Introduction to extrusion

Single screw extruder

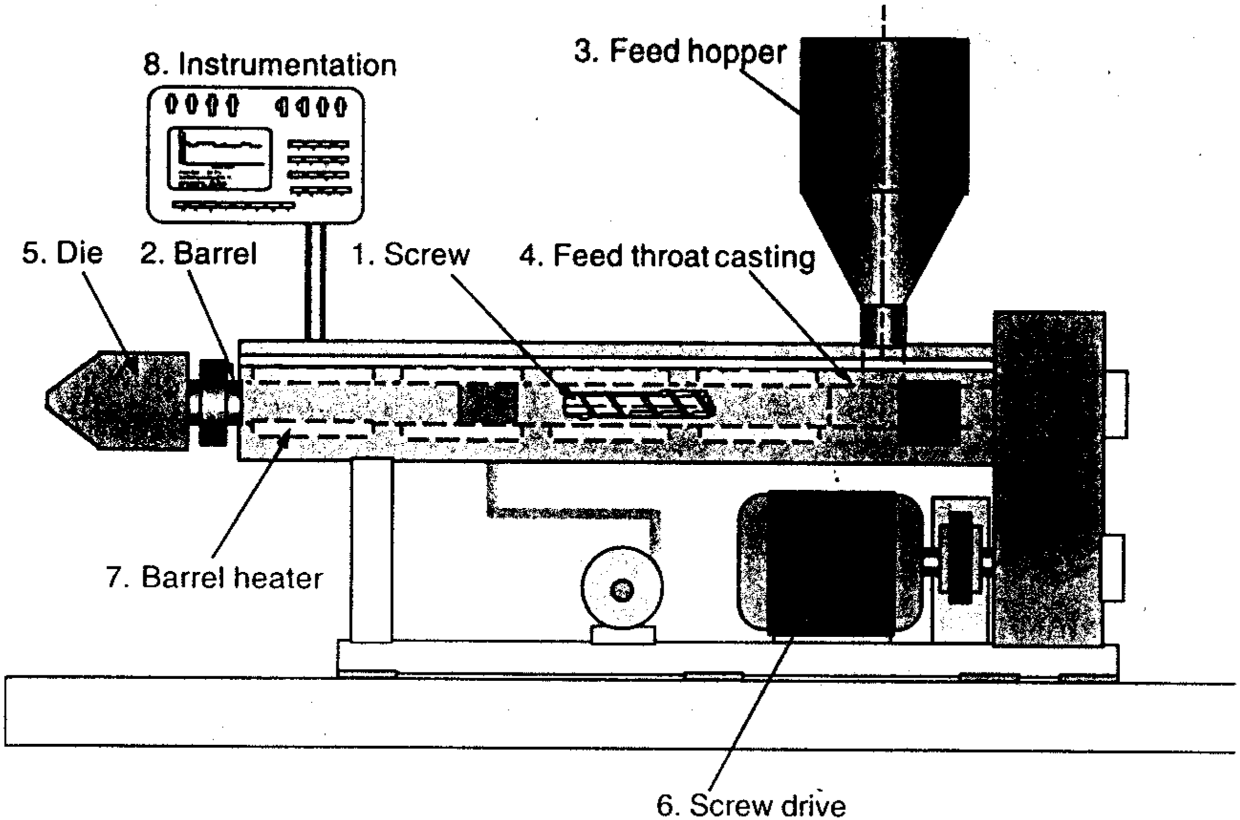
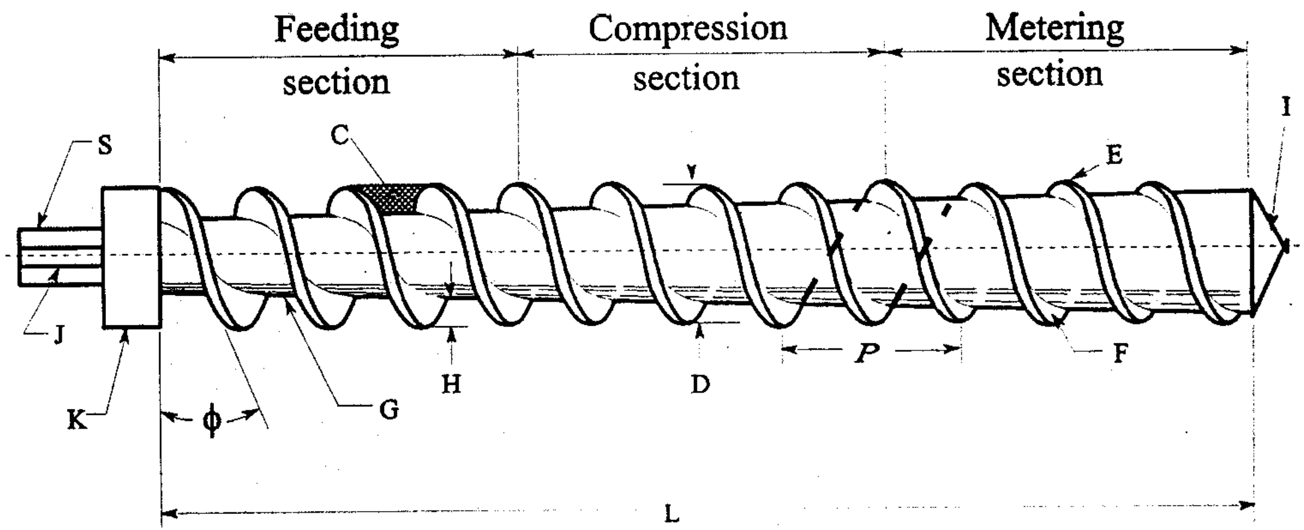


Figure 2.1 The main components of a single screw extruder

- Extrusion
  - a process for the continuous production of plastic products
  - Usually have a constant cross-section
  - Compounding, pipe, sheet, coated wire, fiber, profile, tubing
- Injection molding
  - a process for the discontinuous production of plastic parts
  - Usually do not have a constant cross-section
  - Reciprocating screw

Single screw



C. Channel
G. Root
K. Hub
ϕ. Helix angle

D. Diameter
H. Channel depth
L. Length

E. Flight land
I. Tip
P. Pitch or lead

F. Flight
J. Key
S. Shank

Figure 1.3 Geometric features of a single-screw (double-flighted)

Determines the stability of the process and the quality of the product.
need to improve mixing performance

Functions of an extruder

- Conveying
- Heating and melting
- Mixing
- Die forming
- Degassing

Conveying

In the barrel, due to drag forces between the plastic and the barrel
In the die, due to the pressure developed by the screw

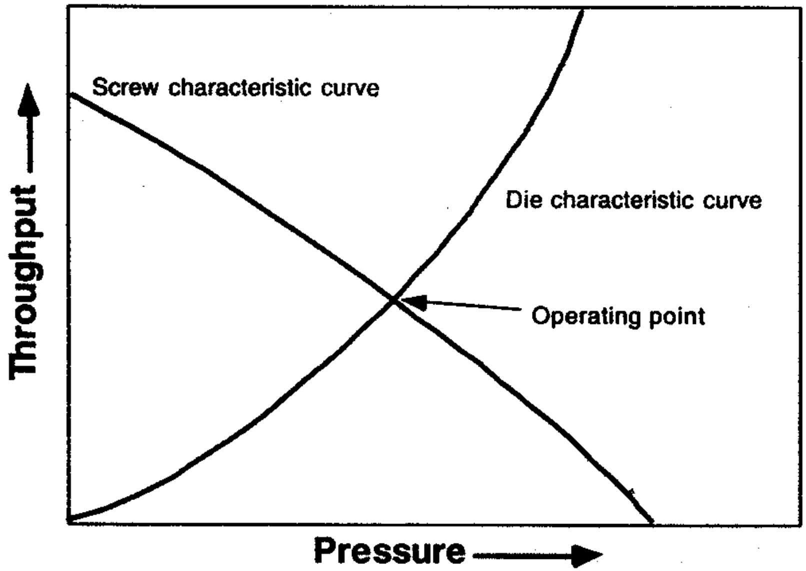


Figure 2.4 Screw and die characteristic curves

Determined by the machine(screw,die) geometry, operating conditions, the flow properties of the plastic.

