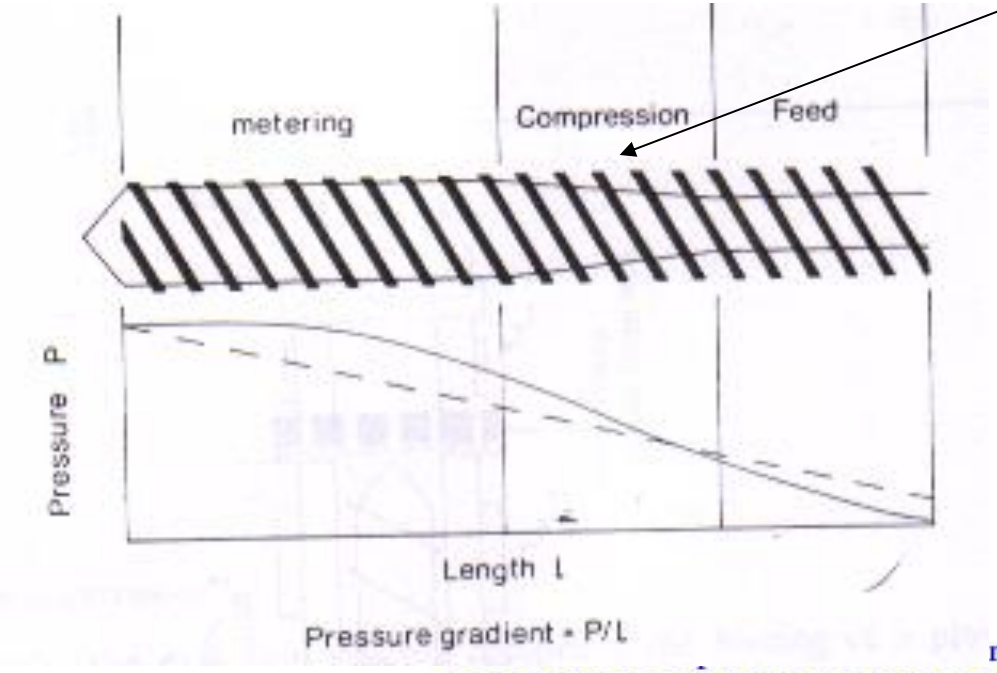




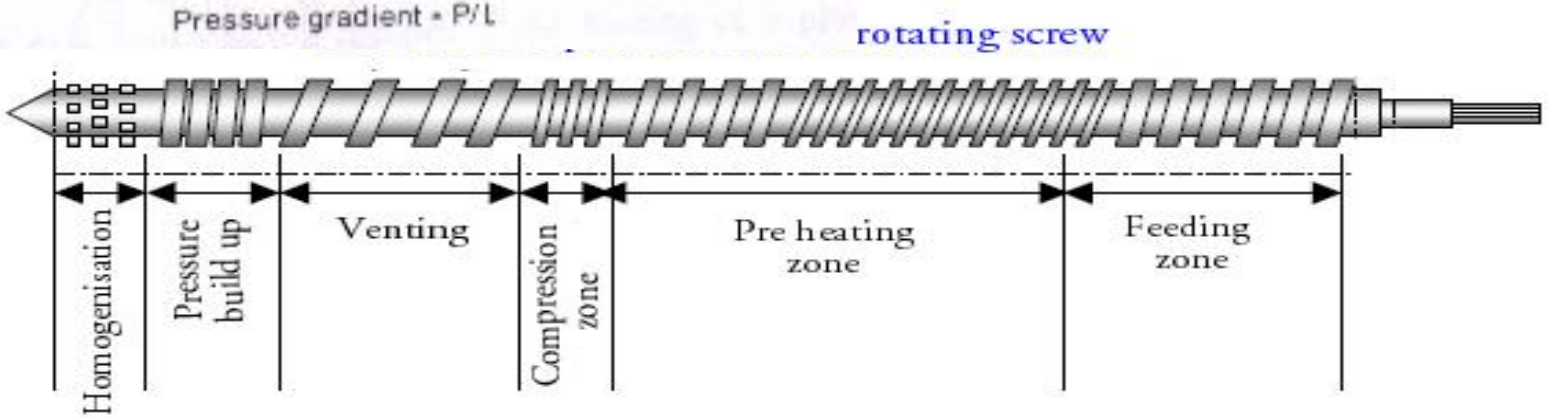
Extruder screw

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



Screw Zones

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

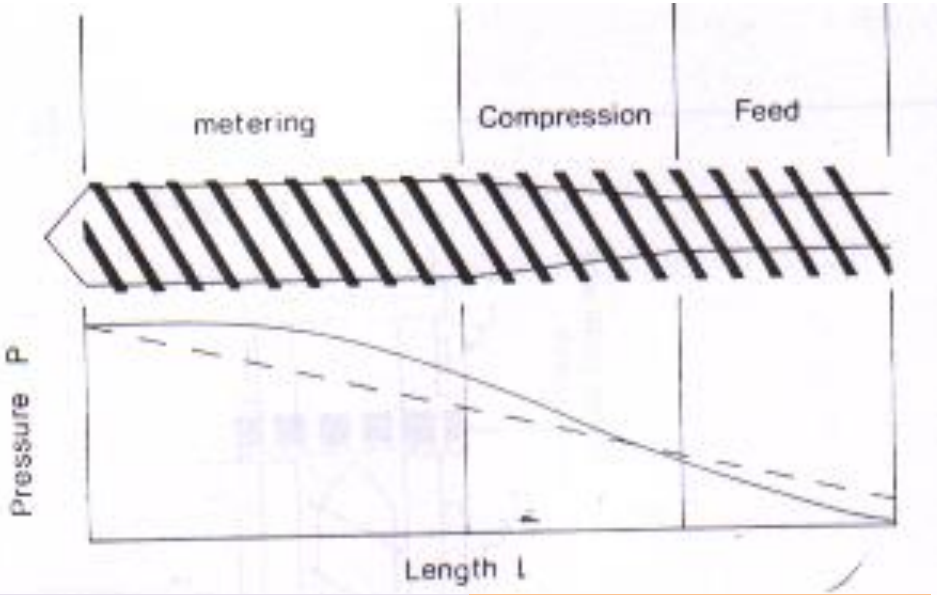
- The second zone- decreasing channel depth
- Usually called as ‘compression’ and ‘transition’ zone
- Compresses the material conveys from the feed zone and plasticates it
- Can be identified as by the gradual increase in the diameter of the root along the length of the section
