Equipment and processing update for the blown-film extrusion of linear low-density polyethylene

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With sales of linear low-density polyethylene (LLDPE) projected to overtake low-density polyethylene by 1990, the expansion of LLDPE extrusion technology will continue.

Linear low-density polyethylene (LLDPE) was introduced in the early 1970s and had gained substantial commercial use by 1982. When LLDPE first appeared, processors tried to extrude these resins on existing equipment that had been designed for low-density polyethylene (LDPE). They experimented with a variety of process modifications, including shorter, deeper screws (with torpedoes to fill the void left in the barrel) and wider die gaps. The technology for processing LLDPE resins has grown since then, and with sales of LLDPE projected to overtake LDPE by 1990, the technology of LLDPE extrusion will continue to grow.

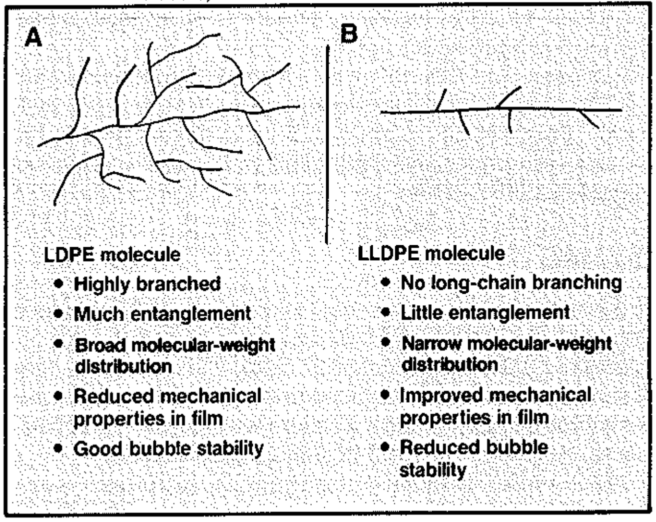
LLDPE vs. LDPE: What are the differences?

There are fundamental rheological differences between LDPE and LLDPE. **Figure 1A** illustrates the highly branched nature of the LDPE molecule. Branching imparts a high degree of entanglement or polymerization, resulting in a resin with a broad molecular-weight distribution. This promotes extrusion and bubble stability but reduces draw capability and the mechanical properties in the film.

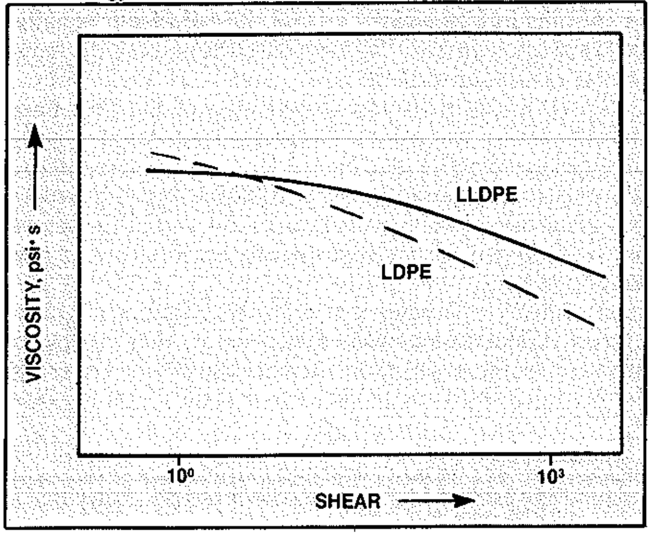
Figure 1B shows that the LLDPE molecule has no long-chain branching and only a few short side chains, primarily the result of copolymerizing polyethylene with certain α-olefins (typically butene, hexene, or octene). These short side chains alter the processing characteristics of LLDPE resin chiefly by changing the molecular-weight distribution. A butene LLDPE, for example, has few side chains and, hence, has a narrow molecular-weight distribution. This provides a film with superior mechanical properties, no entanglement, and good draw-down ability, but it reduces the ease of extrusion and bubble stability.