Shear rate

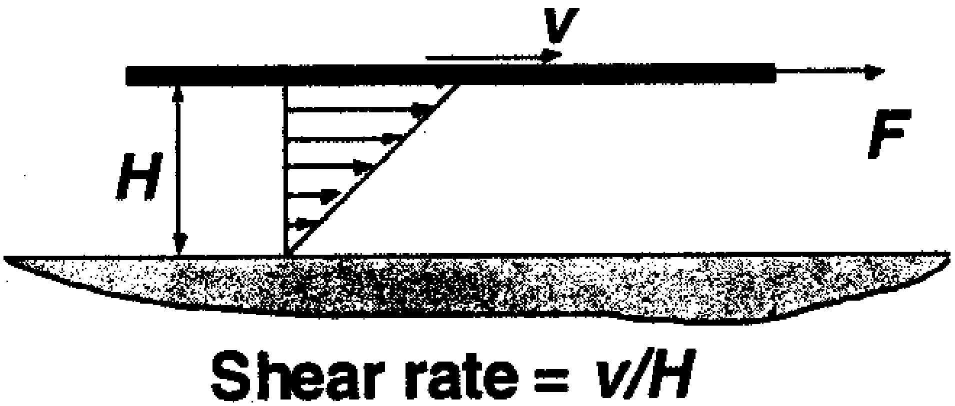


Figure 2.7 Illustration of shear rate

Roughly equals to the screw rpm

Heating

Heat from heating elements

The frictional and viscous heat generation with the plastic

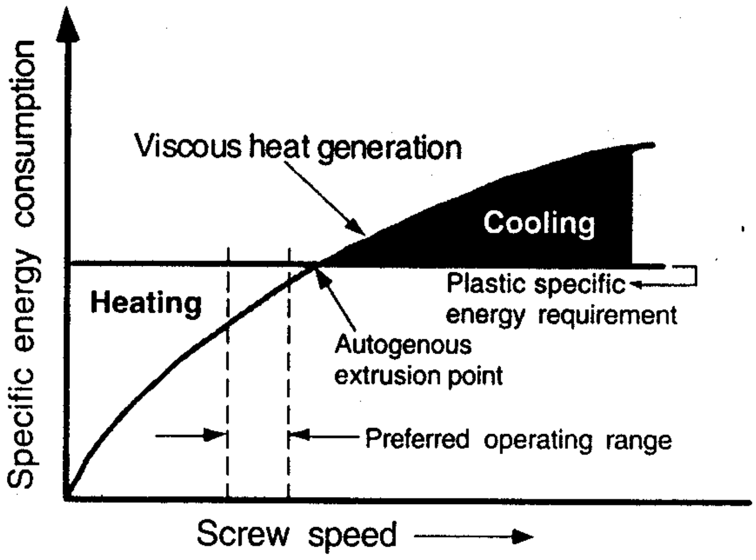


Figure 2.8 Specific energy consumption versus screw speed

Frictional and viscous heat generation is a transformation of mechanical energy from the extruder drive into thermal energy to increase the plastic temperature.

Melting mechanism

Clearance is 1/1000 of the barrel diameter

Clearance determines the melting rate

(a)

(b)

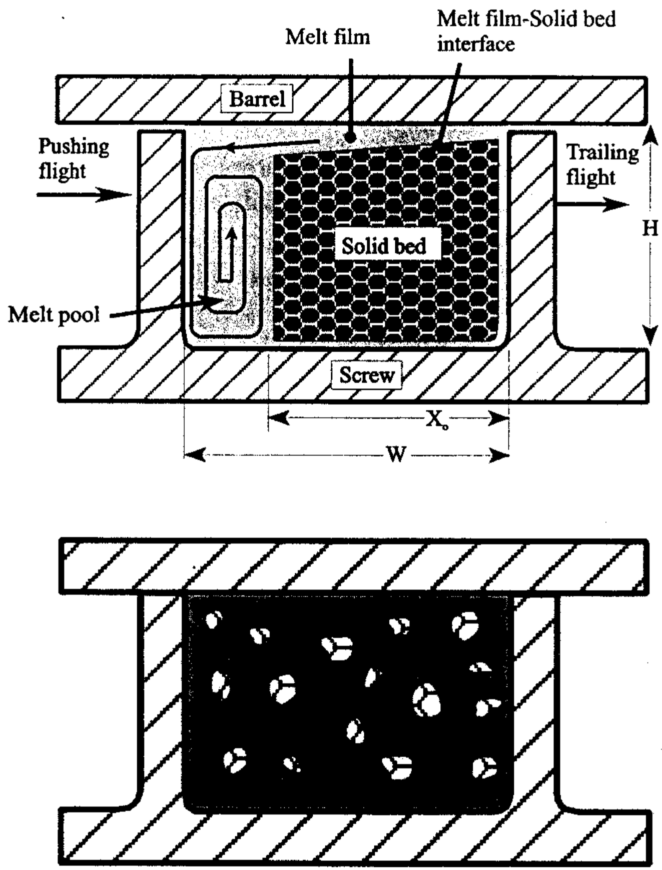


Figure 2.7 Two types of melting mechanisms: (a) Dissipative melting of solid bed; (b) Conduction melting after solid bed breakup (color version is presented in Appendix A)

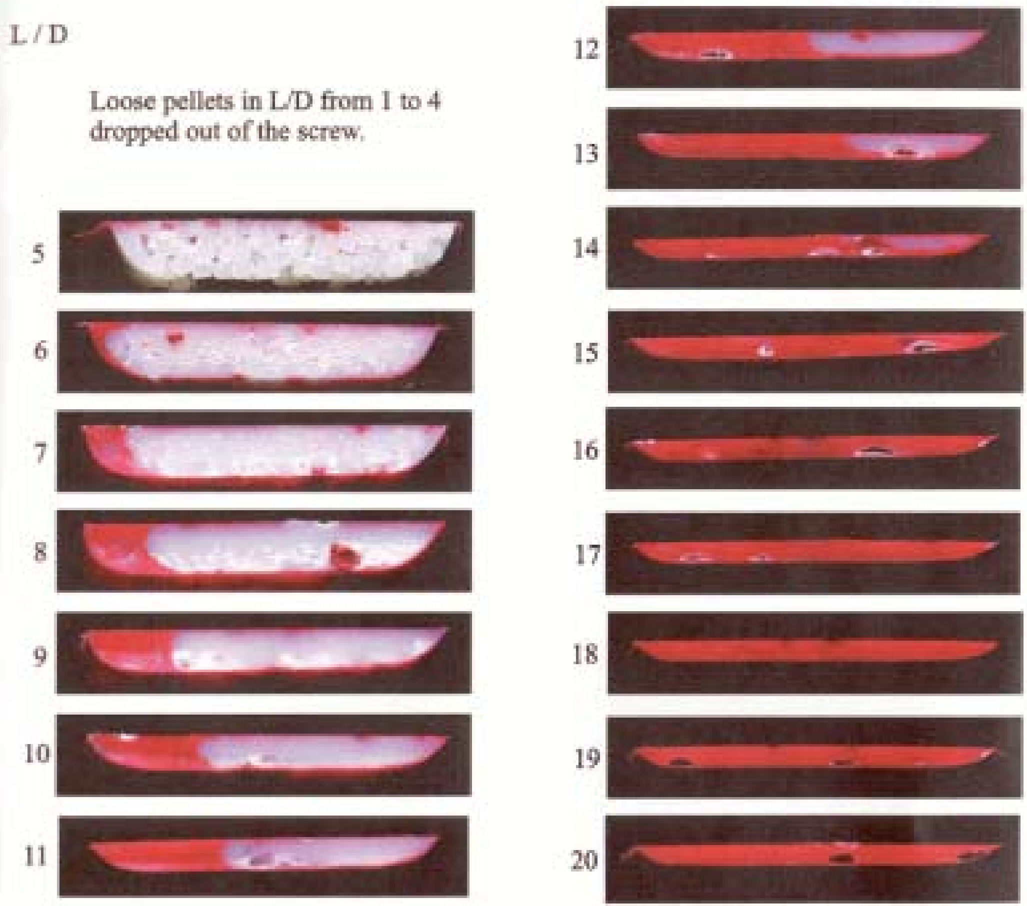
When the barrel temperature increases

- the amount of heat for melting from the barrel heater increases
- higher barrel temperature reduces the viscosity
- viscous heat generation is reduced