- root diameter increase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

Screw Zones

Metering zone

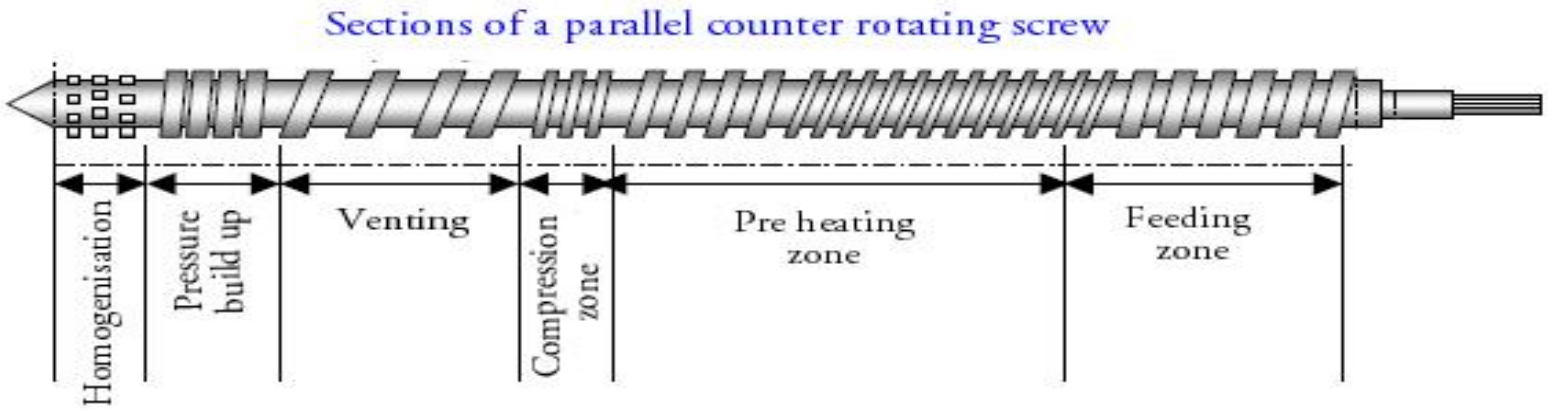
- Constant screw depth and very shallow flight depth
- The function is to homogenize the melt and supply to die region (give final mixing)
- Shallow flight depth ensure that high shear is added to the resin to accomplish any melting of the residual solids.
- High shear also builds pressure on the melted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



