A Guide to Polyolefin Blow Molding

lyondellbasell

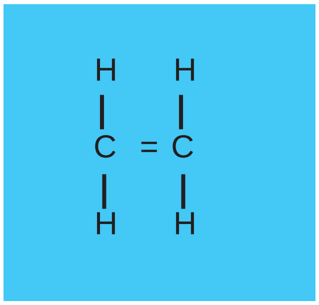


Figure 1. Ethylene monomer molecular structure

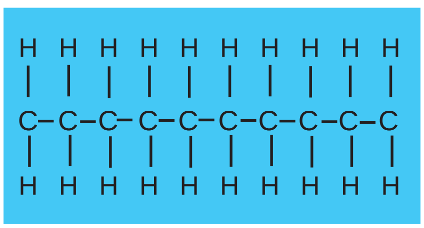


Figure 2. Polyethylene molecular chain.

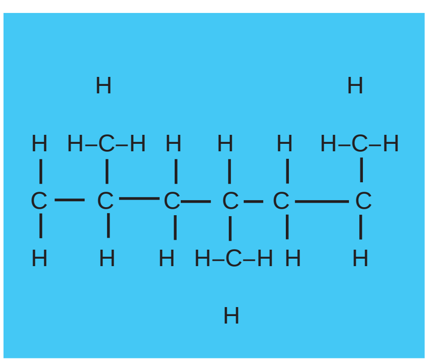


Figure 3. Polypropylene molecular chain.

Polyolefins for Blow Molding

Polyolefins are the most widely used plastic for blow molding. This book, "A Guide to Polyolefin Blow Molding," contains general information concerning materials, methods and equipment for producing high quality polyolefin blow molded products at optimum production rates.

Blow-Moldable Polyolefins and Applications

Polyolefins that can be blow molded include:

- Low density polyethylene (LDPE)
- Linear low density polyethylene (LLDPE)
- Medium density polyethylene (MDPE)
- High density polyethylene (HDPE)
- Ethylene copolymers, such as ethylene vinyl acetate (EVA)
- Polypropylene and propylene copolymers (PP)

In general, the advantages of polyolefin blow molding resins are good processability, light weight, good toughness, outstanding chemical resistance and relatively low cost compared to other plastics. Furthermore, the basic properties of polyolefins can be modified to cover a broad range of end use properties. Polyolefins can also be coextruded with various other polymers, including ethylene vinyl alcohol (EVOH), nylon and tie-layers, to produce multilayer containers with improved barrier properties.

Major application areas for polyolefin in blow molded products include:

- Packaging for such products as milk and other foods, cleaning fluids, medicines, cosmetics and personal care products
- Automotive items, such as gas tanks, oil bottles and windshield fluid containers, air ducts and seat backs
- Consumer products, including toys, housewares and sporting goods
- Objects for materials handling, including 55-gallon drums and chemical carboys
- Industrial products, such as business machine fluid containers,
- Bellows-shaped shields and doublewall instrument and tool carrying cases.

This book contains extensive information on polyolefin blow molding; however, it makes no specific recommendations for the processing of LyondellBasell Chemicals' resins for specific applications. For more detailed information, please contact your LyondellBasell polyolefins sales representative.

Other Products from LyondellBasell
Chemicals offers an extensive range of polyolefin resins, plus polyolefin-based tie-layer resins not only for blow molding, but also for:

- Injection Molding
- Film Extrusion
- Extrusion Coating
- Sheet and Profile Extrusion
- Wire and Cable Coating
- Rotational Molding and Powder coating
- Blending and Compounding
- Flame Retardant Applications
- Pipe

LyondellBasell also produces ethyl alcohol, ethyl ether, ethylene glycol and ethylene oxide. Information on all these products also can be obtained from your LyondellBasell sales representative.

Polyolefins are Thermoplastics Derived from Petrochemicals

Polyolefins are plastic resins polymerized from petroleum-based gases. The two principal gases are ethylene and propylene: Ethylene is the principal raw material for making polyethylene and ethylene copolymer resins; propylene is the main ingredient for making polypropylene and propylene copolymer resins.

Polyolefin resins are classified as thermoplastics, which means that they can be melted, solidified and melted again. This contrasts with thermoset resins which, once molded, can not be reprocessed.

Polyolefin resins for blow molding generally are produced in pellet form. The pellets are about one-eighth inch long and one-eighth inch in diameter and are usually somewhat translucent and water-white in color. Polyolefin resins sometimes will contain additives, such as thermal stabilizers. They can also be compounded with colorants, antistats, UV stabilizers, etc. to meet specific end-use needs.

Effects of Molecular Structure

The uses for polyolefin resins are primarily determined by three basic properties. These are:

- Average Molecular Weight
- Molecular Weight Distribution
- Crystallinity, or Density

These properties are essentially fixed by the catalyst technology and manufacturing process used to produce a specific grade of resin.

The basic building blocks for the gases from which polyolefins are derived are hydrogen and carbon atoms. For polyethylene, these atoms are combined to form the ethylene monomer, CA, i.e., two carbon atoms and four hydrogen atoms **(see Fig. 1).** In the polymerization process, the double bond connecting the carbon atoms is broken. Under the right conditions, these bonds reform with other ethylene molecules to form long molecular chains **(Fig. 2)**. The resulting product is polyethylene resin.

For polypropylene, the hydrogen and carbon atoms are combined to form the propylene monomer, $CH_3CH{:}CH_2$, which has three carbon atoms and six hydrogen atoms **(Fig. 3)**. The third carbon atom remains pendant and spirals regularly around the backbone chains.

Ethylene copolymers, such as ethylene-vinyl acetate (EVA) are made by the polymerization of ethylene units with randomly distributed comonomer groups, such as vinyl acetate (VA).

The polymerization of monomers creates a mixture of molecular chains of varying lengths. Some are short, others enormously long, containing several hundred thousand monomer units. For polyethylene, the ethylene chains have numerous side branches. For every 1,000 ethylene units in the molecular chain, there are about one to ten short or long branches. The branches radiate three-dimensionally **(Fig. 4).**

Branching affects many polymer properties, including density, hardness, flexibility and transparency. Chain branches also become points in the molecular network where oxidation may occur. In some processing techniques where high temperatures are reached, oxidation can adversely affect the polymer's properties.

Density

Polyolefin blow molded products have a mixture of crystalline and amorphous areas. Molecular chains in crystalline areas are arranged somewhat parallel to each other. In amorphous areas, they are randomly arranged. This mixture of crystalline and amorphous regions (Fig. 5) is necessary for the proper balance of properties in good blow molded products. A totally amorphous polyolefin would be grease-like and have poor physical properties; a totally crystalline polymer would be very hard and brittle. HDPE resins have molecular chains with comparatively few side branches. Therefore, the molecular chains are packed more closely together. The result is crystallinity up to 95%. LDPE resins generally are 60 to 75% crystalline, while LLDPE resins' crystallinity levels range from 60 to 85%. PP resins are highly crystalline, but they are not very dense. For polyethylene, the higher the crystallinity, the higher the resin density. Density is a primary indicator of the level of crystallinity in a polyethylene.

Polyolefin blow molding resins have the following density ranges:

- LLDPE resins have densities ranging from 0.910 to 0.940 grams per cubic centimeter (g/CM^3).
- LDPE resins range from 0.916 to 0.925 (g/CM^3)
- MDPE resins range from 0.926 to 0.940 (g/CM^3)
- HDPE resins range from 0.941 to 0.965 (g/CM^3)
- PP resins range from 0.890 to 0.905 (g/CM^3)

EVA copolymers' densities are functions of the proportion of vinyl acetate incorporated into the resin; as VA increases, density increases.

The density of polyethylene resins influences numerous properties **(Table 1).** With increasing density, some properties, such as stiffness, are enhanced, while others, such as environmental stress crack resistance and low temperature toughness, are reduced toughness.

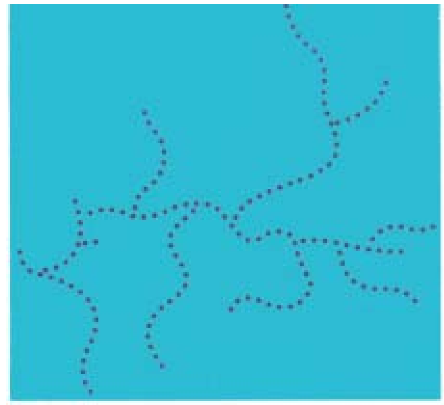


Figure 4. Polyethylene chain with side branches.

Figure 5. Crystalline (A) and amorphous (B) regions in polyolefin.

Table 1: General Guide to the Effects of Polyolefin Physical Properties on Resin Mechanical Properties and Processing.

	Melt Index Increases	Density Increases
Chemical Resistance	Stays the Same	Increases
Clarity	Increases	Decreases
Elongation at Break	Decreases	Decreases
Flexibility	Stays the Same	Decreases
Gloss	Improves	Stays the Same
Heat Resistance (softening point)	Decreases	Increases
Impermeability to Gases/Liquids	Stays the Same	Increases
Low Temperature Flexibiity	Decreases	Decreases
Melt Viscosity	Decreases	Stays the Same
Mechanical Flex Life	Decreases	Decreases
Stress Crack Resistance	Decreases	Decreases
Tensile Strength at Break	Decreases	Increases

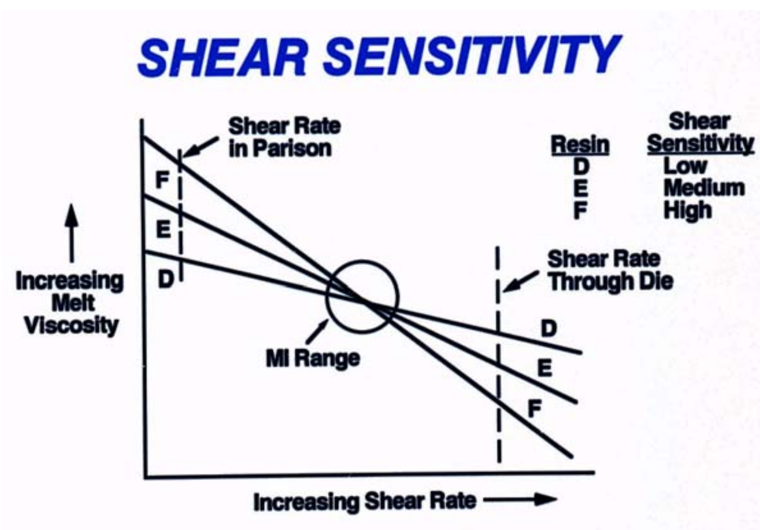


Figure 6. The importance of good shear sensitivity—high viscosity in the parison, low viscosity through the die.

Molecular Weight

Atoms of different elements, such as carbon, hydrogen, etc., have different atomic weights. For carbon, the atomic weight is 12, and for hydrogen, it is 1. Thus, the molecular weight of the ethylene unit is the sum of its six atoms (2 carbon + 4 hydrogen) or 28. The molecular weight of an individual polymer molecule is the sum total of teh atomic weights of all combined ethylene units.

Every polyolefin resin consists of a mixture of large and small chains, i.e., chains of high and low molecular weights. The molecular weight of the polymer chain generally is in the thousands. The average of these is called, quite appropriately, the average molecular weight. As average molecular weight increases, resin toughness increases. The same holds true for telongational properties and environmental stress crack resistance (cracking brought on when a molded part is subjected to stresses in the presence of solvents, oils, detergents, etc.).

Melt Index

Melt Index (for polyethylene)and Melt Flow Rates (for Polypropylene) are an indirect, simple measurement of the polymer's average molecular weight. Polyethylene resin melt index is expressed in terms of the weight of flow through a standard orifice in a ten-minute time period. This property is tested under standard conditions of temperature and pressure. Melt index (MI) is inversely related to the resin's average molecular weight: as average molecular weight increases, MI decreases. Generally, a polyolefin resin with high molecular weight has a low MI, and vice versa.

Melt index is an extremely important property since it describes both the flow of the molten polymer and many of the polymer's end-use properties. The resin's flow (or output in pounds/hour through an extruder) increases with increasing MI. Polyolefins with lower MI levels can sometimes require higher extrusion temperatures to make them flow easier. Conversely, most physial properties of the solid polymer are enhanced with lower melt index.

Pressure can also influence flow properties. Two resins may have the same MI, but different high-pressure flow properties. MI data **(Table 2)** must therefore be used in conjunction with other properties, such as molecular weight distribution, to fully characterize the processability of a resin.

Shear Sensitivity

Melt index and density are two extremely useful numbers for describing a polyethylene resin; a third is “shear sensitivity.” The viscosity of melted HDPE appears to change depending on how rapidly it is undergoing shear, i.e, how fast it is being pushed through the extruder or die. Under moderate rates of shear, HDPE is moderately viscous. When it is forced at high speed through a narrow die gap, the HDPE melt is sheared at a fast rate; at this point it appears to have a low viscosity. Then, when it hangs from the die as a blow molding parison, under practically no shear, the same HDPE appears to be very viscous.

All HDPE resins show varying degrees of shear sensitivity; in general, the faster the shear rate, the lower the apparent viscosity. HDPE resins with high shear sensitivity require less power and heat input to yield faster extrusion rates **(Fig. 6)**.

Molecular Weight Distribution

The relative distribution of large, medium and small molecular chains in the polyolefin resin is important to its properties and especially to shear sensitivity. When the distribution is made up of chains close to the average length, the resin is said to have a “narrow molecular weight distribution” (Fig. 7). “Broad molecular weight distribution” polyolefins are those resins with a wider range of chain lengths. In general, resins with narrow molecular weight distributions will have greater stress crack resistance and better optical properties than resins with broad molecular weight distributions. Broader molecular weight distribution resins exhibit greater shear sensitivity, providing certain processing advantages in the blowmolding process.

Comonomers

Polyolefins made with one basic type of monomer are called homopolymers. Many polyolefins, called copolymers, consist of two or more monomers, each of which is called a “comonomer.” Many blow molding grades of LLDPE, LDPE, HDPE and PP incorporate varying types and amounts of comonomers, which provide specific property alterations.

The comonomers most often used with LLDPE and HDPE are called alpha olefins, and include butene, hexene and octene. Another comonomer used with ethylene to make blow molding grades is vinyl acetate (VA), yielding ethylene vinyl acetate (EVA). The incorporation of small amounts of VA with polyethylene results in a resin which extrudes similarly to polyethylene, but also provides tougher blow molded products with less stiffness and potentially greater clarity. A wide range of properties is possible depending upon the amount of VA incorporated and the synthesis conditions used to make the modified resins.

Ethylene is the primary comonomer used with PP. PP random copolymers have scattered ethylene groups connected to the propylene backbone of the polymer. Such resins are distinguished by their superior clarity. PP impact copolymers have propylene backbones containing series of ethylene groups. These propylene copolymers are known for their medium to high impact strength at and below room temperature.

Modifiers, Additives and Tie-Layers

Numerous additives are commonly compounded with polyolefin blow molding resins **(Table 3).** In some grades thermal stabilizers, antistatic agents and nucleating agents are added during resin manufacture.

Tie-layers are polyolefin-based resins that are used to bond one type of normally incompatible polymer with another during coextrusion. Tie-layers are specifically designed for use with such barrier materials as ethylene vinyl alcohol (EVOH), nylon (PA), polyester (PET) and polyvinylidene chloride (PVdC).

Blow Molding Resins Available from LyondellBasell

offers a wide range of polyolefin resins for blow molding, including PETROTHENE® , LLDPE, LDPE, HDPE and PP, ALATHON® HDPE, FLEXATHENE® TPO, and ULTRATHENE® EVA copolymers. These resins can be tailored to meet the requirements of many applications. Some typical specialty grades are:

Table 2: Polyolefin General Purpose Blow Molding Resins/ Melt Indices

Resin	Melt Index Ranges* g/10 min.
LLDPE	<1 to 2 MI
LDPE	<1 to 2 MI
HDPE	<1 to 2 MI
EVA	<1 to 3 MI
PP	<1 to 2** MFR

* Melt Index describes the flow behavior of a resin at a specified test temperature (374°F, 190°C) and using a specified test weight (2,160g). Resins with a higher melt index flow more easily in the hot, molten state than those with a lower melt index.

**Melt flow rate (MFR), rather than MI is used to describe the flow behavior of polypropylene resins, MFR describes their behavior at a specific test temperature of 445°F (230°C) and weight of 2k160g.

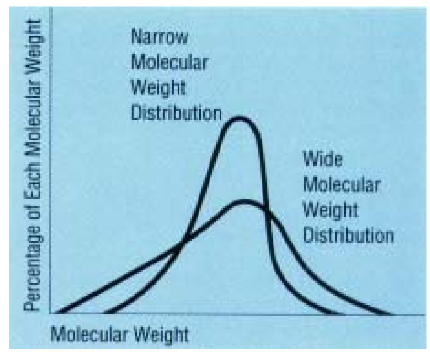


Figure 7. Schematic representation of molecular weight distribution.

Table 3: Typical Additives Used with Polyolefin Blow Molding Resins.

Additive	Primary Benefit
Antistatic Agents	Static buildup resistance
Clarifiers	Improved clarity
Nucleating Agents	Faster processing
Processing Aids	Reduce melt fracturing
Thermal Stabilizers	Resistance to oxidation during processing
UV Stabilizers	Resistance to effects of sunlight

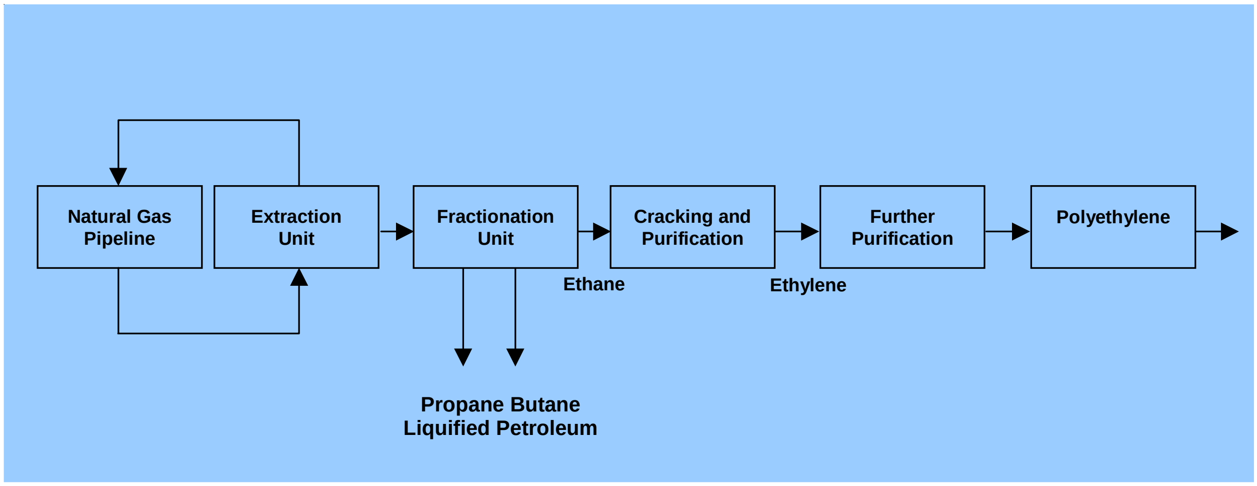


Figure 8. Diagram of the polyethylene process from natuaral gas to resin pellets.

- High Clarity Polypropylene
- Injection Blow Molding HDPE
- High Stiffness HDPE
- Excellent ESCR HDPE
- Soft, Flexible LDPE
- Injection Blow Molding PP
- High Clarity EVA

In summary, polyolefin resins with distinctly different properties can be made by varying the three basic molecular properties of density, molecular weight and melt viscosity and by adding comonomers and additives. Processors can work closely with their LyondellBasell polyolefins sales representatives to determine which polyethylene, polypropylene or EVA best meets their needs.

Shipping and Handling Polyolefin Blow Molding Resins

It is of utmost importance to keep polyolefin resins clean. Contaminated resins can produce poor products. Polyolefin resins are shipped to processors by LyondellBasell in rail cars, hopper trucks, 1000- and 1500-pound polyethylene-lined corrugated boxes and 50-pound plastic bags. Strict quality control throughout resin manufacture and subsequent handling, right through delivery to the customer, ensures the cleanliness of the products.

When bulk containers are delivered, the processor must use clean, efficient procedures for unloading the resin. Maintenance of the in-plant materials handling system also is essential. When bags and boxes are used, special care must be taken in opening the containers, as well as covering them as they are unloaded and used.

Stringent precautions must also be taken when using reground resin, whether as a blend or alone, to keep it free of contamination. Whenever possible, the regrind should be used as it is generated. When this is not possible, the scrap should be collected in a closed system and recycled with the same precautions taken for virgin resin.

How Polyolefin Resins are Made

High-purity ethylene and propylene gases are the basic feedstocks for making polyolefins **(Fig. 8)**. These gases can be a petroleum refinery by-product or they can be extracted from ethane/propane liquefied gas coming through pipelines from gas fields. High efficiency in the ethane/propane cracking and purification process results in very pure ethylene and propylene **(Fig. 9)** that LyondellBasell then uses to produce its polyolefins. LyondellBasell can produce polyolefins by more polymerization technologies and with a greater range of catalysts than most any other supplier.

LDPE

To make LDPE resins **(Fig. 10)**, LyondellBasell uses high pressure, high temperature polymerization reactors. Ethylene gas, pumped into the reactors, is polymerized in the presence of a catalyst under controlled pressure and temperature conditions. The molten LDPE product flows to a separator where unused gas is removed and recycled. Next, the LDPE goes to a compounding extruder where additives are incorporated prior to pelletizing.

HDPE

There are two basic processes for making HDPE **(Fig. 11)**: the more common particle form slurry process and the gas phase process. The flow of these processes is quite similar to the LDPE process except that relatively low pressure, low temperature reactors are used.

LLDPE

LyondellBasell also uses a low pressure, gas phase process for making LLDPE **(Fig. 12)**. LLDPE processes are quite different from the LDPE process, but similar to the HDPE process. The major difference from the LDPE process is that low pressure, low temperature polymerization reactors are used. Another difference is that the ethylene is copolymerized with butene or hexene comonomers in the reactor. A final distinction is that the polymer exits the reactor as granules that are then compounded with additives in an extruder and pelletized. HDPE resins also can be made in these reactors.