→ Counter effect exists

Melting mechanism

Melting length
2-3 diameters
for twin screw



63.5 mm (2.5 in.) D., L/D = 26, extruder, running acrylonitrile butadiene styrene copolymer (ABS) pellets.
40 rpm – 34.9 kg/h (77 lbs/h), 262 °C melt, 7.59 MPa (1,100 psi) head pressure

Figure 2.1 Cross-sections of ABS strip along screw channel from screw-freezing experiment (courtesy of Mark Spalding, Kun S. Hyun, and Kevin Hughes, the Dow Chemical Co. USA)

Melting length,
10-15 diameters

Melt temperature distribution

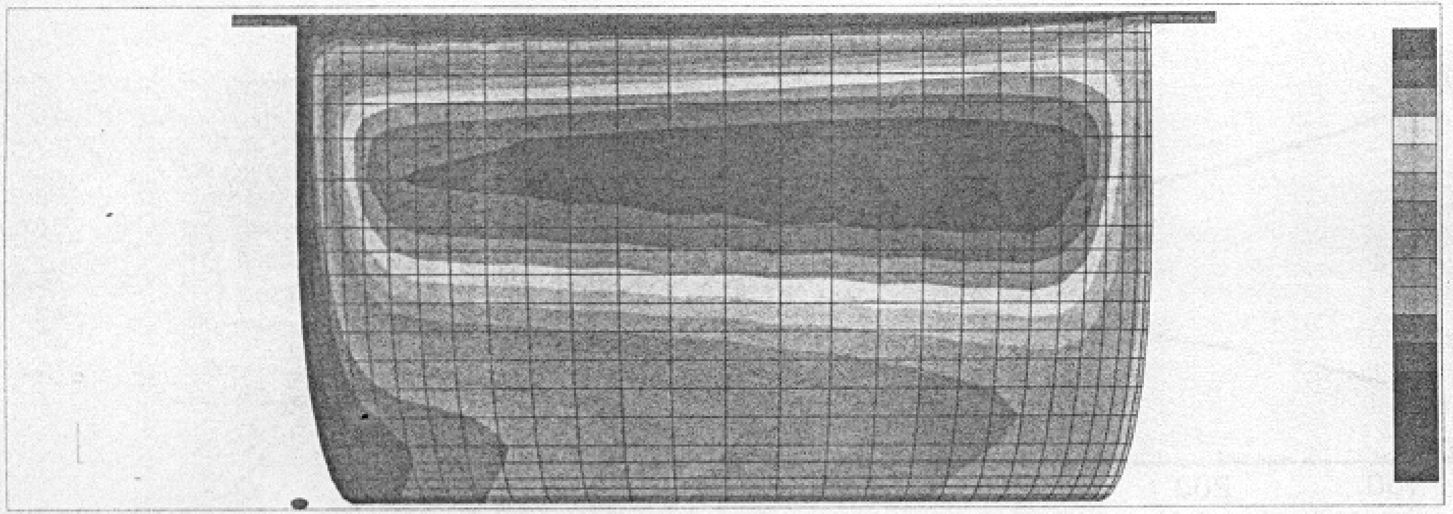


Figure 2.13 Melt temperature distribution in screw channel; barrel temperature is 175 °C

Recirculating flow → non-uniform mixing
non-uniform temp.

→ Need efficient mixing device to improve the melt quality

Mixing

Splitting & reorientation

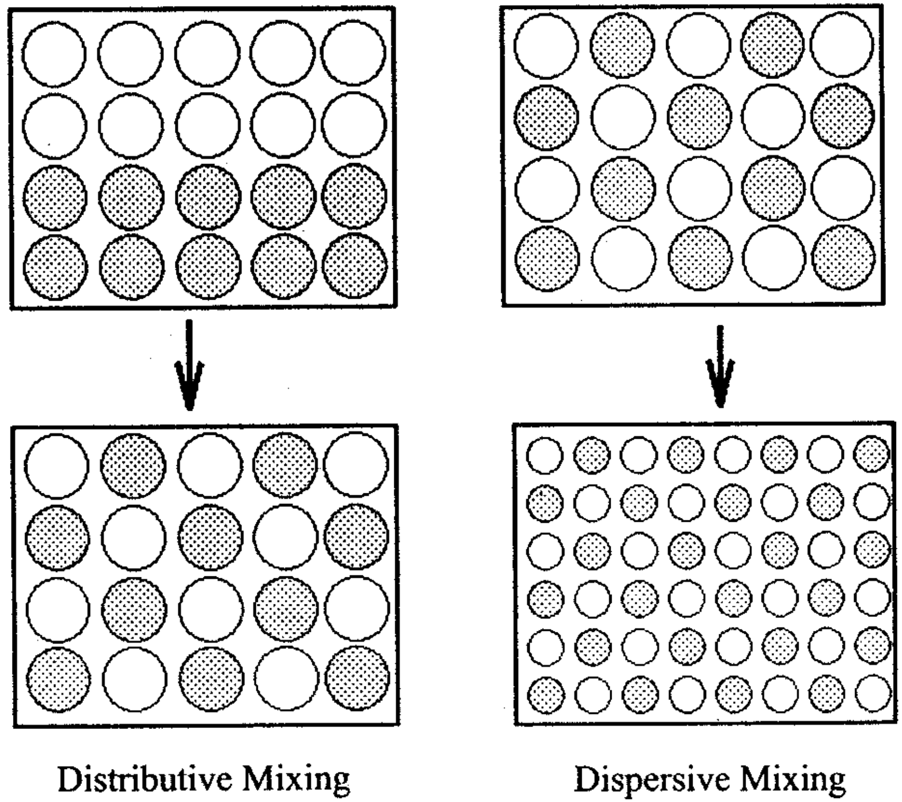


Figure 2.13 Distributive mixing and dispersive mixing

High stress & elongational stress

(twin screw)

