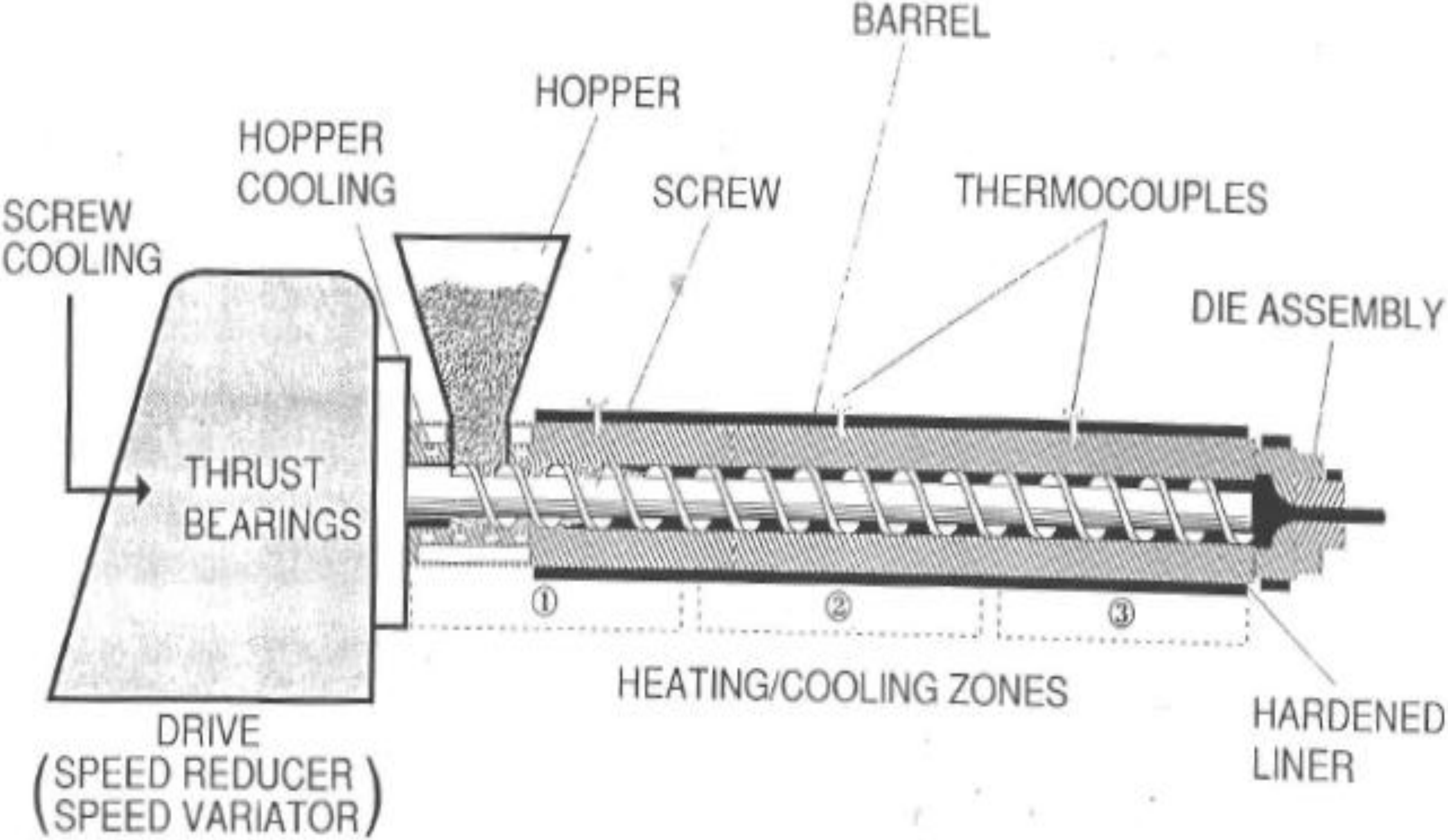
EXTRUSION

Extrusion

is used for processing most types of thermoplastics and rubbers. The extrusion process is a simple process in which molten polymer is forced through a shaped die using pressure. The pressure is generated from the action of screw rotation against barrel wall.

- The compoents of an extruder include:
- Drive
- Gearbox and Thrustbearing
- Feedhopper
- Barrel

BASIC EXTRUDER



EXTRUSION

Screw

The basic functions of the screw are:

(1) To transport the polymer from the feed hopper to the extruder outlet.

(2) To bring about the melting of the polymer.

(3) To carry out any mixing required during the process.

(4) To generate a stable and homogeneous supply of polymer melt.

EXTRUSION

L/D ratio of screws usually in the region of 20:1 - 30:1.

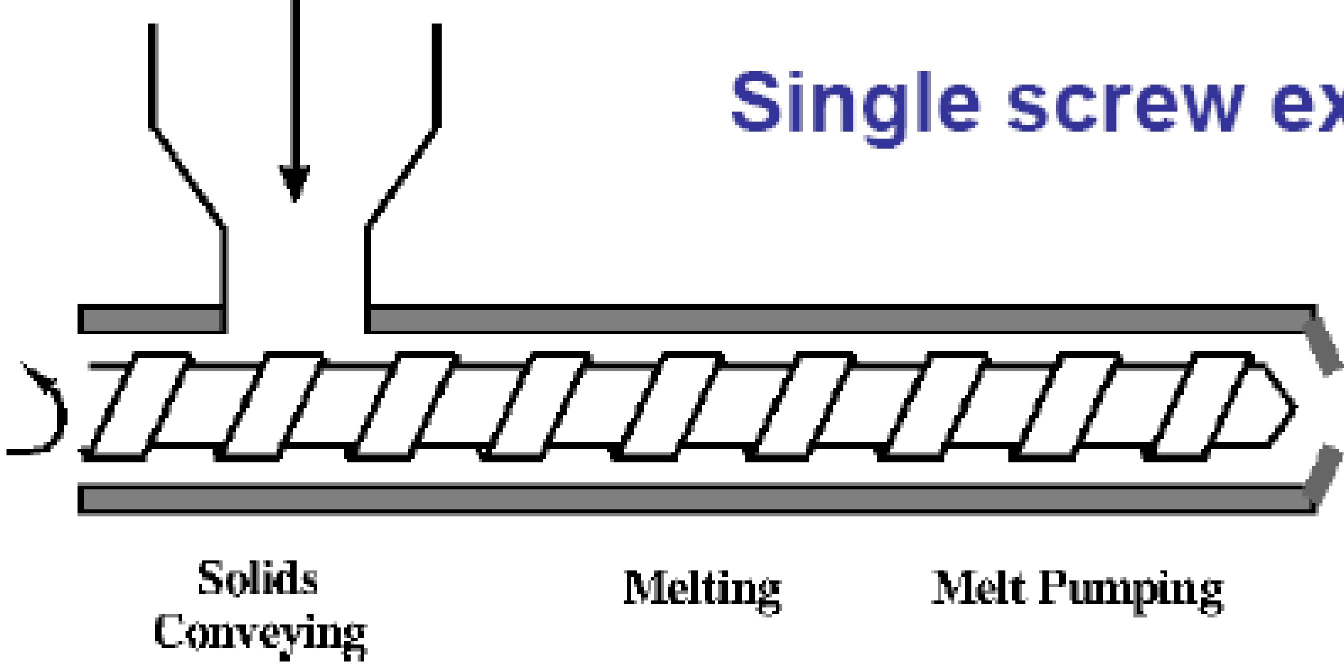
A typical single-stage screw consists of three regions:

(a) The Feed Zone

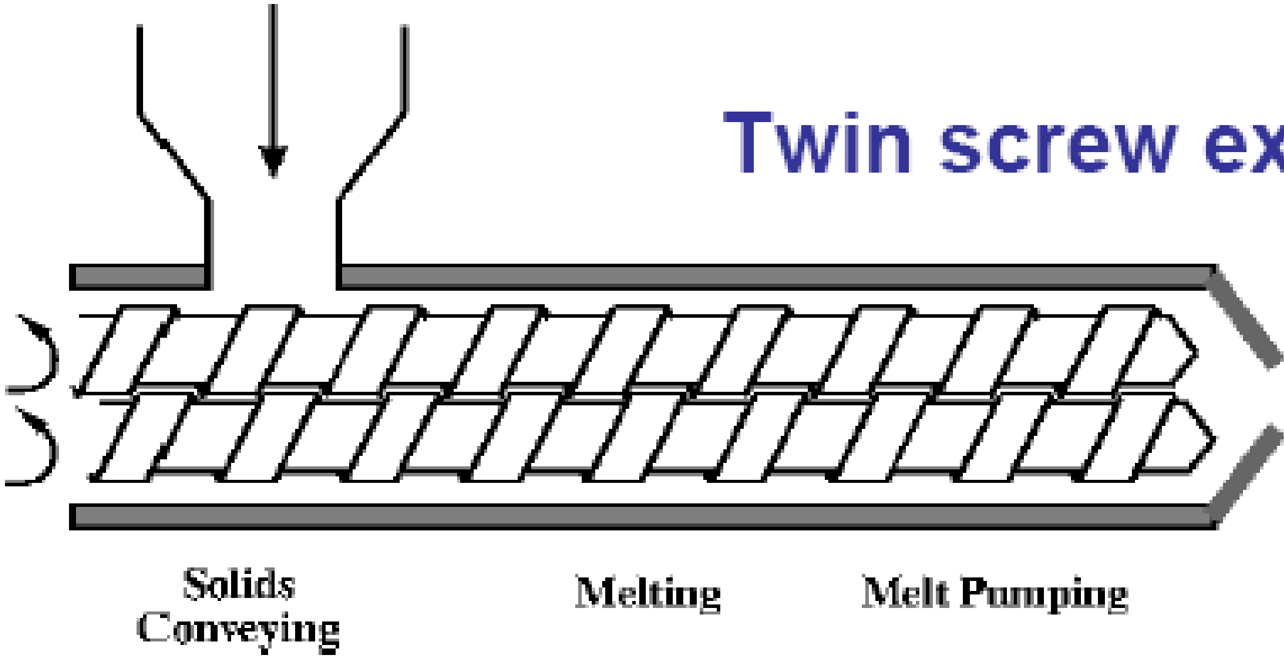
(b) Compression Zone

(c) Metering (pumping) Zone

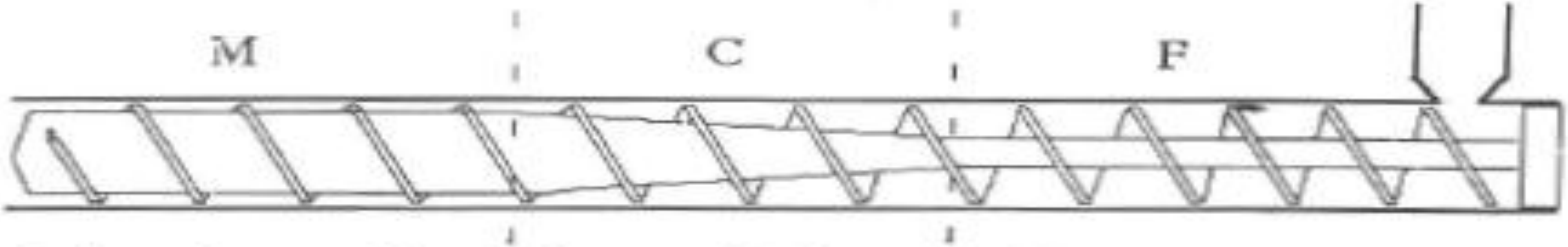
Single screw extruder



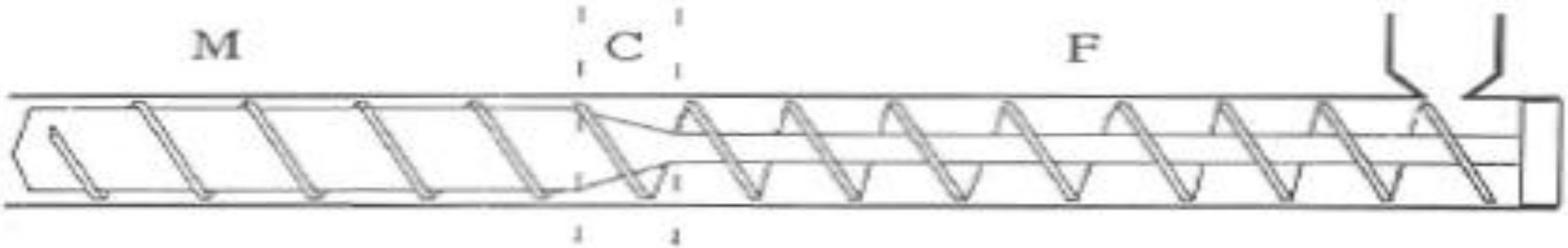
Twin screw extruder



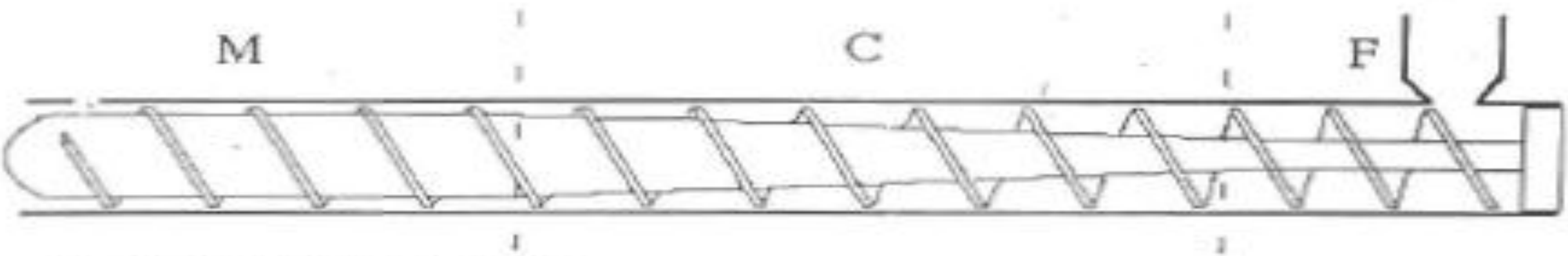
Schematic screw profiles



(a) semi-crystalline polymer with broad melting range

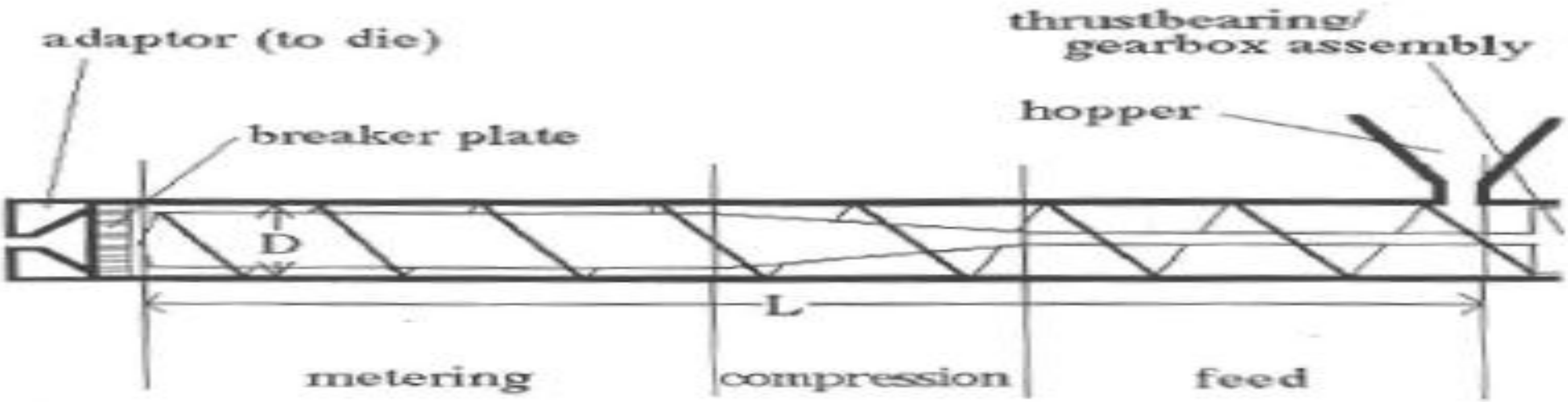


(b) semi-crystalline polymer with narrow melting range

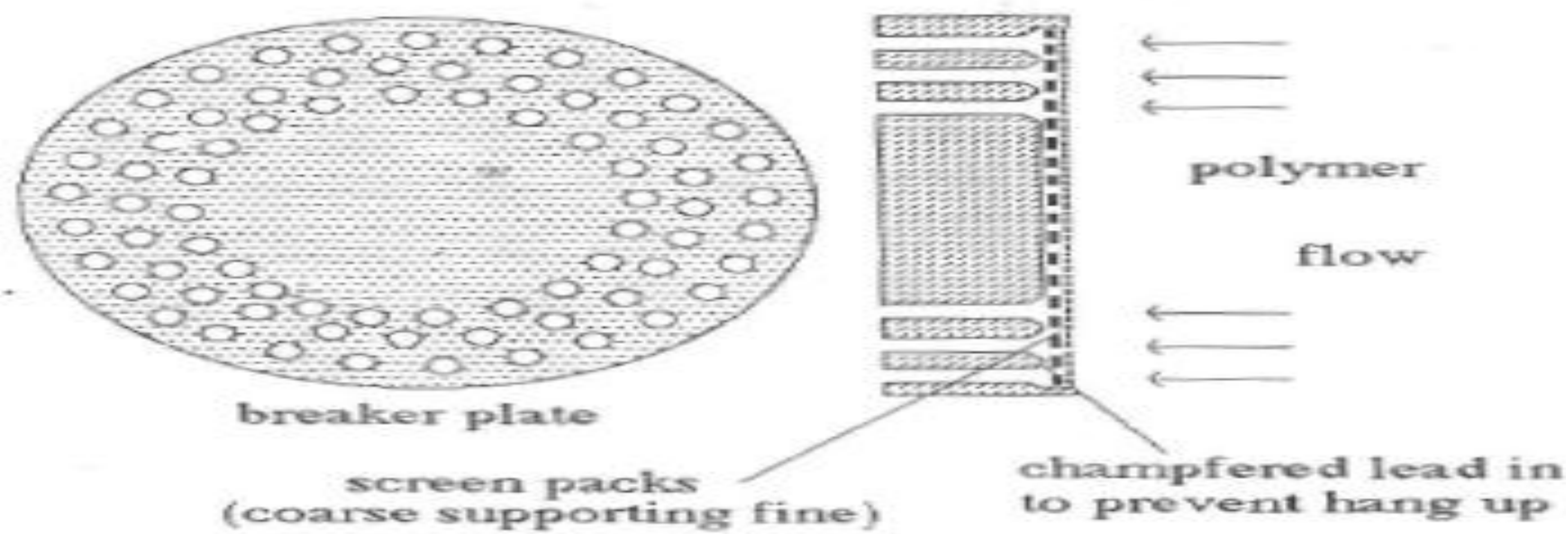


(c) amorphous polymer

Single Screw Extrusion



Breaker plate construction



$$\underline{\text{L/D ratio}} = \frac{\text{useful flighted length of screw}}{\text{barrel diameter}}$$

Typical L/D ratios

(i) Rubber(hot feed) - 3:1 to 8:1
(ii) Rubber(cold feed) - 8:1 to 20:1
(iii) Thermoplastics - 18:1 to 40:1

EXTRUSION

<u>Breaker plate</u> - A breaker plate is located at the front end of an extruder between screw and die. The main purpose of the beaker plate is to support wire mesh filters, this screening out dirt or forien sunstances that may have mixed with the polymers.

