Insulated vs. non-insulated TCs

with the insulated TC becomes quite small. With the noninsulated TC, the indicated temperature is substantially less than the actual temperature, even with a well depth of 60 mm.

The effect of air currents around the extruder on the measured temperature is shown in Fig. 2.7. When the air velocity increases, the indicated temperature drops as much as 10 to 15 °C. The drop is larger with the conventional TC compared to the insulated TC. The practical result of this is that drafts around the extruder can cause substantial temperature measurement errors.

2.3 Temperature Control

In the extrusion process, good temperature control is important to achieve good process stability. There are two main types of temperature control, on-off control and proportional control.

2.3.1 On-Off Control

Cyclical temperature variations

In on-off control, the power is either fully on or completely off. The temperature vs. time for on-off control is show in Fig. 2.8; the power vs. time is shown as well. When the measured temperature is below the setpoint, the power is fully on. As a result, the temperature rises. When it reaches the setpoint, the power shuts off; however, the temperature continues to increase for some time, up to several minutes. When eventually the temperature drops below the setpoint, the power turns on again. After the initial increase from room temperature, the temperature varies in a cyclical manner with a corresponding on-off cycling of the power.

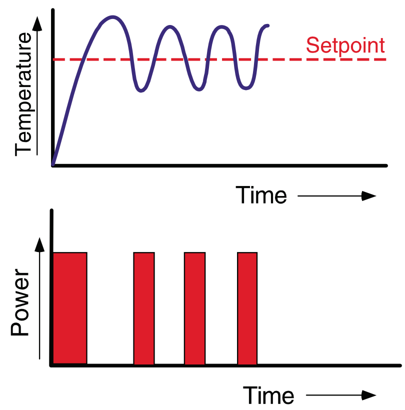

Figure 2.8 Temperature and power versus time in on-off control

The advantage of on-off control is that it is simple and the average temperature is right at the setpoint. The disadvantage is that the actual temperature always cycles with a variation that can be quite large, as much as 10 to 20 °C. The larger the extruder, the greater the temperature variation tends to get. Because of this, on-off control is not recommended in extrusion, except for non-critical processes.

2.3.2 Proportional Control

In proportional control, the power is proportional to the temperature within a certain temperature region called the proportional band. The temperature versus time for proportional control is shown in Fig. 2.9; the power vs. time is shown as well.

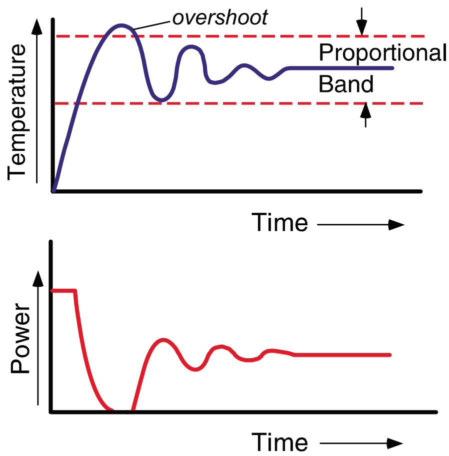

Figure 2.9 Temperature and power versus time in proportional control

Initially, when the machine heats up from room temperature, the power is fully on until the temperature reaches the proportional band. Within the proportional band, the power decreases as the temperature increases. If the temperature exceeds the proportional band, the power completely shuts off. When the temperature decreases in the proportional band, the power increases. The amplitude of the oscillations gradually decreases and eventually the temperature and power reach a steady value.

The advantage of proportional control is that the temperature can be kept steady, unlike with on-off control. The power level can adjust itself exactly to the level that is required to maintain the correct temperature. A limitation of simple proportional control, or P-control, is that the temperature can be steady only as long as the thermal conditions around the extruder are constant. When there is an upset in the thermal conditions, such as a change in ambient temperature, the actual temperature changes and the P-control is not able to correct it, see Fig. 2.10. In other words, in P-control, there is no reset capability.