Figure 9. **Left, Polypropylene unit at LyondellBasell's Morris, IL, plant; Right, HDPE unit at LyondellBasell's Matagorda, TX, plant.**

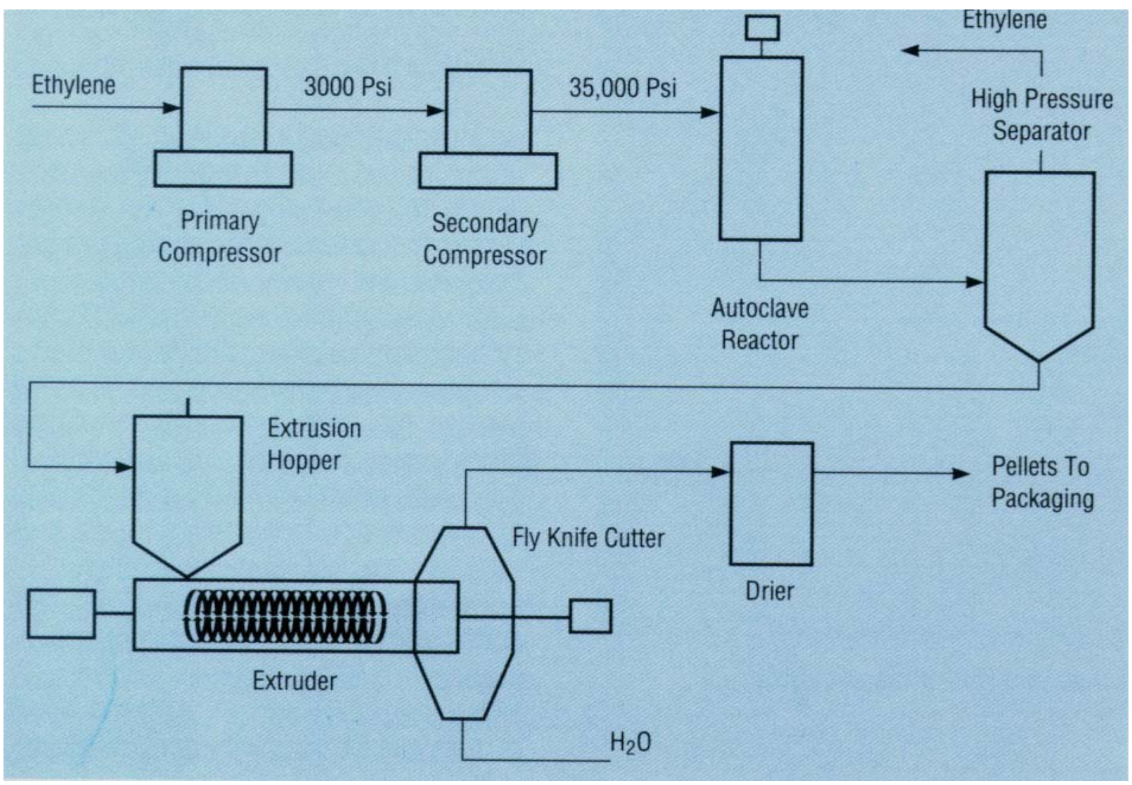


Figure 10. **Process diagram for LDPE production in an autoclave reactor.**

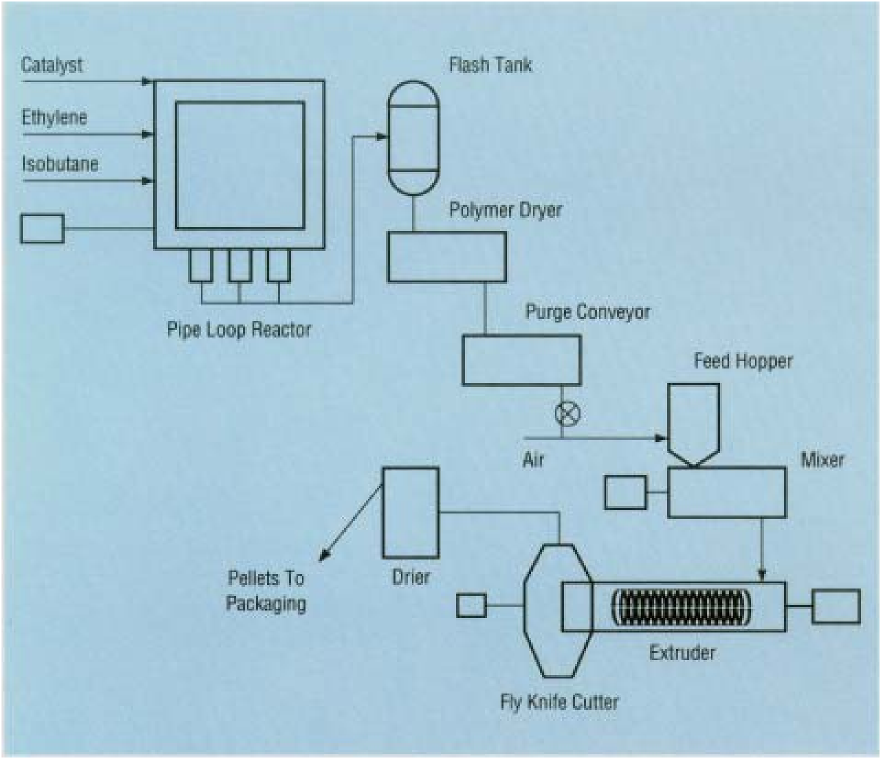


Figure 11. Process diagram for HDPE production in a particle-form reactor.

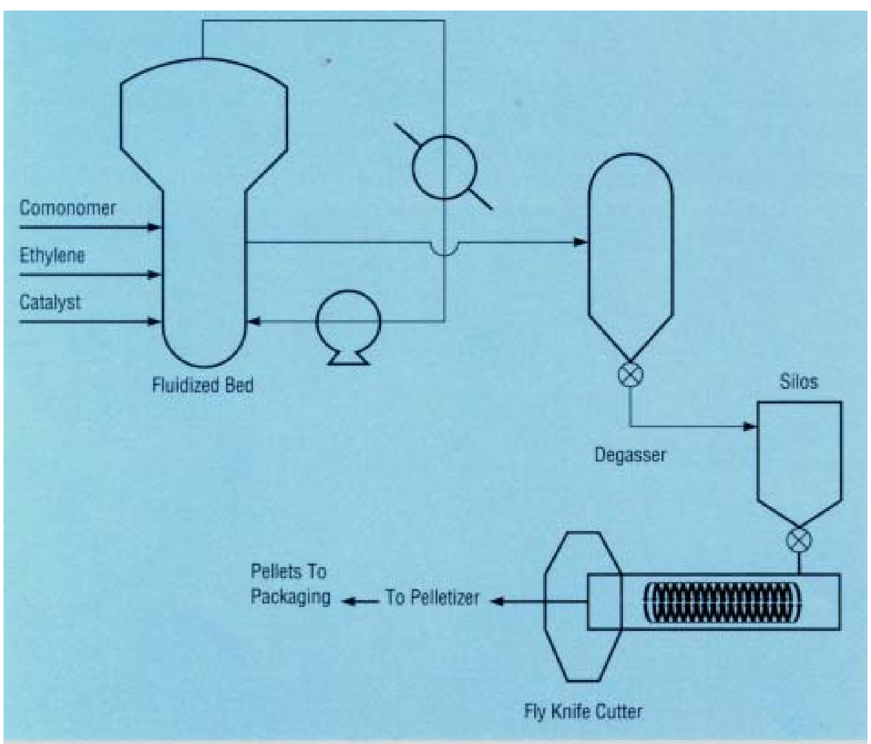


Figure 12. Process diagram for LLDPE production in a gas-phase reactor.

PP

To manufacture PP, LyondellBasell uses a vertical, stirred fluidized-bed, gas-phase reactor **(Fig.13).** LyondellBasell was the first polypropylene supplier in the U.S. to use gas-phase polypropylene technology. This process is more energy efficient and produces a more uniform product than other polypropylene processes.

Materials Conditioning and Handling

At its resin manufacturing plants, LyondellBasell has extensive systems, such as filters, cyclones, elutriators, etc. to prevent resin contamination during production, storage, loading and shipping. Since polyolefin resins are non-hygroscopic (they absorb virtually no water), they do not require drying prior to being molded. However, precautions should be taken to ensure the cleanliness of the polyolefin pellets as they are handled at the processor's facilities.

One of the best ways to improve polyolefin resin utilization is to eliminate contaminants from transfer systems. Whenever a polyolefin resin is transferred by a current of air, contamination is possible. This is because dust, fines, "streamers" and "angel hair" can be generated during the movement of the resin from shipping containers to storage silos to extruder hoppers.

These contaminants can clog filters in the transfer system or in the mechanisms connected directly to the blow molding machines. The result is starvation of the extruder. Occasionally, large clumps of angel hair or streamers can accumulate in a storage silo and clog the exit port. All of these problems can lead to extruder downtime, excessive scrap and lost work as time and money are spent cleaning silos, transfer lines and filters instead of blow molding end products.

Many transfer systems consist of smooth bore piping and include in their structures long radius bends for conveying the resin from a hopper car to the silo or holding bin. A polyolefin pellet conveyed through a transfer line travels at a very high velocity and as it comes in contact with the smooth pipe wall, it slides and slows down due to friction. The friction, in turn, creates sufficient heat to raise the pellet's surface temperature to the resin's melting point. As this happens, a small deposit of molten polyolefin is left on the pipe wall. This deposit freezes almost instantly.

Eventually, the deposits are dislodged from the pipe wall and find their way into the extrusion process, the storage silo or the transfer filters. The dislodged angel hair and streamers may have different melt indices and densities than the polyolefin being molded at the time. They contaminate the polyolefin melt and can cause problems in the end product. The amount of angel hair and streamers formed increases with increases in conveying air temperature and velocity and is greater with smooth bore piping.

Materials Handling Equipment Design

Since smooth piping is a leading contributor to angel hair and streamers, the ' logical solution is to roughen the interior wall of the piping. This roughness causes the pellets to tumble instead of slide along the pipe and streamer formation is minimized. However, as a rapidly moving polyolefin pellet comes in contact with an extremely rough surface, small particles are broken off, and fines or dust are created.

Two pipe wall finishes, in particular, have proved to be the best performers and give the longest life. One is a sand blasted finish of 600 to 700 RMS roughness. This finish is probably the easiest to obtain; however, due to its sharp edges, it will create dust and fines until the edges become rounded. The other finish is achieved with shot blasting with a #55 shot with 55-60 Rockwell hardness to produce a 900 RMS roughness. Variations of this finish are commonly known as "hammer finished" surfaces. The shot blasting allows deeper penetration and increases hardness, which in turn leads to longer surface life. The rounded edges obtained minimize the initial problems encountered with dust and fines. They also reduce the potential for contamination associated with the sandblasted finish.

Whenever a new transfer system is installed or when a portion of an existing system is replaced, the interior surfaces should be treated either by sand or, shot blasting. The initial cost is far outweighed by the prevention of future problems.

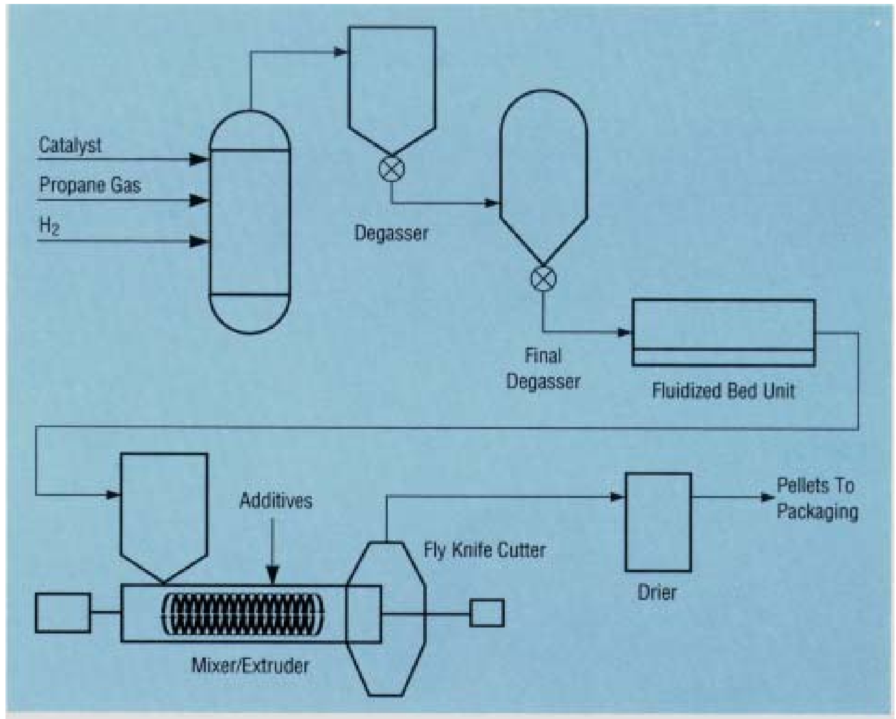


Figure 13. Process for polypropylene production.

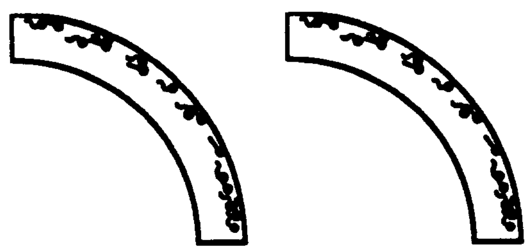


Figure 14:
Interior surfaces of long radius blends should be roughened to minimize "angel hair" and streamer formation in transfer systems.

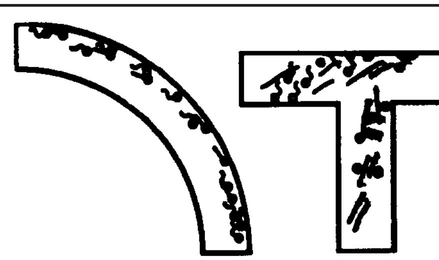


Figure 14A:

Eliminate long radius bends where possible by using self-cleaning stainless steel "tees" instead. These "tees" prevent the formation of streamers along the curvature of the bend.

Courtesy of HydReclaim Corp.

Figure 15. Gravimetric blending units accurately measure components in polyolefin extrusion.

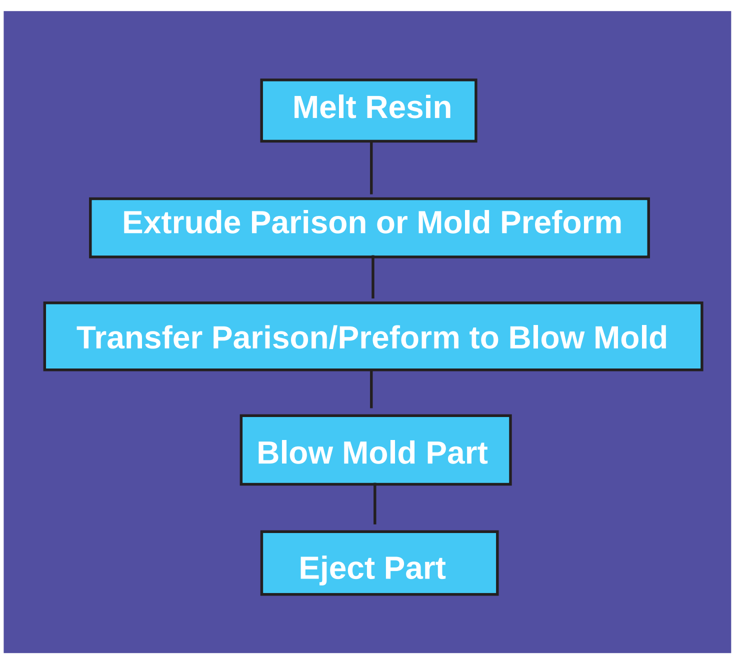


Figure 16. The five steps in the blow molding process.

Eliminating long radius bends where possible also is important (Fig. 14). Long radius bends are probably the leading contributor to streamer formation. When this type of bend is used, the interior wall should either be sand or shot blasted. Using self-cleaning stainless steel "tees" in place of long bends prevents the formation of streamers along the curvature of the bend **(Fig. 14A)** because the resin tumbles instead of sliding. However, some loss of efficiency will occur in the transfer system when this method is used.

These transfer lines should be rotated 90 degrees periodically to minimize the grooves resin pellets wear in the bottom of the piping as they are transferred. The grooves contribute to fines and streamer formation.

Sufficient blower capacity should be available to prevent the transfer lines from clogging and to maintain the required transfer rate.

Regardless of the type of equipment used or the material transferred, the transfer system should be maintained and kept clean. Silos and holding bins should be washed periodically to reduce the problem of fines and dust build-up from static charges. Other steps to take to eliminate contamination include:

- Cleaning all filters in the transfer system regularly;
- Ensuring that suction lines are not lying on the ground when the system is started; this will prevent debris or gravel from entering the system;
- Placing air filters over hopper car hatches and bottom valves during unloading to prevent debris or moisture from contaminating material;
- First purging lines with air and then with a small amount of product prior to filling storage silos or bins;
- And running blowers several minutes after unloading to clean lines and reduce the chance of cross-contamination.

Additional information regarding transfer systems and available interior finishes can be obtained from most suppliers of material handling equipment.

Blending With Colorants and Additives

Colorants and additives are blended with natural polyolefins during extrusion to enhance the performance and/or asthetics of the finished part.

Accurate and complete blending is essential for consistent quality in the end product. On-the-machine blending units consist of multiple hoppers which are fed different resin compound ingredients **(Fig. 15)**. Colorant or additive concentrates, regrind and base resin are combined using either volumetric or weightloss feeding (gravimetric) techniques. The latter usually more accurate. Microprocessor controls determine and monitor the amounts of materials fed into a mixing chamber. Recipes can be stored in the control unit for instant recall. Central blending units also can be used when much higher throughputs are needed than are possible with on-the machine blenders. Transfer to the extruder is done by a central vacuum loading system.

The Main Blow Molding Methods

There are three basic blow molding techniques: continuous extrusion, intermittent extrusion and injection blow molding. There are numerous variations of each. However, all the blow molding processes consist of five successive stages **(Fig. 16)**:

1. **Melting the resin**
   This is done using a continuous extruder, a reciprocating screw extruder or a reciprocating screw injection unit.
2. **Forming the parison or preform**
   In continuous extrusion and reciprocating screw extrusion, a parison is formed by forcing the plastic melt through a die. The parison is a hot tube, usually with a circular, but sometimes an elliptical or even rectangular cross section. In continuous extrusion, the parison is continuously extruded.
   In the reciprocating extrusion technique, parisons are intermittently formed to set lengths. In injection blow molding, the melt is injected into a mold cavity to form a "test tube"- like preform. Multiple preforms are usually molded in a single injection cycle.
3. **Transferring the parison or preform**
   In continuous extrusion, an open mold moves to the parison, closes on the parison, cuts a section off, and then reverses its path, allowing the extruder to continue extruding a parison for the next cycle. In reciprocating extrusion, the mold halves generally are positioned directly around the parison extrusion area and they close onto the parison.
   In injection blow molding, there are two basic methods for transferring the preforms:
   a. directly to the blowing station (most common with polyolefins).
   b. indirectly -the preforms cool, are ejected and then stored in inventory for subsequent forming in a separate blow molding unit.
   In the direct method, the mold indexes to a second blowing position. In the indirect method, the cooled preforms are loaded onto a conveyor that first transports them through a heating oven and then to a blow molding station (common with PET processing).
4. **Inflating the parison or preform**
   All of the various blow molding techniques use the same basic process for forming the hollow, blow molded part: high pressure air injected into the hot parison or preform forces it out against the inside surfaces of a mold cavity. The high pressure air enters the parison or preform held in the closed mold through a blow pin.
5. **Ejecting the finished blow molded container or other article**
   After the part has been blown in the mold cavity and cooled sufficiently for handling without distortion, the mold opens and the object is ejected. With injection blow molding, the ejected item is totally finished, i.e., it requires no subsequent machining to remove any scrap. With continuous extrusion and reciprocating extrusion blow molding, the ejected part usually is transferred to a trimming station where scrap from the bottom and top of the part— called flash— is cut off. Some extrusion blow molding machines trim parts directly in the mold.

Blow Molding Equipment

Both continuous extrusion blow molding, the most widely used technique, and intermittent blow molding systems include a hopper, extruder, die head and blow handling unit. The primary differences between these two systems concern the operation of the extruder screw — whether it continually moves or stops between parisons —and the design of the blow molding unit. This section will review the basic equipment common to both systems and then deal with the differences.

Hopper

On top of the hopper, an automatic loader periodically feeds the resin into the hopper, which, in turn, passes it along to the extruder. Some set ups may have hopper blenders which feed and proportion resin pellets, regrind, color concentrate and/or additive concentrate to the extruder.

Two basic types of automatic hopper feeding systems are common:

1. Volumetric feeders that refill the hopper on a schedule based on the extrusion system's output.
2. Gravimetric feeders, also called loss-in-weight feeders, that directly feed resin into the extruder feed throat. These feeders measure the weight of material fed to the extruder from a special weigh hopper and determine the rate at which it is being consumed.
   Gravimetric feeders ensure that the amount of resin in the feed section of the screw is always the same; with volumetric feeders, resin pellets tend to compact in the screw when the hopper is full. A computer compares the actual material consumption rate against set points, performs statistical analysis and makes adjustments as necessary to maintain specified output. When a deviation is detected, the control system corrects this by changing the screw speed.

Hopper throats may be water-cooled to prevent resin pellets from sticking together and "bridging over." During shut down, if an extruder

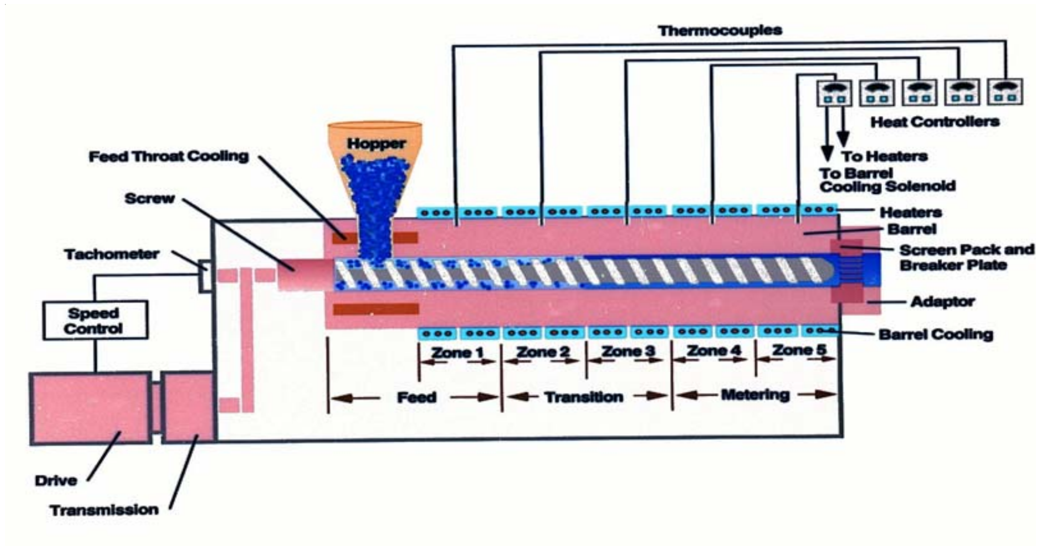


Figure 17. Cross section of an extruder

is run "neutral," i.e., hot, the screw should be kept turning until all resin has moved out of the screw flights visible from the hopper. Otherwise, resin may melt and "bridge" near the hopper and choke off output.

Extruder

The extruder consists of a barrel that encloses a screw, heaters on the outside of the barrel, thermocouples to measure melt temperature and, sometimes, a screen pack through which the melt is forced as it flows into the die head **(Fig. 17)**.

Barrels

Extruder barrels are lined with wear-resistant metal liners, made from materials such as tungsten carbide. With such liners, these barrels can last for years under continuous use. Most barrels have smooth bores, but those used for processing high-molecular weight (HMW) HDPE and PP can have a grooved feed zone for greater throughput efficiency **(Fig. 18)**. Most common extruder barrels have heaters along their entire length. In the specific case of grooved feed-zone extruders, the feed zones are water cooled.

Heaters

Heat to melt the resin on its way through the barrel is supplied internally by frictional forces caused by the mixing and compressing action of the screw; and externally by heaters. The adapter and die head also are heated to prevent heat loss from the melt. Band heaters are the most common type of electric heater used. They respond rapidly, are easy to adjust and require minimal maintenance. As shown in **Fig. 17**, the heater bands are distributed along the barrel's length in zones; generally there are three or four independent zones, each with its own heating control. About 25 to 45 watt/in. (4 to 7 watt/cm) of barrel surface gives adequate heat.