Die design

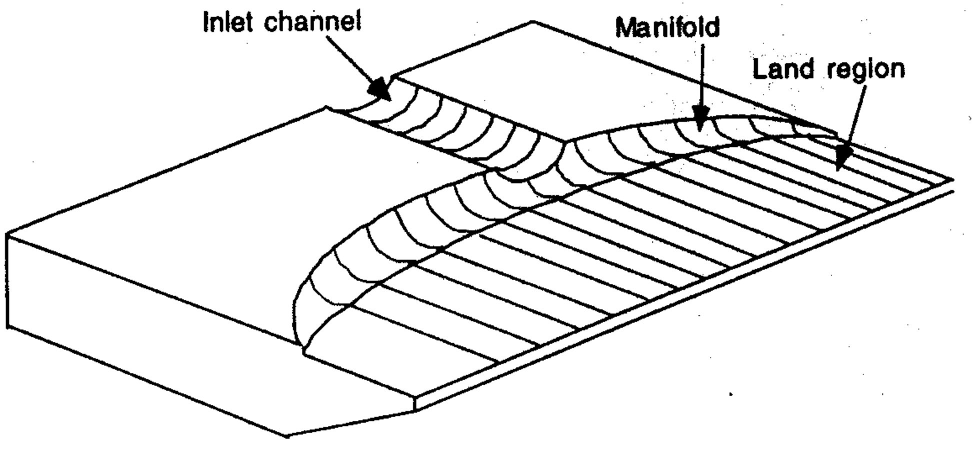
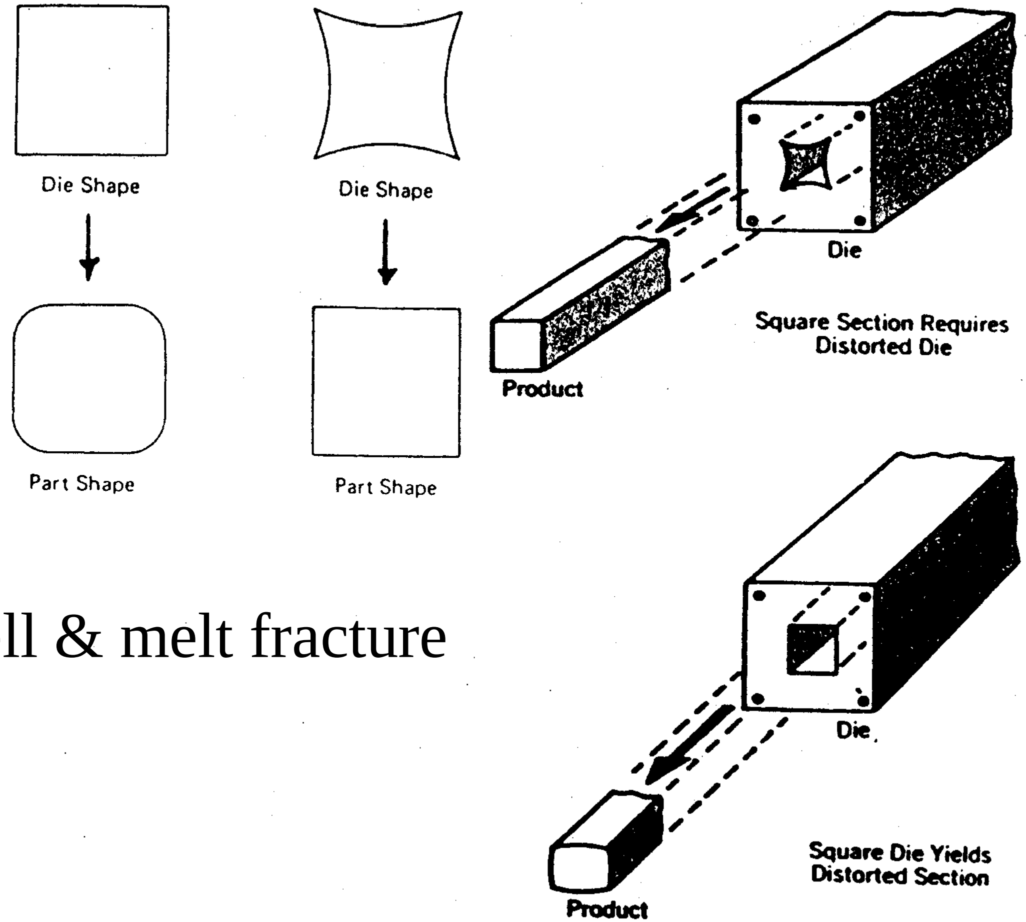


Figure 2.17 Coathanger manifold for sheet and flat film extrusion

Uniform flow, if not, thickness variation
uniform temp, if not, distortion
land length reduces from middle to the side
fine tuning: mechanical, thermal

Die design



Die swell & melt fracture

Figure 5.16 Effect of die orifice shape on 'square' extrudate.

Degassing

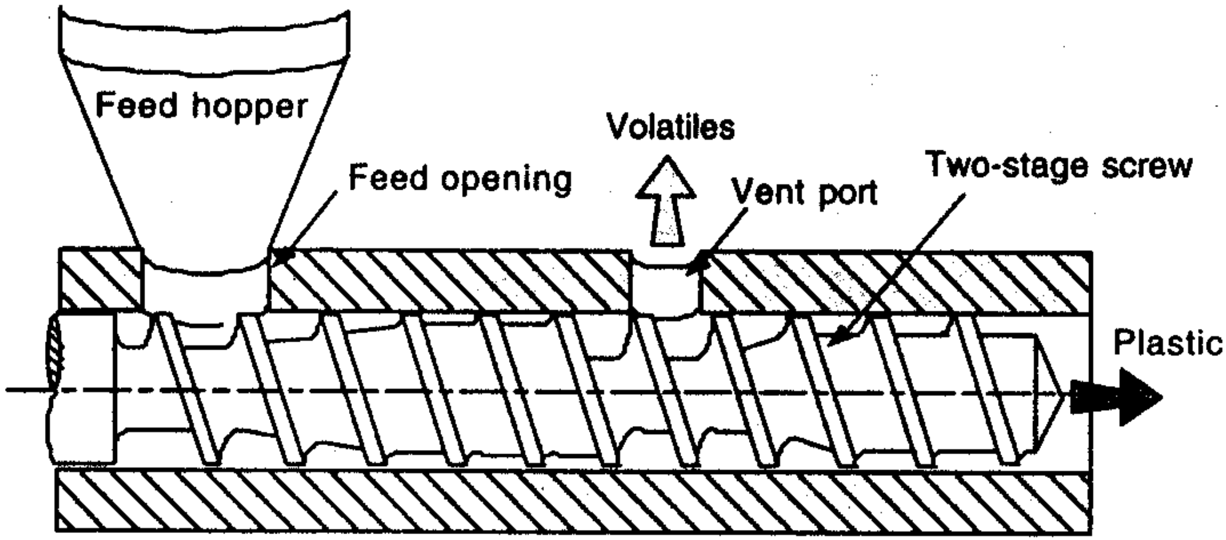


Figure 2.18 A two-stage extruder screw

Vent port: partially filled, zero-pressure
Downstream has larger conveying capability than upstream to prevent vent-up.

Twin screw extrusion

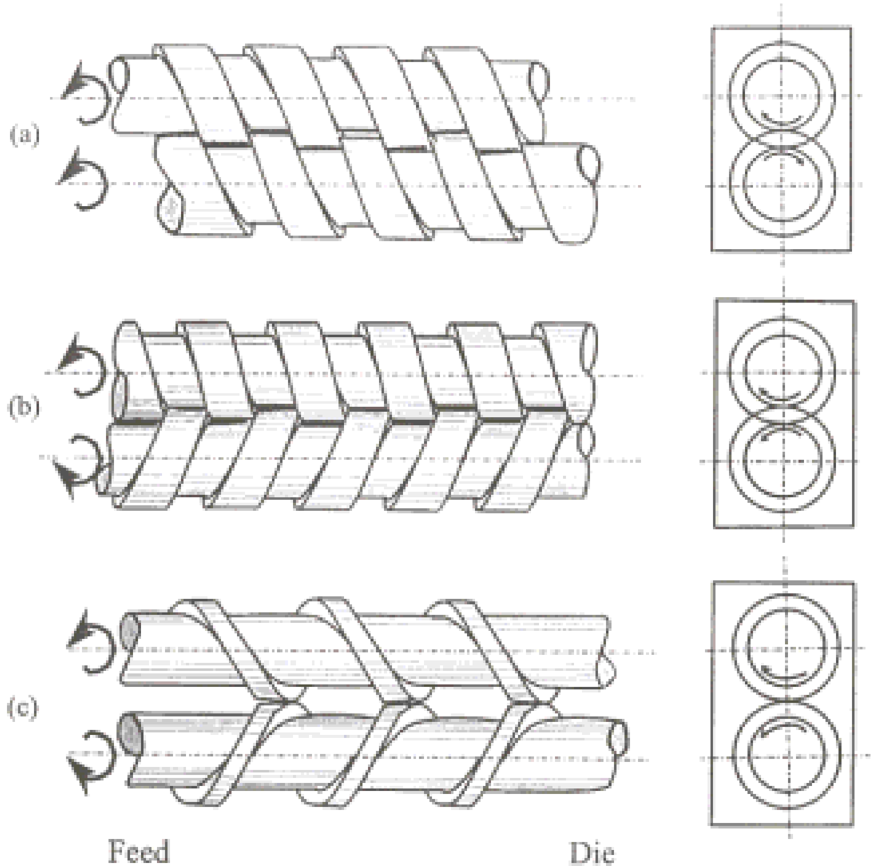


Figure 1.6 Three common types of twin-screw extruders: (a) Intermeshing co-rotating; (b) Intermeshing counter-rotating; (c) Non-intermeshing counter-rotating