<u>Die</u> - Die is attached to the extruder via an adaptor, the adaptor also being used to change the direction of the flow. The geometry (size and shape) and final properties of polymer products are considerably influenced by die design.

Description of extruders

In general, extruders are described in terms of:

- **Screw (outside) diameter - typically 25mm to 300mm.**
- **The type of materials they processes, e.g. thermoplastics or rubber.**
- **The compression ratio of the screw are 4:1 for PE screw and 1:1 for a rubber screw.**
- **The L/D (length/diameter) ratio of the screw, this typically being 25:1 to 35:1 for a thermoplastics extruder and 12:1 to 20:1 for a rubber extruder, where:**

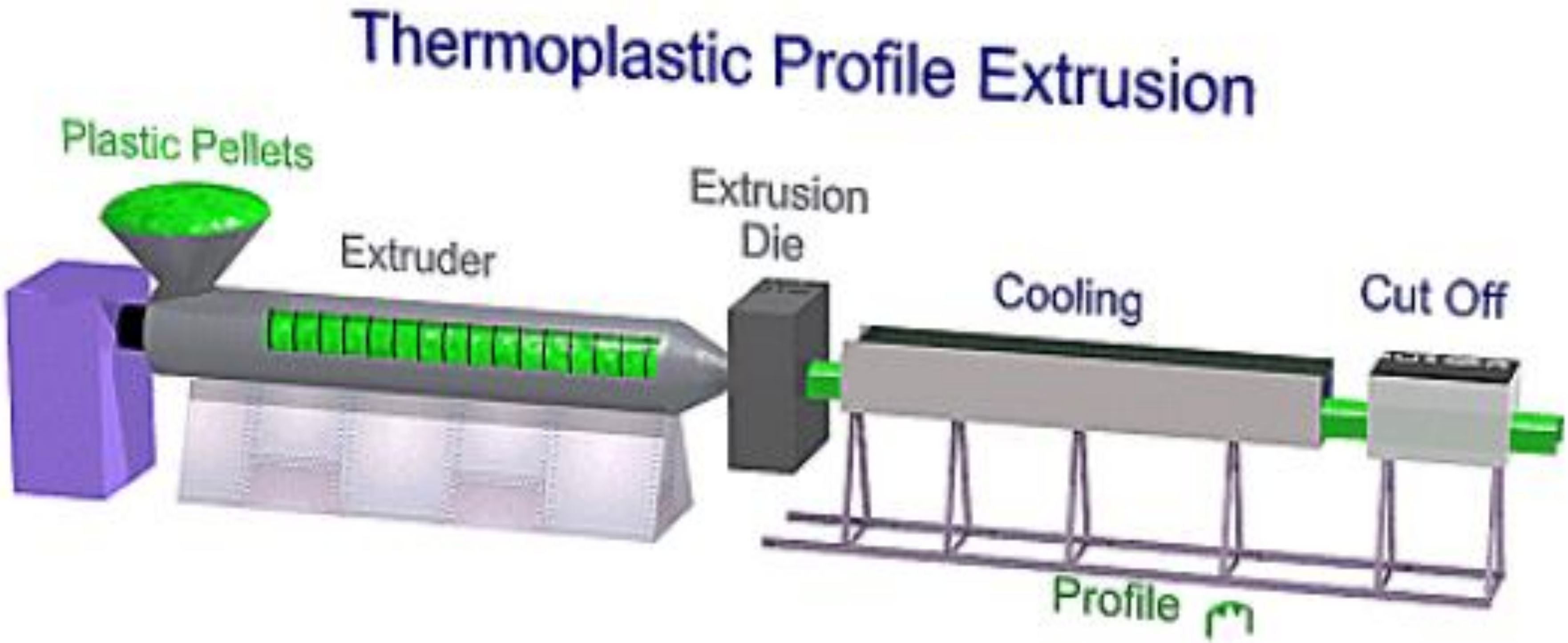
$$L/D\,ratio = \frac{useful \quad flighte \quad length \quad of \quad the \quad screw}{screw \quad diameter}$$