Electric resistance heating is usually provided on extruders, although induction heating is occasionally used. Each of the independent electrical heating zones is regulated by a controller, such as an indicator mounted on the temperature control board. A drop in one zone may indicate a defective heater; a rise may point to a hot spot due, for instance, to the rubbing of a damaged screw on the barrel lining.

It the heating capacity of the extruder is inadequate, heaters will stay "on" most of the time. To determine if and where heaters are not working, some extruders are equipped with a heat -failure safety alarm system. The alarm warns of heat loss or blown fuses somewhere in the extruder or die. However, heater failures occurring during operation may not be detected since internal frictional heat may be sufficient to maintain operating temperatures. When an extruder has been shut down, the heat controllers should be checked before starting a new production run.

Blowers

Blowers, located along the barrel length, can be activated to decrease barrel temperatures. The blowers also permit rapid barrel cooling when the extruder is shut down. Some blow molding equipment may also come equipped with water-cooled or heat-transfer fluid zones for improved heat transfer.

Thermocouples

Thermocouples, inserted deep into the barrel wall in the various heating zones and in some cases even into the melt, monitor processing temperatures (**Fig. 17)**. Thermocouples signal electronic temperature controllers which in turn, regulate heater bands and cooling devices. Regular maintenance checks should be made to make sure thermocouples are tightly seated in the barrel wall.

Screw

A motor-driven screw rotates within the hardened liner of the barrel. Screws typically run between 50 to 100 revolutions per minute (rpm). Most screws have three sections, with channel depth becoming shallower in each progressive section (Fig. 19).

Some screws have an additional mixing section. As the screw rotates, the screw flights force resin in the screw channel forward through the sections where it is heated, melted, thoroughly mixed and compressed **(Table 4).**

A long, properly designed screw results in better melting and mixing of the resin than a short one. Long screws also yield better appearance and wall thickness uniformity in the parison, and an increased production rate. Furthermore, melt temperature is easier to control. The screw should be at least 20 times as long as its diameter, and should have a compression ratio of 3.1 to 4:1, depending on the resin used. For example, because of its higher melting point, HDPE generally processed better using a higher compression ratio than LDPE.

For polyolefin blow molding, a screw with a feed section of six or seven turns, a compression (or transition) section of four or five turns and a metering section of five to eight turns has been found most efficient. Such a screw provides a steady melt flow and increases output at moderate speeds. At high compression, the melt is mixed well and internally generated heat is high. Any air carried forward with the melt is pushed back and out through the hopper. Otherwise, this air can cause bubbles and, if temperatures are high enough, oxidization of the resin in the barrel. Screws for polyolefin blow molding extruders are practically always run “neutral,” that is, without the cooling that can be achieved by circulating water through an axial bore about halfway through the length of the screw.

Breaker Plate

After travelling the length of the screw, the melt passes through a screen pack, supporting breaker plate and the adapter on its way to the die. The round breaker plate **(Fig. 17, Table 5),** is located between the end of the barrel and the head adapter, usually fitting into both, but sometimes only into the adapter. This prevents leakage. The thick breaker plate is enclosed by a sturdy ring and is pierced by a large number of equally spaced holes measuring one-sixteenth to one-eighth in. (1.6 to 3.2 mm) in diameter.

Blow molding operators should always keep a spare breaker plate available in case the one in use is damaged or is exchanged along with

Courtesy ofBattenfeld Fischer Blow Molding Machines, Inc.

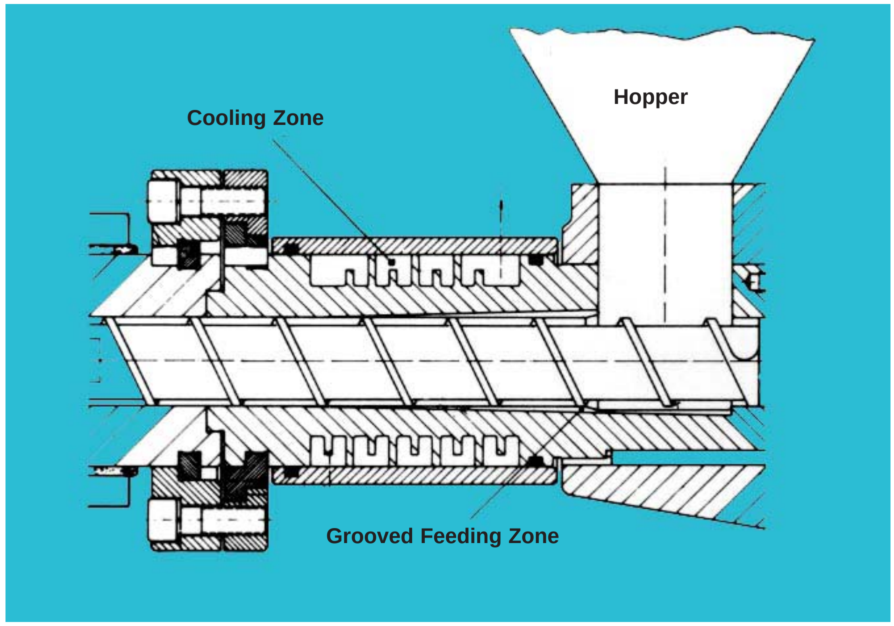


Figure 18. A cross section of the extruder barrel.

Table 4: Functions of the Four Sections of a Polyethylene Extrusion Screw

Sections	Channel Depth	Functions
Feed	Deep	Cool resin pellets are moved forward into hotter barrel zones.
Compression	Decreasing	Resin is compressed, melted and mixed. Air carried along slips back to the feed section.
Metering	Shallow	Sufficient back pressure is created to make the melt homo-geneous (uniform), make its temperature uniform.
Mixing	—	Thorough blending of melt before feeding it into the die system.

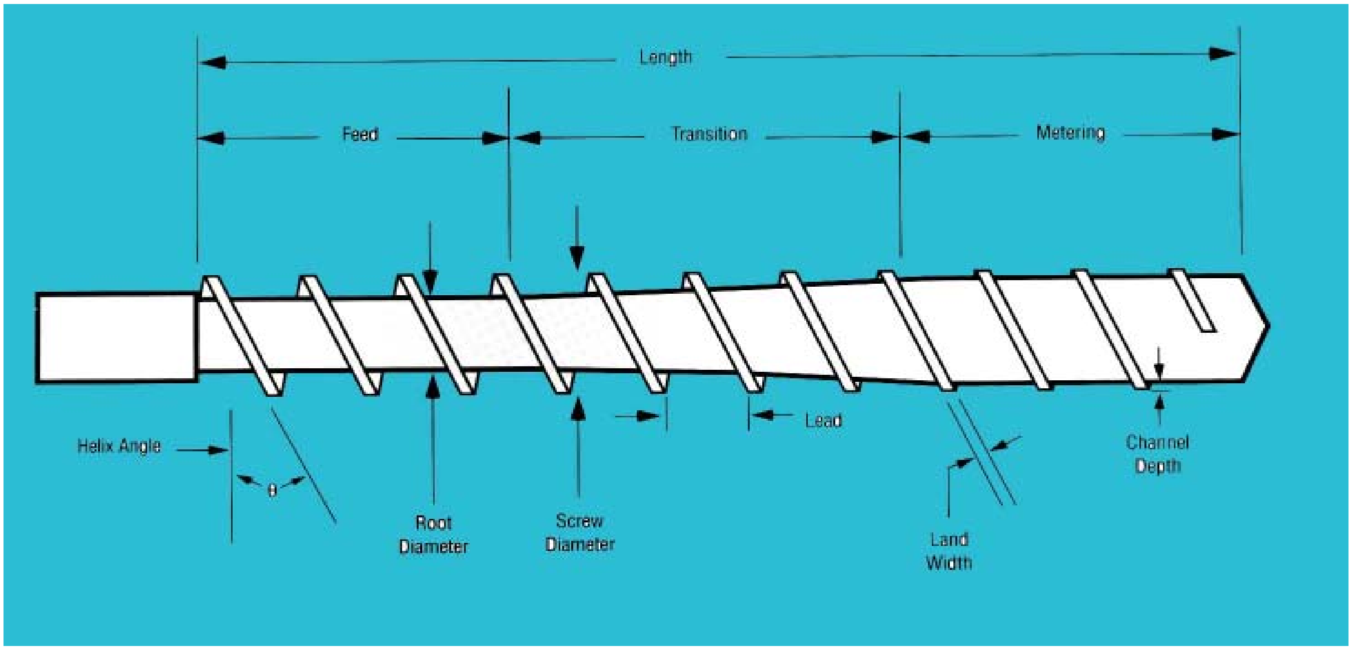


Figure 19. Typical extruder screw for HDPE

Table 5: Functions of a Breaker Plate

Support the screen pack
Develop back pressure
Reinforce screen pack's action
Align the barrel and adapater
Straighten out the spiral flow of the melt caused by the screw
Serve as a seal between the barrel and the adapter (which a loose breaker plate can not do)

the screen pack. Having a clean breaker plate ready may eliminate downtime, because the spare can be placed in service while the "used" breaker plate is burned out and cleaned.

Screen Pack

The screen pack, located in the breaker plate (Fig. 17), consists of a number of stainless steel screens. The mesh number associated with a screen represents the number of openings present per inch of screen. Therefore, higher mesh number screens are finer (have smaller openings) than lower mesh number screens. The screen pack acts as a filter for foreign matter that may be inadvertently mixed in the resin. A screen pack can help increase back pressure in the barrel, particularly if an extruder (or pressure) valve is not used for this purpose. This can be a benefit in terms of improved melt homogeneity and color dispersion. On the negative side, a screen pack (or switching to a heavier screen pack), can result in higher resin temperatures.

There is no "typical" screen pack; different packs are best suited for different jobs. A 20-80-20 mesh screen pack is sometimes recommended for blow molding, meaning a finer 80-mesh screen is sandwiched between two coarser 80-mesh screens. Fine-meshed (dense) screens should generally be located between coarser screens as this offers better physical support. The temperature of the melt may be raised slightly by using a much heavier screen pack (more or finer screens, or both) which, by increasing the back pressure, may also generate additional frictional heat.

Always use stainless-steel screens, never copper screens, although they are less expensive. Copper is too soft for such a high pressure application; moreover, it may oxidize and contaminate the resin. A hinged or swing-gate collar may be used to attach the adapter tightly to the barrel head and to facilitate screen pack changes. Screen packs do need to be replaced on a periodic basis.

Automatic Screen Changers

Automatic screen changers, which have either a continuous screen band or rotary units that index when exposed sections become clogged, can be used with continuous extrusion blow molding machines. The indexing occurs without interrupting the melt flow. These eliminate downtime necessary for manual screen changes.

Pressure valves

Pressure valves permit a constant check on internal pressures; these have a significant effect on melt temperatures. Two types of pressure valves are common:

1. The internal pressure valve is a movable screw that can be adjusted forward or backward to increase or decrease pressure. Moving thescrew varies the size of the opening between the end of the screw and the breaker plate and adapter.
2. External pressure valves use a pin arrangement that varies the size of the opening at the extruder's adapter, thereby varying pressure. At the end of the extruder barrel, between the melt screen and the parison die head, there is an adapter **(Fig. 17)** that constricts and guides the resin melt flow in a streamlined path with a minimum of resin hangup.

Melt Pumps

Melt pumps, also called gear pumps, can be attached between the end of the extruder and the die head to greatly increase melt quality. For continuous extrusion multilayer blow molding, these units can deliver a stable, surge-free melt output and provide excellent layer uniformity. These benefits are particularly important for thin barrier layers and adhesive tie-layers found in coextrusion blow molding.

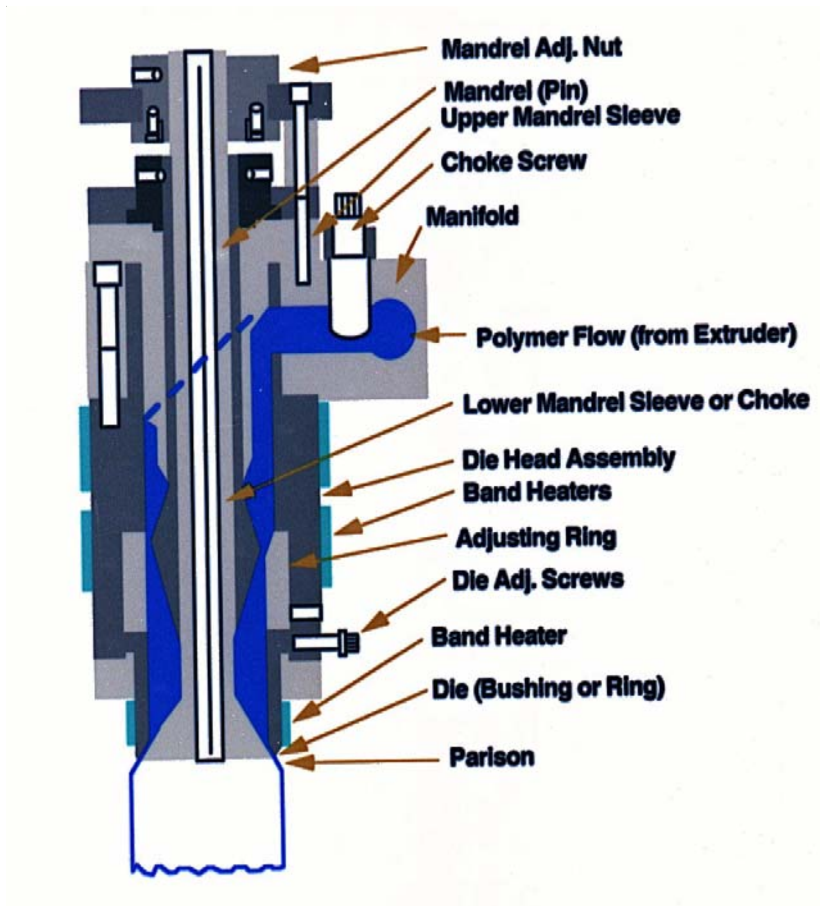


Figure 20. Typical Die Head

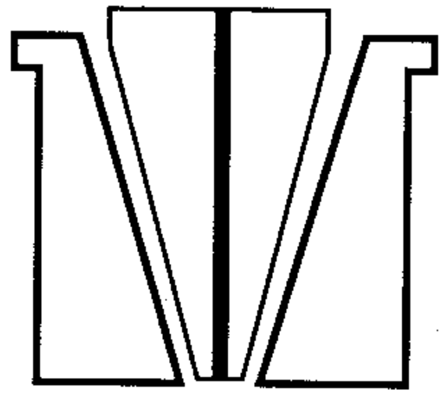
Die Head Unit

The functions of the die head unit **(Fig. 20)** are:

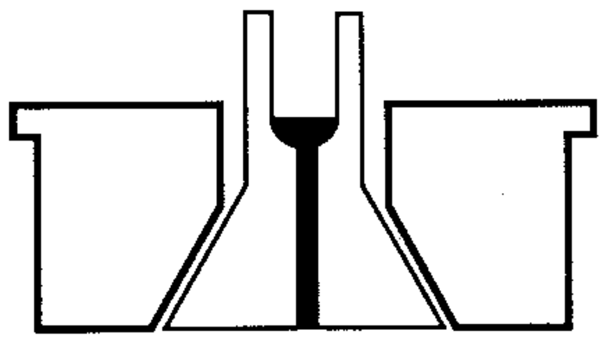
- to form the melt into its final shape, the parison
- to maintain the melt at a constant temperature
- to meter out the melt at a constant pressure and rate to form a parison with a desired wall thickness.

The die head unit opens to the outside through an accurately machined tube-shaped orifice, through which the melt is pressed in a steady flow. The die head should be designed without sharp corners or edges that the resin must pass over. Sharp corners or edges tend to bleed off heat and can cause heat streaks in the finished parison. With most die head designs, the resin must flow around a mandrel and reknit on the other side to form the tubular parison. Die heads should be constructed so that the length is great enough to allow the resin to "remarry" after forming the parison tube. If the die head length is inadequate, a noticeable weld line will show on the parison, which may remain as a defect on the finished product. Die heads are usually designed so that dies can be exchanged easily.

Heaters keep the adapter and die head at the required temperature. They are controlled in the same way as barrel heaters. However, the adapter



Die and Mandrel for 16-Ounce Container



Die and Mandrel for One-Gallon Jug

Figure 21. Typical Converging and Diverging Dies

and die head heaters maintain melt temperature and should not be used to increase it. Melt temperature at the die head, where the parison forms, ranges from 290 to 32°F (145 to 165°C) for LDPE; 350 to 400°F (175 to 205°C) for HDPE; and 375° to 425°F (1900 to 220°C) for PP (PP homopolymers have slightly higher, melting temperatures than random copolymers). Resins with lower melt indices require melt temperatures at the higher end of these ranges than higher melt index resins.

Generally, LDPE resins for blow molding have melt indices below 2 g/10 min.; HDPE, below 1.0 g/10 min.; and PP, melt flow rates below 2 g/10 min. If resin melt temperatures are too low, the parison will be cloudy or dull in appearance and may also show signs of melt fracturing or aligatoring. A parison of this type will not be hot enough to yield good weld lines at the pinch-off areas. On the other hand, if the melt temperature is too high, the parison will look clear, have glossy areas and may emit smoke. The hot parison will be stringy and tend to stretch easily, resulting in thin areas. Pinch-off problems may also occur, as well as extremely thin weld lines.

In a crosshead die unit, the melt flow is almost always turned 90 degrees (in a right angle) and diverted from the horizontal to the vertical and extruded downward. Some types of extrusion blow molding machines do not require a crosshead die because the extruder itself is positioned to extrude the parison tube vertically downward. In these more unusual cases, there is no need to turn the melt flow in the die head to obtain a seamless tube. At the die face, the melt should flow straight down to form a parison with uniform wall thickness. The die and mandrel in the lower section of the die head can typically be changed for individual jobs. Usually, dies are one of two types: converging or diverging **(Fig.21).**

Dies and mandrels for parison extrusion normally have a land. This is a flat section machined at the end of the die and mandrel. The land is the working area of the die and mandrel where the volume of the resin being extruded is constant. Some blow molders recommend a die land length 10 to 40 times as long as the die opening or clearance, that is, the width of the die slot. Other molders prefer very short die lands. A long die land increases back pressure on the melt in the extruder head and improves mixing. Longer die lands are beneficial when the total head length does not allow the resin to properly reweld itself after flowing around the core.

A pressure ring above the die and mandrel is often used to erase or smooth out flow lines in the melt before it is extruded as a parison **(Fig. 20)**. A short die land, in conjunction with high extrusion speed, may result in outer surface roughness of the parison and the blown part. This is known as “melt fracture”. Finding the most favorable die land length for a particular job is a matter of experience and trial runs. It may be necessary to modify the core and the die body in the land area, or if the end product permits a change in wall thickness, to modify the die gap opening.

Parison Die Designs

There are various parison die designs. The two kinds generally used with continuous extrusion blow molding are center-fed and side-fed.

In a center-fed die, the melt flows vertically downward around the core, also called the pin **(Fig. 22)**. Center-fed dies have an advantage in that the melt distribution around the core is rather uniform. The melt flows down toward the tip of the torpedo-shaped core for a certain distance after having been turned by 90 degrees in the die head, resulting in straight flow all around the core. The core is supported inside the die head unit by either a breaker plate or a spider **(Fig. 23)**.

Generally, the breaker-plate type is preferable because it will keep the melt flow more uniform. However, both types of support may yield flow and knit lines in the blown part, especially when lower melt index resins are used. Flow lines will result in blow molded items with poor appearance and impaired strength along these lines.

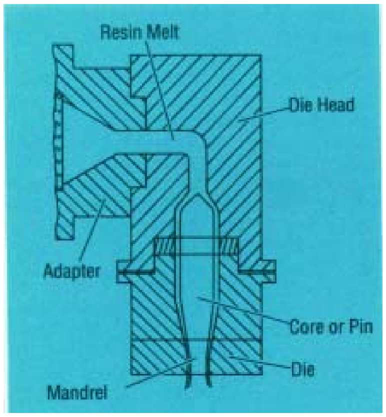


Figure 22. Schematic of center-fed die.

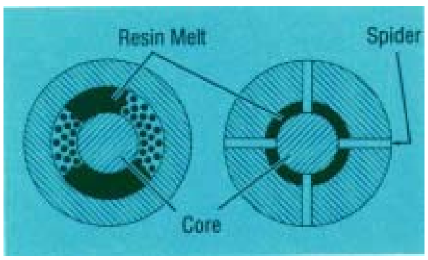


Figure 23. Left: perforated (breaker plate); Right: spider (cross-piece type of core support in a blow molding die.

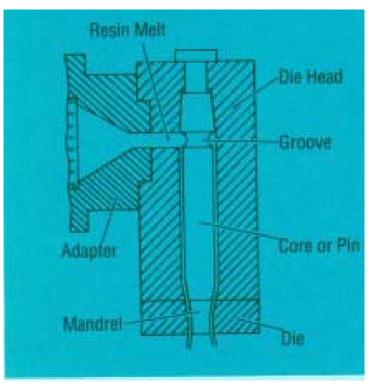


Figure 24. Schematic drawing of a side-fed die with a grooved core.

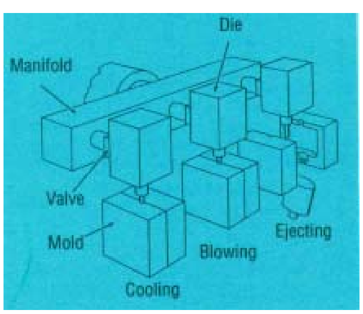


Figure 25. Multiple-dies, multiple-stationary-mold equipment.

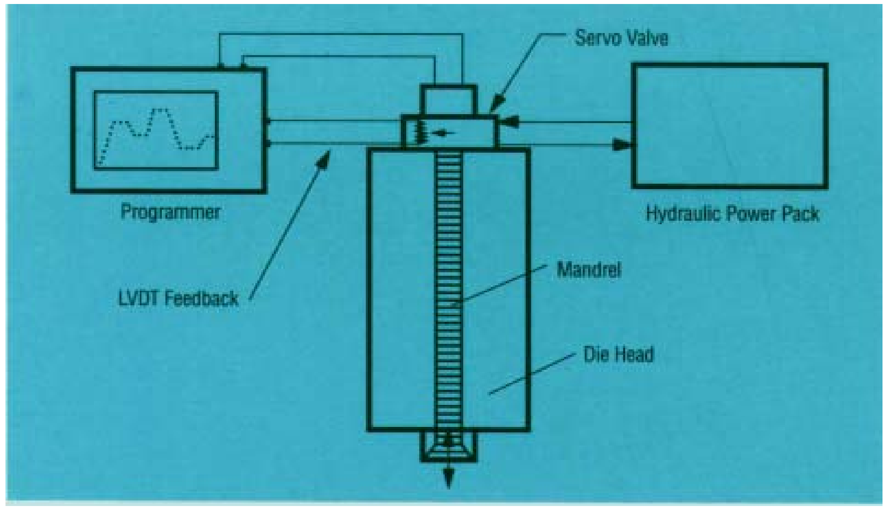


Figure 26. Parison programming system.

In side-fed dies, the melt flow hits the core, or flow pin, sideways **(Fig. 24)**. To obtain uniform melt flow around the side-fed core and out of the die, a groove is frequently machined into the core.