Steady temperature level

No reset capability

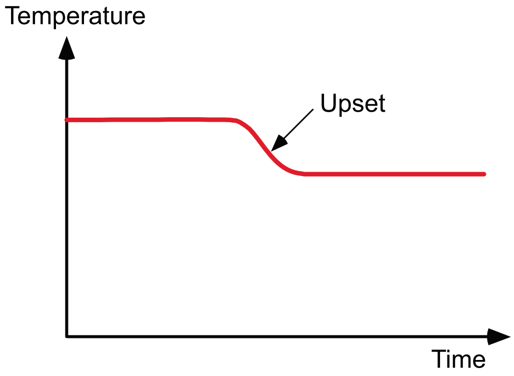

Figure 2.10 The effect of a thermal upset in P-only temperature control

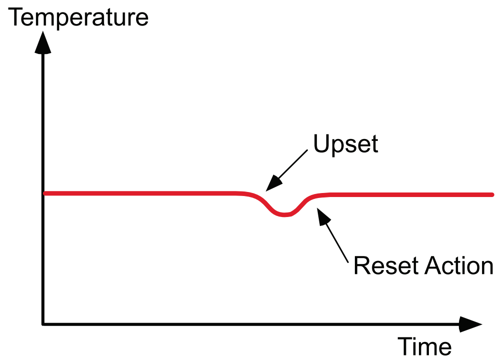

Figure 2.11 The effect of a thermal upset in PI temperature control

Reset capability

In proportional control with integrating action, called PI-control, there is reset capability, see Fig. 2.11. The controller integrates the difference between actual temperature and setpoint and continues to act on the process until the difference is zero.

When there is an upset in the process, there is a temporary deviation from the setpoint, but eventually the actual temperature will reach the setpoint again.

Proportional controllers can also have derivative action. This means that the controller reacts to changes in the rate of temperature change. The rate of temperature change is determined by the derivative of the temperature-time curve; that is why this is called derivative action. Proportional control with derivative action is called a PD-control; with both integrating and derivative action, PID-control. PID-control is commonly used on extruders.

Tuning of PID controller

For a controller to work properly on an extruder, the controller has to be tuned to the characteristics of the extruder. Tuning a PID controller involves determining the correct width of the proportional band and the time constants for integrating and derivative action. Even the best controller will provide very poor control if is not properly tuned. As a result, careful attention should be paid to tuning controllers that require manual tuning. Nowadays, there are number of controllers that tune themselves automatically, so-called “self-tuning” or “auto-tuning” controllers. With these controllers one does not have to worry about manually tuning the controllers.

2.3.3 Fuzzy Logic Control

Enhanced process control

A relatively new method of control is fuzzy logic control or FLC. FLC is an artificial intelligence-based technology, designed to simulate human decision-making. It can be used in systems that use many variables to enhance process control. Developing a fuzzy logic application requires the generation of a knowledge base; this can be a time consuming process. It involves identifying:

- process variables that are important in control
- membership functions for each variable, such as high, low, and medium
- fuzzy rules which define the knowledge of what to do about an observation, based on previous operating experience

FLC is slowly starting to be used in the plastics processing industry. It has already been applied a number of times in injection molding; fewer applications have been reported in extrusion. It has been shown that FLC can outperform conventional PID control if the knowledge base is sufficiently developed.

3 Complete Extrusion Lines

In this section we will discuss typical components of an extrusion line as well as different types of extrusion lines.

It is obvious that the extruder alone is not sufficient to make an extruded product. In addition to the extruder, we need upstream and downstream equipment to produce a useful product. The main elements of an extrusion line are:

Elements of an extrusion line

- resin handling system
- drying system
- extruder
- post-shaping or calibrating device
- cooling device
- take-up device
- cutter or saw

The main types of extrusion lines are:

- tubing and pipe extrusion lines
- film and sheet extrusion lines
- extrusion compounding lines
- profile extrusion lines

Besides these four main types there are quite a few more, such as fiber spinning lines, extrusion blow molding machines, and integrated sheet and thermoforming lines.

3.1 Tubing and Pipe Extrusion Lines

Sizing/calibrating

Dies for tubing and pipe were discussed earlier. Small diameter tubing (less than 10 mm) is usually made with a free extrusion process; this is a process without a sizing or calibrating unit. Large diameter tubing and pipe is made with a sizing device just downstream of the die. The purpose of the sizer or calibrator is to solidify the plastic to a thickness sufficient to transfer the stresses acting on the product, while maintaining the desired shape and dimensions. The main components of a typical tubing extrusion line are shown in Fig. 3.1.