Twin screw elements

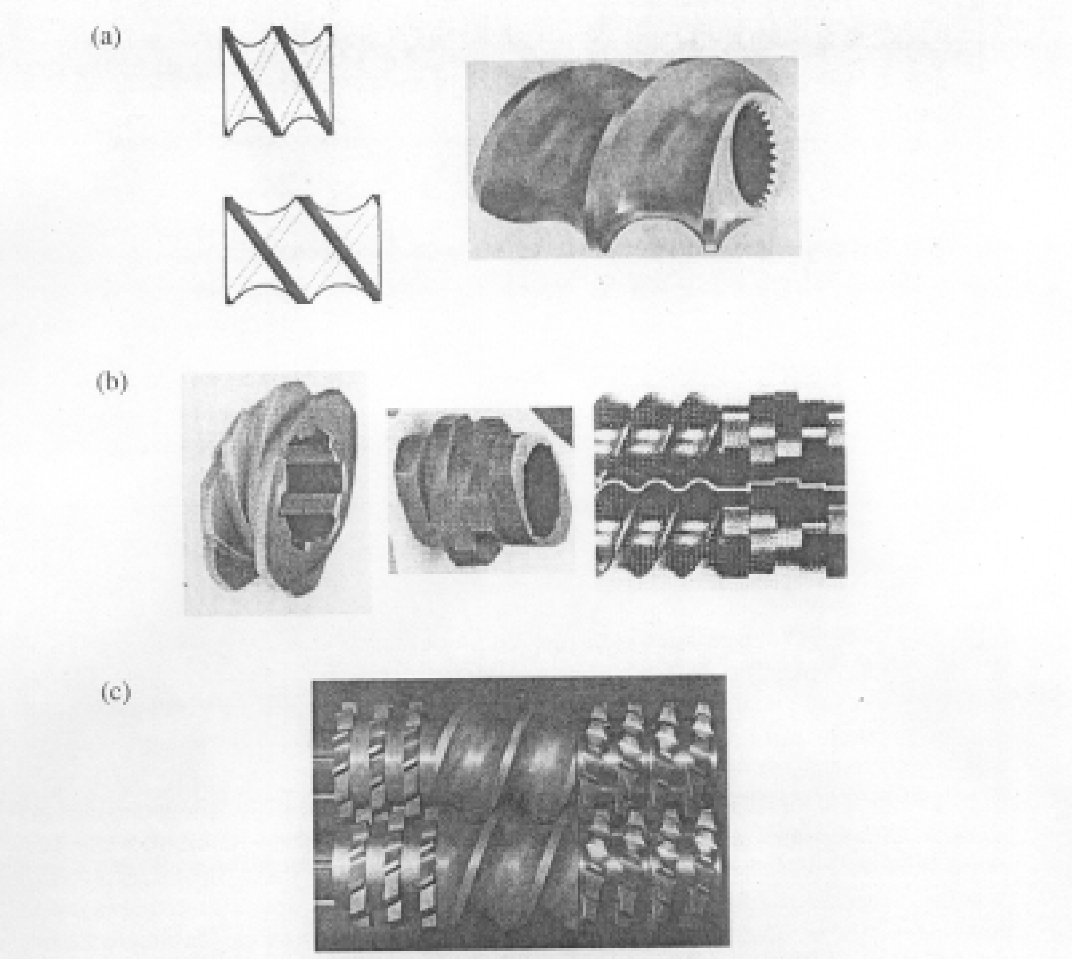


Figure 7.2 Three different kinds of 2-lobe screw elements for modular intermeshing co-rotating twin-screws: (a) Conveying elements; (b) Kneading blocks; (c) Mixing blocks (Reproduced from Ref. [1])

Screw configuration

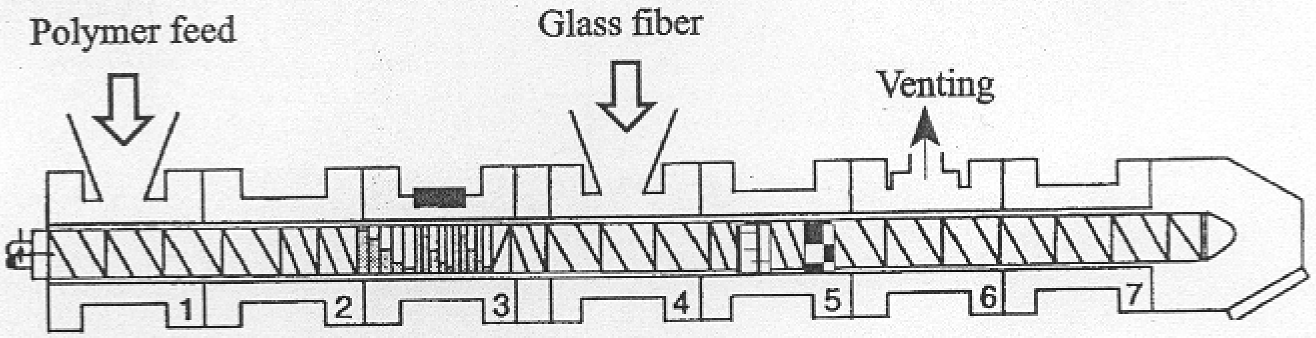


Figure 7.3 Screw configuration assembled from screw elements for compounding glass fiber (redrawn from Ref. [1])

Melt temperature and pressure

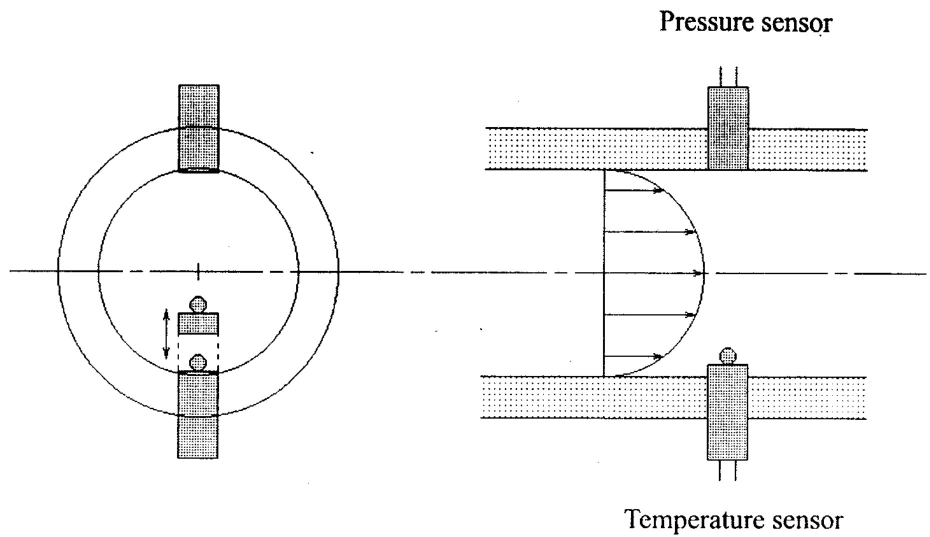


Figure 2.9 Melt temperature and melt pressure measurements at adaptor

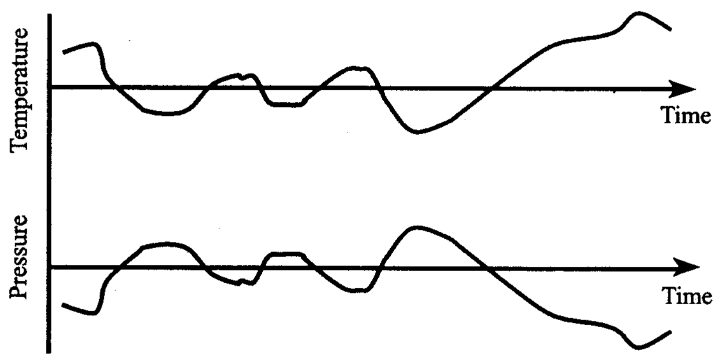


Figure 2.10 Melt temperature and melt pressure recordings with time

Why SPC in polymer processing?