Multiple dies

In extrusion systems with multiple dies, the melt from the extruder passes through a manifold into a series of parison-forming dies. The amount of material reaching each die is controlled by choke values in the manifold or, if the die is equipped with a parison programmer, by weight control settings **(Fig. 25).**

Parison Programmer

While being formed, the parison is subject to the distorting downward pull of gravity. Unless extrusion is very fast, the parison thins out at the top and thickens toward the bottom instead of maintaining uniform wall thickness. This parison sag, also called draw-down and neck-down, results in excessive wall thickness of the blown item near the bottom of the mold. Sometimes, this may be preferred, as excess resin often strengthens the shoulder, neck or bottom of a container. But in most instances, sag is to be avoided.

Deviations in wall thickness can be overcome by gradually increasing wall thickness during extrusion. This is done by means of a movable mandrel. The motion of the mandrel in the die is controlled by a servo valve assembly called a parison programmer. The parison programmer raises or lowers the mandrel while the parison is being formed **(Fig. 26)**. The mandrel's position is recorded and fed back to the controller via a LVDT.

As a result, resin is extruded to form a parison with a controlled variability in its wall thickness **(center section in Fig. 27),** resulting in an end product with more uniform wall thickness. Parison programming also is used if the blown end product is not symmetrical and thus, requires an uneven resin distribution. Parison programmers **(Fig. 28)** can have 100 or more profile points, thus permitting excellent control of the parison cross section.

Cut-Off Devices

A parison cut-off device, frequently mounted under the die face, severs the parison from the constantly extruded tube when the parison reaches the required length and the blow mold halves have closed around it. The cuffing device, as well as the parison length are controlled by a sensor, such as a limit switch photoelectric cell or even a laser beam. There are various types of cutting devices, including stab knives (for parisons up to three inches in diameter), hot wire knives (required with PP parisons as well as thin-walled parisons), impact knives and cold parison knives (the most common type of cuffing device).

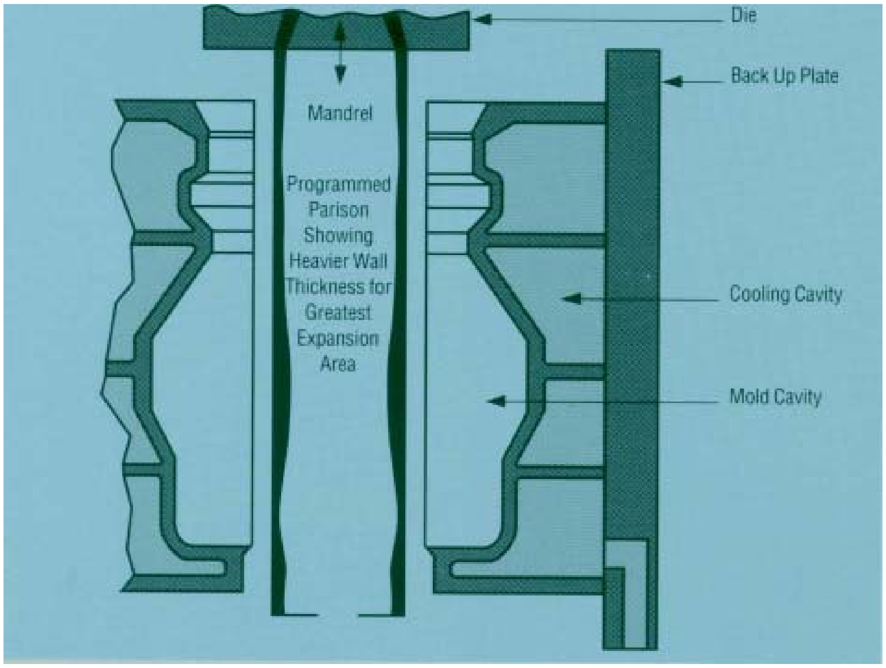


Figure 27. A programmed parison designed to fit a particular mold configuration.

Courtesy of Krupp Kautex.

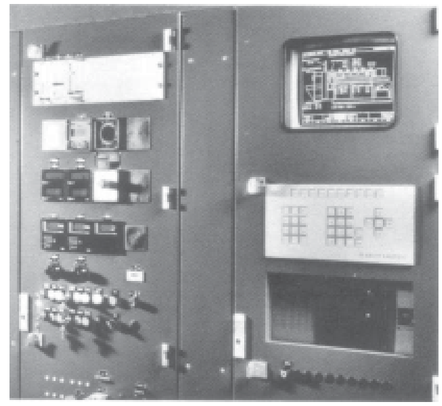


Figure 28. Control unit for a parison programmer.

Courtesy of Graham Engineering Corporation

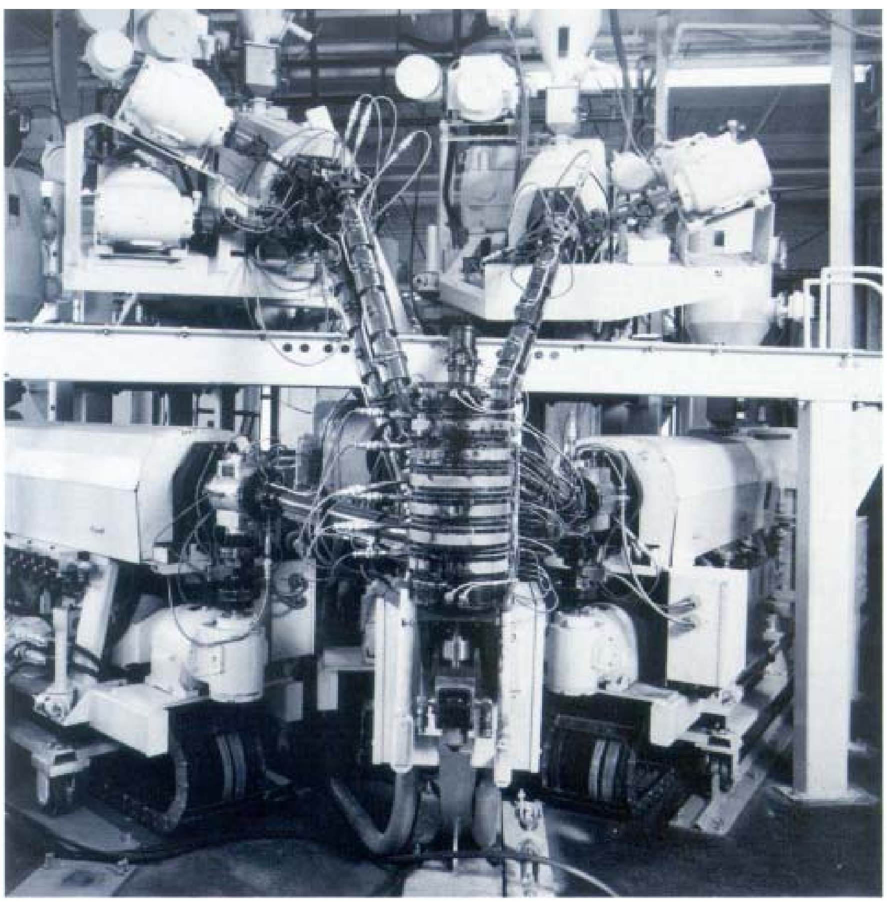


Figure 29. Multiple extruders and special die heads are needed for coextruded multiple-layer bottles.

Coextrusion

Multilayer blow molded containers are produced by using multiple extruders, one for each type of resin ‘ processed, and special coextrusion die heads and parison dies **(Fig. 29)**. Coextruded containers can provide:

- Excellent odor, moisture, and/or oxygen barrier characteristics, such as needed for many food products
- Specially colored outer surfaces, such as needed with fluorescents and metallics
- Greater environmental stress crack resistance, such as HDPE bleach bottles with an inner lower density PE layer and coextruded blow molded gasoline tanks.

Another growing use of coextrusion is the production of multilayer blow molded containers with a middle layer of post consumer resin, i.e., recycled resin from discarded HDPE and PP containers, sandwiched between two virgin resin layers.

The Blow Molding Unit for Continuous Extrusion Blow Molding

Continuous extrusion systems are available with various types of blow molding clamp designs, which differ each other mainly in the way the molds are mounted and presented to the die to close around the parison **(Fig. 30)**. The two basic designs are:

Courtesy of Cincinnati Milacron

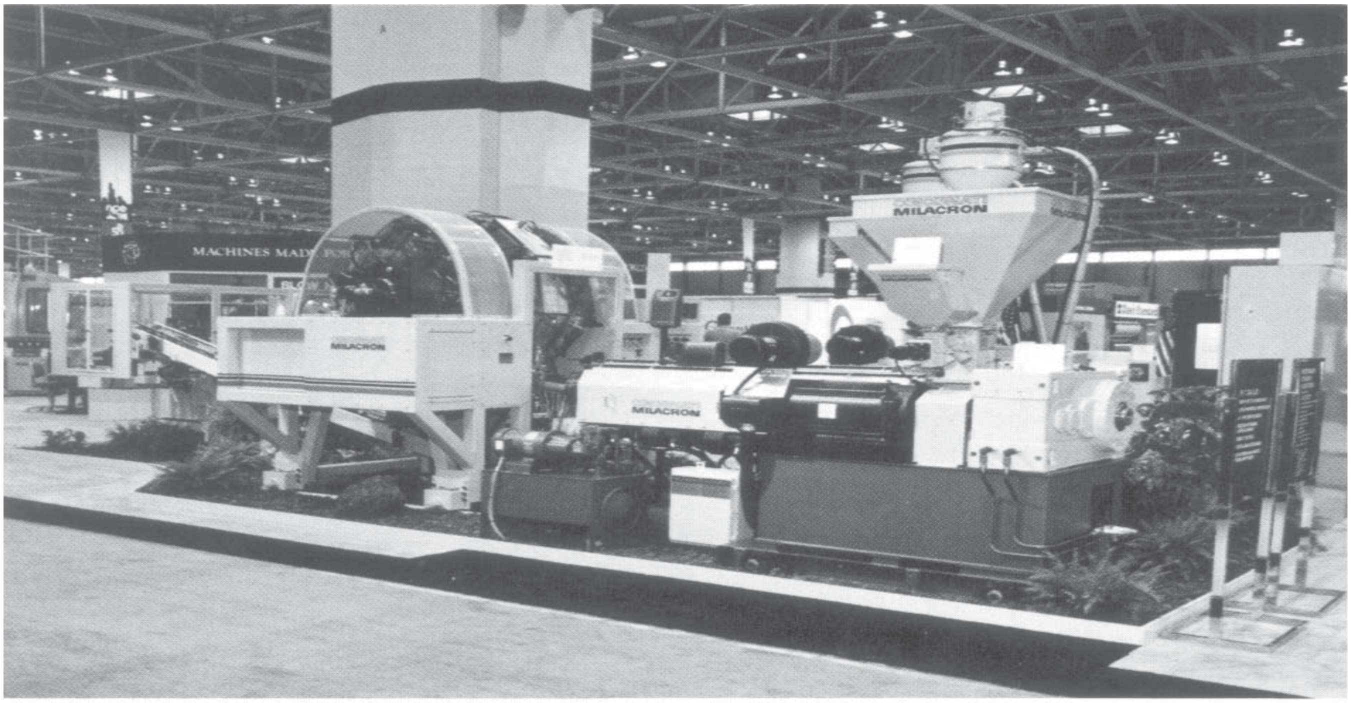


Figure 30. A rotary blow molding machine

Courtesy of Wilmington

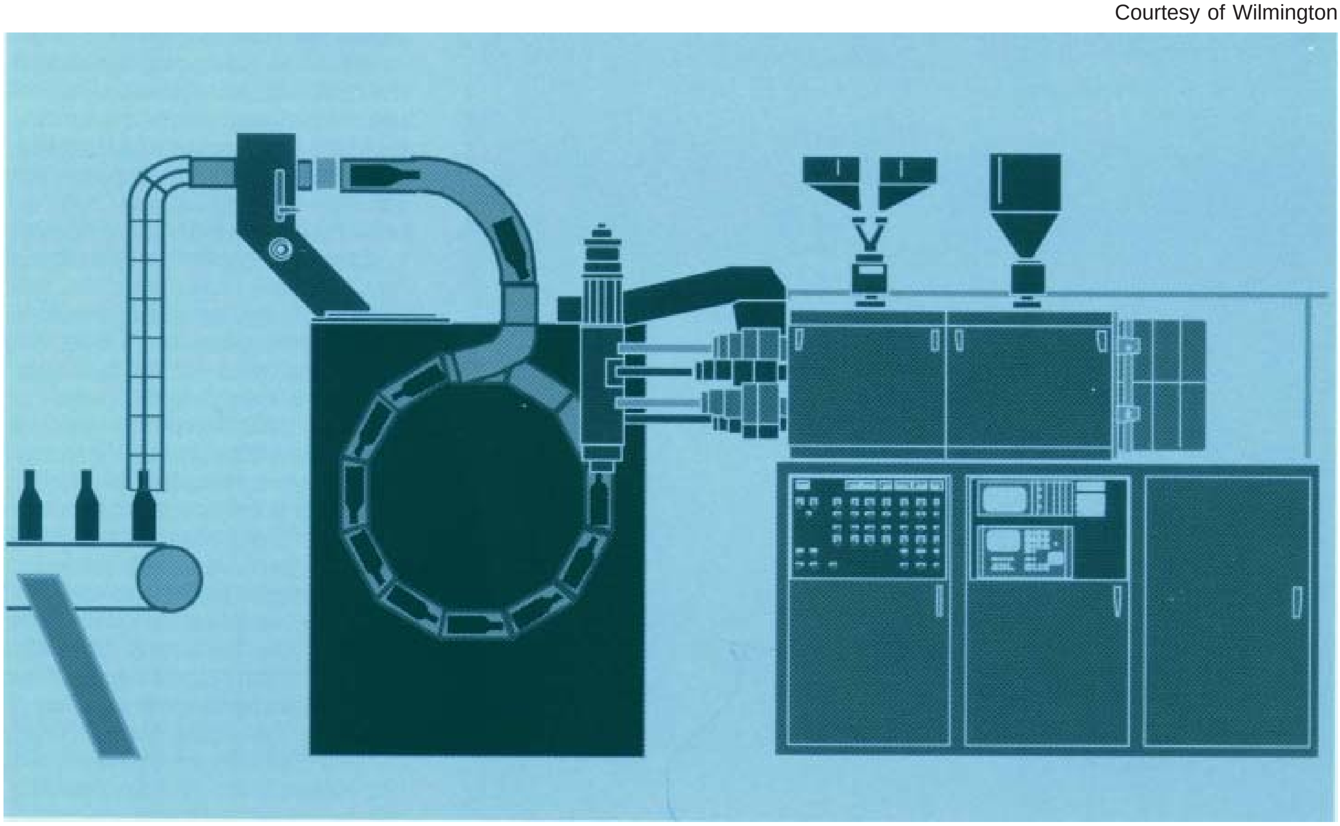


Figure 31. Continuous extrusion blow molding machine with a vertical wheel.

- molds that move on a rotating wheel or table
- molds that are shuttled to the parison die.

The mold halves, mounted on platens, are held together during the blowing step by presses that are actuated either by a mechanical toggle mechanism or hydraulic cylinders. Low clamping pressures, compared with those used with injection molding machines, are used with extrusion blow molding. On some blow molding presses, mold closing is carried out in two steps, first at high speed, with lower pressure and then slower to full close, with higher pressure. This sequence protects the mold from damage by anything that might have fallen between the halves. It also enhances and increases operator safety.

Vertical Wheel Mold Carrier

Continuous extrusion blow molding machines with vertical wheel mold carriers **(Fig. 31)** offer greater productivity compared to continuous extrusion shuttle or fixed mold reciprocating equipment. While the wheel continuously turns, one mold at a time passes around the die to receive and close around the parison. In some vertical wheel machines, the mold halves are connected by a hinge; in other designs they are separate. Vertical wheel machines are available in which the parison is extruded downward or, in others, upward. In both cases, the wheel moves faster than the parison, and as a result, the parison is stretched. The control of the parison in these cases is excellent. The ejected items may be connected by sections of the parison. This requires trimming steps at both ends of the molded item however, creating a substantial amount of scrap that must be granulated and reused. Vertical rotary wheels may carry 20 or more molds. Machines also have been built with two cavities per mold, yielding 28 to 36 parts per revolution. Cycle times yielding 150 parts per minute can be achieved.

Horizontal Wheel Mold Carrier

Continuous extrusion blow molding machines also are available with the molds mounted on a horizontal turntable **(Fig. 32)**, typically with 4 to 8 mold stations. Their productivity is generally less than the vertical wheel

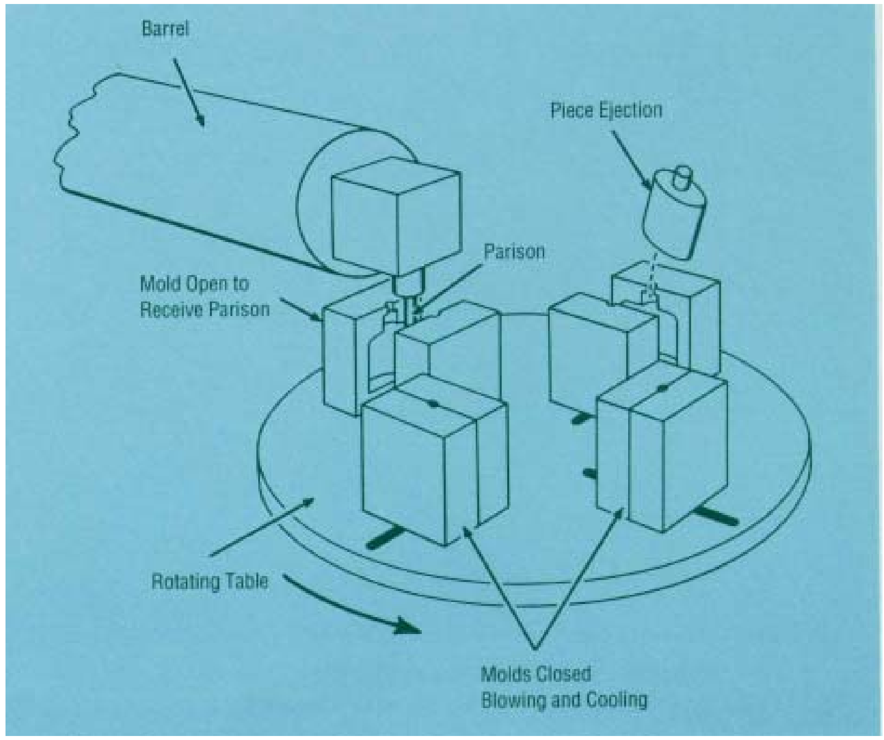


Figure 32. Multiple-station turntable.

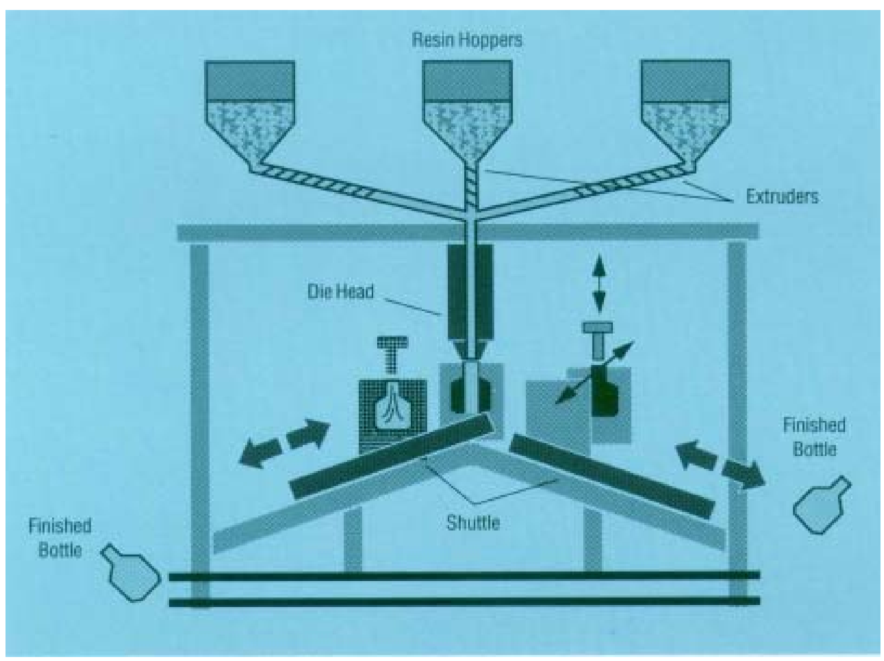


Figure 33. Continuous extrusion blow molding machine, with a shuttle system.

Courtesy of Uniloy Blow Molding Systems, a division of Johnson Controls

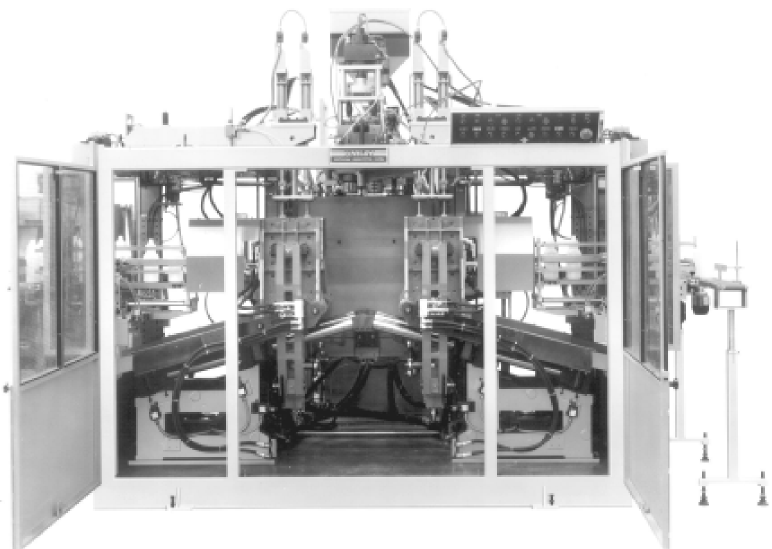


Figure 34. Continuous extrusion blow moding machine with a shuttle mold carrier.

Courtesy of Battenfeld Fischer Blow Molding Machines, Inc.

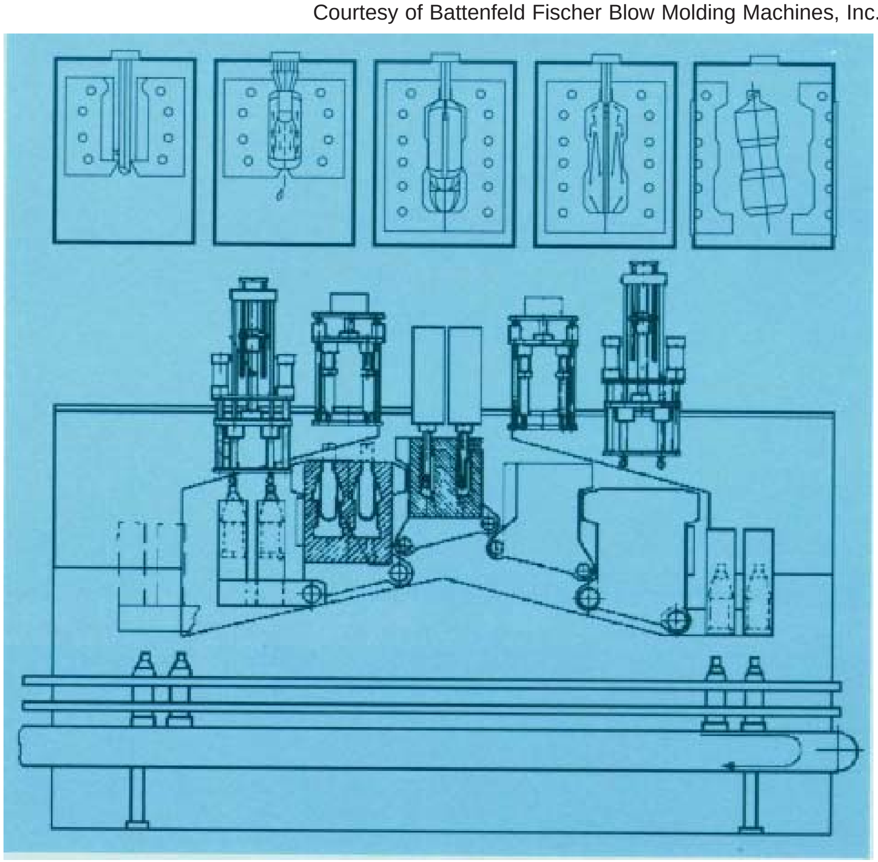


Figure 35. Extrusion stretch blow molding.

machines which carry more mold stations. The operation of the continuously moving turntable is essentially the same as that of the rotary wheel. Indexing turntables and wheels also are available.