Figure 2 shows that the rheology curves for LDPE and

1. A: LDPE molecule; B: LLDPE molecule



2. Rheology curves for LDPE and LLDPE



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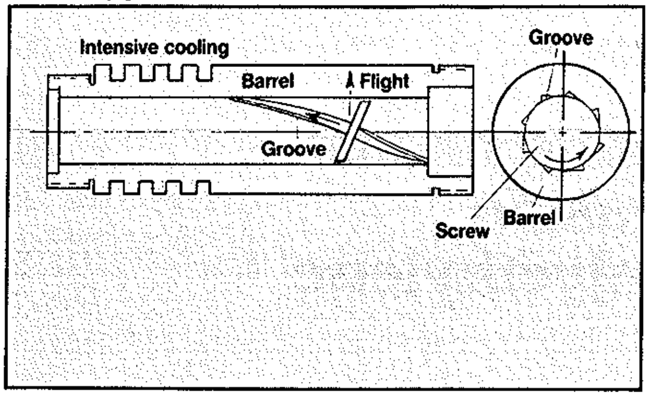
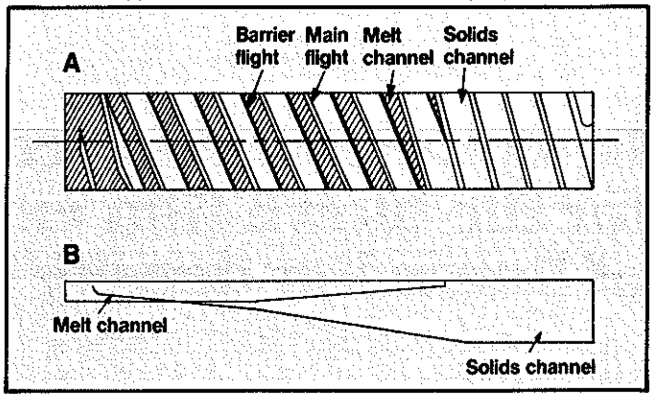
3. Helically grooved barrel section for extrusion of LLDPE



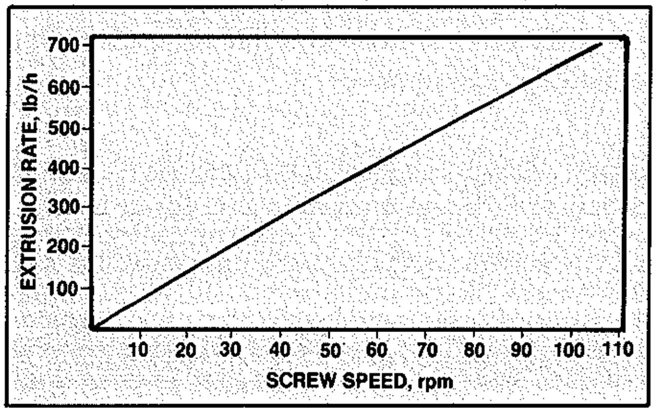
4. A: Unwrapped HG barrier screw; B: Groove-depth profile



LLDPE [of similar melt index (MI)] are different. LLDPE is less viscous at low shear rates and more viscous at high shear rates than LDPE. The latter property accounts for higher melt temperatures, higher shear stress during processing and, hence, a higher pressure drop in an extrusion system. These factors increase both energy consumption and the mechanical demand on the extruder. LLDPE's low viscosity at low shear rates explains the difficulty in film blowing, which is discussed more thoroughly later in this article.

Although LLDPE is more difficult to extrude than LDPE, it has many desirable properties in an end-product form. This article examines recent developments in process techniques and equipment that make it easier to extrude LLDPE resins.

5. Performance of 80-mm HG barrier screw while extruding Dowlex 2056, a 1-MI octene LLDPE (Melt temperature × 400°F)



Extruder

It did not take processors long to discover that extruders designed for LDPE did not generate enough torque to process LLDPE at commercial rates. This led to the use of shorter screws, as mentioned previously. Then came the early barrier screws and extruders with beefed-up drives. These, however, were still in smooth-bore barrels.

Meanwhile, European equipment suppliers were developing straight-grooved-barrel extruders for high-density polyethylene (HDPE). This led to the development of a more efficient spin-off—the helically grooved (HG) extruder. While the HG extruder was originally developed for high-molecular-weight HDPE, it lends itself equally well to processing LLDPE. Both LLDPE and HDPE have similar molecular structures.

Figure 3 shows an unwrapped view of the first four diameters of an HG barrel. The screw lead, running with an opposite hand to the barrel lead, packs the helical grooves to pressures in excess of 10,000 psi. With the screw lead generating such high pressures, the rest of the screw can be designed for optimal melting and mixing at low temperatures.