Description of extruders

Ancillary equipment

- Calibration or sizing
- Cooling system
- Haul-off units
- Reel-up system

4.Extrusion



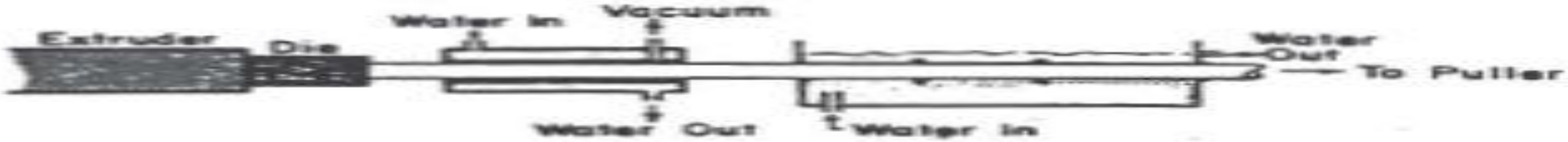
-the forcing of a plastic or molten material through a shaped die by means of pressure.

Various Tube Sizing Techniques

7a

7b

7c



7d

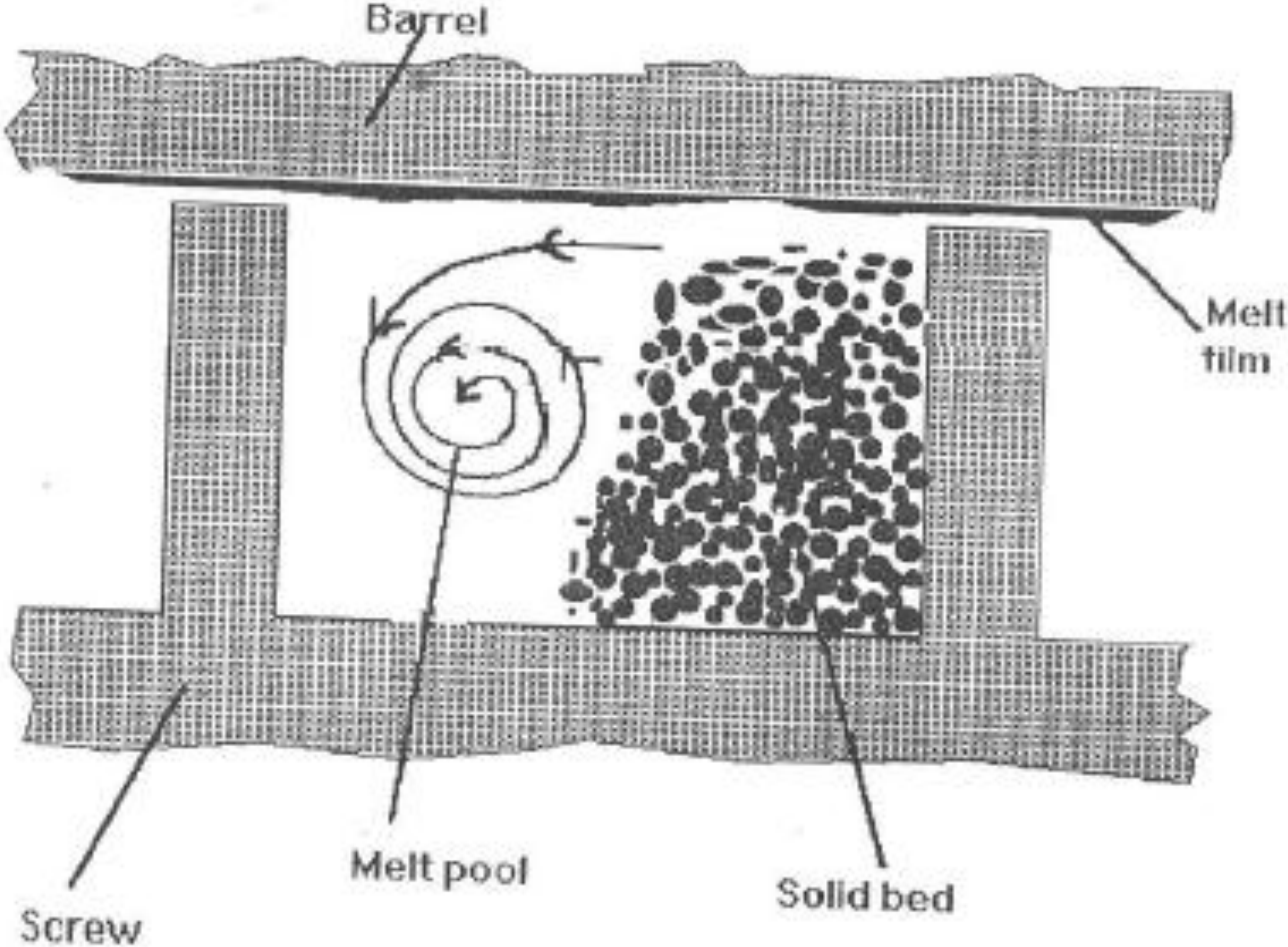
Analysis of polymer flow in extruders

Examinations of polymer flow occurring inside an extruder are usually focussed on the following topics:

(a) Solid transport in the feed section

(b) Melting machanism in the extruder

(c) Polymer melt flow in the flights of a screw


Barrel
Melt film
Melt pool
Solid bed
Screw

Solid transport in the feed section

In the feed section of the extruder screw, the feeding of the solid polymer is controlled by a balance of forces. I n practice the flow rates along the three sections of the screw should be equal, that is:

Qfeed = Qcompression = Qmetering

Melting machanism in the extruder

- Melting is not instantaneous.
- The onset of melting does not occur immediately the polymer enters the extruder barrel.
- The energy for melting comes from two sources (external and ineternal)
- Melting starts at the interface between the solids bed and the barrel.
- Gradually the thickness of the melt film increases until being wiped off the surface of the barrel by the advancing screw flight

Melting machanism in the extruder

- As the melt pool develops the solids bed becomes narrower, the height of the bed being maintained.
- Eventually, the solid bed breaks up and the melting process is complete.
- Factors affecting the melting process