Horizontal turntables may produce less scrap than vertical wheels because the parison is cut from the die face by a cut-off knife. Consequently, the blown pieces are not connected to each other and the "tail" flash can be kept short. Automatic ejection can also be easier than from a mold on a rotary wheel, without the need for knockout pins. The advantages of higher output are obvious. However, the higher output machines are more expensive initially, as are dual cavity molds.

Shuttle Mold Carrier

In continuous extrusion blow molding machines with a shuttle mold clamp unit, one or more parisons are extruded and the molds move to the die head horizontally from side-to-side or diagonally up and down from both sides of the die head **(Fig. 33 and 34).**

Open molds, carried along on way bars, alternately move up to close around and pinch the parison. The parison is then separated from the extruding tube by a cutting device attached to the die or the extruder. Next, the closed mold swings back down to the clamping station. Blowing can be done by means of a blowing pin in the bottom of the mold or, as is more common, by injecting the air through a blowing pin that enters the top of the mold. In the latter case, finishing work is considerably reduced because no reaming is required. However, flash may occur on the outside of the part. After the molds open and the blown part is ejected, the mold rises again to receive another parison.

Production rates are high with this type of equipment. One extruder head may form multiple parisons simultaneously to feed multiple mold cavities.

Dies are of the crosshead type. Or, to increase production, several heads on one extruder may shape several parisons simultaneously. In this case, a valved manifold die is required to compensate for pressure and temperature differences in the melt flow or to feed two sets of molds alternately.

In equipment where the mold moves sideways, a second mold closes over the continuously forming parison the moment the first mold moves to the right or left for blowing. Compared with

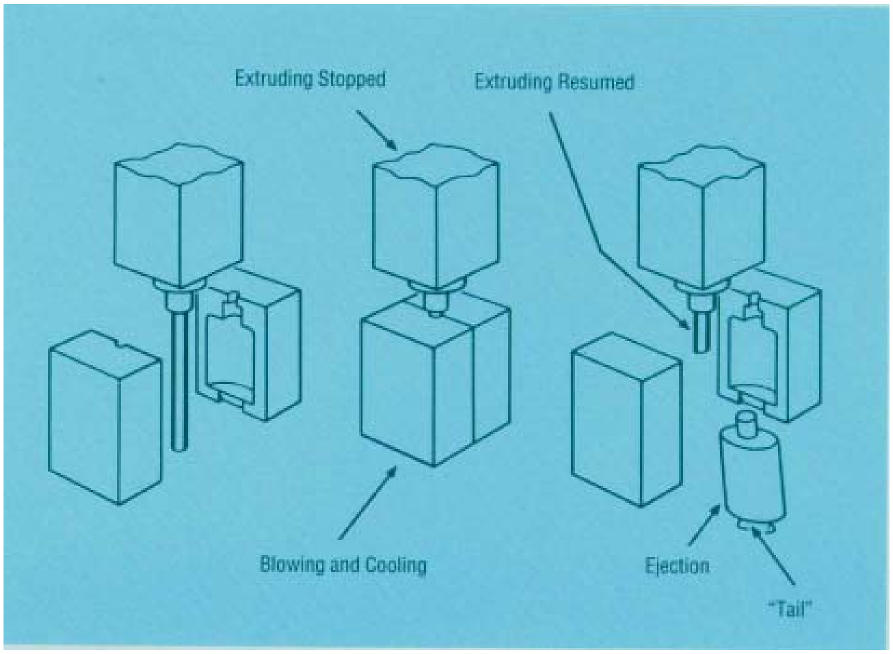


Figure 36. Schematic of intermittent parison extrusion into a stationary mold. Extruder operation is interrupted after the parison has reached the desired length and before the mold halves have closed around it (left). Operation is resumed only at the end of the ejection step (right).

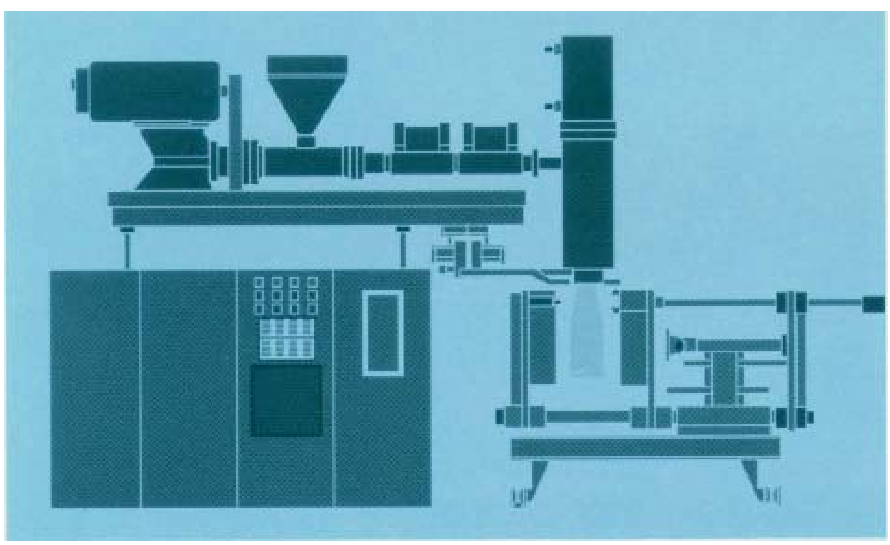


Figure 37. Continuous extrusion, accumulator head.

the swinging-mold procedure, the sliding-mold method either may permit higher production rates or allow for a longer cooling period, which may be advantageous to obtain certain end product properties.

Hydraulic systems generally are used for clamping and moving the molds, the platens on which they are mounted and other heavy parts of the molding equipment, such as rams used in accumulator heads.

Extrusion Stretch Blow Molding

Extrusion stretch blow molding is a variation of extrusion blow molding with shuffle molds **(Fig. 35)** that produces transparent containers having high side wall stiffness. Initially, the parison is blown to form a "preform," which is then transferred, while still hot, to a second larger and longer mold cavity. Here, a long blow pin is inserted into the hot preform to stretch it to the bottom of the mold cavity. Air is then injected through the pin to form the container. With certain types of materials this stretching results in high transparency and thin side walls with good stiffness. Impact properties are also enhanced.

Blowing air can be injected downward through the core via a blowing needle inserted sideways through the mold wall, or from below through a blowing pin moved up into the end of the parison that will become the neck of a bottle. Sometimes, different blowing devices are used in combination. To obtain rapid inflation of the hollow piece, the volume of blowing air should be as large as possible. The opening through which the air enters the mold must be large enough to handle this air volume. The thinner the wall thickness and the lower the melt and mold temperatures, the faster the blowing rate should be and the higher the blowing pressure, up to about 150 lb./in. (10. 5 kg/c m).

Compressed air injected into a cold mold may lose some pressure because a cooling gas contracts. High blowing pressure requires high clamp pressure to keep the mold tightly closed during the blowing step.

Moisture in the blowing air may result in marks on the blown part. Blowing air can be dried by a heat exchanger, which cools the compressed air, or by traps and separators in the air lines. Blow pins also can serve as in-mold finishing units for blow molded containers.

Courtesy of Hartig Plastics Machinery

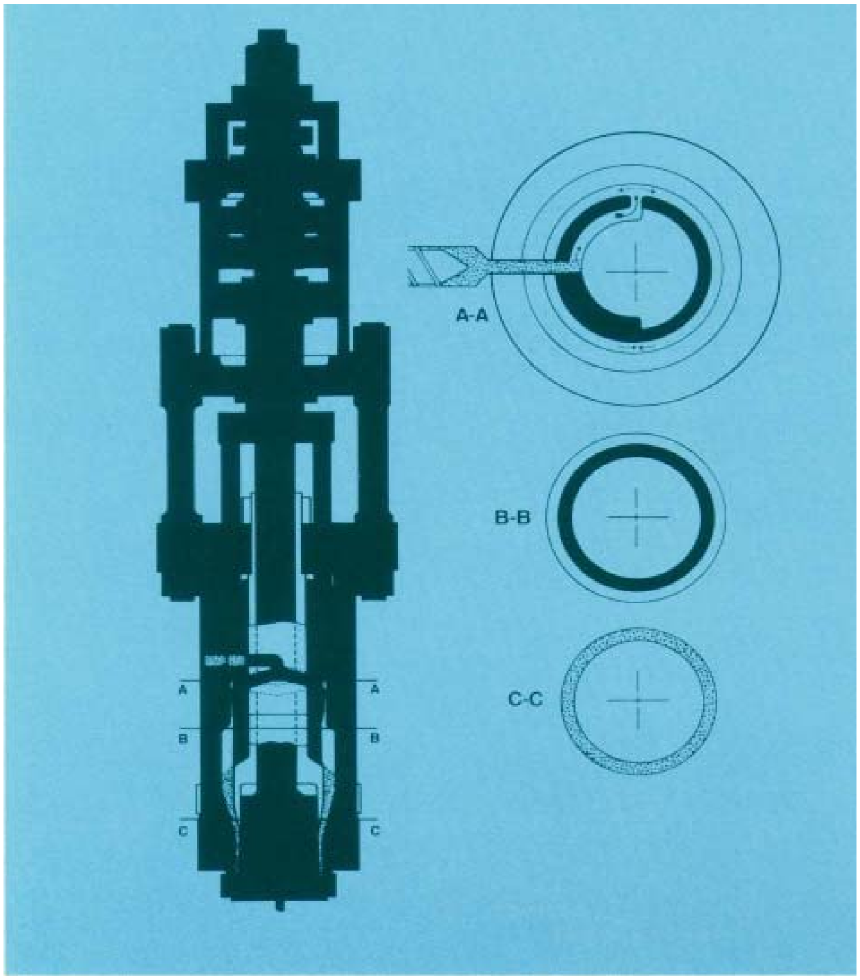


Figure 38. Example of an accumulator used for blow molding large parts.

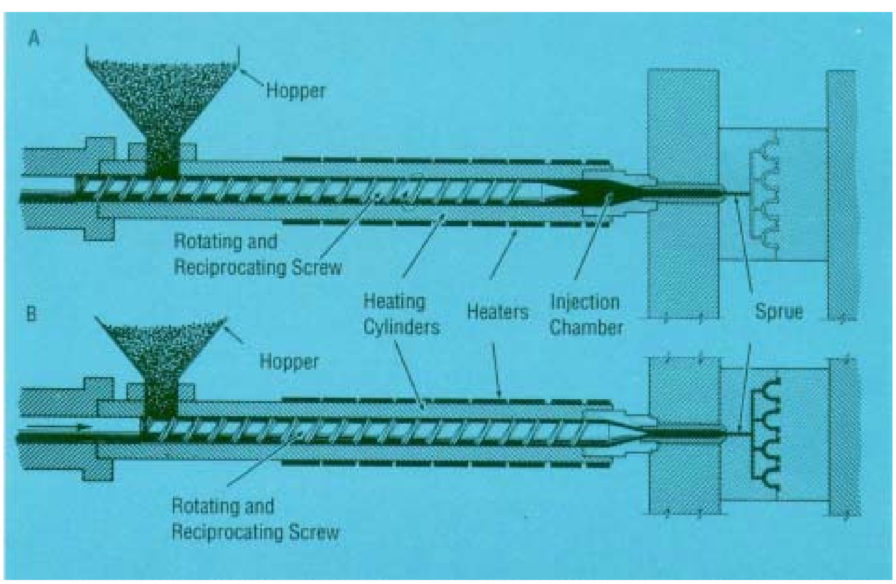


Figure 39. Schematic cross section of a typical screw injection molding unit showing the screw in the retracted (A) and the forward (B) position.

Various types of blow pins for in-mold neck finishing are available (see "In-mold Trimming" pg. 27).

Intermittent Blow Molding Systems

There are three basic types of intermittent blow molding systems:

1. Intermittent extrusion blow molding
2. Reciprocating Extrusion Blow Molding
3. Injection Blow Molding

Intermittent Extrusion Blow Molding

Intermittent extruder operation with a stationary mold is the simplest possible blow molding arrangement. The stationary mold is located directly below the crosshead die that extrudes the parison between the mold halves. There may be several molds if more than one parison is extruded simultaneously. Air is blown into the mold usually through the core in the die or through a mandrel (blow stick) inserted from below.

In intermittent extrusion blow molding (**Fig. 36)**, the extruder screw operation is halted when the parison has reached the desired length. The mold halves close around the parison, the finished part is blown, cooled and ejected. The next parison is then is extruded. Because the extruder operation is stopped for the greater part of every blow molding cycle, this process is less efficient than those in which the extruder operates continuously and the cycle times of the various moldings overlap.

Accumulators for Making Large Parts

Intermittent extrusion blow molding machines can be equipped with an accumulator, a reservoir for gathering and holding a substantial volume of well plasticized melt. A ram in the accumulator forces the melt at high speed into and through the extrusion die to form the parison tube **(Fig. 37)**. The accumulator unit usually is located between the adapter, or transition block, and the die. Most accumulators are vertical units, but horizontal types also are available.

In the setup illustrated in **Fig. 38**, the melt enters the accumulator unit from the side, filling the annular chamber from two different inlet points, each 180 degrees away from the other (see points A-A in both diagrams). This produces an inner and an outer ring of melt in the chamber (B-B). The result is

Courtesy of Uniloy Blow Molding Systems, a division of Johnson Controls

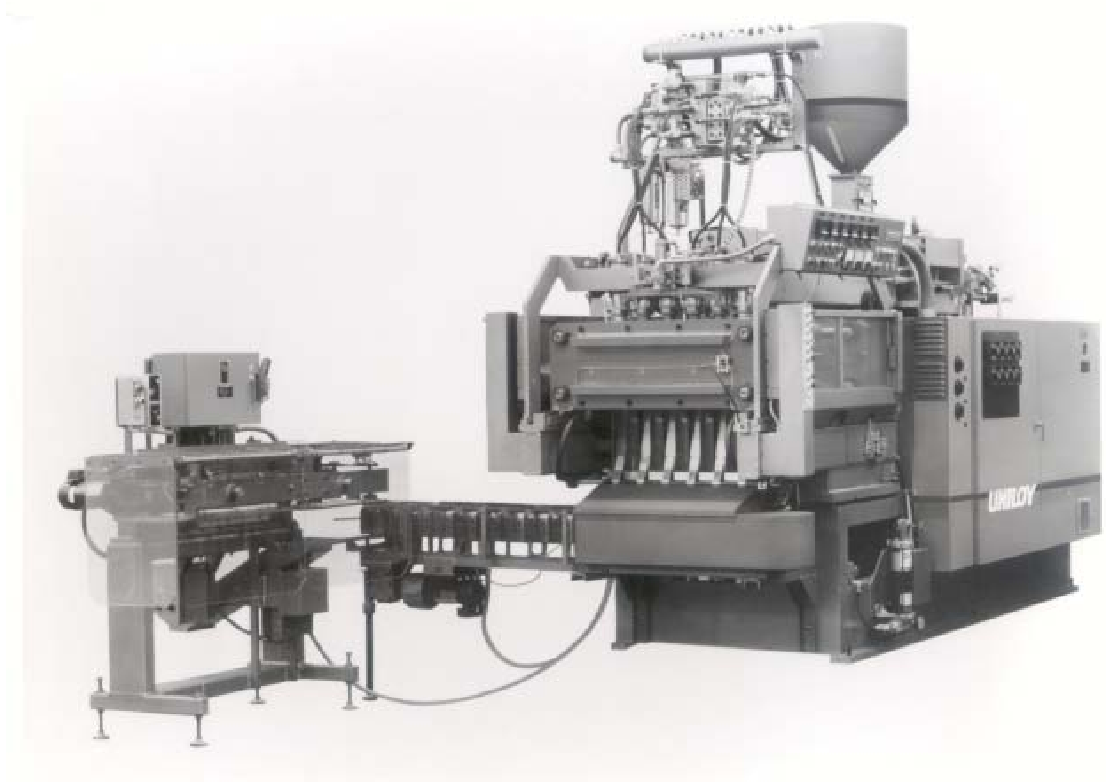


Figure 40. Reciprocating screw extrusion blow molding system.

that the seam formed by the material in the inner ring is directly opposite the seam formed by the material in the outer ring. When the material from the inner and outer rings comes together further downstream in the flow process (C-C), there is no weld or seam line that goes all the way through the parison at any one point, thus ensuring wall integrity.

An accumulator offers these advantages:

1. It holds ready a large volume of melt for large items requiring very long molding (cooling) cycles, up to several minutes in length.
2. It permits high production rates.
3. It enables fast extrusion of large parisons (short parison formation time) and consequently, short suspension time for the parison and thus, very little sag.
4. It results in good parison wall uniformity.
5. It enables uniform shot sizes and, thus, a minimum of waste.
6. It decreases idle mold time to a minimum.

An accumulator may hold up to 300 lb. (135 kg) of resin. One accumulator may cover several molds or each mold may have its own accumulator. In the latter case, while the extruder operates continuously, the molds may be fed alternately; while some will receive their parisons, others are in the cooling stage, etc.

In accumulator type systems, back pressure can be increased by a needle valve in the hydraulic system. This valve (restriction) controls the hydraulic oil flow from the accumulator so that more pressure is required from the compaction of the resin to force the ram back and the oil from the cylinder reservoir into the tank reservoir. The same principle holds true for reciprocating screw machines. (See next section.)

Manifold die heads, generally without sequence valves, are also used in machines equipped with an accumulator. In such equipment, extrusion through all the dies takes place simultaneously, so there is no valve-controlled alternate flow required. For best results in die heads that produce intermittent resin flow, the area in the heads should be great enough to produce a complete parison for the next "shot." This permits the resin to become heat stabilized and produce a more uniform parison.

Reciprocating Screw Extrusion Blow Molding

In reciprocating screw extrusion blow molding (**Fig. 39**), parisons are intermittently produced in separate "injection" cycles similar to those of an injection molding machine. However, the parisons are formed using an extrusion die head rather than a closed mold. The blow molding unit is located directly under the die head. When a parison of the desired length has dropped, the clamp closes on it and the container is formed.

The reciprocating screw extrusion blow molding system is widely used to produce small-mouthed polyethylene milk bottles and juice containers **(Fig 40)**, as well as various wide-mouthed containers. The machines are simpler in construction than continuous extrusion blow molding machines, since

Courtesy of Uniloy Blow Molding Systems, a division of Johnson Controls

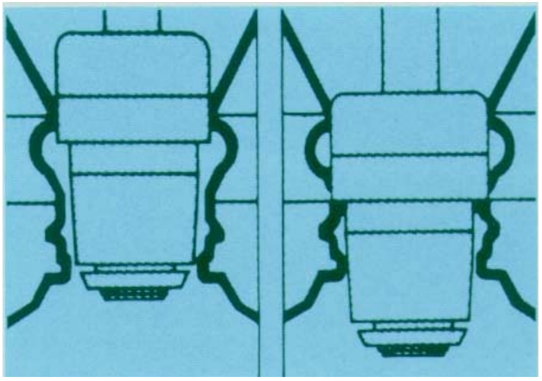


Figure 41. Ram down finishing.

Courtesy of Uniloy Blow Molding Systems, a division of Johnson Controls

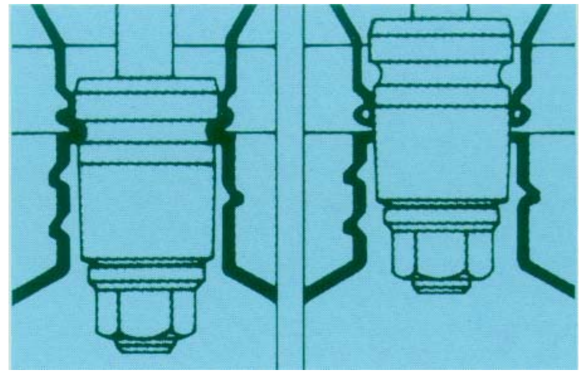


Figure 42. Pull-up finishing.

the clamp unit is stationary and does not require any mold shuttling mechanism. Further, tooling costs are lower (only one set is needed), and handleware and off -set neck containers can be easily formed. The fast parison formation that occurs in the "injection" cycle permits resins with higher melt indices to be used since melt strength requirements are less stringent than those needed for continuous extrusion blow molding.

In reciprocating screw extrusion blow molding, polyolefin pellets are first fed into the hopper of the plasticating unit **(see Fig. 39).** The screw, in an electrically heated barrel, rotates and retracts as the resin is pushed forward. As the resin pellets move forward in the screw channels, they melt by the combined action of screw and barrel shear forces and heaters located along the barrel. Gradually a melt forms; it is mixed, becomes more fluid, and reaches the viscosity required for injection into the die head. While the pellets are melted in the barrel, the gradually decreasing depth of the screw channels squeezes the air out of the softened mass; the air flows back along the clearance between the screw flights and the barrel and out through the hopper. The melt then flows over the screw tip into a chamber at the front of the barrel. The build-up of the melt forces the screw backwards.

When the desired amount of melt (shot size) is reached in the chamber, the screw pushes forward and forces the melt, at a high speed, through the nozzle and out through the die head. The screw then begins to turn again and retracts within the barrel to prepare the next shot. The speed of the screw is in balance with the parison size and the container blow time. Reciprocating screw extrusion blow molding machines are available with shot capacities up to 2,500 grams (HDPE) and throughput rates up to 750 lbs./hr.

Generally, reciprocating screw extrusion blow molding machines have die heads with as many as 10 parison dies. Parison programming also can be incorporated. Container necks can be finished during the blow molding cycle in a process called prefinishing.
In ram down finishing (Fig. 41), the blow pin is inserted into the mold after the mold closes on the parison. The blow pin moves downward to compress the plastic in the neck area and form the neck finish. This method is used when neck strength and reliability are required.

In pull-up finishing (**Fig. 42)**, the neck is finished when the blow pin is inserted just before the mold closes on the parison. At the end of the blow cycle, but before mold opening, the blow pin moves upward to shear the inside diameter of the neck opening. This method often is used for lightweight, single use containers. Reciprocating screw extrusion blow molding machines can also be equipped with a cooling conveyor to permit containers to cool more before being trimmed. The additional cooling step increases productivity.

Molds

The blow mold may have a number of parts, including various inserts, but it usually consists of two halves (**Fig. 43)**. When closed, these halves will form one or more cavities, which will pinch-off and enclose one or more parisons for blowing. The two mold halves are usually alike and must have built-in channels for cooling water. Sets of guide pins and bushings or side plates in both mold halves ensure cavity alignment and proper mold closing.

