4 Analytical Procedures for Troubleshooting Extrusion Screws

Extrusion is one of the most widely used polymer converting operations for manufacturing blown film, pipes, sheets, and laminations, to list the most significant industrial applications. Fig. 4.1 shows a modern large scale machine for making blown film. The extruder, which constitutes the central unit of these machines, is shown in Fig. 4.2. The polymer is fed into the hopper in the form of granulate or powder. It is kept at the desired temperature and humidity by controlled air circulation. The solids are conveyed by the rotating screw and slowly melted, in part, by barrel heating but mainly by the frictional heat generated by the shear between the polymer and the barrel (Fig. 4.3). The melt at the desired temperature and pressure flows through the die, in which the shaping of the melt into the desired shape takes place.

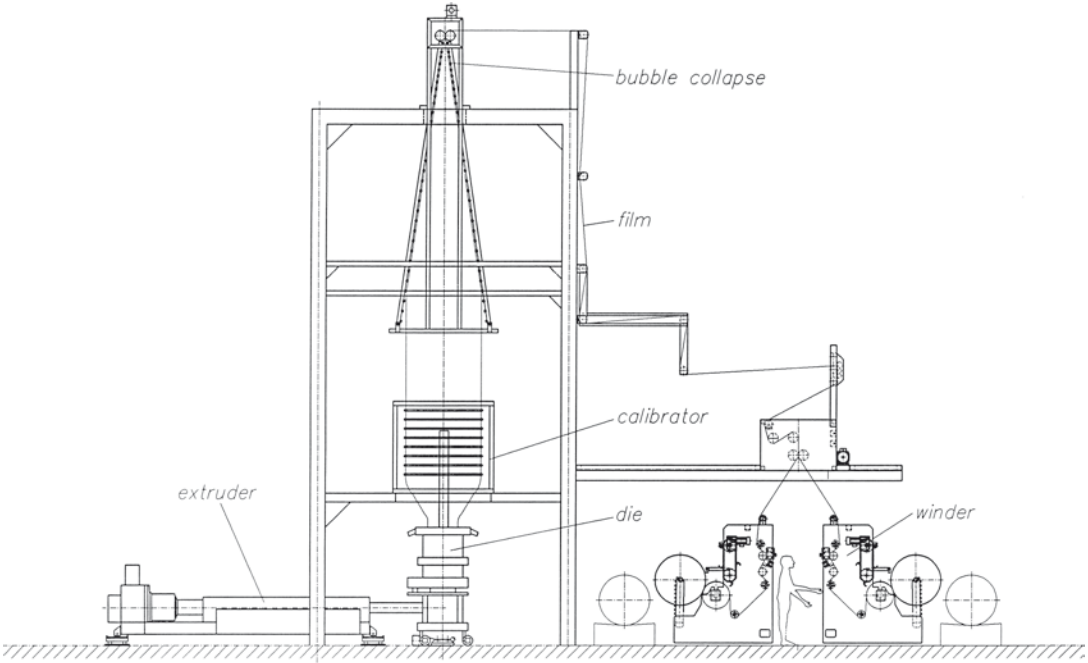

FIGURE 4.1 Large scale blown film line [2]

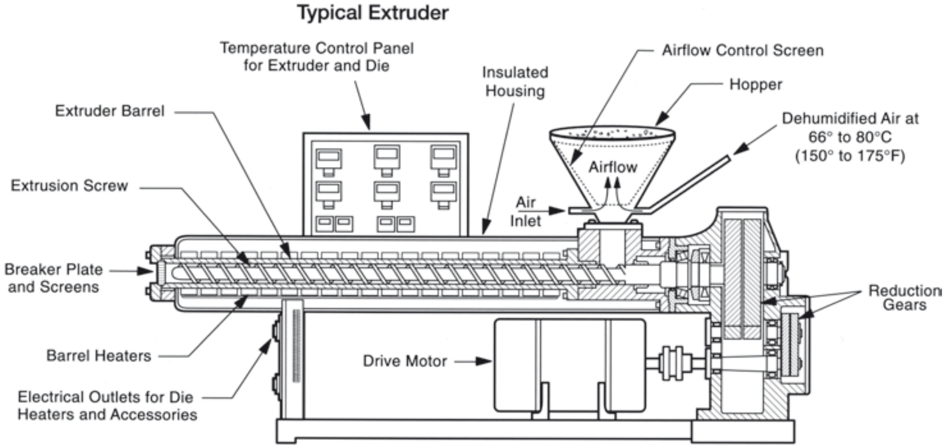

FIGURE 4.2 Extruder with auxialiary equipment [3]

4.1 Three-Zone Screw

Basically extrusion consists of transporting the solid polymer in an extruder by means of a rotating screw, melting the solid, homogenizing the melt, and forcing the melt through a die (Fig. 4.3).

The extruder screw of a conventional plasticating extruder has three geometrically different zones (Fig. 4.4), whose functions can be described as follows:

Feed zone: Transport and preheating of the solid material
Transition zone: Compression and plastication of the polymer
Metering zone: Melt conveying, melt mixing and pumping of the melt to the die

However, the functions of a zone are not limited to that particular zone alone. The processes mentioned can continue to occur in the adjoining zone as well.