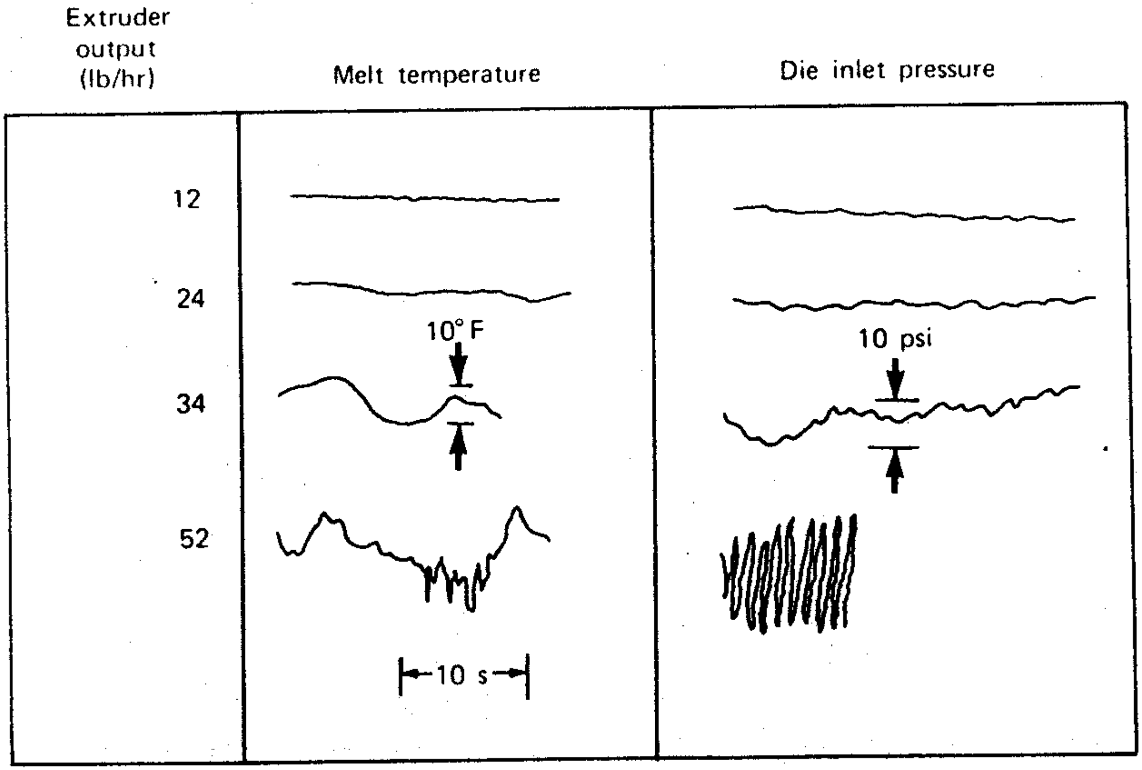


Fig. 13.3 Types of actual melt temperature and die inlet pressure variations obtained with LDPE. The last two would result in product nonuniformities in the machine direction. [Reprinted with permission from H. B. Kessler, R. M. Bonner, P. H. Squires and C. F. Wolf, *Soc. Plast. Eng. J.*, **16**, 267 (1960).]

Melt fracture

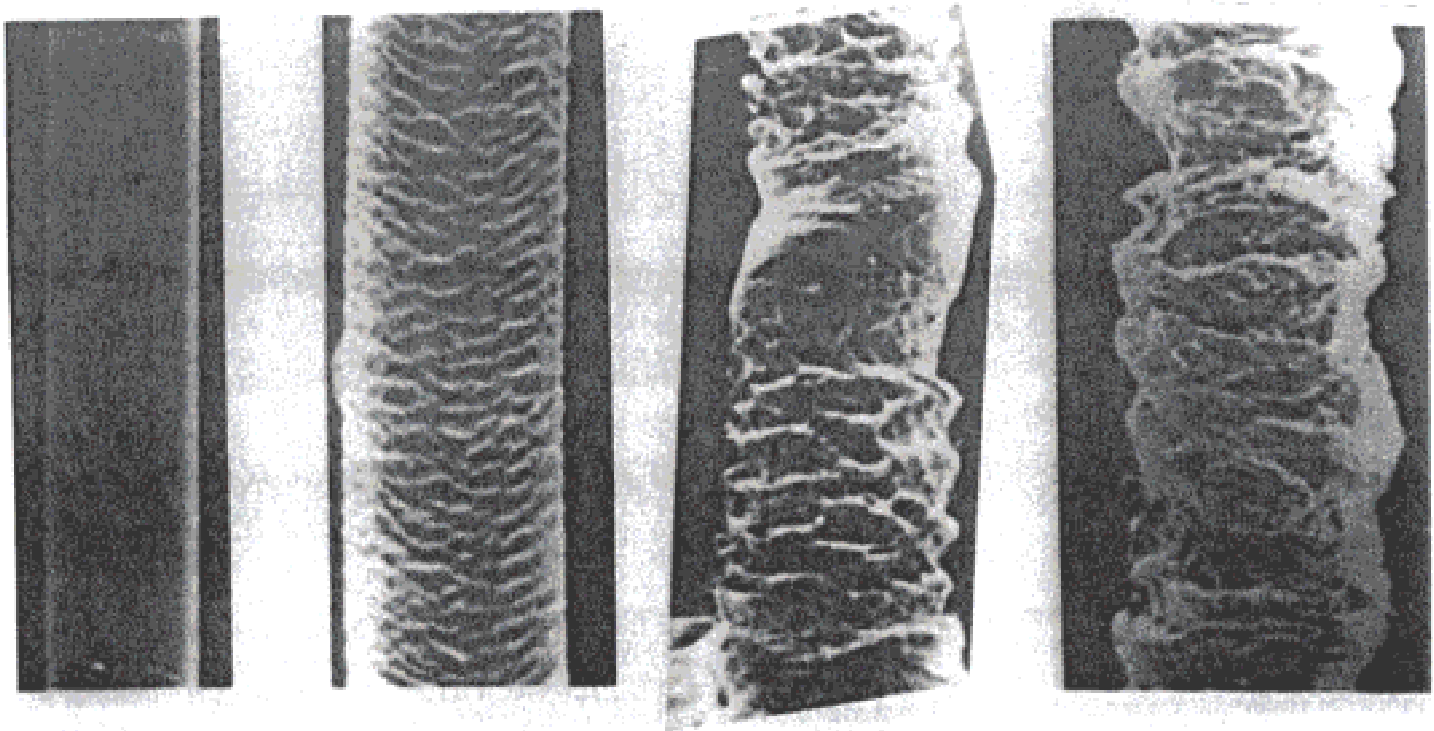
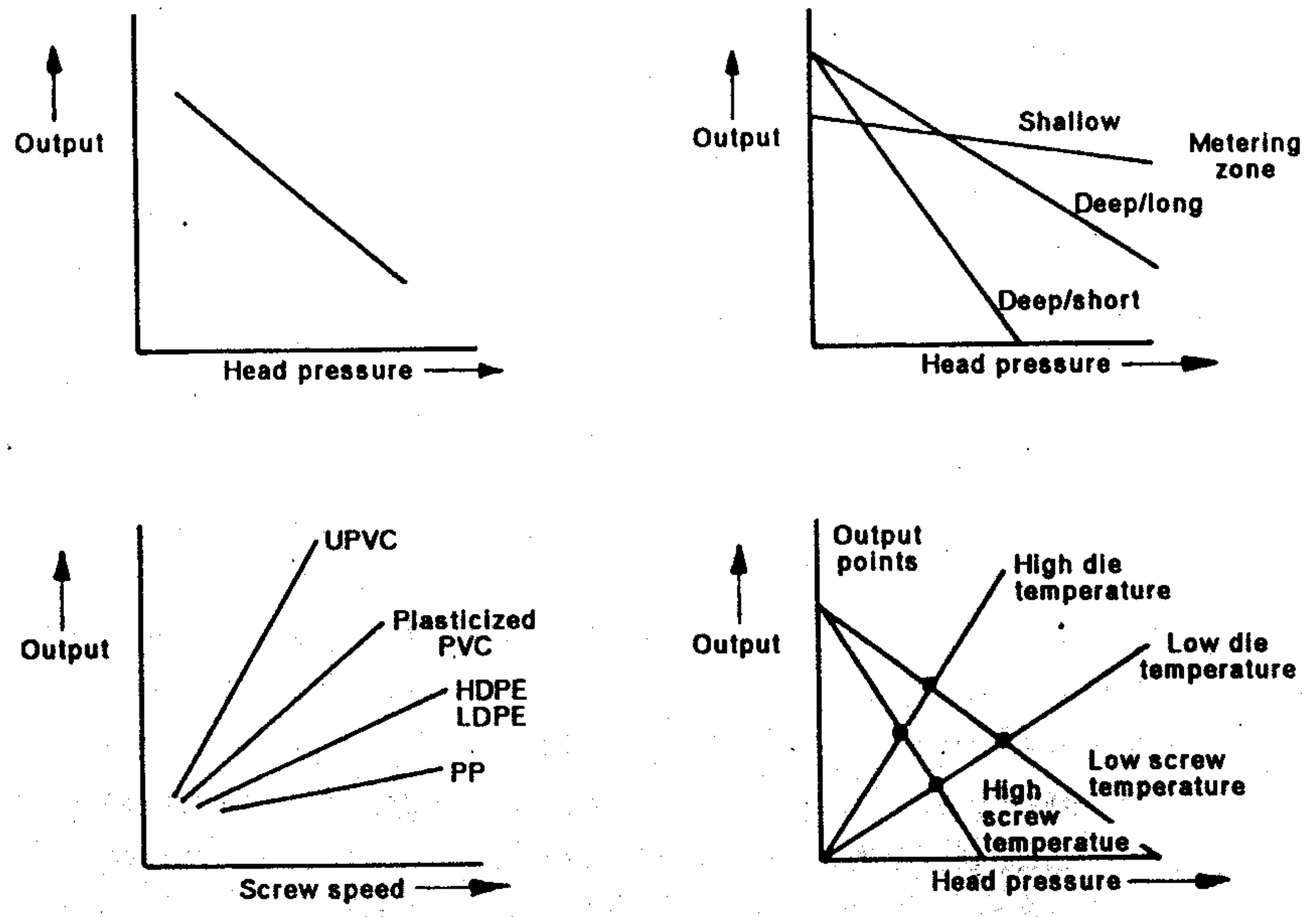
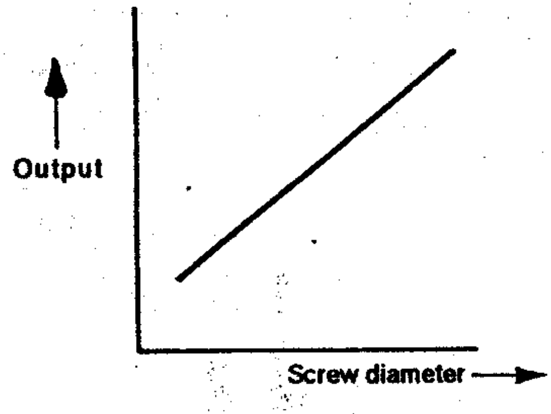