Frequently, the head of the mold is equipped with a cut-off device (shear steel) level with the upper end of the protruding mandrel which cuts the parison. A blowing pin in the mold may have the additional function of shaping and finishing the neck interior, referred to as calibrating.

Pinch-off

Pinch-off edges generally are provided at both ends of the mold halves. The pinch-off sections **(Fig. 44)** do not cut off the parison "tail." Their protruding edges, about 0.005 to 0.015 inches (0.1 to 0.5mm) wide, squeeze the two sides of the parison together, creating an airtight closure. These edges are called the pinch-off lands. Much depends on the construction of the pinch-off insert. The total angle outward from the pinch-off lands should be acute, up to 15 degrees. The pinch-off should not form a groove, which would weaken the bottom of the blown item along the seam **(Fig. 45)**. A straight line pinch-off makes it easier to remove the "tail" piece.

Courtesy of Uniloy Blow Molding Systems, a division of Johnson Controls

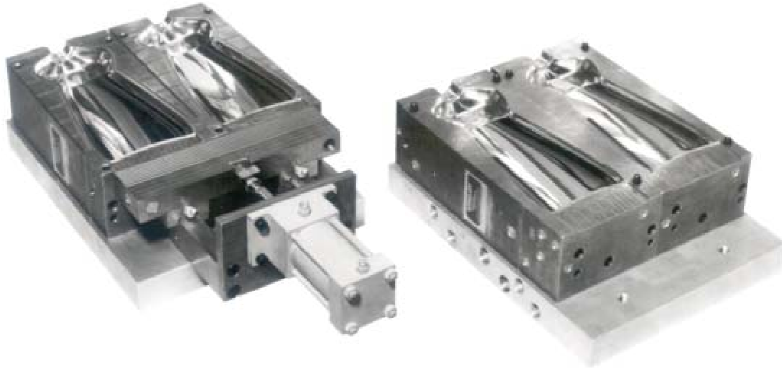


Figure 43. Blow molds

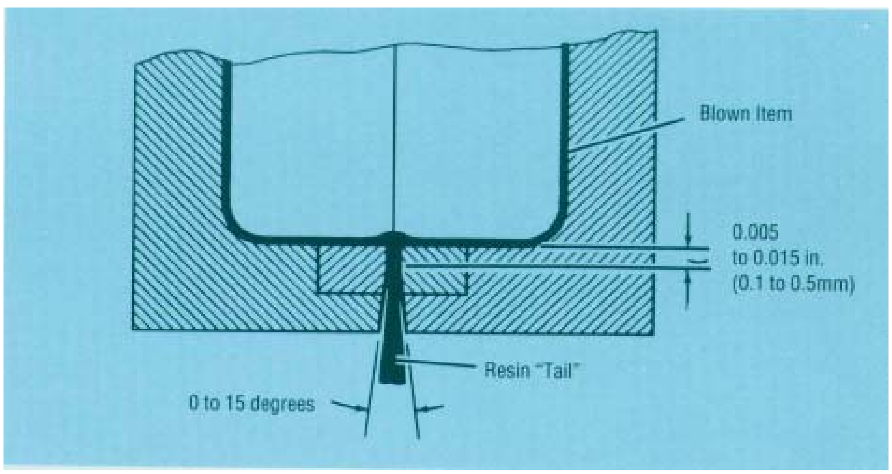


Figure 44. Shape of a pinch-off with insert as recommended by some molders.

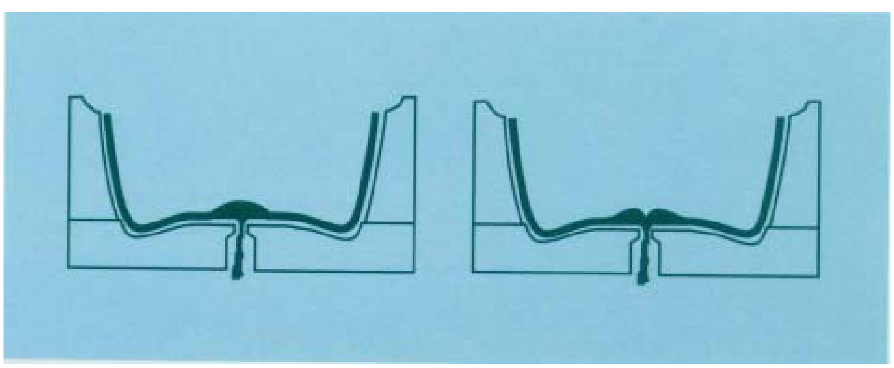


Figure 45. Good weld (left) and poor weld (right).

A high quality pinch-off on a thick-walled parison is more difficult to obtain than on a thin-walled parison. One method of obtaining more uniform welds at the pinch-off is to build "dams" into the mold halves at the pinch-off areas. These "dams" force some of the molten resin back into the mold cavities to produce strong, even weld lines. The pinch-off area on finished containers should not contain heavy globs or folds at the ends, since they may cause container failure. Also, these heavy deposits of resin retain heat. When the containers are ejected from the mold, these areas cool and shrink causing high stresses to be formed in the adjacent areas.

Mold Materials

Because of the comparatively low clamping and blowing pressures used, the blow mold need not be made of a high tensile strength material, although molds for very long production runs sometimes are made of steel. Blow molds are most often made from aluminum, cast aluminum, cast beryllium-copper alloy and cast zinc alloys, such as Kirksite. Durability and heat transfer rates are key factors in the decision about mold materials.

High-grade aluminum alloy molds are the easiest to machine. On the other hand, aluminum, one of the softest of these mold materials, is most easily damaged and worn, Cast aluminum, which has a lower thermal conductivity than cut aluminum, and beryllium-copper molds may be slightly porous. This porous surface may affect the appearance of the blown part. The remedy is to coat the inside of the mold halves with a sealer, but this may affect the heat transfer between the resin blown against the mold and the mold walls.

Steel molds are heavier, more expensive and more difficult to machine than those made of non-ferrous alloys. The higher weight results in more set-up time. Further, the heat conductivity of steel is less than that of the three nonferrous mold materials. This results in a slower cooling rate, a correspondingly longer cooling cycle and consequently, a lower production rate for steel molds. However, since nonferrous metals lack the strength and hardness required for maintaining a good pinch-off, these areas might be made with steel or beryllium-copper inserts.

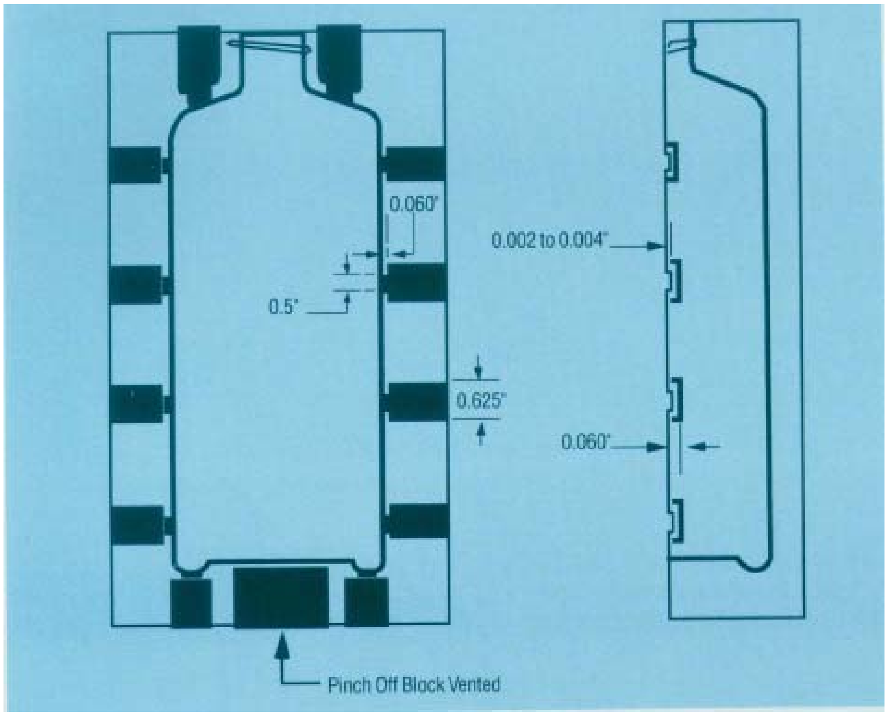


Figure 46. Mold Venting

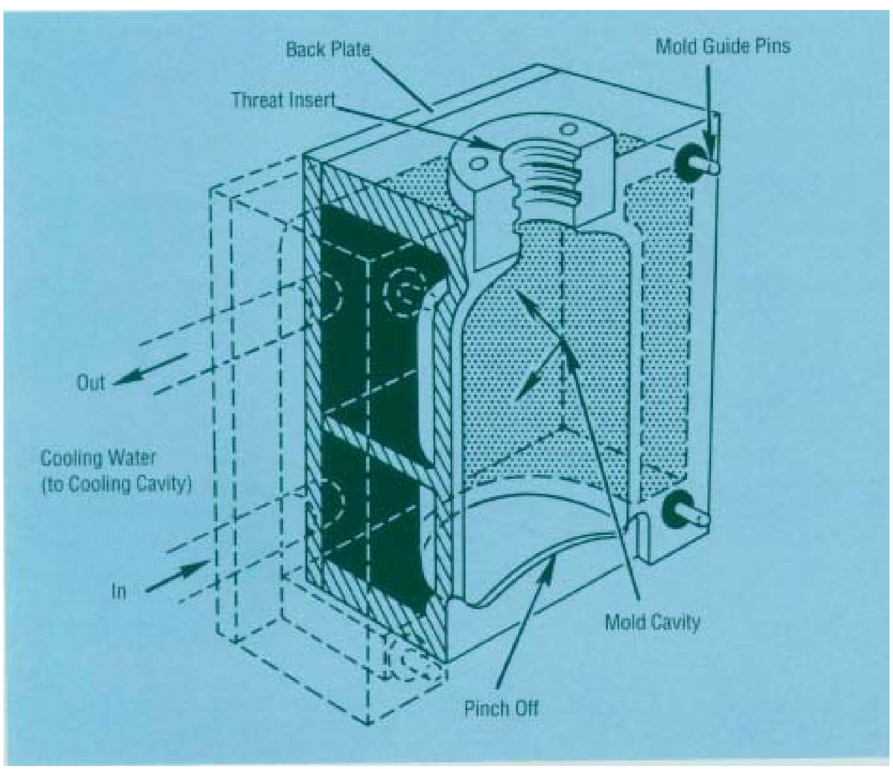


Figure 47. Schematic of a blowing mold half, with the cooling water channels indicated.

Fast heat transfer of the mold material is of utmost importance because the cooling step is roughly 40 to 80% of the entire blowing cycle and controls its length, Considering only their heat transfer rate, the principal blowing mold materials follow each other in this order of efficiency: beryllium-copper, Kirksite, aluminum and steel.

Occasionally, several different alloys are used in the same mold to obtain desired strength and special cooling conditions. However, as these mold materials have different heat transfer rates, a blow mold, with the exception of the steel or beryllium-copper pinch-off inserts, should be made of only one material. Different materials, with consequently different heat conductivity at various points of the mold, result in non-uniform cooling. This, in turn, might result in warpage and stress in the finished piece.

Mold surface

High quality mold cavity finish and undamaged interior surfaces are essential in polyolefin blow molding to prevent surface imperfections in the end product. If high gloss is desired, the mold cavity should be sandblasted with 100 grit flint sand and have vacuum assists for the removal of entrapped air. If other end product finishes are desired, the mold cavity should be finished accordingly. Even an excellent machining of the mold cavity cannot prevent the occurrence of parting lines, especially if the blown item has a very thin wall.

Venting

In highly polished molds, air may be trapped between the mold walls and the hot, still soft piece, marring its surface. This will happen especially when thick-walled, large objects are blown. In such cases, the mold must be vented by sandblasting, resulting in a matte surface; by grooves in the separation lines (called "face venting"); or, in extreme cases, by valves in the mold (called "pin venting").

With venting of the mold parting lines, generally about one-half of the parting line periphery is vented to a depth of 0.002 to 0.004 in. **(0.05,to 0.1 mm, Fig. 46).** In venting difficult areas, such as handles or thread inserts, holes 0.008 to 0.010 in. (0.2 to 0.25 mm) in diameter are usually drilled so that they vent to the atmosphere.

Particular care must be taken when drilling these holes so that the mold cooling channels are not pierced.

Cooling

An increase, or decrease, of about 10°F (5°C) in melt temperature can extend, or shorten, the cooling cycle by as much as one second. Efficient mold collingn is essential to achieve optimal cycle times. Mold halves have built-in channels for cooling water **(Fig. 47)**. Adequate cooling is needed to solidify the part immediately after the parison has been blown out against the mold walls. If locally available water for cooling has a high mineral content, a closed system for circulating purified water may be needed. The water should be cold; if necessary, it should be chilled by a heat exchanger to 40° to 70°F (40 to 20°C). However, low temperatures below the dew point may cause water condensation on mold walls, a situation to be avoided as it can lead to "orange peel" surface imperfections on the molded item.

Sometimes, copper tubing water channels are cast into the mold. However, to create the most useful flow, water channels are machined into the material cast into the mold halves. Well-placed channels ensure the cooling water comes as close to the mold cavity surface as possible. Larger molds may be equipped with three or more independent cooling zones.

Generally, in the top or base areas of a blown container, greater masses of resin are required. Such areas, as well as thicker wall sections, often require additional cooling. Otherwise, these sections are still very hot when the piece is ejected, resulting in non-uniform shrinkage and warpage.

Occasionally, the blow pin also is vented, allowing air to circulate inside the blown part and speeding up its cooling. Cold carbon dioxide (CO_2) from dry ice, introduced through the blow pin, can significantly reduce cycle time for HDPE containers. Also, air cooling occasionally is directed at the pinched "tail" of the parison sticking out of the mold bottom, additionally cooling this thicker area.

Postcooling Station

A postcooling station, i.e., after the blown part has been ejected from the mold, can significantly reduce the blow molding cycle time and yield higher productivity, particularly for parts with thick walls. Postcooling units include conveyor lines with chilled air directed against the warm blown parts or with chilled metal holding fixtures in which the blown parts are inserted.

In-Mold Trimming

Generally, in continuous extrusion shuttle blow molding, containers with and without handles are trimmed in the mold, after the product has been sufficiently cooled **(Fig. 48)**. Special blow pins can trim the neck and the bottom and the mold can have a cutting tool for removing the "tail." Also, the calibration of the neck area generally is done in-mold. Parts made on continuous extrusion wheels are trimmed in a post-molding operation and the neck or finished areas are not calibrated.

Wide mouth containers also can be trimmed in the mold. The container is blown with a dome on top of the neck. A knife trimmer, which is part of the mold assembly, cuts the dome off to produce the wide mouth container **(Fig. 49)**.

In-Mold Decorating/Labeling

Labels can be inserted into mold cavities, on one or both sides, before the container is blow molded. The in-mold labeling system consists of a magazine containing the labels, a transfer device for placing individual labels against the mold cavity surface, and a vacuum unit for holding the labels in place. Labels are designed so that there is no distortion on curved surfaces. The in-mold labels have heat activated adhesives that ensure excellent bonding to the container without wrinkles and bubbles.

Ejection System

Blow molded products can be ejected forward between the mold halves or downward, provided the press is built in such a way that a free fall from between the open mold halves is possible. Many machines have an automatic ejector, or stripper assembly. Ejector, or knock-out, pins or plates push the piece out with a rapid motion, preferably hitting it on the flash area so that the piece itself is not distorted. If the piece is not too large, it can be blown forward out of the mold by an air jet from behind. Very large pieces are sometimes manually removed from the mold.

Container dimensions, in general, are controlled by the mold cavity.

Courtesy of Uniloy Blow Molding Systems, a division of Johnson Controls

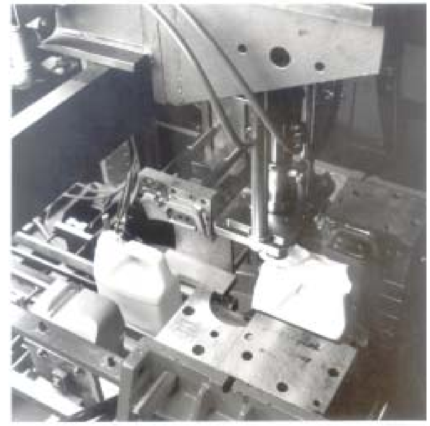


Figure 48. Containers are finished in the machine and oriented to stand-up position for take-away conveyers.

Courtesy of Uniloy Blow Molding Systems, a division of Johnson Controls

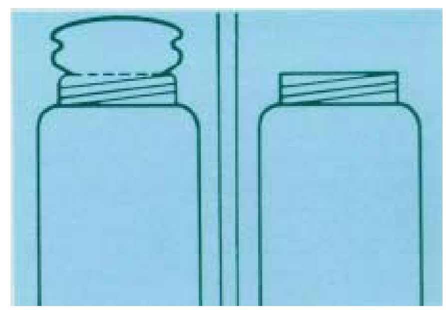


Figure 49. A knife trimmer cuts the "dome" off wide-mouthed, blow molded containers.

However, removing molded parts from the mold while they are still too hot or have hot areas because of thick sections or poor heat transfer, will result in warpage and/or excessive shrinkage. If the finish is too hot when the container is removed from the mold, it may shrink and become undersized or ovalized. Periodically feel the containers coming from the mold for hot spots and overall temperature. At no time should any area, except the flash, be too hot to touch. Furthermore, the temperature of the entire object should be relatively the same for best results.

Trimming Equipment

Once the flash is cooled enough for proper removal, the container is transferred to one of several different types of trimmers. Rotary trimmers are normally used for non-handle

Courtesy of Bekum America Corp.

Figure 50. Testing bottles for leaks using an air pressure system.

Courtesy of Uniloy Blow Molding Systems, a division of Johnson Controls

Figure 51. Take off equipment on a blow molding machine

containers that are produced by captured parisons and need only facing of the neck and removal of the tail. However, as pre-finished neck systems become more common, rotary trimmers are less necessary.

For flashed containers with handles, the bed-type trimmer is most commonly used. This type of trimmer utilizes cups or buckets that index the container to the trimming station. Here a lower movable nest picks the container from the bucket and moves it upward. The container contacts the fixed upper nest where the flash is broken off and removed for recycling. The lower nest now moves down and returns the container to the bucket. The bucket then indexes, and the entire cycle is repeated.

Scrap Recovery

Efficient recovery of trim scrap and rejected containers is essential to an economic production operation. For this reason, container blow molding systems generally have in-line scrap recovery equipment. Scrap from the tail, neck area, handle finishing, etc. are directly conveyed to a granulator and then back to the extruder's hopper blending unit. The percentage of regrind varies with the design of the blown part. With coextruded blow moldings, regrind is usually buried in an inner layer or blended with the outer layer. One hundred percent regrind can be used in blow molded layers, but it is important to maintain a consistent blend of whatever proportion of regrind is chosen. Otherwise, extruder feed problems can result.

Leak Detector

After containers have been deflashed, they may have irregularities in the areas that have been trimmed. To test for possible "leakers," a leak tester can be used (Fig. 50). As containers move along a conveyor line, an air plunger is lowered into the neck of each container to form a tight seal. The air pressure in the container is measured. If the pressure remains constant, the container is accepted. If not, the container is rejected.

Take-Off Equipment

Blown polyolefin pieces often are ejected into a chute that guides them onto a conveyor or they "free fall" onto a conveyor or into a box. For larger parts or where parts are placed in secondary finishing systems, special fixtures are designed to reach into the mold area and grab parts **(Fig. 51)**. Large pieces also can be removed manually.

Pieces dropped or placed onto a conveyor must be sufficiently cool so they do not stick together or get distorted. Frequently, the "tail," since it is bulkier and warmer than other sections of the part, tends to stick to other parts on the conveyor. Therefore, it is essential that the piece stay in the mold long enough for the "tail" and nearby areas to cool and solidify. To minimize the hazards of sticking and distortion, compartmentalized conveyor systems, which prevent ejected pieces from falling on top of one another, are advantageous. On some conveyors, each blown item may be gripped and automatically centered in a holding fixture, to be deflashed and reamed.

Decorating

The principal decorating methods used for blow molded items are silk screen printing, foil stamping, decal transfer and labelling. Plastic labels, such as printed PP film, permit the blow molded containers to be more easily recycled, i.e., there is no need to separate paper labels from the regrind. Generally it is preferable, and less costly, to treat and print polyolefin pieces without delay after blowing and finishing. But first, the surfaces of blown polyolefin products must be oxidized by flame treatment (**Fig. 52)** or electronic treatment **(Fig. 53)**. Good adhesion for decoration can also be achieved with surface primers instead of oxidation.

Running the Extrusion Blow Molding Equipment

This section discusses the start-up, shut-down and operation of a continuous extrusion blow molding machine. It is followed by a section on how the continuous extrusion blow molding process can be optimized.

Implementing optimum procedures is important in minimizing material degradation which causes black specks and/or gel contamination upon start-up. During the extrusion process, polyolefin resins are subjected to heat which, when combined with oxygen, can cause a build-up of oxidized material on the

Courtesy of Society of the Plastics Industry, Inc.

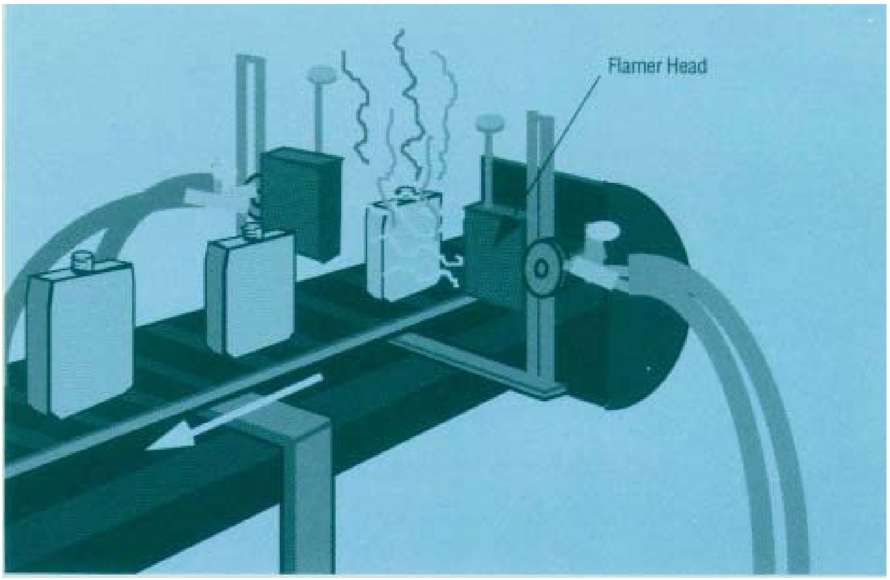


Figure 52. Flame treating.

Courtesy of Society of the Plastics Industry, Inc.