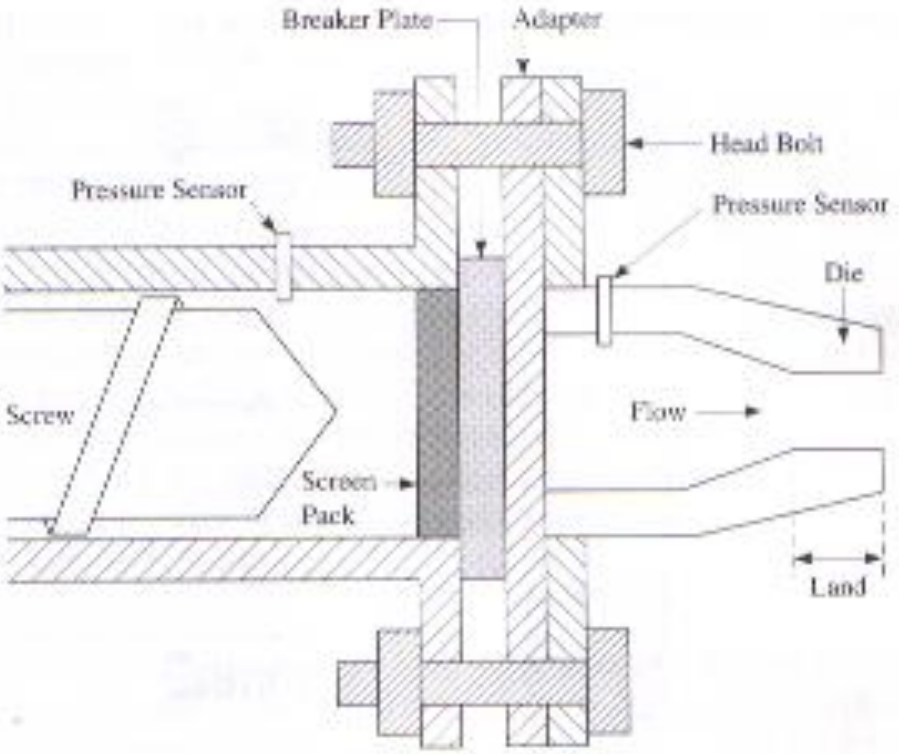
Extruder screw

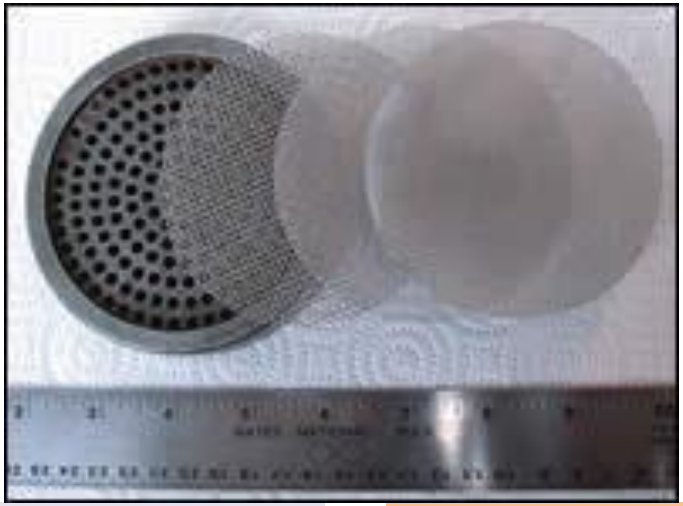
- The screw is the heart of an extruder
- The geometry of the screw changes along the length
- Modification of the screw basic design is needed to obtain good distribution of filler
- However changing screw design is a difficult task, thus **general purpose screw** is used
- The performance of these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