Kurzbuch*, who notes that melt temperature (T_m) has a strong effect on extrusion rates, claims that extrusion rates can be increased by as much as 20-25% by lowering the T_m from 440°F to 420°F with a 1-MI LLDPE. (Our experience indicates about a 10% increase.)

A barrier screw design for an HG extruder has a compression ratio of less than one because the compaction takes place in the grooved feed area of the barrel. **Figure 4** shows that both the main and barrier leads vary in this design, allowing for a large melting area without compromising the size of the melt channel.

The results in **Fig. 5**, based on data gathered while processing Dowlex 2056 (a 1-MI octene LLDPE) at 400°F, show that extrusion rate increases linearly with screw speed. At a screw speed of 105 rpm, the extruder is capable of pumping as much as 700 lb/h. This translates to a specific rate of 6.67 lb/h for each unit of screw rpm and 8.64 lb/h for each unit of horsepower.

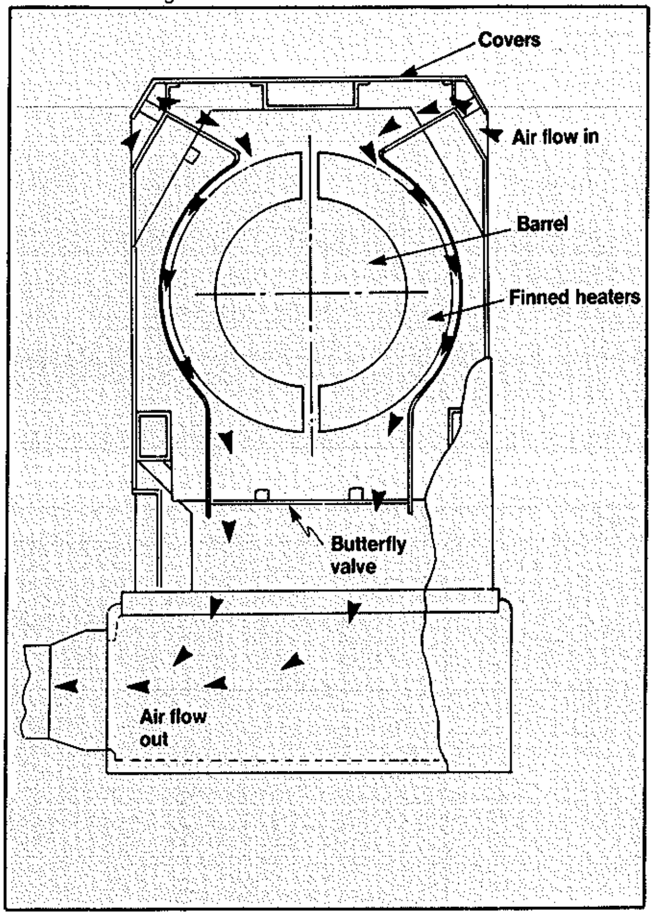
The HG extruder is (a) air-cooled with four damper-controlled zones and (b) intensively water-cooled in the grooved feed area. **Figure 6** shows that cooling air is directed down through the covers and out through the base. This configuration allows the heated air to be expelled away from the extruder side of the bubble, where it cannot affect roll quality.