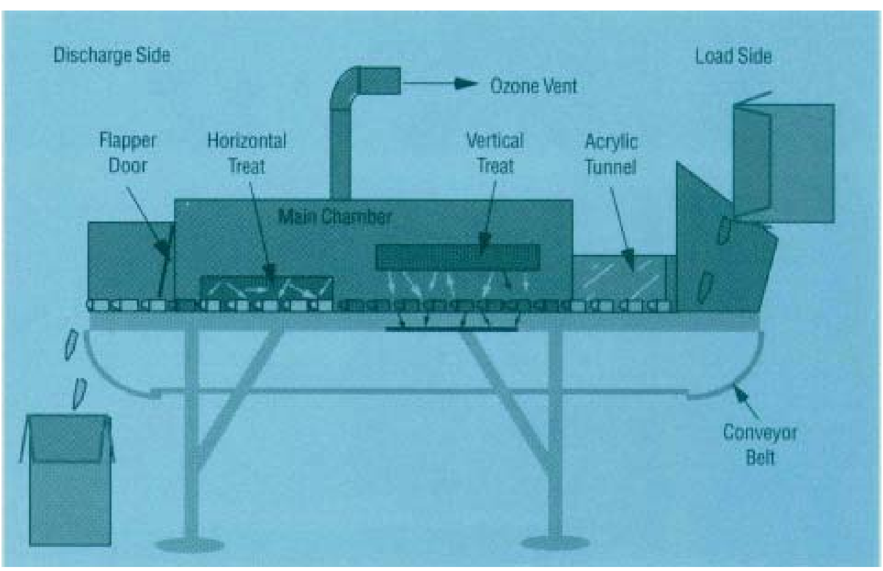


Figure 53. Electronic corona-discharge treatment.

internal surfaces of the extruder and head tooling. Resins are often stabilized with antioxidants to help prevent this oxidation, but even the best additive package can not protect the material if it is abused by very high temperatures and/or long residence times. The lowest useable temperature profile and optimum shut-down and start-up procedures will minimize material degradation. Improper procedures or operating conditions can cause large quantities of degraded material to be generated. If this occurs, various forms of purging may help reduce the amount of built-up char, but most often the equipment must be dismantled and thoroughly cleaned. The optimum start-up and shut-down procedures are best found through experimentation. Because blow molding equipment varies, the following guidelines are only general suggestions. If you have any specific questions or need any additional information, please contact an LyondellBasell Technical Service Representative.

Suggested Start-up Procedure

I. Heating the extruder may be accomplished by a number of methods. Option A and B are two which can be used. If polymer degradation is a problem, option A is suggested.

A. 1. Turn on power to die head heater bands. If applicable, turn on die head preheaters. Set die head heater set points to 275°F (135°C).

2. After die head temperatures have reached the set points, turn on power to extruder heaters. Set heater set points to 275°F(135°C).

3. After extruder temperatures have reached the set points, raise all set points to 325°F (163°C).

4. After die head and extruder temperatures have reached set points, proceed to step II.

B.1. Turn on power to all extruder and die heater bands. If applicable, turn on die head preheaters. Set temperature set points at 325°F (163°C).

2. After die head and extruder temperatures have reached the set points, allow one half hour for machine heat to stabilize.

3. Proceed with step II.

II. After the temperatures have reached the set points:
  A. Turn off die head preheaters.
  B. Start hydraulic system.
  C. Start extruding polymer at minimum screw speed. CAUTION: Head pressure and extruder motor amperage should be watched closely and should not exceed the machine manufacturer's recommended maximums.
  D. Set temperatures at desired operating levels.

III. After temperatures have once again reached set points:
  A. Turn on chiller for mold cooling.
  B. Gradually increase extruder speed to proper operating level. CAUTION: Head pressure and extruder motor amperage should be watched closely and should not exceed the machine manufacturer's recommended maximums.
  C. Open valve which supplies pressurized air to blow molding machine. Air pressure should be regulated at 80 psi to 120 psi while preblow air should be 5 psi to 15 psi for most typical blow molding operations.

IV. Set timers and die programmers to the established settings.

V. Start blow molder on automatic cycle for continuous operation. **(See Table 7 for Suggested Operating Conditions.)**

Suggested Shut-Down Procedure

I. If equipment will be down for less than one hour, leave heaters at operating set points. Periodically run extruder at low speed for a few minutes to reduce the chance of resin degradation.

II. If equipment will be down for more than one hour:
  A. Reduce heater set points to 325°F (163°C)
  B. Lower extruder speed to minimum. CAUTION: Head pressure and extruder motor amperage should be watched closely and should not exceed recommended maximums.
  C. Cover face of die tooling with plastic-coated tin foil, plastic side facing the tooling. This will minimize the amount of oxygen which can enter the system and help to prevent polymer degradation.

III. When temperatures reach the set points:
  A. Stop extruder.
  B. Lower heater set points to 275°F (135°C). CAUTION: Equipment should not be left unattended in this state. An electrical malfunction could cause equipment damage. Electrically energized equipment should be checked periodically. Unattended equipment should be completely shut down.

Troubleshooting start-up

- It the "tail" is too short, adjust the cycle so that the mold closed time is increased and the blowing time is lengthened.
- If the container weight is too high, decrease the extrusion rate of the parison or reduce the tooling gap opening, if possible.
- If the flash is excessive, shorten the mold open time very slightly. If this does not reduce the flash enough, decrease the exhaust time. If necessary, decrease the blowing time.
- If the parison hits the top of a closed mold, shorten the blowing time and adjust for minimum exhaust time.
- If the parison is ready ahead of the mold and the blown parts produced are as warm as they can be, then reduce the extruder speed to balance the cycle.
- If the parison does not drop straight from the die opening, adjust the die bolts. Turn the bolts on opposite sides of the bolt circle alternately and establish a bolt tightening and loosening pattern.
- If the parison is too long and off center, causing it to hit the table or the blowing pin, shorten the cycle or decrease the extruder screw speed, whichever is feasible. Adjust tooling as indicated above so parison drops (is extruded) straight.
- If the parison is too short, a situation that can result in no blow, lengthen the blowing time or increase the screw speed.
- If the ejected item is so hot there is danger of deformation when the item drops onto the conveyor, slow down the extrusion speed and lengthen the blowing time. Check the temperature and flow of the mold coolant.
- If the parting line protrudes from the surface of the finished item, the air pressure may be too high, causing the molds to blow open slightly. Check for leaking or inadequate hydraulic cylinders.

Table 7: Sugested Operating Conditions

Temperature Zones Setting, °F	LDPE	LLDPE	HDPE	PP
Rear	310	315	330	370
Transition	320	325	350	390
Metering	330	330	360	400
Head	330	330	375	410
Molds	60	60	60	60
Air Pressure, psi Blow Air	90	90	90	90
Pre-Blow	10	10	10	10

Lower the air pressure and check for blowing air coming on before the mold is completely closed.

- If the blown object is complete but not blown properly, check for a plugged blow nozzle or a cold parison.
- If resin leaks at the hinge between the extruder head and the adapter, the cause may be loose collar bolts at the adapter or a crack in the collar. Shut down the extruder; open and clean it; repair or replace the adapter; and reseal the extruder. Follow the general tightening procedure outlined earlier.
- Determine the source of leaking cooling water and repair.

Optimizing the Extrusion Blow Molding Process

This section discusses processing steps to achieve good blow molded polyolefin products using the extrusion blow molding process.

Molding Cycle

The molding cycle should be as short as possible in order to make maximum use of the equipment and to produce items as inexpensively as possible while maintaining desired quality. Since cooling takes up most of the molding cycle, reducing cycle time can be done by decreasing the melt temperature and/or lowering the mold temperature. Increasing the turbulence and flow volume of water to the molds aids in heat transfer and keeping the humidity around the molds low decreases the need for excessive mold cooling. Increased blowing pressure makes the hot parison press more closely to the inside mold surface, speeding heat transfer and frequently resulting in shorter cycle times. The cycle sometimes can be lowered by separately cooling the thick parison "tail."

The higher a resin's meting point, the faster the temperature is reached at which a blow molded part becomes stiff enough to retain its form when ejected. For polyethylenes, higher density corresponds with a higher melting point. The resin-density effect on cycle time is greatest at lower mold temperatures and part weights.

Parison Swell

Parison swell has two components: diameter swell and weight swell. If a parison is affected by diameter swell, it balloons outwards from the die; in other words, the parison's diameter becomes considerably larger than the die diameter. Weight swell can occur during the short time the molds are open and the parisons are dropping. The parisons may actually shrink in length and concurrently, their walls thicken and become heavier.

Some diameter swell is necessary, but too much increases pleating. The operator knows when there is too little swell: the handle of the bottle being blown is not caught. The only way to determine whether there is too much swell is to run tests using resins with different swell properties. LyondellBasell's Technical Service engineers can provide further information **(Figs. 54 and 55).**

Weight swell should be minimized. To counteract high weight swell, close down the die gap. Small die gaps are however, extremely sensitive to impurities. Narrow die gaps also result in high shear which can lead to high diameter swell in the parison. The final bottle may be complete, but surrounded by heavy flash.

Parison swell can be solved best by good die design. A smooth, gradual change in the melt path from the solid column in the head to the thin-walled cylinder issuing from the die minimizes the problems. Also of great importance are polyolefin resins with inherently good and consistent swell properties.

Parison Sag

Sag can be influenced by operating conditions and resin properties. For continuous extrusion machines, an increase in extruder screw speed, if practical, decreases sag to a degree by reducing drop time. Lower parison processing temperatures render the resin more viscous and thus, the tube less subject to drawdown (sag).

Within the processing temperature range for polyolefins (from 290° to 390° F, 145° to 200°C), the effect of melt temperature on sag decreases as the melt index decreases. Lower melt index polyolefin resins are more viscous, that is, they yield less to the pull of their own weight in the hot melt stage than higher melt index resins. Consequently, lower melt index resins have less tendency to sag.

Sag and swell are interrelated and some changes in operating conditions and basic resin properties may affect them conversely. As shown in **Table 8,** a decrease in extruder speed will unfavorably affect sag because the parison hangs unsupported for a longer time. However, swell might be reduced under these conditions because the slower extrusion speed can result in less orientation in the resin. This swell reduction however, may be offset for the same reason sagging may increase: the greater length of time the parison hangs unsupported. Therefore, as is obvious, modifications to operating conditions can control sag and swell only to a limited extent. A major factor is the inherent behavior of the resins selected.

Along with its melt index, the resin chosen will be partly determined by the size of the part to be blow molded in order to minimize sagging. Since parisons for larger items weigh more than those for smaller ones, they are affected more by the pull of gravity that causes them to sag. For such large parts, lower melt index resins are preferable.

Parison Curving

Curving of the parison, that is, its moving away from the vertical axis, is caused by non-uniformity in its wall thickness. The parison tends to swing away from the heavy side and toward the light side. This can be remedied by adjusting the bolts on the die and checking the core for accurate centering **(Fig. 56)** Curving may also be caused by nonuniform heating, which can be eliminated by checking the heaters for good contact.

Sharkskin Melt Fracture

A sharkskin inner surface looks like wide, alternating bands of thick and thin wall sections. If this occurs with continuous extrusion blow molding, the solution is to slow down the process; if reciprocating extrusion, increase the extrusion speed.

Sharkskin surfaces occur because of the complex behavior of high density polyethylene as it is pushed through the die. In general, as pressure is increased, the extrusion rate increases. However, in reality, there is a point in the pressure curve where increases in pressure do not result in increased extrusion speed. This is called the "pressure plateau" and bottles blown

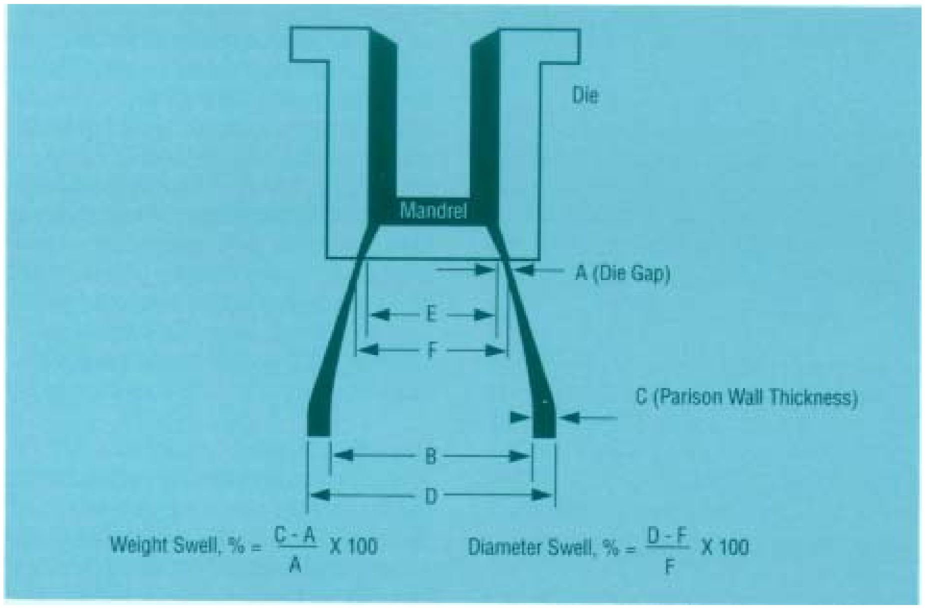


Figure 54. Parison swell.

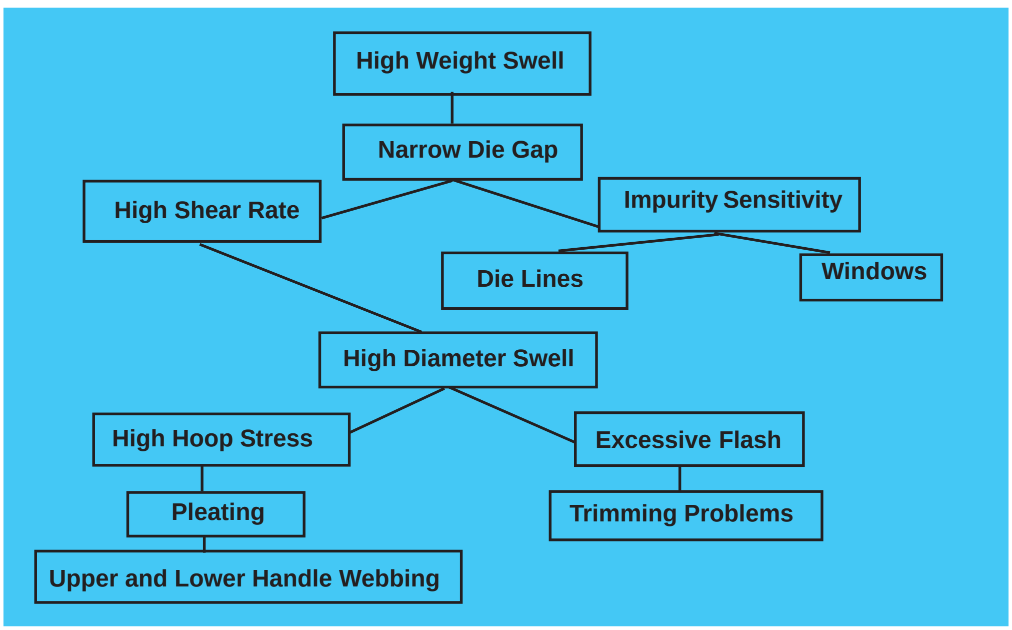


Figure 55. Problems encountered in counteracting high weight swell.

Table 8: Means of reducing Swell and Sag (other than die modifications).

To Decrease Swell	Increase melt temperature (results in lower viscosity)	Generaly decrease extruder speed (results in less orientation) Occasionally increase extruder speed (shortens the parison extrusion step)	Use resin with higher MI (results in lower viscosity)
To Decrease Sag	Decrease melt temperture (results in higher viscosity; effect small for resins with MI<2.0)	Increase extruder speed (parison hangs for less time)	Use resins with lower MI (results in higher viscosity)

under these conditions exhibit sharkskin. The solution is to keep increasing pressure, and shortly, the sharkskin disappears. Bottles produced at these higher extrusion speeds have a microscopic roughness, but are acceptable. If pressures go very high however, the high degree of roughness reappears and bottles blown are rejected.

Blow-up ratio

The blow-up ratio is defined as the ratio of the average diameter of the finished product to the average diameter of the parison. The maximum recommended blow-up ratio for most applications is 5:1, but 3:1 is more commonly used. Generally, lower blow-up ratios are used when blow molding containers with handles or products that are significantly broader in one dimension than in the other two. In the end product, the thicknesses of the container walls are proportional to the thickness of the parison and the distance the parison is blown in each dimension before making contact with the mold.

Because parisons are blown to different degrees in different dimensions, with resulting variations in wall thickness in the finished product, the tooling either in the die or on the mandrel must be altered to obtain end products of uniform wall thickness. With conventional tooling, the action of the mold closing around the parison at the pinch-offs causes the parison to change in cross sectional shape from a true circle to a partial oval **(see “A” and “B” in Fig. 57).** The result is less blow-up distance along the mold parting line than 90 degrees from the parting line. When the working land of the tooling is ovalized and the clearances between the die and mandrel are increased in areas needing greater blowup ratios, then the parison’s walls have varying thicknesses around its circumference, but the end product’s walls are more uniform.

Ovalization

Ovalization may be done either on the die or the mandrel, although it is best done on the die because it is usually easier to maintain in proper alignment **(see “C” in Fig. 57).** Ovalization may change the shape of the tooling several degrees in a specific area **(see “D” in Fig. 57);** generally, the tooling should not be completely oval in shape, and should only be ovalized where a greater blow-up ratio is required. To ovalize the tooling, the excess metal is ground off and all exposed edges smoothed. Indeed, the ovalization in a small, well-made tool may not be detectable to the eye, although on larger tools the effect can be quite obvious.

The degree of ovalization necessary can be estimated from information on the parison shape in the mold and by calculating blow-up ratios to the mold surfaces in the different areas. From these ratios, the parison thicknesses required can be determined, leading to the calculation of the degree of ovalization necessary in each part of the tool. Initially, it is best to ovalize the tool less than the calculated value and test the tool in actual production. If more ovalization is needed, it can then be done.

Ovalization can also be done in the tooling where angles converge or diverge at the top of the die land, instead of at the tooling opening. This ovalization procedure changes the volume in these semi-restricted areas, resulting in a difference in compressibility when the resin is extruded under pressure. Different volumes of resin are deposited in different areas of the blown product as a result. Experiments must be undertaken to determine the effects various degrees of this kind of ovalization have on the finished product.

As might be expected, melt temperature becomes more critical when extruding a parison with wall thickness variations, as is done when tooling is ovalized. If the melt temperature is too low, the thicker areas may end up as thin areas in the blown product because of differences in stretching and heat retention.

Blowing Failures

There are two kinds of blowing failures:

- “No blow” -the parison does not fully expand to fill the mold cavity.
- “Blowout” -the blowing air ruptures the parison wall.

“No blow” occurs when the blowing air supply is not operating properly or the air line has been pinched off. To correct, first check the air supply. If nothing is wrong with the blowing-air line, the mold pinch-off maybe either too sharp (cutting into the parison) or not tight enough (not fully pinching off the parison). Pinch-off and neck areas should be checked regularly for wear. “No blow” also occurs when the parison is too short for the mold. To lengthen the parison, lengthen the molding cycle or increase the screw speed.

When the parison is too long, the parison may be pushed off center by the moving table. A flash between the halves may, moreover, hold the mold open. If a die head holds more than one die, the melt flow requires a simple adjustment if only one of the parisons is too long (or too short).

If holes or patches of unplasticized resin occur in the parison, heating in the first two extruder zones should be increased. This may be especially necessary at higher extruder speeds.

“Blow-out” can be caused by separation of the mold halves due to excessive blowing pressure. It can also occur if the air pressure is not bled off before the mold opens. This problem also can be remedied by checking and tightening the mold clamp. “Blow-out” also may result if the part to be blown is too large for the equipment. For this, the only adjustment possible is to switch the job to a larger blow molding machine.

Part Weight

The moment the mold halves close around the parison and pinch the “tail,” the weight of the blow molded product is fixed. The parison weight is determined by the die opening, the extruder output rate and the melt temperature. The weight increases with increasing the die opening and screw speed and decreasing melt temperature.

Part Wall Thickness

Wall thickness is the most difficult problem in blow molding, particularly extrusion blow molding. Thin areas may be too weak or may mar the appearance of a blown part; thick areas mean resin waste and overweight parts.

Wall thickness depends on the parison’s resin volume and the blow-up distance, determined by the dimensions of the mold and location of the parison in the mold cavity. A direct relationship exists between the wall thickness of the blown piece and its weight. A too thin overall wall thickness can be corrected most effectively by operating with a smaller die pin or a larger die opening and at lower temperatures. Also, using

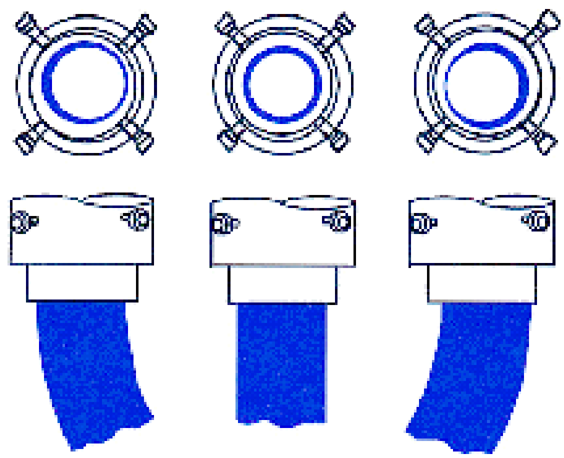


Figure 56: Adjusting die bolts to prevent parison curving.

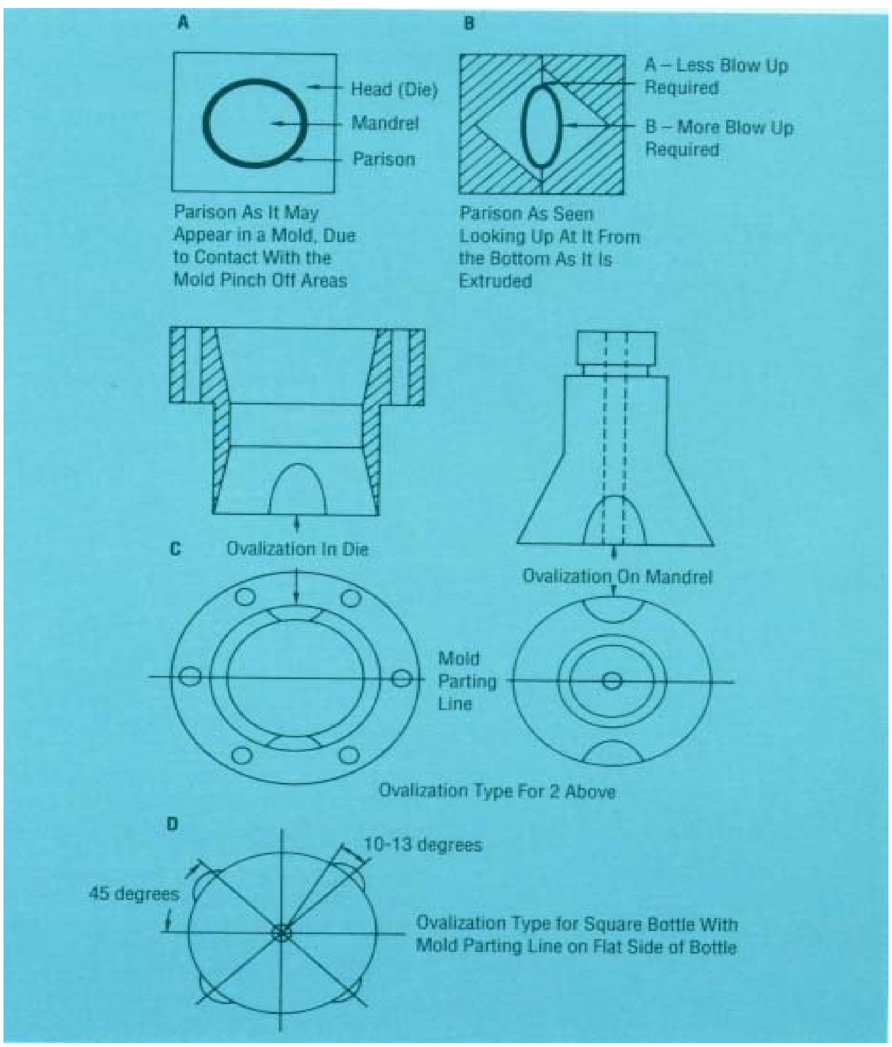


Figure 57 A schematic representation of ovalized tooling.

a resin with a greater or lesser die swell characteristic influences parison wall thickness. Further, if a vertical rotary wheel blow molding machine is used, wall thickness may be increased by increasing screw speed or reducing drawdown.