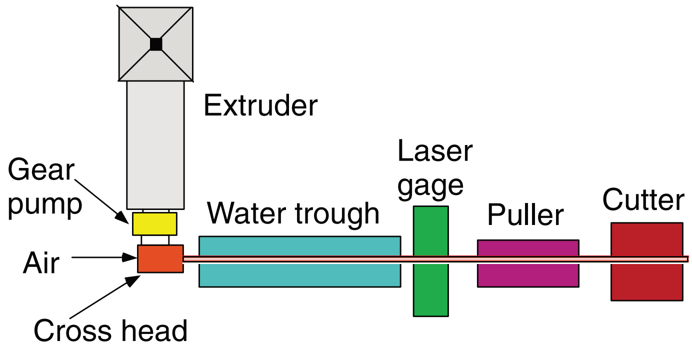

Figure 3.1 Components of a typical tubing extrusion line

Controlling diameter and wall thickness

This line does not use a sizing unit and thus would be used for small diameter tubing. A gear pump may or may not be used, depending on the precision required in the extrusion process. The internal air pressure of the tubing is controlled to achieve the correct values for the outside diameter and wall thickness. The diameter is often measured with a laser gage to allow close monitoring and control. The diameter and the wall thickness are primarily determined by the extruder output, the puller speed, and the internal air pressure.

Gaging wall thickness

Closed loop control systems are available that automatically set the appropriate screw or gear pump speed, the puller speed, and internal air pressure. After the puller, the tubing may be cut or reeled up on a spool. In some lines, the wall thickness is measured directly; this can be done with ultrasonic sensors positioned around the circumference of the tubing or pipe as shown in Fig. 3.2.

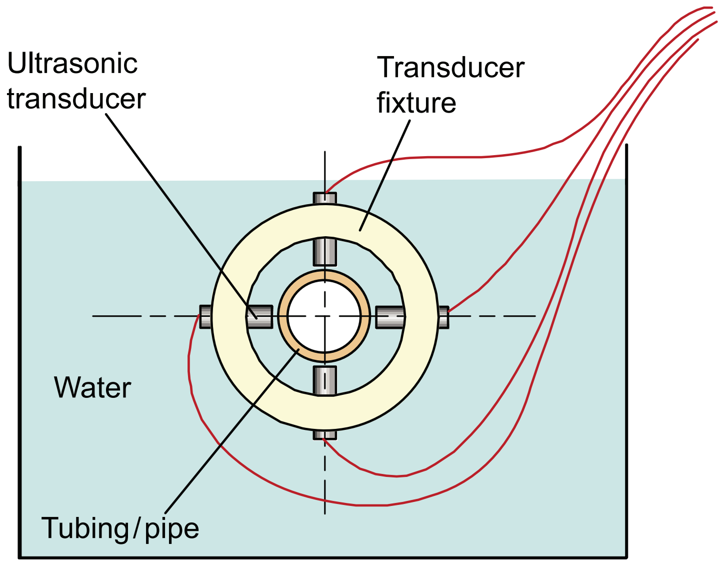

Figure 3.2 Ultrasonic wall thickness gage

3.2 Film and Sheet Lines Using the Roll Stack Process

Textured surfaces

There are no major differences between the extrusion of flat film and sheet. The main components of a sheet line are the extruder, the roll stack, the cooling section, the nip roll section, and the winder, see Fig. 3.3. The roll stack contains three rolls that are often referred to as polishing rolls. They are used to exert pressure on the sheet and to impart the surface conditions of the rolls to the plastic sheet. If a smooth surface is required, smooth rolls are used. If a textured surface is needed, a textured surface is used on the roll. The roll texture is the negative of the texture required on the sheet. It is possible to produce a sheet with one textured surface and the other smooth by using a smooth and a textured roll next to each other.

Different stack modes

Figure 3.3 shows the plastic sheet going up along the center roll and making an S-wrap around the center roll and the top roll, this is called “upstack” operation. Sheet lines can also run in the “downstack” mode, where the material makes an S-wrap around the center roll and the bottom roll. The rolls do not have to be in the vertical position; they can be in a horizontal position or at any angle between vertical and horizontal. In fact, in some roll stacks, the angle is adjustable.

Temperature control of rolls

The rolls are normally cored so that the temperature of the rolls can be controlled. This is usually done with circulating hot oil. It should be possible to adjust the temperature of each roll separately. The cooling section consists of a number of rolls positioned in a frame; the sheet runs over and under the rolls to keep the sheet flat. At the end of the cooling section are the pull rolls or nip rolls; these are rubber rolls that pull the sheet from the roll stack to maintain a certain tension in the sheet. After the nip rolls, the sheet is led to the winder that rolls the sheet on a core. Many different winders are available; some winders automatically transfer the sheet to a new core when one package is full.