Although the following equations apply to the 3-zone screws, they can be used segmentwise for designing screws of other geometries as well.

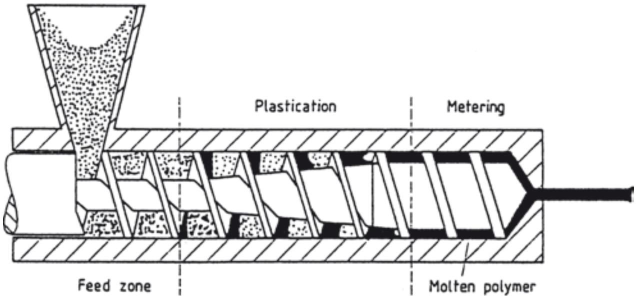

FIGURE 4.3 Plasticating extrusion [4]

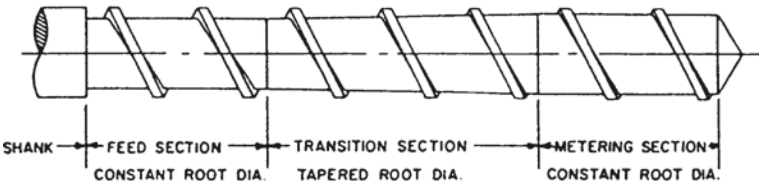

FIGURE 4.4 Three-zone screw [10]

4.1.1 Extruder Output

Depending on the type of extruder, the output is determined either by the geometry of the solids feeding zone alone, as in the case of a grooved extruder [7], or by the solids and melt zones to be found in a smooth barrel extruder. A too high or too low output results when the dimensions of the screw and die are not matched with each other.

4.1.2 Feed Zone

A good estimate of the solids flow rate can be obtained from Eq. (4.1) as a function of the conveying efficiency and the feed depth. The desired output can be found by simulating the effect of these factors on the flow rate by means of Eq. (4.1).

Calculated Example

The solids transport is largely influenced by the frictional forces between the solid polymer and barrel and screw surfaces. A detailed analysis of the solids conveying mechanism was performed by Darnell and Mol [8]. The following example presents an empirical equation that provides good results in practice [1].

The geometry of the feed zone of a screw (Fig. 4.5) is given by the following data:

Barrel diameter	D_b	= 30 mm
Screw lead	s	= 30 mm
Number of flights	ν	= 1
Flight width	w_{FLT}	= 3 mm
Channel width	W	= 28.6 mm
Depth of the feed zone	H	= 5 mm
Conveying efficiency	η_F	= 0.436
Screw speed	N	= 250 rpm
Bulk density of the polymer	ρ_o	= 800 kg/m^3

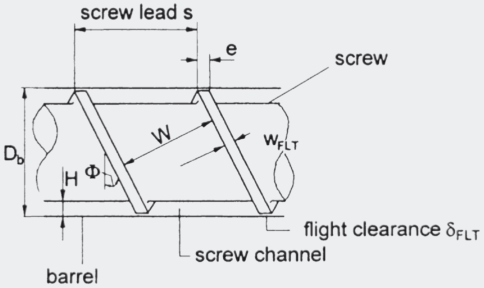

FIGURE 4.5 Screw zone of a single screw extruder [5]

The solids conveying rate in the feed zone of the extruder can be calculated according to [4]

$$G = 60 \cdot \rho_o \cdot N \cdot \eta_F \cdot \pi^2 \cdot H \cdot D_b \left(D_b - H\right) \frac{W}{W + w_{FLT}} \cdot \sin\phi \cdot \cos\phi \tag{4.1}$$

with the helix angle ϕ

$$\phi = \tan^{-1}\left[s / \left(\pi \cdot D_b\right)\right] \tag{4.2}$$

The conveying efficiency η_F in Eq. (4.1) as defined here is the ratio between the actual extrusion rate and the theoretical maximum extrusion rate attainable under the assumption of no friction between the solid polymer and the screw. It depends on the type of polymer, bulk density, barrel temperature, and the friction between the polymer, barrel and the screw. Experimental values of η_F for some polymers are given in Table 4.1.

TABLE 4.1 Conveying efficiency η_F for some polymers

Polymer	Smooth barrel	Grooved barrel
LDPE	0.44	0.8
HDPE	0.35	0.75
PP	0.25	0.6
PVC-P	0.45	0.8
PA	0.2	0.5
PET	0.17	0.52
PC	0.18	0.51
PS	0.22	0.65

Using the values above with the dimensions in meters in Eq. (4.1) and Eq. (4.2) we get

$$G = 60 \cdot 800 \cdot 250 \cdot 0.44 \cdot \pi^2 \cdot 0.005 \cdot 0.03 \cdot 0.025 \cdot \frac{0.0256}{0.0286} \cdot 0.3034 \cdot 0.953$$

Hence $G \approx 50$ kg/h