Transfer piping

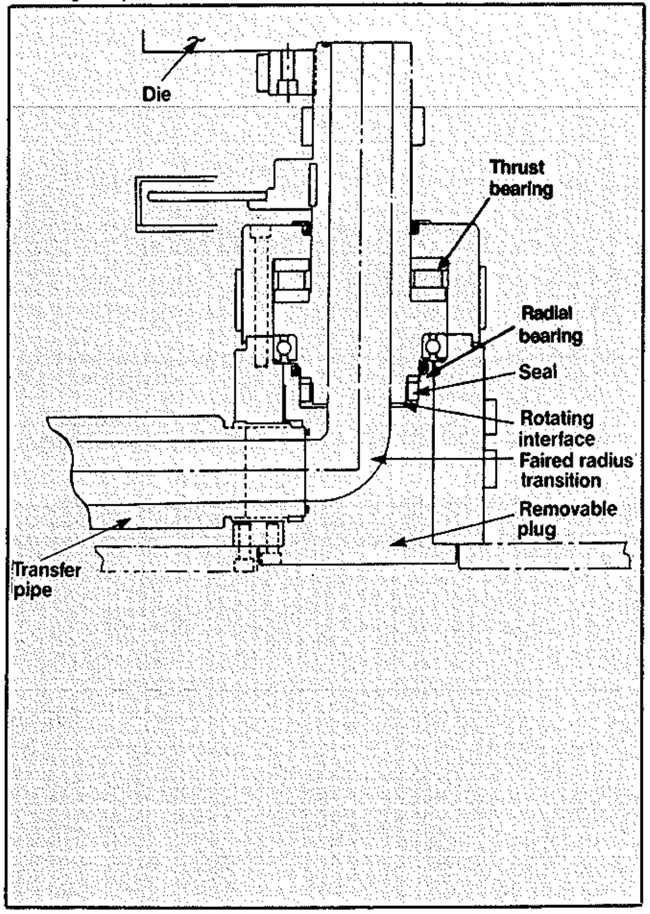
As the film leaves the extruder, the proximity of the screw tip and the breaker plate is an important detail. Because LLDPE is not as inherently stable as LDPE, any stagnant, low-shear areas between the screw tip and the rotator or fixed block should be minimized. In addition, converging

*Kurzbuch, W., LLDPE Blown Film Productivity: Effects of Processing Temperatures and Die Gap on Attainable Production Rates, Exxon Chemical Co., Boytown, Tex., 1987.