The Head

- It is the 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



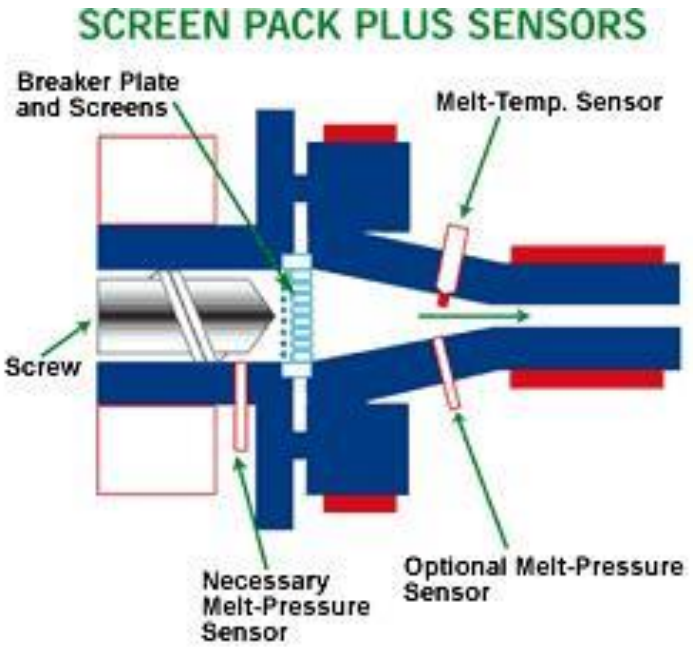


Head Zone

- Located in this region is the screen pack (comprises a perforated steel plate called breaker plate and sieve pack)

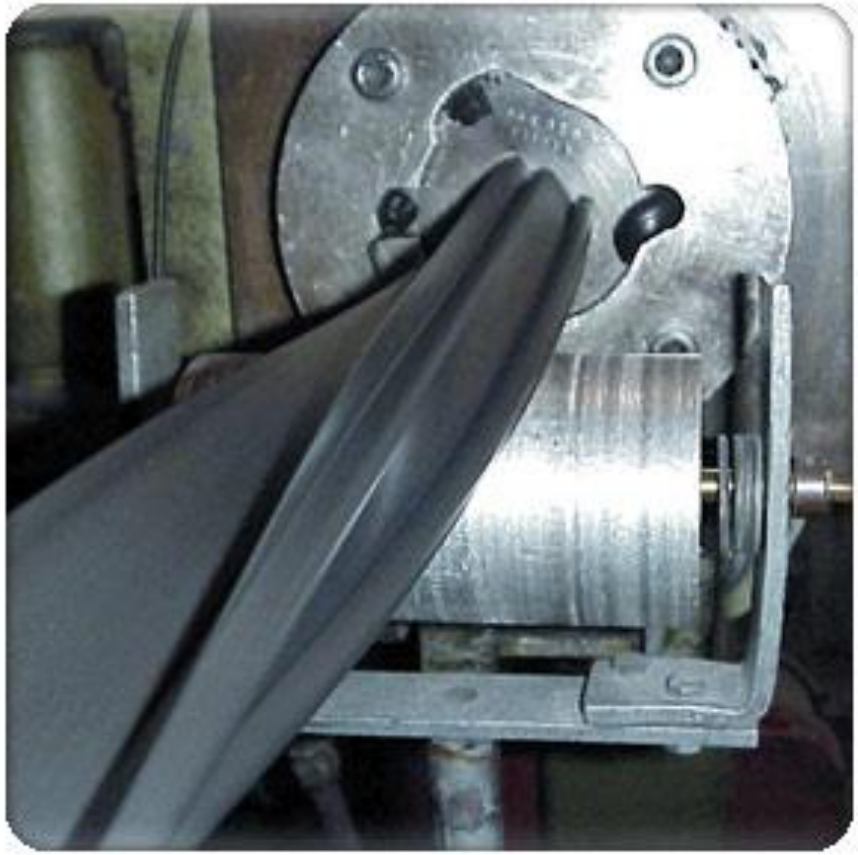
- The breaker plate-screen pack has three functions;