  (a) Channel depth

  (b) Barrel temperature

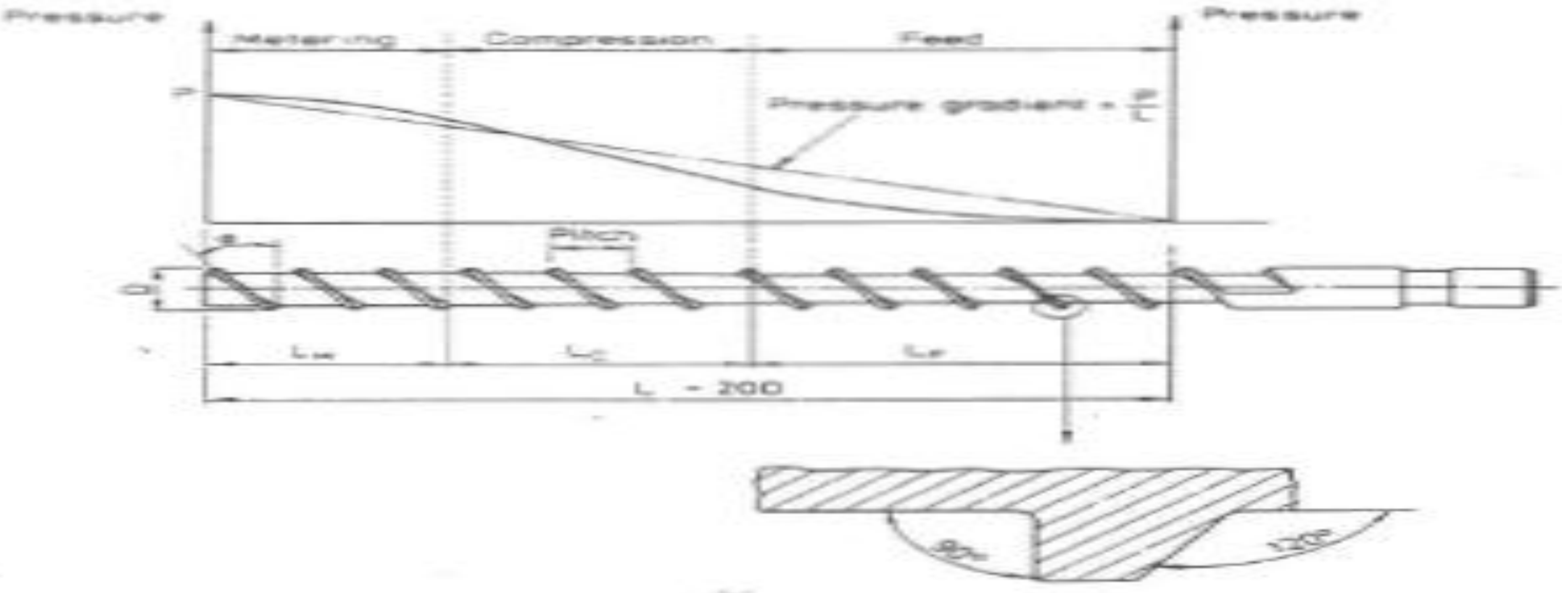
Melting machanism in the extruder

(c) Flow rate
(d) Screw speed
(e) Tapered channel
(f) Number of channels
(g) Flight clearance

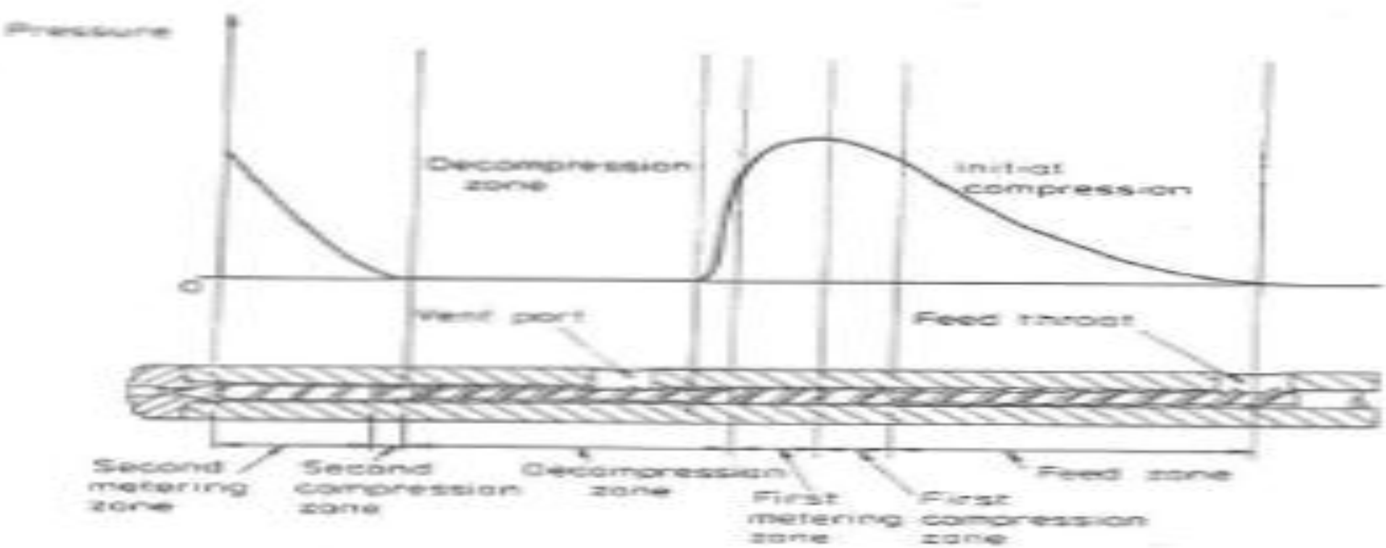
Polymer melt flow in the flights of a screw

In this analysis, a number of assumptions are made in the derivation as follows:

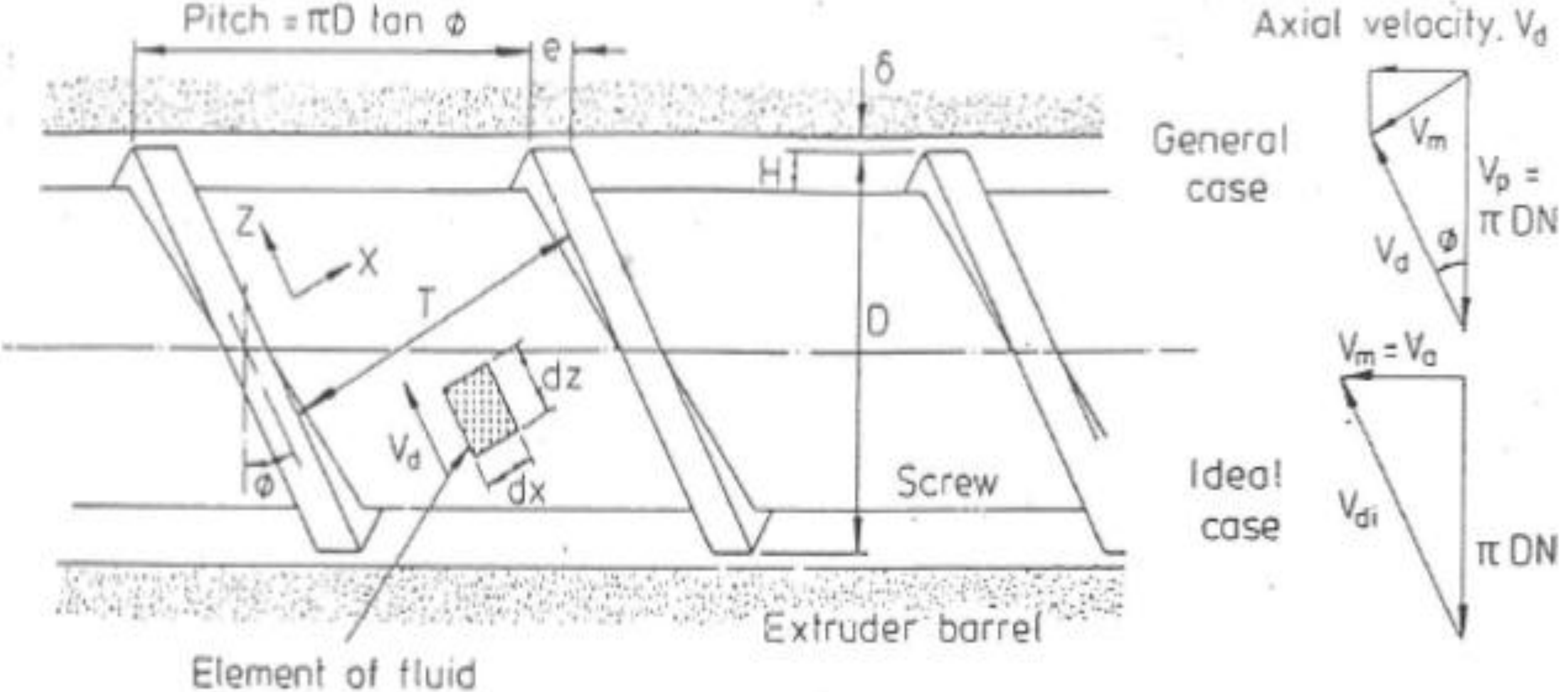
- The fluid is Newtonian
- The flow is isothermal.
- There is no slippage at the barrel wall.
- The screw is running full of fluid.
- The channel is shallow in comparison with its width.
- The fluid is incompressible.
- The flow pattern is fully developed and laminar.
- The effect of gravity can be neglected.



Typical zones on an extruder screw [CRAWFORD: 1989]

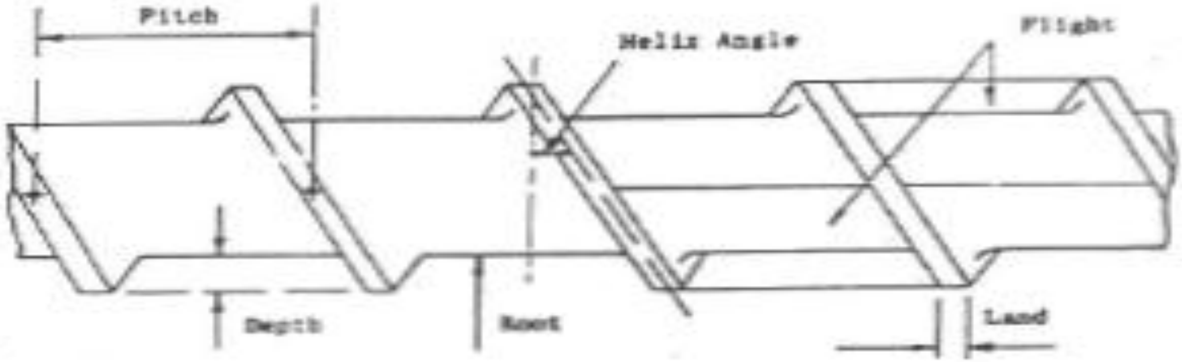


Zones on a vented extruder [CRAWFORD: 1987]



Reproduced from Crawford: 1987

- **Screw Definitions**



1.	Depth	the perpendicular distance from the top of the thread to the root surface
2.	Flight	-the space enclosed by the thread and the surface of the root in one complete turn of the screw
3.	Helix Angle	the angle between the screw thread and the transverse plane of the screw
4.	Land	the surface at the radial extremity of the screw thread constituting the periphery or outside diameter of the screw.
5.	Lead	the horizontal distance travelled by the material in one complete revolution of the screw, assuming 100% efficiency. It is equal to the pitch multiplied by the number of starts.
6.	Number of starts	the number of separate threads traced along the length of the screw.
7.	Pitch	the horizontal distance between corresponding points of two successive lands.
8.	Root	the continuous central shaft, usuallyof cylindrical or conical shape.

Anaylsis of flows in the extruder

Total flow = Drag flow - Pressure flow - Leak flow

Drag flow

$$Q_d = \tfrac{1}{2}\pi^2 D^2 N \sin\phi \cos\phi H$$

where Qd is the output of the flow

D² is the screw diameter

H is the channel depth of the screw

N is the screw rotation speed

ϕ is helix angle

Anaylsis of flows in the extruder

Factos affecting the drage flow include:

- screw diameter screw speed *N*
- channel depth *H*
- helix angle

Pressure flow

$$Q_p = \frac{\pi D H^3 \sin^2 \phi}{12\eta}\left(\frac{dP}{dl}\right)$$

where dP is the pressure drop along the extruder

dl is the length of the flow path

$H=\delta,$

Anaylsis of flows in the extruder

Factors affecting the pressure flow include:

- **screw dimension, with dependence on channel depth cubed**
- **pressure gradient**
- **fluid viscosity.**

Leak flow

$$Q_L = \frac{1}{12\eta}\frac{\Delta P}{e\cos\phi}\frac{\pi D}{\cos\phi}\delta^3$$

where $H=\delta,$ the depth of the slit

e is the width of the screw flight

However leak flow is small compared with drag flow and pressure flow and may be neglected in finding total flow.

Total flow in Extrusion

$$Q = Q_d - Q_P$$

$$Q = \tfrac{1}{2}\pi^2 D^2 NH \sin\phi \cos\phi - \left(\frac{\pi D H^3 \sin^2 \phi P}{12 \eta l} \right)$$

This is a somewhat cumbersome expression, which for practical purposes is simplified. For a given extruder l, D, H and ϕ are all fixed, and total flow is obtained by:

Total flow in Extrusion

$$Q = \alpha N - \left(\frac{\beta P}{\eta}\right)$$

The practical variables for operating the extruder are, screw rotation speed , head pressure and melt viscosity.

Screw, die and material characteristics in extrusion

- Important!!! that correct die and screw are used because of influencing the properties of the final products.
- The characteristics in extrusion involve:
- screw characteristics
- die characteristics
- material characteristics