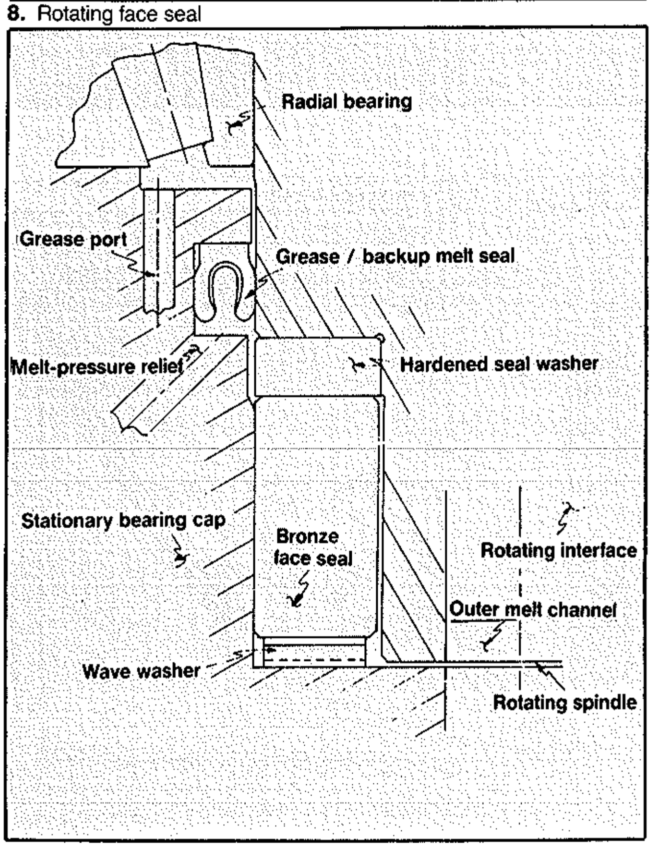
6. Flow of cooling air in HG extruder



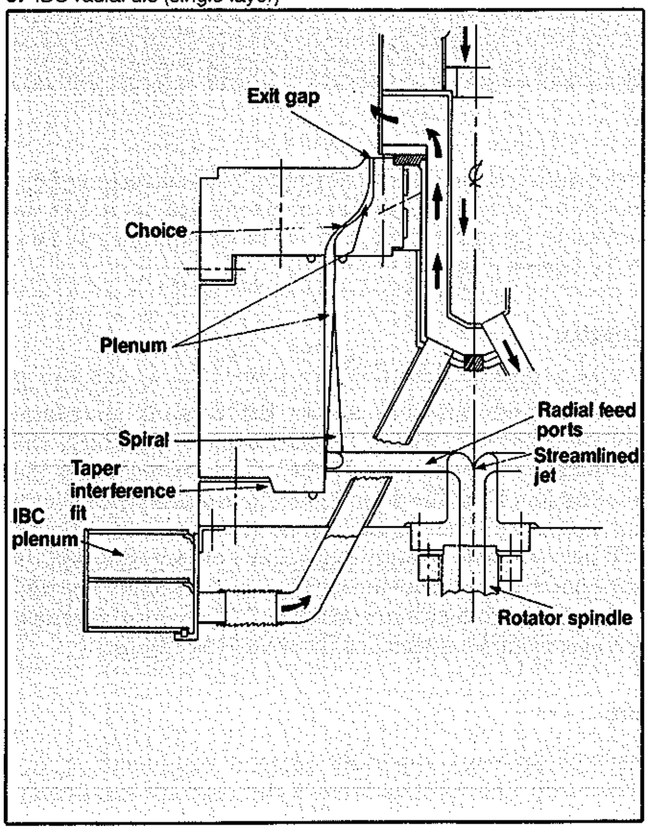
7. Single-layer rotator



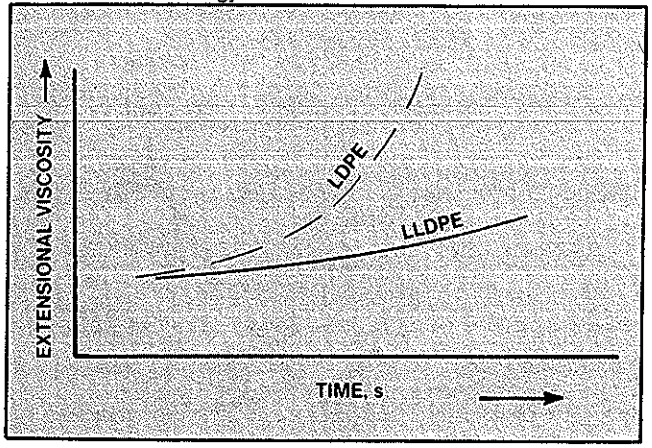
8. Rotating face seal



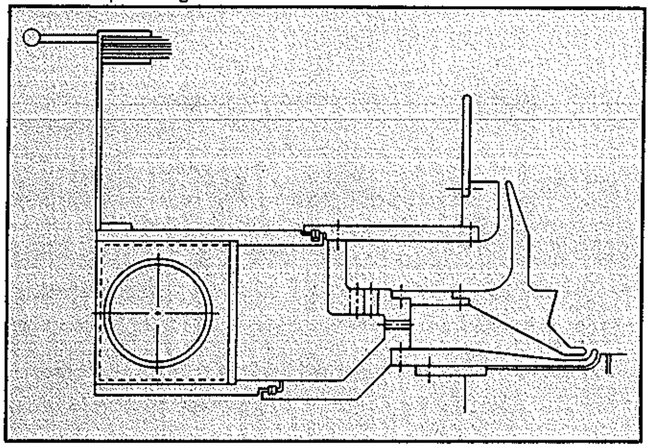
9. IBC radial die (single layer)



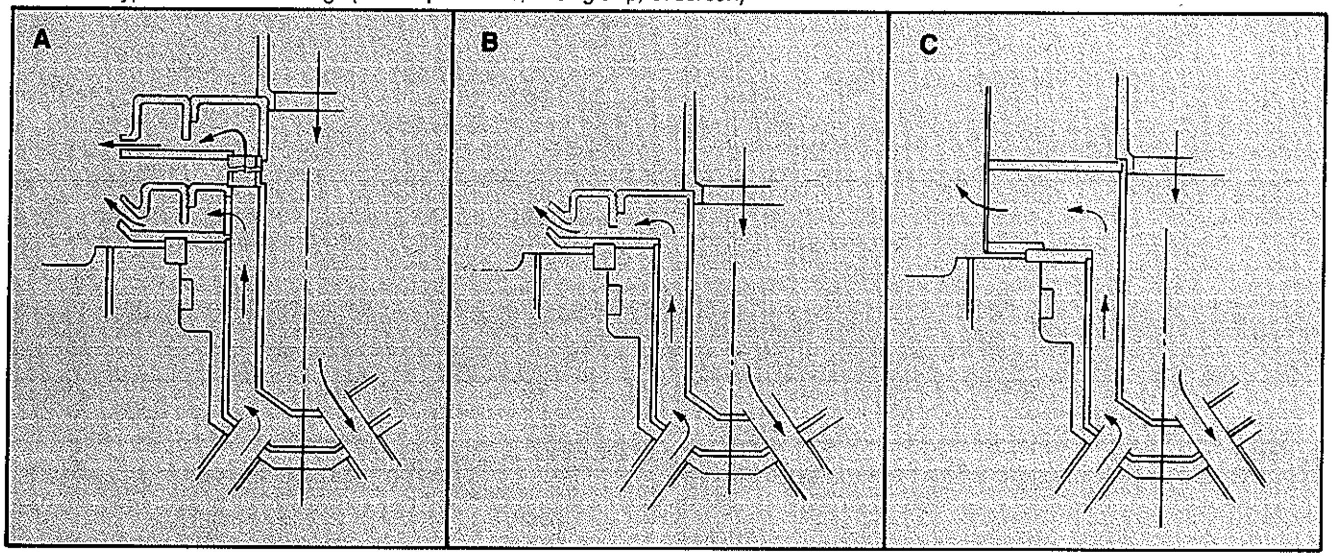
10. Extensional rheology of LDPE and LLDPE