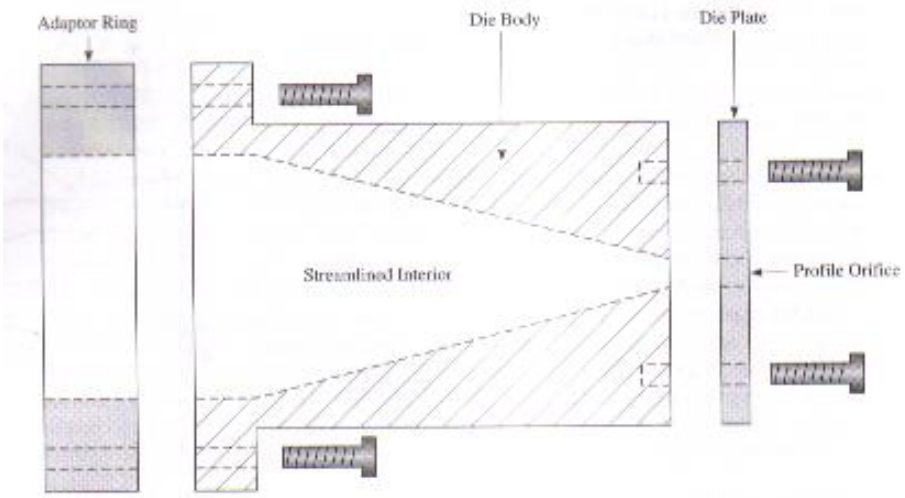
  - ✓ To sieve out/remove unwanted particles, e.g. dirt, foreign bodies (dies are expensive and difficult to repair)
  - ✓ To develop a head pressure that provides the driving force for the die
  - ✓ To remove 'turning memory along the spiral screw' from the melt (Polymers are made up of long chain molecules, coiled, etc. , they have tendency towards elastic recovery)



The 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





Cooling & Pulling

- Upon exiting the die, the extrudate must be cooled to retain its shape
- The extrudate is introduced into a cooling bath
- 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

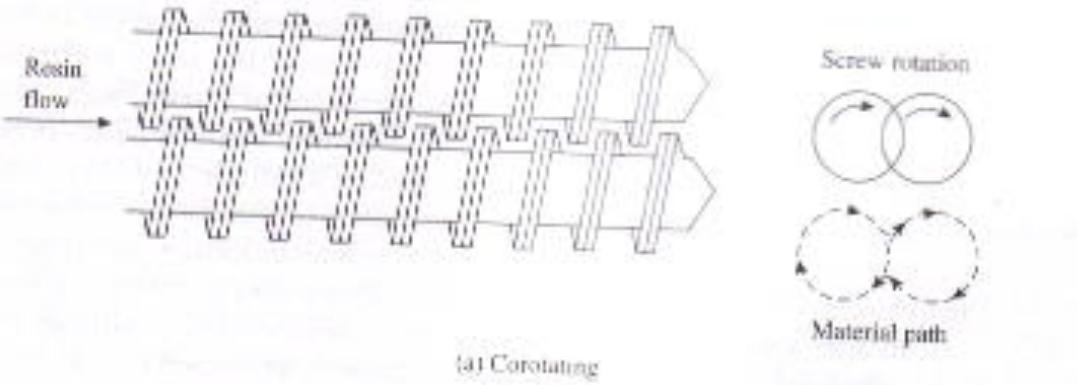
- Can be divided into co-rotating and counter-rotating types,

- Twin-screw extruder is a relatively expensive machine:

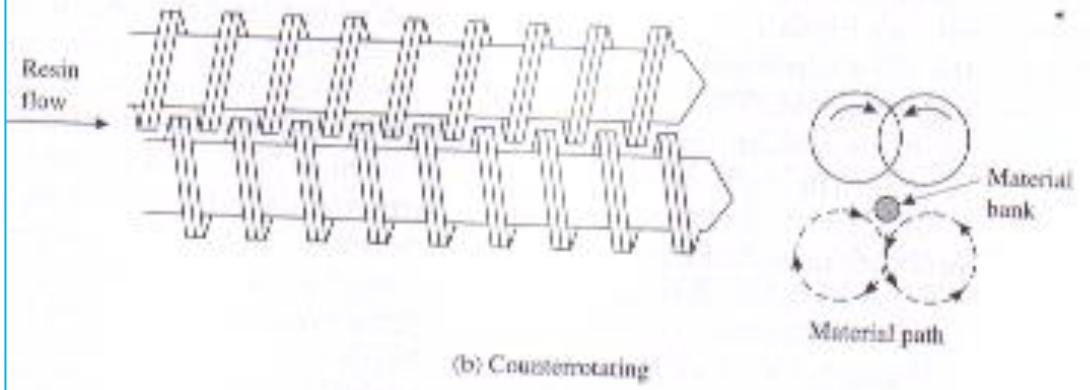
  - Difficult to accommodate bearings (dimensions limited)
  - Complicated gear boxes
  - Two screws