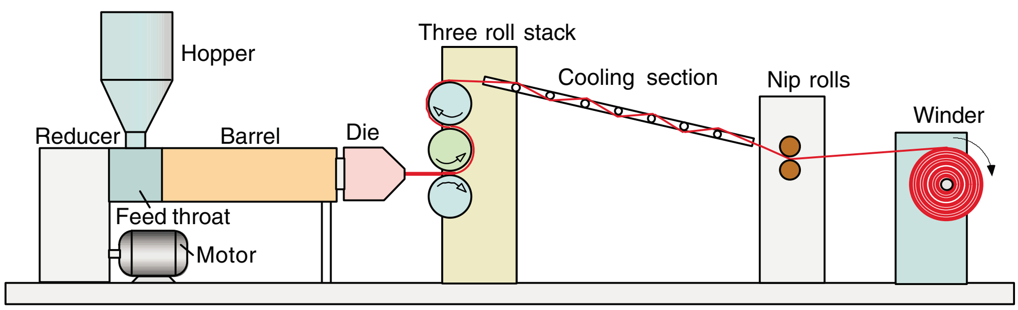

Figure 3.3 Components of a sheet or flat film extrusion line

3.3 Film Lines Using Chill Roll Casting

Chilling

Thin films are often cast on a chill roll rather than extruded into a roll stack. The main components of a cast film line are the extruder, the film die, the chill roll unit, the thickness gauging system, the surface treatment unit, and the winder.

The film is extruded downward onto the chill roll. The initial contact between the film and the chill roll is established by the use of an air knife. The air knife produces a thin stream of high velocity air across the width of the chill roll; the air stream pushes the film against the roll surface as shown in Fig. 3.4.

Gaging

From the chill roll unit the film is led to a thickness-gauging unit where the thickness of the sheet is measured across the width of the film. Most thickness gages for film and sheet have a scanning measuring head that traverses across the film back and forth to measure thickness both along the length and across the width of the film.

Surface treatment

After the thickness-gauging unit, the film passes through a surface treatment unit. Such a unit is incorporated if surface treatment of the film is required. This is usually done to improve adhesion, for instance, for a subsequent printing or laminating operation. The most important adhesion promoters are:

- flame treatment
- corona discharge treatment
- ozone treatment
- primers

Winding

From the treatment unit, the film is led to the winder unit. Just as with sheet extrusion, many different types of winders are available.

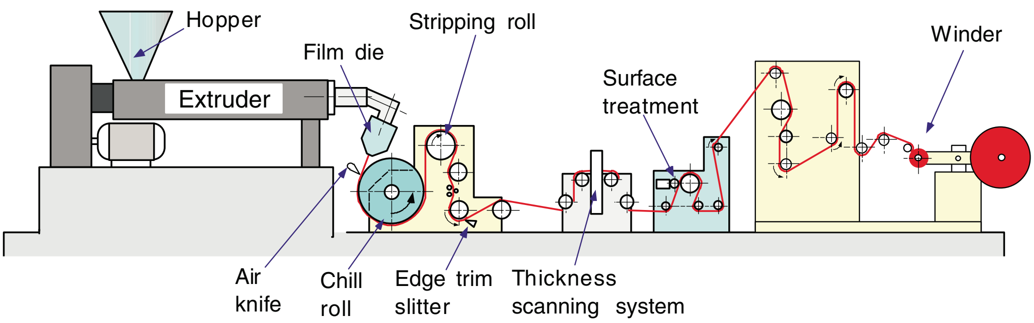

Figure 3.4 Components of a cast film extrusion line

3.4 Combination of Materials

The requirements of many products, particularly in packaging applications, are such that a single plastic cannot meet all of them. To meet the requirements, often two or more materials have to be combined. There are a number of techniques to combine different materials; some of the more important ones are coextrusion, coating, and lamination.

3.4.1 Coextrusion

Coextrusion is a commonly used technique to combine two or more plastics passing through a single extrusion die. There are two major coextrusion techniques, the feed block system and the multi-manifold system. In the feed block system the different plastics are combined in the feed block module, as was shown in Fig. 1.18, and then enter into a regular extrusion die with a single inlet, manifold, and outlet.

Easy combination of many layers

The advantage of the feed block system is that it is simple, inexpensive, and allows many layers to be combined. The main drawback is that the flow properties of the different plastics have to be quite close to avoid interface distortion. This limits the choice of materials that can be combined through feed block coextrusion.