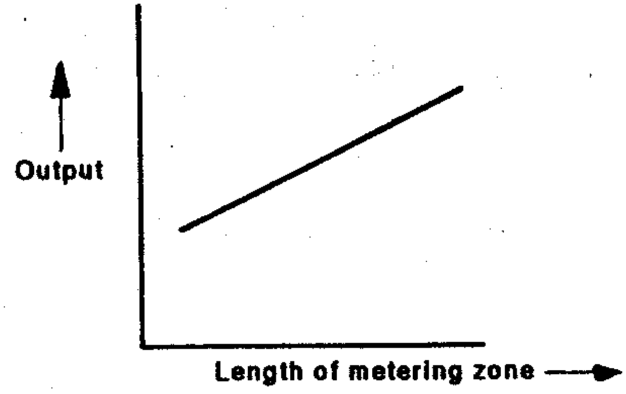
Figure 7.8 LLDPE extrudates obtained from a capillary at different apparent shear rates, $\dot{\gamma}_a$. From left to right the values of $\dot{\gamma}_a$ are 37, 112, 750, and 2250 s^{-1}. (Data from R. H. Moynihan, *The Flow at Polymer and Metal Interfaces*. Ph.D. Thesis, Department of Chemical Engineering, Virginia Tech., Blackburg, VA, 1990.)

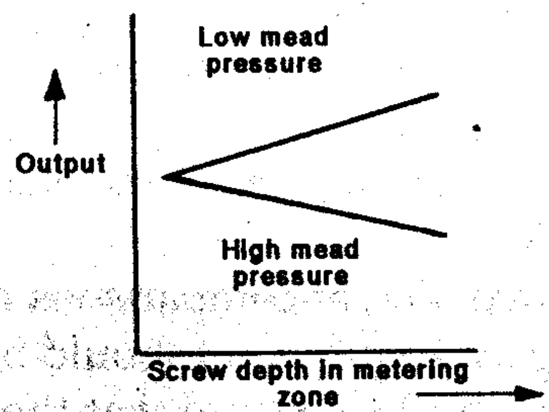
Operations

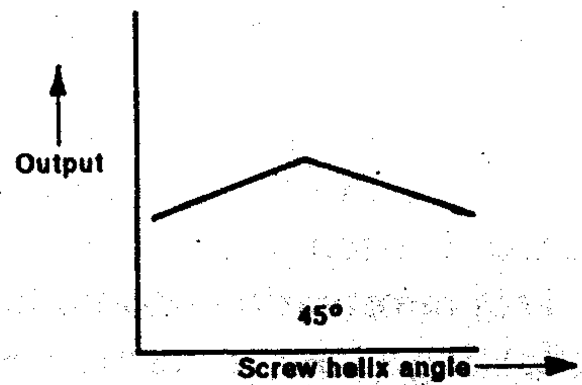

Output
Head pressure
Output
Shallow
Metering zone
Deep/long
Deep/short
Head pressure
Output
UPVC
Plasticized PVC
HDPE LDPE
PP
Screw speed
Output points
High die temperature
Output
Low die temperature
Low screw temperature
High screw temperatue
Head pressure