Screw characteristics

Maximum output

$$Q = Q_{\max} = \tfrac{1}{2}\pi^2 D^2 N \sin\phi \cos\phi H$$

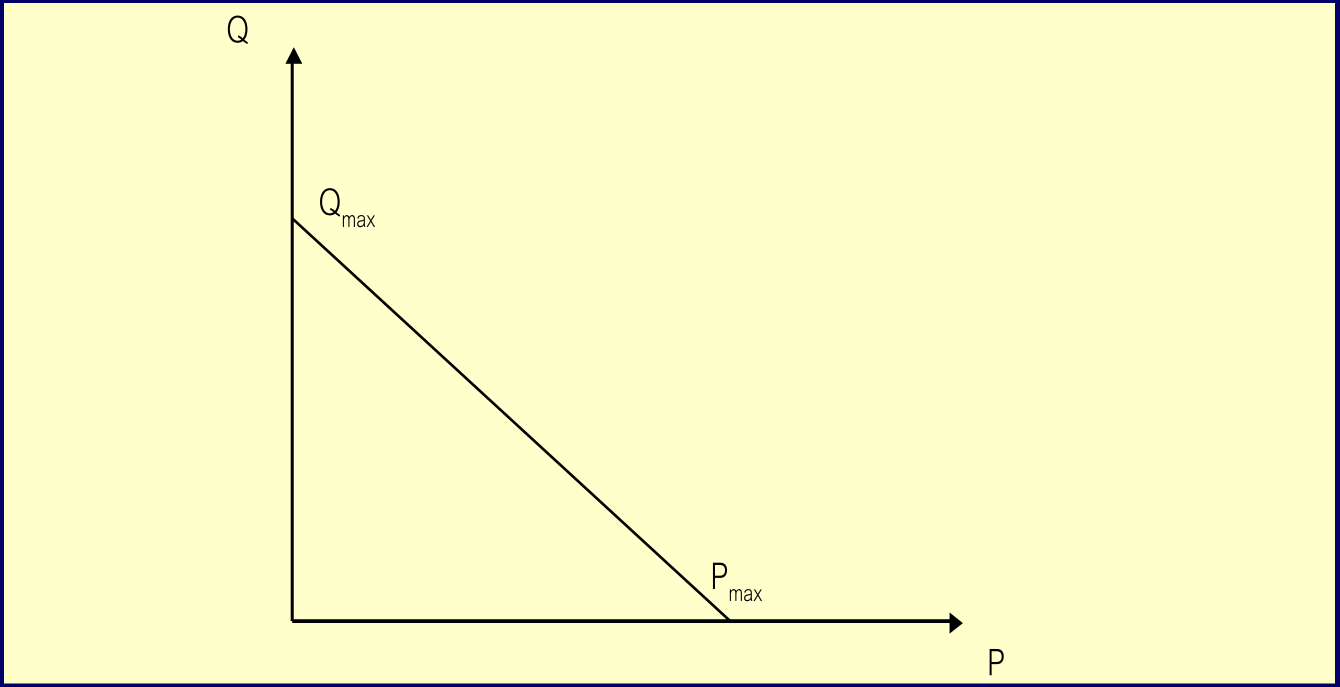
Minimum output

$$P = P_{\max} \quad and\; Q = 0$$

$$\tfrac{1}{2}\pi^2 D^2 NH \sin\phi \cos\phi = \frac{\pi DH^3 \sin^2\phi P}{12\eta l}$$

$$P = P_{\max} = \frac{6\pi DlN\eta}{H^2 \tan\phi}$$

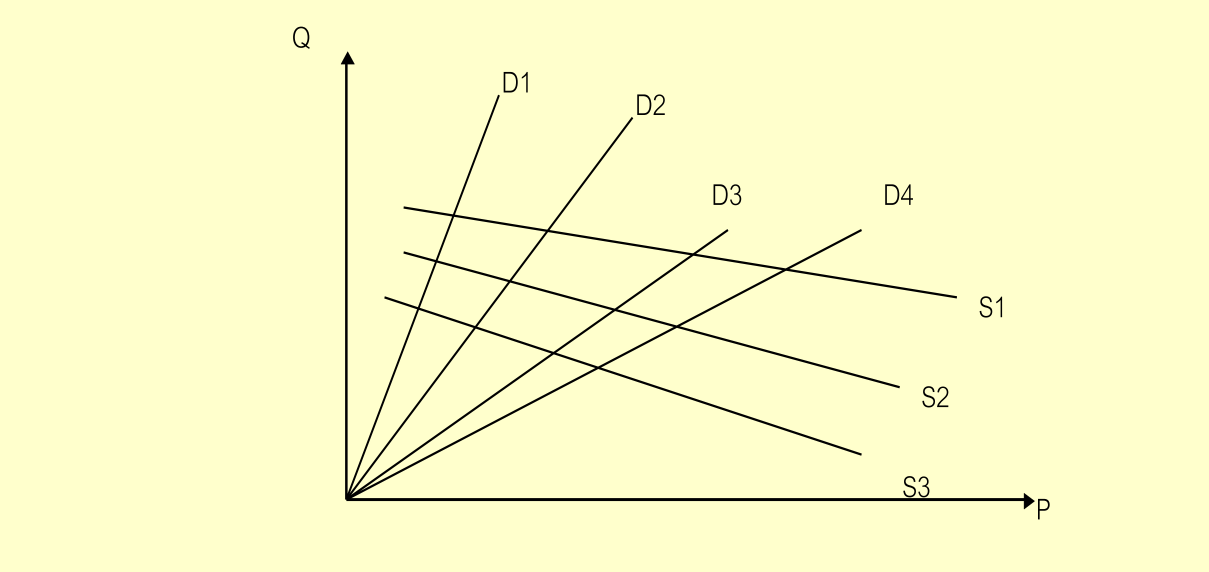
Screw characteristics



Screw characteristics (Maximum Q and P)

Relationship between the output and pressure

$$Q = KP = \frac{\pi R^4}{8\eta L} P$$



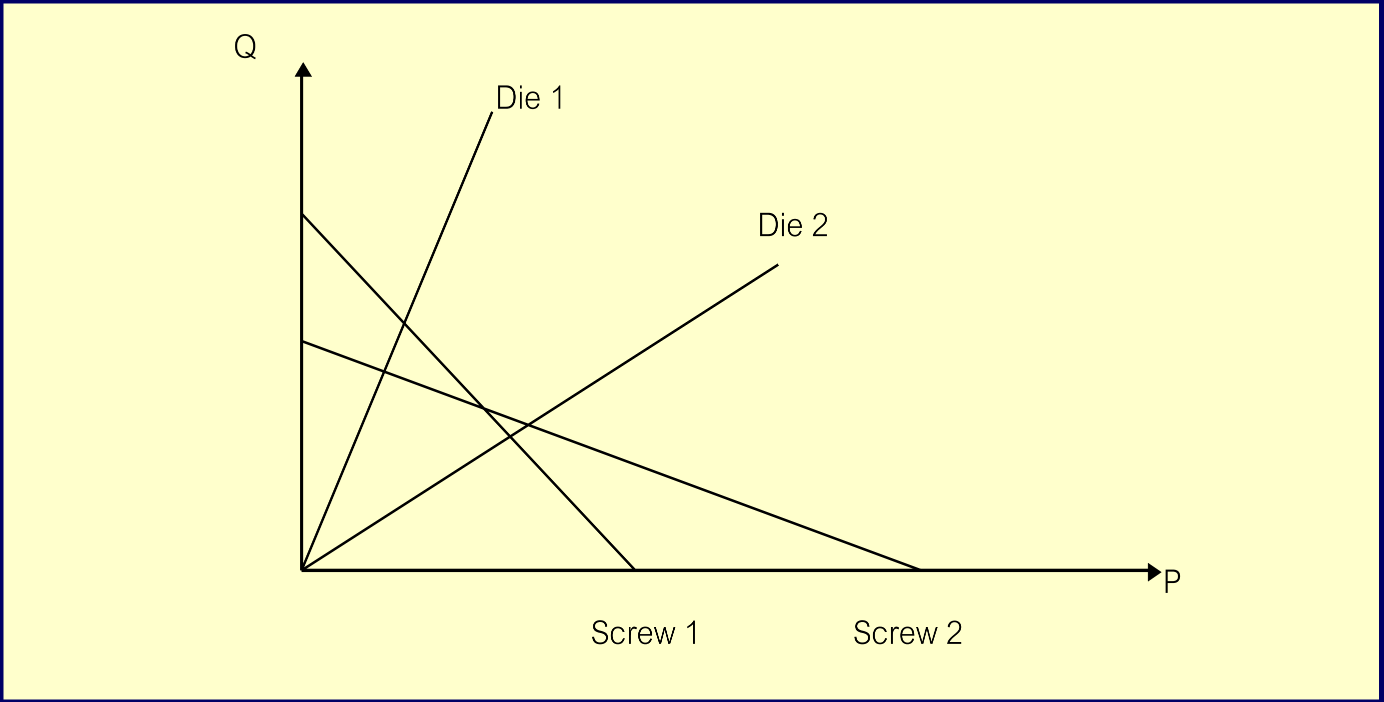
Screw and die design

Relationship between the output and pressure

From the equations of screw and die characteritics and the equation of output-pressure relationship, it can be seen that the operating point (all the lines) can be shifted depending on the following:

- Screw rotation speed (N)
- Die dimensions
- Polymer viscosity

Relationship between the output and pressure



Different configurations of the screw and die characteristics

Material characteristics

- **Elastic and viscous components**
- **Deborah number (Ndeb) - Involving the determination of material relaxation time (tm) and processing time (tp).**

$$N_{deb} = \frac{t_m}{t_p}$$

$$t_m = \frac{viscosity}{modulus}$$

Material characteristics

- If the Ndeb value is less than unity the process dominantly viscous
- if the Ndeb value is larger than unity the process is dominantly elastic.
- For example, a polymer having a viscosity value of 10^5 Nsm-2 and modulus of 10^3 Nm-2 undergoes an extrusion process for 10 seconds. The polymer will behave elastically.
- Elastic effects - Die swell, Sharkskin and Melt fracture.
- Viscous effects - Temperature rise and Chemical reactions related degradation.

The extrusion die

1. Basic flow patterns

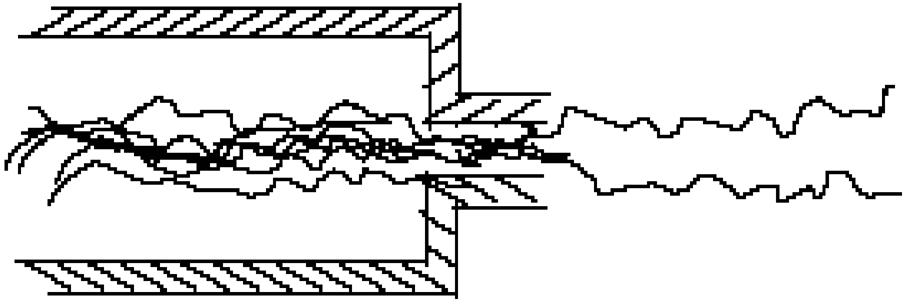
Maintain laminar flow

2. Die entry effects

Tensile stress exceed the tensile strength of the melt

→ extrudate will be of irregular shape

→ called *melt fracture*



The die entrance is tapered:

1. Eliminate the dead spots in the corners, maintaining a steady heat and shear history

2. Minimize the development of tensile stresses, and minimize distortion of the streamlines

Long die land → extend the process time which helps to eliminate memory of earlier processing, e.g. screw turning memory

Deborah Number, N_{deb}^{*}

Relaxation time – the characteristic timescale for which a melt has memory

-describe as its viscous and elastic responses to an applied stress

$$relaxation\_time = \frac{viscosity}{modulus} = \frac{Ns \times m^2}{m^2 \times N} = s$$

$$N_{deb} = \frac{relaxation\_time\_of\_material, in\_process}{timescale\_of\_process}$$

If $N_{deb} > 1$, process is dominantly elastic.

If $N_{deb} < 1$, process is predominantly viscous.

3. Die exit instabilities

sharkskin

-roughening of the surface of the extrudate

-caused by tensile stresses:

the melt, with max velocity at the center and zero at the wall, leaves the die lips

→material at the wall accelerate to the velocity at which the extrudate is leaving the die

→generate tensile stress.. If tensile stress exceeds tensile strength, surface ruptures.

orange peel

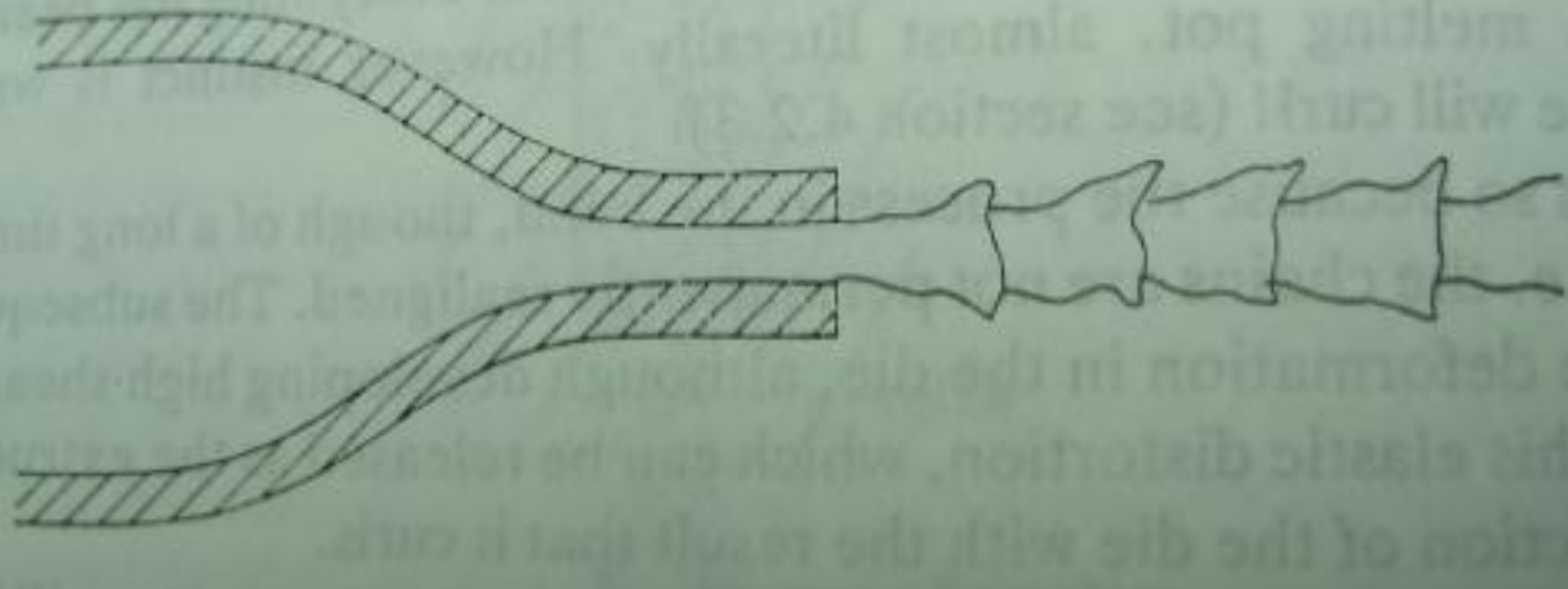
-when conditions become more intense, e.g. P at the extruder becomes excessive, or the die T drops

-coarser-grained appearance

<u>bambooing</u>

-the whole extrudate 'snaps back'

Extra heating of the die will often help to remedy these defects, by thermally relaxing the stresses and lowering viscosity



'Bambooing' at a die.

4. **Die swell**

-Effect in which the polymer swells as it leaves the die.

-Extrudate differs in its dimensions from those of the die orifice.

-Extruded rod has larger diameter and pipe has thicker walls, e.g. o.d. ↑, i.d. ↓

Result of the elastic component in the overall response of the polymer melt to stress. → recovery of the elastic deformation as the extrudate leaves the constraint of the die channel and before it freezes.