Wide range of material combination

In the multi-manifold system, each plastic has its own entrance and manifold in the coextrusion die. The different melt streams are combined just before they exit the die, so that only minimum interface distortion will occur. The advantage of the multi-manifold system is that plastics with widely different flow properties can be combined. As a result, there is a wide choice of materials that can be combined through this extrusion technique. The disadvantage is that the design of the die is more complicated and therefore, more expensive.

Figure 3.5 shows a multi-manifold sheet or film die. This die has two inlets, two manifolds, and a single outlet. The flow of the upper layer can be adjusted by flexing the choker bar, using the adjustment nuts. The two plastics combine at the entrance to the land region; this is the last parallel section of the die flow channel. The flow in the land region can be adjusted with the flex lip adjustment bolts. These bolts are

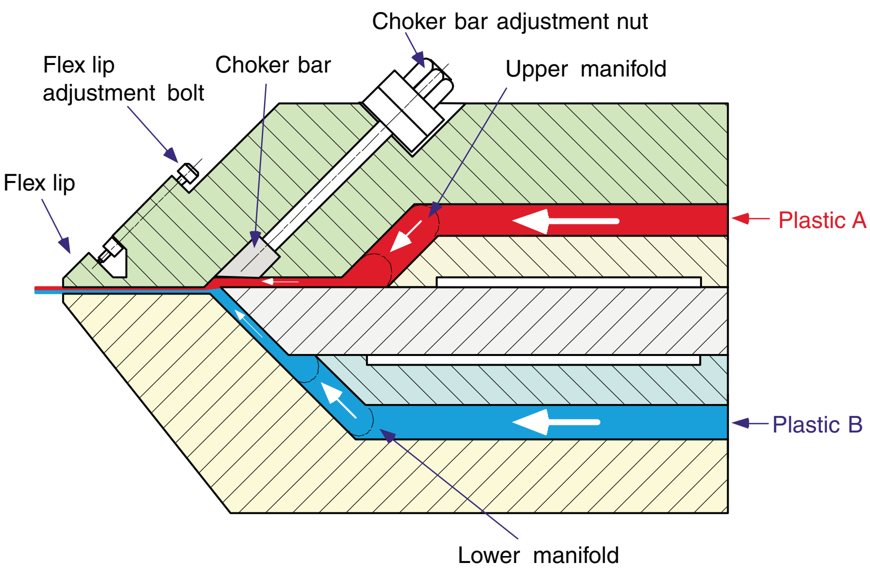

Figure 3.5 Example of a multi-manifold sheet die

located along the width of the die exit with a spacing of about 25 to 40 mm (1.0 to 1.5 inch) and allow local adjustment of the die gap. Some newer sheet and film dies have a flexible membrane to allow adjustment of the flow. Many multi-manifold dies are possible, including flat film and sheet dies, tubing and pipe dies, blown film dies, and profile dies.

3.4.2 Extrusion Coating

Molten plastic on solid substrate

In extrusion coating, a molten layer of plastic film is combined with a moving solid web or substrate. The substrate can be paper, paperboard, foil, plastic film, or fabric; the substrate can also be a multi-layer product. A schematic of an extrusion coating operation is shown in Fig. 3.6.