Twin screw rotating

- Corotating – 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



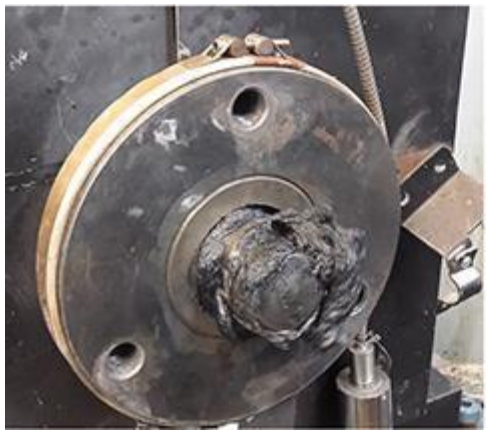
- Counterrotating- Material is brought to the junction of the two screws and material bank is built up on top of the junction
- This build up of the material is conveyed along the length of the screw by the screw flights
- Total shear is lower than in single-screw and corotating twin screw

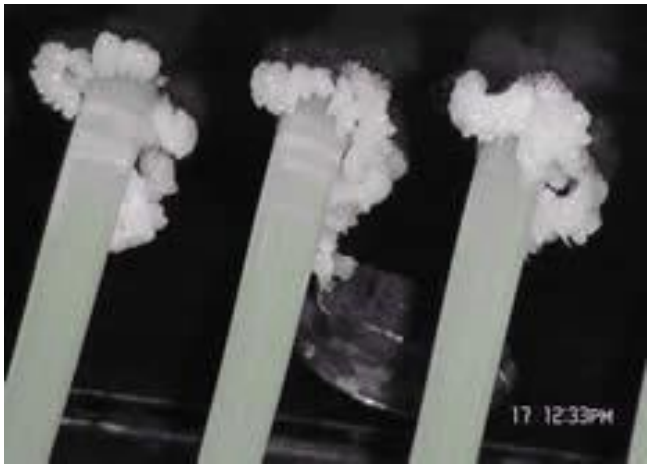


Operation Start-up

- 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

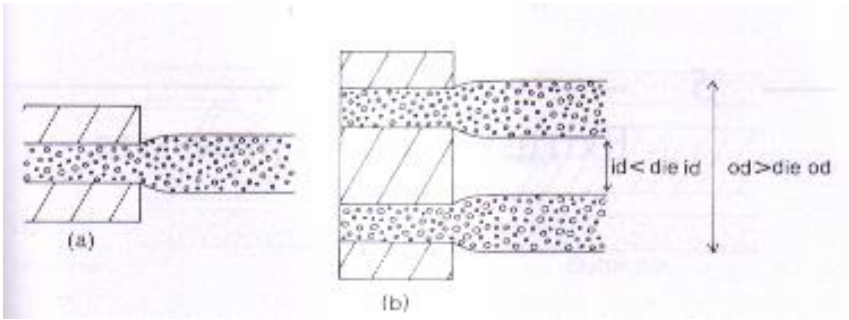
Extrusion technical problems





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
- Is caused by the viscoelastic nature of the polymer melt (also has been called as 'plastic memory'-as it restore the shape previously held)