11. Dual-lip air ring



12. Three types of internal air rings (A: multiple stacks; B: single lip; C: screen)



areas should have a steep transition, while diverging flow should be more gradual. The important points are (a) to minimize residence time and (b) to streamline the flow in the transfer piping.

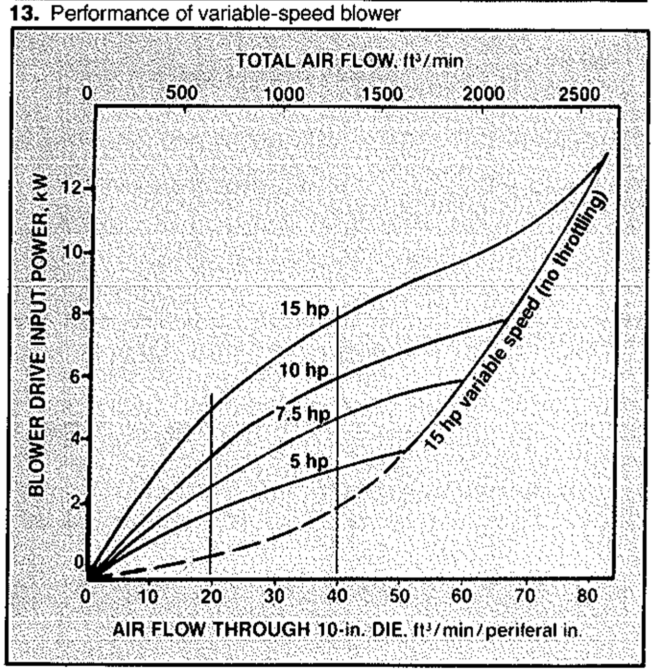
Rotator

A rotator design suitable for LLDPE must be capable of handling high pressure across the rotating interface. **Figure 7** shows a design that utilizes two bearings, one for radial support and one for thrust generated across the rotating junction. The design has a faired transition where the melt stream enters and turns 90° toward the die, as well as a modular design that allows the rotating seal to be removed from below the cart for maintenance. The seal design, which is a pressure-balanced mechanical face seal of a proprietary material, is illustrated in **Fig. 8.**

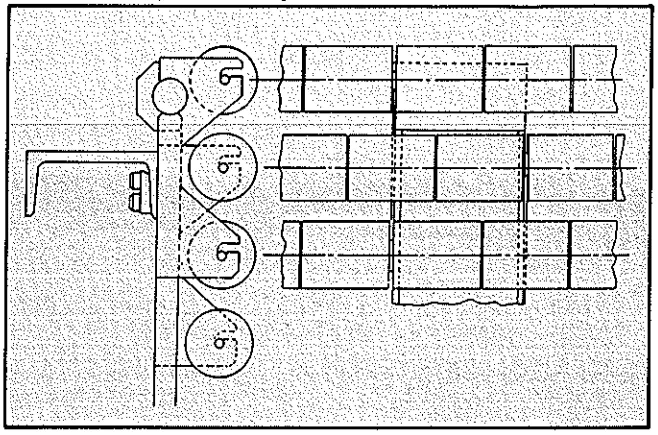
Die

Perhaps the most important piece of equipment in any blown-film line, at least from a film quality standpoint, is the die. When LLDPE was first introduced, the existing

13. Performance of variable-speed blower



14. Roller-collapser assembly



dies that were used for LDPE proved to be marginally adequate. Steps were taken to reduce pressure by widening die gaps, but performance still was not acceptable. Many equipment suppliers then started building low-pressure and ultra-low-pressure dies, but these did not induce enough shear in the polymer, and hence resulted in low physical properties.