Operations

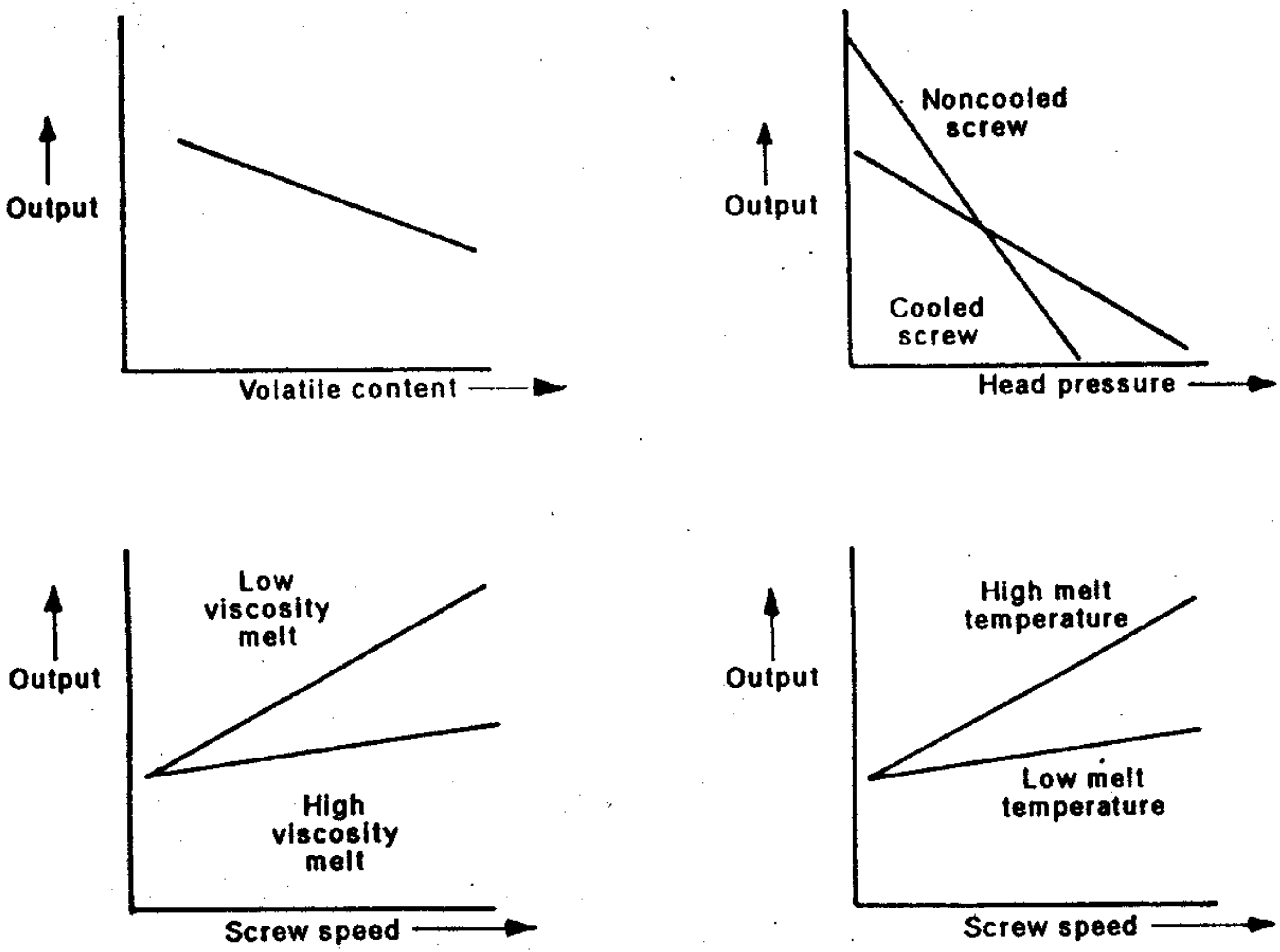

Output
Screw diameter


Output
Length of metering zone

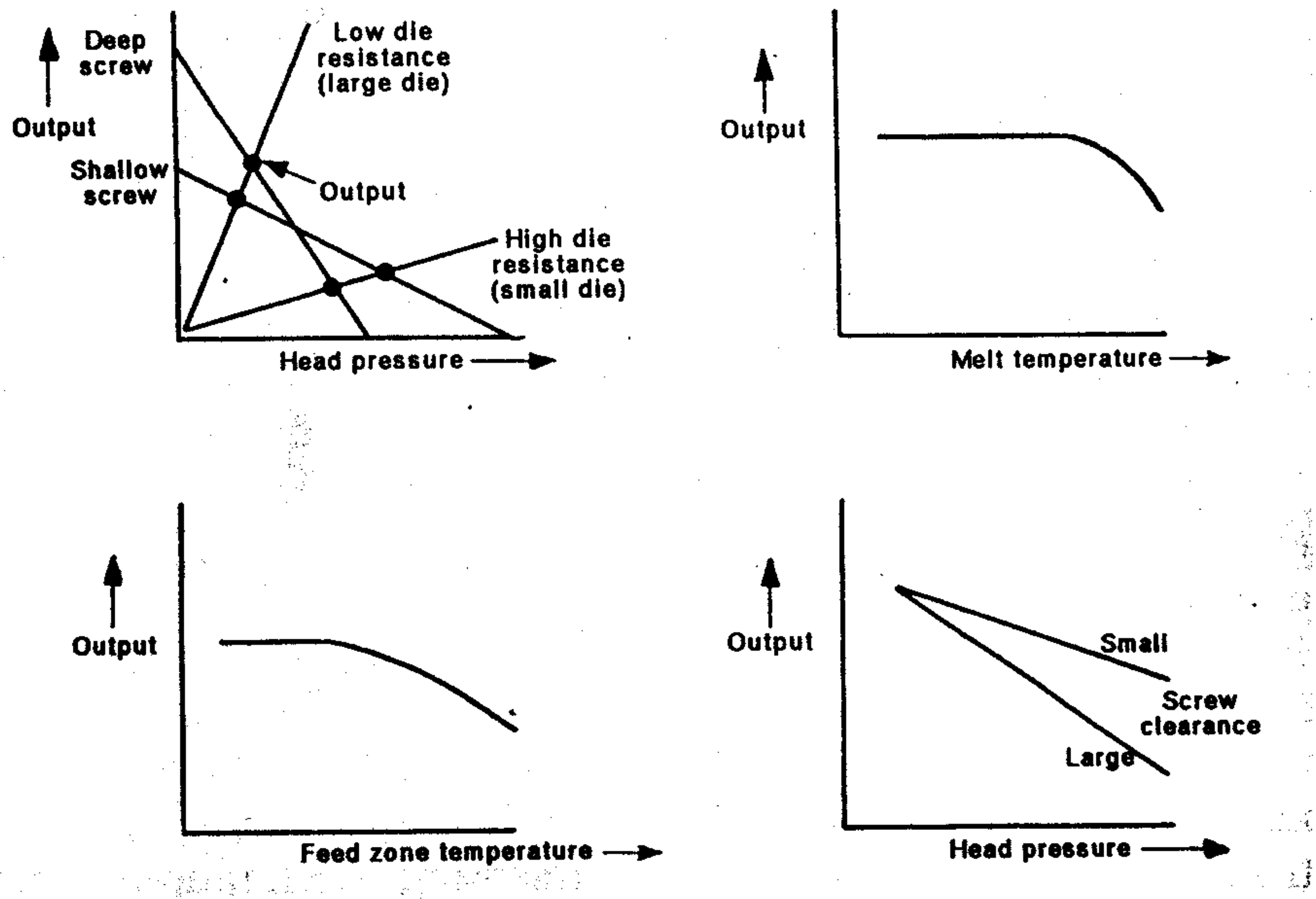

Output
Low mead pressure
High mead pressure
Screw depth in metering zone


Output
45°
Screw helix angle

Operations


Output
Volatile content
Output
Noncooled screw
Cooled screw
Head pressure
Output
Low viscosity melt
High viscosity melt
Screw speed
Output
High melt temperature
Low melt temperature
Screw speed

Operations


Deep screw
Output
Shallow screw
Low die resistance (large die)
Output
High die resistance (small die)
Head pressure
Output
Melt temperature
Output
Feed zone temperature
Output
Small
Screw clearance
Large
Head pressure

Important process parameters

- Extrudate dimensions
- Diehead pressure
- Barrel pressure
- Motor load
- Screw speed
- Take-up speed
- Power consumption
- Cooling rate
- Barrel and die temperature
- 50-100 process parameters

Important material properties

- Bulk density
- Compressibility
- Friction coefficient
- Melting point
- Stabilizer level and type
- Specific heat
- Thermal conductivity
- Additives
- Rheological properties → QC

Temperature control

- Typical process temp
  - 50C above the melting temp for semicrystalline polymer
  - 100C above the glass transition temp for amorphous
- Keep temp high to reduce melt viscosity and make the material easily processible
- Keep temp low to reduce degradation
- Keep feed throat temp low to avoid premature heating
  - As it causes the plastic to stick to the wall, resulting in lower output and unstable flow
- To keep the dieheat pressure fluctuation minimum
- To keep the melt temp variation minimum