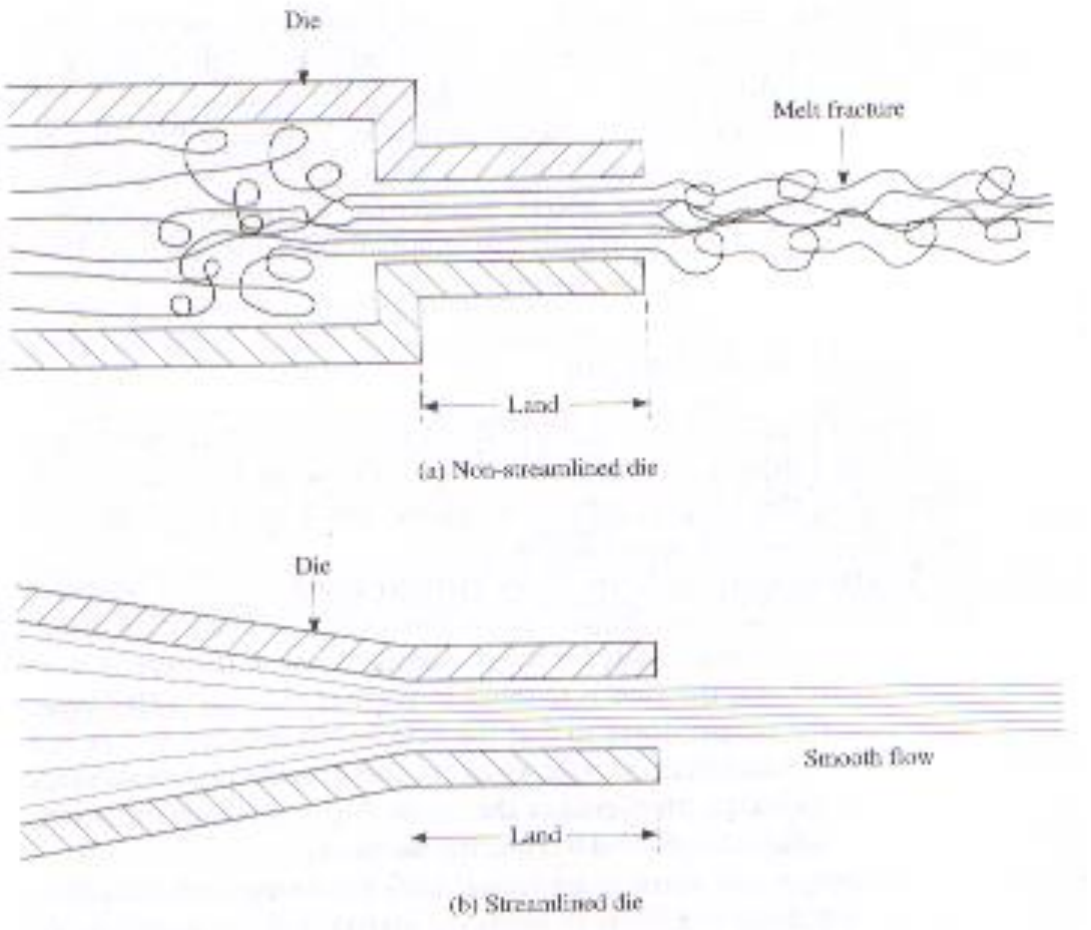


Die swell in (a) rod and (b) pipes

- 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

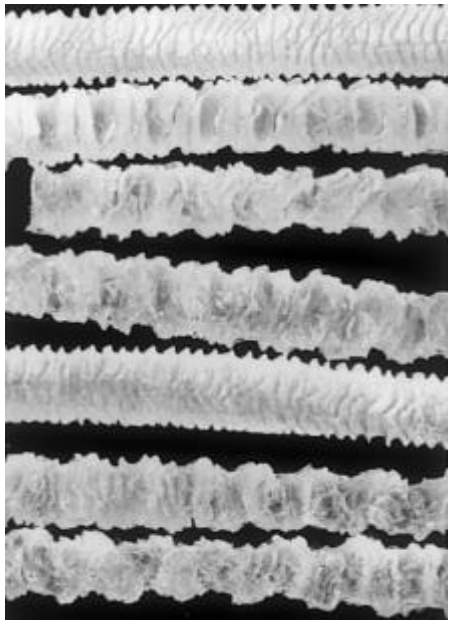
- Melt fracture- Skin rupture usually occurs only on the outside surface of the film when stretching and cooling occur too fast and cause micro tears.
- Melt fracture caused by skin rupture occurs when the surface of the film is stretched too quickly on leaving the die.
- the extrudate has a rough surface, 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.



Effect of streamlined in a die to prevent melt fracture

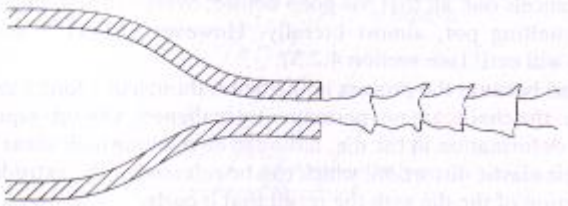
Die exit instability

- 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 & Contamination

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.

Contamination

- Detected by sports (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.