LLDPE is not as stable as LDPE and tends to form gels and possible cross-linked material if allowed to stagnate in the die, rotator, and transfer pipes. In addition, low pressure can cause inadequate mixing in the extruder, resulting in poor-quality extrudate with a rough texture or with gels on the film surface. In coextrusion dies, residence times tend to increase, especially in the outer layer. To compensate for this, an additional antioxidant package may have to be added to the resin.

Figure 9 shows a current die design for LLDPE. Note the streamlined junction between the radial feed holes at the center hole. The spiral, 6–7 pitches in height, provides a good balance between minimal residence time, reduces sensitivity to changes in resins, and provides uniform polymer flow. The spiral ends in a plenum, followed by a moderate shear-rate choke, another plenum, and the final die land.

There are arguments for both narrow and wide die gaps for processing LLDPE. Narrow gaps generally result in better machine-direction (MD) tear resistance, down-gauging potential, and orientation balance in the film than wide gaps. However, the benefits of extrusion through a narrow gap are obtained at the cost of adding processing aids to the resin to prevent melt fracture.

Wide die gaps offer reduced costs while providing higher extrusion rates, lower pressures, and better optics. Die-lip heating zones are sometimes added to provide additional heat to delay the onset of melt fracture. This eliminates the use of processing aids, which are needed on narrow gaps. Generally, the best results for preventing melt fracture are obtained when the pin- and ring-heating zones are maintained above the melt temperature. Many processors avoid melt fracture by using die gaps between 0.050 in. and 0.090 in. while adding smaller amounts of processing aids. These measures provide a balance of the desirable features of both narrow and wide die gaps.

Air ring

The extensional rheology curve in **Fig. 10** shows why LLDPE is more sensitive to film blowing than LDPE. As film is drawn off the die surface, LDPE strain-hardens and can accept high-velocity air flows. The lower-viscosity LLDPE does not strain-harden and has little tolerance to high-speed air flows.

A dual-lip air-ring design for LLDPE should provide a high volume of air directed tangentially to the bubble surface and as close to the die as possible. The fixed criteria for determining the rate of air flow is the stability and uniformity of the film bubble. The air ring shown in **Fig. 11** accomplishes this and provides other desirable features, including tangential feeding of air from the hoses to the air ring and a low-pressure drop. The low-pressure drop is important, since for every 2 in. of water pressure rise in an air-handling system, there is a 1°F temperature rise in the air temperature. The air ring in Fig. 11 has a plenum pressure of 5–8 in. of water when delivering 40–50 ft^3/min per inch of die circumference.

Internal bubble cooling systems

There are at least three different IBC internal air rings that are typically used. These are illustrated in **Fig. 12.** Stacked air rings with multiple annular gaps work well for LLDPE, but they are a complicated assembly. The single-lip air ring has the highest heat-transfer rate. However, it directs its air from one small orifice and impinges hard on the bubble surface. Thus it is not preferred for low-melt-strength resins. The screen-type air ring floats a large volume of air onto the bubble surface through a large open area. The single-lip and screen-type air rings are easy to manage for assembly.

Variable-speed blowers

The film industry is starting to use variable-speed drives on blowers to replace the dampers in both external and internal air-ring systems. The main reason is economy. Variable-speed drives provide substantial savings over fixed-speed drives with dampers whenever air volume is throttled below maximum.

We conducted laboratory tests on a 15-hp blower with a variable-speed drive. The results, shown in **Fig. 13,** indicated an annual power savings as high as $2900 by operating three variable-speed blowers over three fixed-speed fans (a) supplying 1250 ft^3/min for an external air ring and (b) exchanging 600 ft^3/min for an IBC air ring.

Bubble collapse

One-piece roller collapsers help alleviate some of the collapsing problems inherent in the film industry, namely wrinkles caused by high friction on the slats. Segmented roller collapsers, illustrated in **Fig. 14**, are also useful in preventing wrinkles. Roller collapsers contribute to flat rolls by drawing the film away from center in a manner similar to that of a bowed roll.

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