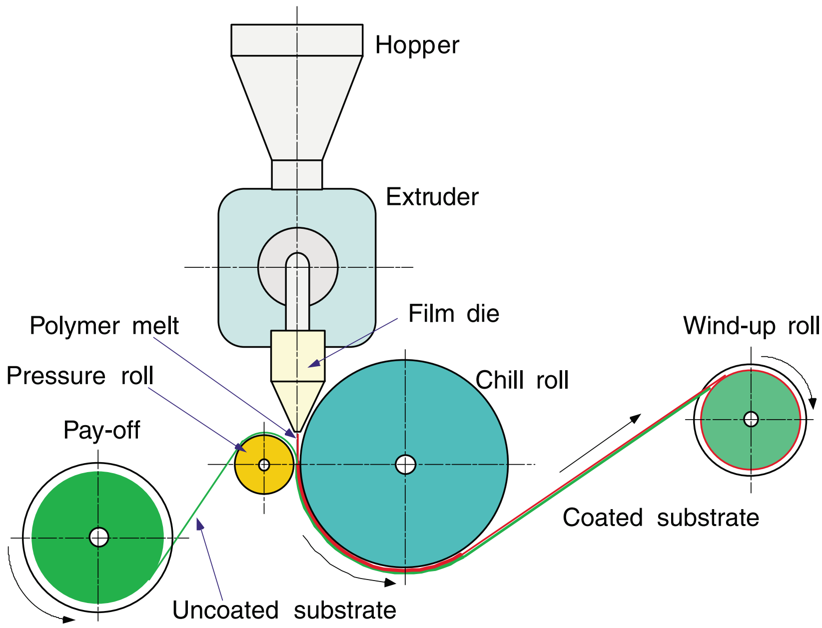

Figure 3.6 Schematic of extrusion coating operation

3.4.3 Extrusion Lamination

Using plastic layer as adhesive

Extrusion lamination involves the combination of two or more substrates, such as paper and aluminum foil, by using a plastic film as the adhesive between the two substrates, see Fig. 3.7. The webs may be preheated or surface treated to improve bonding with the plastic film.

The extruded sheet or film can be laminated with a film on one side or on both sides. The laminate can be paper, foil, mesh, or a number of other materials. With lamination many different structures of sheet or film products can be made. The laminate is unrolled from a payoff, combined with the film, and immediately led into a set of nip rolls. After lamination, the film is handled like a regular film.

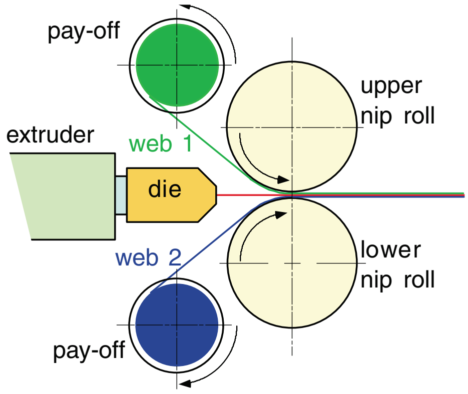

Figure 3.7 Schematic of extrusion lamination

3.5 Blown Film Lines

Expanding tubes by using air

A blown film line is quite different from a flat film line. In a blown film line, a tubular film is extruded vertically upwards as shown in Fig. 3.8. Air is introduced to the inside of the tube; as a result, the tube expands to a bubble with a diameter larger than the diameter of the die. The ratio of the bubble diameter to the die diameter is called the blow up ratio. Typical blow-up ratios used in LDPE film extrusion for packaging are in the range of 2.0 to 2.5:1. When the bubble has cooled sufficiently, it is flattened in a collapsing frame and pulled through a set of nip rolls. From there, the layflat film is guided over several idler rollers to the winder where it is rolled up over a core.

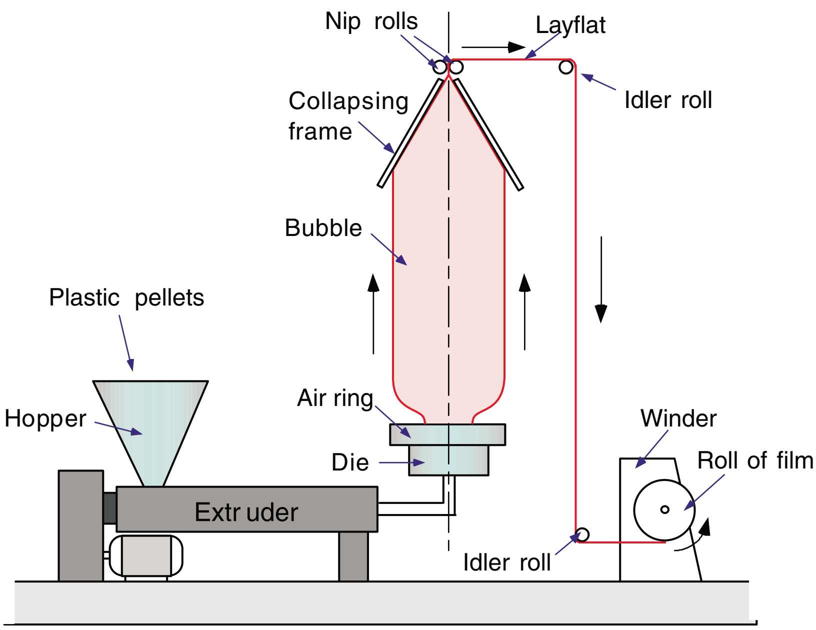

Figure 3.8 Schematic of blown film line