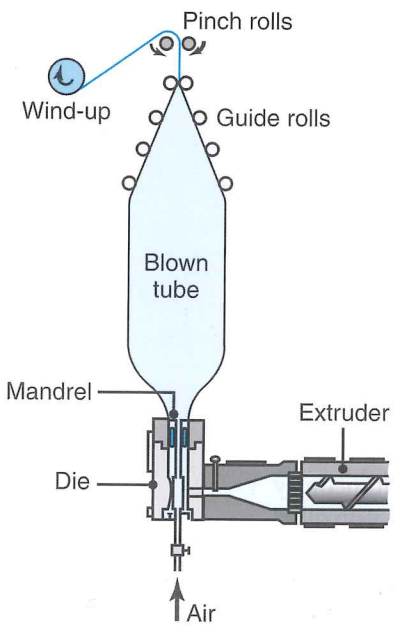
Thin Polymer Films. Common *plastic bags* and other thin polymer film products are made from **blown film**, which itself is made from a thin-walled tube produced by an extruder. In this process, a tube is extruded vertically (Fig. 19.5), continuously pulled upward and expanded into a balloon shape, by blowing air through the center of the extrusion die until the desired film thickness is reached. Because of the molecular orientation of thermoplastics (Section 7.3), a *frost line* develops on the balloon, which reduces its transparency.

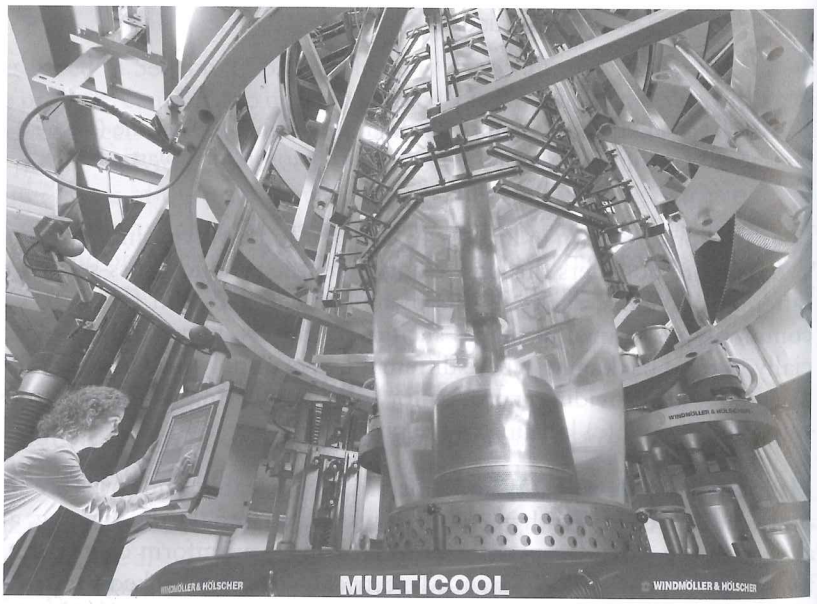
The balloon usually is cooled by air from a cooling ring around it, which can also act as a physical barrier to further diametral expansion of the balloon, thus controlling its dimensions. The cooled bubble is then slit lengthwise, becoming *wrapping film*, or it is pinched/welded and cut off, becoming a plastic bag. The width of the film produced after slitting can be on the order of 6 m or more.

The ratio of the blown diameter to the extruded tube diameter is called the *blow ratio*, which is about 3:1 in Fig. 19.5. Note that, as described in Section 2.2.7, the polymer must have a high strain-rate sensitivity exponent, m, to successfully be blown by this process without tearing. (See also Example 9.1.)

Plastic Films. Plastic films, especially polytetrafluoroethylene (PTFE; trade name: *Teflon*), can be produced by *shaving* the circumference of a solid round plastic billet, with specially designed knives and in a manner similar to producing veneer from a large piece of round wood, in a process called **skiving** (see also Section 24.4).



(a)



(b)

FIGURE 19.5 (a) Schematic illustration of the production of thin film and plastic bags from tube, first produced by an extruder and then blown by air. (b) A blown-film operation; this process is well developed, producing inexpensive and very large quantities of plastic film and shopping bags. *Source:* (b) Courtesy of Windmoeller & Hoelscher Corp.

Pellets. Used as raw material for other plastic-processing methods described in this chapter, pellets also are made by extrusion. A small-diameter, solid rod is extruded continuously, and then chopped into short lengths (pellets). With some modifications, extruders also can be used as simple melters for other shaping processes, such as injection molding and blow molding.

EXAMPLE 19.1 Blown Film

Given: A typical plastic shopping bag made by blown film has a lateral dimension (width) of 400 mm.

Find: a. Determine the extrusion-die diameter. b. These bags are relatively strong in use; how is this strength achieved?

Solution:

a. The perimeter of the flat bag is $(2)(400) = 800$ mm. Since the original cross-section of the film is round, the blown diameter should be $\pi D = 800$, thus $D = 255$ mm. Recall that in this process, a tube is expanded from 1.5 to 2.5 times the extrusion-die diameter. Taking the maximum value of 2.5, the die diameter is $255/2.5 = 100$ mm.

b. Note in Fig. 19.5a that, after extrusion, the balloon is being pulled upward by the pinch rolls. Thus, in addition to diametral stretching and the attendant molecular orientation, the film is *stretched* and *oriented* in the longitudinal direction. The resulting biaxial orientation of the polymer molecules significantly improves the strength and toughness of the plastic bag.