Parting-line thickness should never vary substantially from that of the surrounding wall areas for greatest strength and good appearance. The weld line, to insure a strong seal, must be equal to or slightly thicker than the neighboring bottom area, never thinner.

The thinner the wall thickness and the lower the melt and mold temperatures, the faster the blowing rate should be and the higher the blowing pressure, up to about 150 lb/in. (10.5 kg/cm). Compressed air injected into a cold mold may lose some pressure because a cooling gas contracts. High blowing pressure requires correspondingly high clamp pressure to keep the mold tightly closed during the blowing step.

The die opening can be modified by changing the position of the tapered mandrel. This is the most effective means of changing the parison wall thickness. The effects of screw speed and melt temperature on the parison wall thickness are indirect via the phenomena of sag and swell.

An extruded, freely suspended and more or less irregularly expanding parison can present problems which become even more difficult when the blown item is irregularly shaped or has sharp corners. When a rectangular object is blown from a round parison, more resin accumulates in areas where the resin travels the least distance before contacting the mold. The shortest distance the resin travels is to the long sides of the object: here, the walls are thickest. The least amount of resin reaches the four corners of the object the furthest distance the resin travels before contacting the mold: here, the walls are thinnest. This phenomenon cannot be avoided if an object with a rectangular cross section is blown from a round parison.

If one whole side of a blown piece is thinner than the other, the reason may be the various parts of the die are not centered. They must be adjusted to correct this problem. Local thin spots on the wall can be caused by blowing at too high a temperature or hot spots in the parison.

In addition, uniformity of wall thickness improves with increased and rapidly developing blowing pressure. This causes all sections of the parison to touch the mold wall at the same time and cool at the same rate, as well as reduces surface marks and imperfectly blown sections.

Part shrinkage

Shrinkage of the blown polyolefin piece, which inevitably occurs after ejection, must not be confused with swell, a parison property. Shrinkage generally ranges from 3-4% of the dimensions of the part, up to 6% in extreme cases. There is proportionally more shrinkage in thick sections of the object, frequently the neck and bottom, than in thin-walled sections, if only because thicker sections take longer to cool. Parison shrinkage is higher in the extrusion direction than across it.

In practice, shrinkage may vary considerably in different sections of a blown piece, resulting in warpage (distortion of the cooled piece). This variability should be considered when designing and, if necessary, remachining and adjusting the blow mold.

Molding variables which tend to affect the shrinkage of a part include melt temperature, extrusion rate, head pressure, mold temperature, blowing pressure and mold cooling time. Shrinkage is directly related to the molded part temperature when it is removed from the mold. With lower melt temperatures, shrinkage will be reduced, because the items are demolded at a cooler temperature. An increase in blowing pressure may also reduce shrinkage and warpage. An increase in cooling time, which makes the piece more expensive, also decreases shrinkage in the ejected piece and sometimes prevents the warping of its top or bottom, or distortion of the whole item. Decreasing the mold temperature or lengthening the cooling time may also eliminate warpage. Heavy sections of a blown piece may be cooled at the end of the cycle to prevent distortion.

Part appearance

The appearance of a blown item can be defined as a combination of high or low gloss, absence of flow lines and surface smoothness. Of these properties, gloss is particularly important because there are many applications in which either low or high gloss is required. Lowering the extrusion speed will often decrease exterior surface roughness. However, since extrusion speed is adapted to the molding cycle, such a decrease may also result in an unnecessary lengthening of the molding cycle and therefore, a decreased production rate.

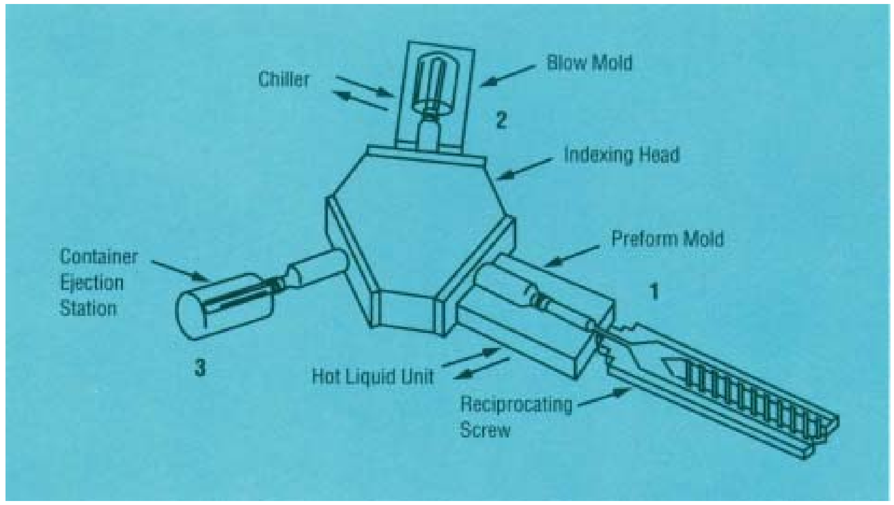


Figure 58. Injection blow molding.

Most appearance defects are caused by burnt resin on the face of the tooling, damaged tooling or uneven heat (hot spots). Higher mold temperatures and longer molding times may favorably affect overall appearance, especially gloss. Surface smoothness and gloss improve slightly with higher extrusion melt temperature. However, an increase in melt or mold temperature may lengthen the blowing cycle, since a warmer piece needs more cooling before it can be ejected without the risk of distortion.

Water marks on the outside of a blown item, caused by condensation on the cold inside surfaces of the open mold, may be avoided by running at higher temperatures. Vertical lines on the surface (die lines) are caused by either scratches in the surface of the parison extrusion die or by oxidized resin stuck in or on the die face. By opening the die gap, material caught in the die may be removed. It may also be dislodged by rubbing a piece of brass shim stock around and between the die lands after stopping the screw. Scratches in the die surface call for a polishing job.

Die lines and surface roughness may also be reduced by increasing the pressure in the die. Die lines may be masked by the blowing process itself, provided the parison melt material is not too viscous, that is, if it has a comparatively high melt index, a high temperature or both.

Exterior surface defects also may be caused by mold defects. These may be eliminated by polishing and sand blasting. Surface defects caused by entrapped air can be prevented by air vents in the mold.

Part Stiffness

Stiffness (rigidity) or flexibility of polyethylene parts depend primarily on the resin density, aside from the wall thickness of a blown item. HDPE resins are stiffer and in general more suitable for making thin-walled rigid containers. The cooling rate also affects stiffness, because faster cooling results in pieces with densities lower than that of the base resin. Stiffness also can be increased by orienting the parison (see "***Extrusion Stretch Blow Molding***," pg. 20).

Stress Crack Resistance

Environmental stress cracking resistance (ESCR) is affected by any operating condition that tends to promote molded-in stresses in the container. Too high a melt temperature also may cause some resin degradation, which may result in lowered ESCR. Improperly designed items, for example, squeeze bottles with sharp corners or residual (dormant) stresses in the edges, are often subject to environmental stress cracking. Changes in operating conditions do not affect a resin's resistance to penetration by chemicals, however.

Injection Blow Molding

Injection blow molding is a intermittent, cyclical process **(Fig. 58)** used almost exclusively to make plastic bottles. Initially, a preform is injection molded around a core pin in a closed injection mold. The core pin is a hollow, valved body that can be transferred with the preform to the blow mold where it may serve as a blow pin through which the blowing air is introduced. The preform has a finished container neck and a body that resembles a test tube **(Fig. 59)**. While one preform is blown, the next one is injected around another core and a finished container is ejected.

Advantages of the injection blow molding process are:

- Fully finished, close-tolerance containers are produced that require no secondary operations other than printing or labeling;
- No scrap from neck trim or pinch-off areas remains;
- Container surfaces are very smooth with no blemishes caused by mold pinch-off;
- Bottle weight, dimensions and internal and external neck finish are very precise.

Limitations of the process are:

- Container size is generally limited to up to about 16 oz., although methods of molding larger sized bottles are under development;
- Tooling costs are high because of the need for two different molds for two different purposes; moreover, injection molds are more expensive than blowing molds because of their complexity and need to withstand high injection pressures;
- Handleware and containers with off-set necks are difficult to make and the tooling very expensive;
- Not all polyolefin blow molding resins can be injection blow molded.

Injection Molding the Preforms

There are two basic injection blow molding processes:

1 . In-line, where the preform molding and blowing are done simultaneously

Courtesy of Cincinnati Milacron

Figure 59. Preforms in injection molding machine.

Courtesy of Uniloy Blow Molding Systems, a division of Johnson Controls

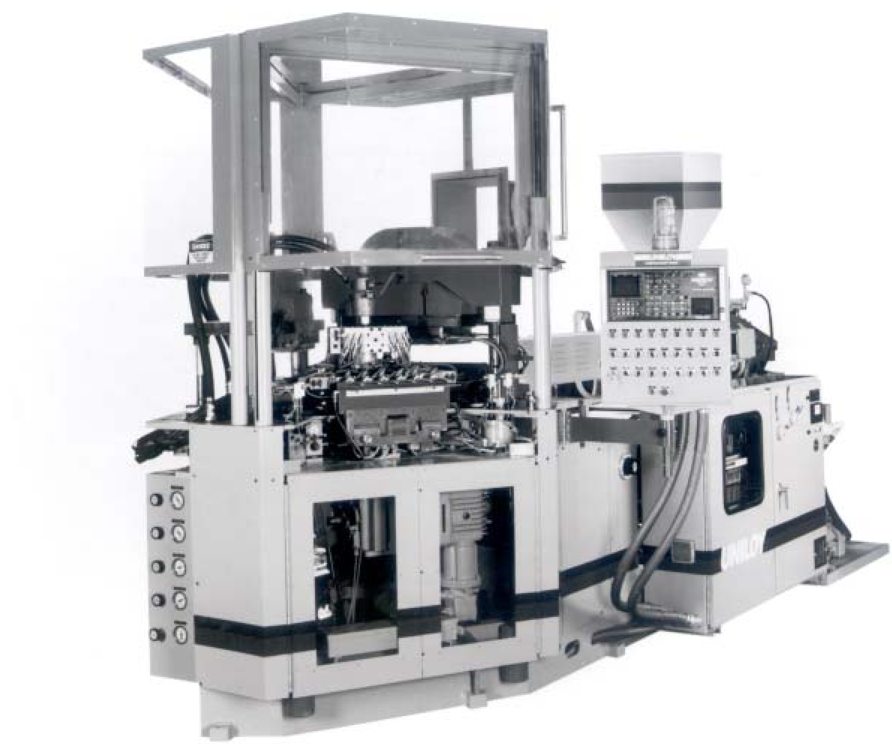


Figure 60. Injection blow molding machine

2. Two-stage, where the preforms are injection molded in a separate operation from the blow molding operation; this technique is referred to as "reheat and blow molding."

In-line injection blow molding machines in use today are either three or four-station equipment **(Fig. 60)**. At the first station, preforms are injection molded; at the second station, they are blown; cooling and ejection take place at the third. A co-injection station may be added between the standard first and second stations for forming a handle, stretching the parison (a technique called "stretch blow molding," used to improve container clarity and/or stiffness by means of biaxially orienting the preform) or for post-treatment of the blown container.

Injection Stretch Blow Molding

Special six-station injection stretch blow molding machines also are available. These machines include two conditioning stations and a post-blow station in addition to the regular injection, blow and ejection stations. The two conditioning stations are used for heating and/or cooling the parison. In the blow step, the parison is stretched and blown into the desired shape. In the post-blow step, labeling, surface treatment and/or leak detection are performed.

The Plasticating and Injection Unit

Whether part of an in-line or two-stage process, the resin melting unit is identical to the reciprocating screw injection unit of a standard injection molding machine. Generally, the injection unit is of the horizontal type, but injection blow molding machines with vertical injection units also are available and considered to be more efficient in providing the low injection pressures required. The process of melting the resin and accumulating the needed shot size is very similar to that found in reciprocating screw extrusion blow molding, explained earlier on p.23.

The Preform Molding Unit

Either a single or multiple cavity mold can be used. The melt flows through a manifold with a hot runner system leading to each mold cavity. Heating fluid maintains the proper temperature distribution in the manifold as well as in the mold. When the cavities are filled, the screw pulls back slightly to decompress the chamber at the front of the barrel; this causes a "suck back" at the injection nozzle and locks the melt, under pressure, in the manifold system. Consistent, reliable mold packing pressure is essential to producing high quality containers by this process.

To make good injection molded preforms requires about the same operating conditions as are needed to produce any good injection molded end product. However, moderate injection temperatures, minimum pressures and warm preform molds are particularly important. Pressures for injection blow molding are in the 5,000 to 10,000 psi range, rather than the 15,000 to 20,000 psi range for standard injection molding.

In injection blow molding, the neck of a container is already shaped in the preform mold. This fact necessitates selective mold cooling: the neck area must be cooled so that the resin there sets. At the same time, the resin from which the body of the item will be blown must stay hot until it is fully blown in the blow mold.

Because the wall thickness of the preform body is not uniform, it is possible to obtain irregularly shaped hollow items with practically uniform wall thickness in the blowing mold. The dimensions of the preform mold and those of the preform must be carefully and accurately tailored to do this.

A blow mold for injection blow molding equipment has only one difference from a mold for extrusion blow molding: it has no pinch-off edges. The injection blow mold needs none because it is fed with a preform of predetermined length and shape instead of an open tube with excess length.

Since the cycle time of all the blow molding process steps is of major importance in productivity, short injecting time is essential. In conventional injection molding, temperatures would be maximized to lower cycle times, but in injection blow molding, barrel temperatures must be kept low enough so that the preforms are at the blow molding step temperature without external cooling. Also, the time the preform is in the blowing mold must also be minimized to keep the total cycle time short and productivity high. The injection blow molding operator must balance all these factors, as well as the properties of the resin being used, in determining process conditions.

Preform Blow Molding Unit

In the preform blow molding unit of the in-line injection blow molding machine, air is injected into the hot preform to form the part. A core maintains the required inside dimensions during the transfer of the hot preform from the injection station to the blowing station.

Two-Stage Injection Blow Molding

With two-stage injection blow molding equipment **(Fig. 61)**, the preforms are blow molded separately from the injection step. This type of blow molding unit includes an oven for heating the preforms to the required temperature.

Optimizing the Injection Blow Molding Process

To obtain the best possible molded item in the shortest time and at lowest cost, two basic variables, injection temperature and injection pressure, must be in balance in the barrel. Since polyolefins become more fluid with increasing temperature, the pressure required to fill a given mold with the resin melt depends to a large extent on the melt temperature. Four basic injection machine variables that can be adjusted to obtain preform mold fill are temperature, pressure, feed rate and injection time. If a particular job is yielding "short shots," either an increase in temperature to obtain lower resin viscosity or an increase in pressure, feed rate or injection time results in the preform mold fill desired.

The higher the melt index of a polyethylene resin (or melt flow rate of a polypropylene resin), the better its flow properties, the lower the injection pressure and/or barrel temperature or both, required to fill a preform mold. Therefore, a reduction in injection pressure without switching to a higher melt index, or higher flow, resin must be accompanied by an increase in barrel temperature to obtain mold fill. Conversely, an increase in pressure without a change in resin melt index must be accompanied by a reduction in temperature to prevent "flashing" of the preform mold.

Use of higher density resins may reduce the preform molding cycle time considerably, owing to their greater stiffness and higher heat softening points. These properties mean higher density preforms can be transferred to the blowing mold at higher temperatures. The amount of time gained depends on the size and shape of the injection molded article and the speed of the machine.

For maximum production, injection rates must be high and injection temperatures as low as possible; the lower limit is fixed by the requirement that the preform must not solidify when transferred to the blowing mold. However, an irregularly frosty surface on items injection blow molded indicates the injection molding temperature is too low. These marks can also result from scaling occurring as the resin is pushed through the nozzle or gating. Increasing the injection temperature to reduce melt viscosity and reducing the pressure correspondingly may eliminate such roughness.

Surface roughness can also occur it the material at the nozzle of the injection molding machine cools too much between cycles. This condition can be eliminated by installing heaters on a conventional nozzle or by restricting the gatings lightly.

Exterior surface defects may also be caused by defects in either the preform mold or the blowing mold. Both types of mold defects can be eliminated by polishing. As in extrusion blow molding, air vents in the blowing mold allow entrapped air to escape and thus eliminate another source of surface defects.

Injection temperatures must be high enough to prevent poor welds. For each type of polyolefin used, the most suitable blow molding temperature must be determined as a function of the blow rate. At this temperature, preform blowout is minimized as well as thin spots in the finished part.

If thin spots do occur in the wall of an injection blown piece, the temperature of the preform is too high when air is injected into the blowing mold. Uniform thickness can be obtained by either lowering the injection temperature or, if this is not feasible, by giving the preform more time for cooling before it is blown.

Cleaning the Extruder and Its Parts

Over long periods of continuous operation, a polyolefin extruder may, under certain conditions, slowly build up a layer of oxidized polymer, particularly on the inside barrel walls and the screw. This degraded resin finally begins to flake off. This, in turn, results in defects such as yellow-brown oxidized particles in the melt. Such particles can affect the appearance and the properties of the blown item. The danger point has been reached when the screen pack has little or no effect in holding back the impurities. It now becomes necessary to pull the screw and give it, as well as the barrel, adapter, breaker plate and die, a thorough cleaning.

Preferably, a preventive maintenance program calls for such cleaning before the danger point is reached. If the extruder is shut down frequently for any length of time, the build-up of oxidized polymer occurs much more often. This means all the parts must be cleaned more frequently. The time between thorough cleanings can best be determined by experience. If the extruder is continuously in use over long periods, every two months might be a good cleaning schedule. The appearance of the ejected blown pieces is the best indicator. If there is a pressure gauge, an increase in pressure may indicate that it is time to clean the breaker plate and change the screen pack.

How to Clean the Extruder, Screw and Barrel

To clean the extruder, the following steps are recommended:

1. Let the extruder run with resin at approximately 300°F (150°C) for LDPE and MDPE resins and 380°F (195°C) for HDPE, without further feeding until the screw can be seen at the bottom of the hopper. Never let the screw run “dry.”
2. Turn off all electricity and water. While the machine is still hot, roll away or remove any equipment in line with the screw. Never touch any hot part of the machine unless wearing protective gloves.
3. Disconnect electrical lines wherever necessary.
4. Remove the die head and dies. For moving heavy machine parts, heavy duty equipment is needed, such as an overhead crane, a lift truck or a chain hoist.
5. Remove the adapter from the barrel.
6. Remove the breaker plate with the screens.
7. Push the screw forward from the back end and remove it. All extruder parts to be cleaned or exchanged are now accessible.
8. To clean the screw, first use a cop per or brass bladed scraper to remove most of the molten resin adhering to the screw. After scrap ing off the bulk of the polymer melt, clean the screw with copper or brass (not steel) wool. Use a silicone grease spray to help remove tightly adhering resin. Next, coat the screw with silicone grease before replacing it. Never use steel tools or steel wool to clean any part of the extruder.
9. Always clean the barrel whenever the screw is cleaned. Run a long-handled brass brush through the barrel to remove the remaining resin. Then use a similar tool to lubricate it with silicone grease.
10. Clean the adapter with copper or brass tools similar to those used for cleaning the screw. Then lubricate with silicone grease. Clean the collar. Clean and lubricate the seat of the adapter and breaker plate, also the end of the screw if the screw has not been removed for cleaning or exchanging by the procedure just described.
11. The face of the adapter as well as that of the barrel is clean and needs no further attention if fitted accurately during the previous run. Exchange, do not clean, the screen pack. Used screen packs must be removed from the breaker plate at regular intervals, otherwise they become an obstruction instead of a filter. Since they are bound to be damaged when removed, discard them. The screen pack should be removed from the breaker plate with a sharp brass knife. Never use any device such as a screwdriver. Steel may damage the breaker plate and result in defective blow molded pieces and rejects. The screen pack should be changed about once each week, if the extruder is in continuous operation.

When changing the screen pack between extruder cleanings, the following steps are recommended, provided breaker plate and screen pack are located between extruder head and adapter:

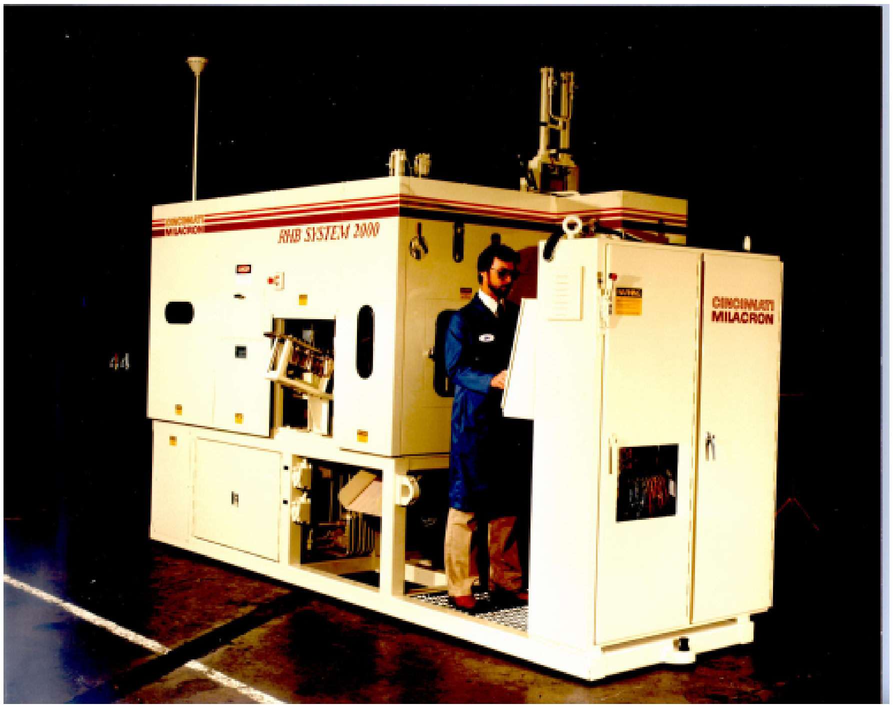


Figure 61. Two-stage injection blow molding machine.

1. Move the die and adapter out of the way, as described, while the extruder is running with resin.
2. Turn the screw speed to very low. Then turn off all electricity and water. The screw comes to a stop.
3. Remove the used screen pack from the breaker plate in the adapter, as described, and discard it.
4. Clean all machine parts located around the breaker plate, as described. Clean the breaker plate by burning it out as described below.
5. Put all removed parts back and replace the discarded screen pack with a new one.
6. Reconnect all disconnected electrical and water lines.

How to Burn the Breaker Plate Clean

The oxidized polymer clinging to, and possibly clogging, the breaker plate should be burned out. This is done with the flame of a Bunsen burner, burning clean first one side, then the other. To prevent molten resin from dripping into the burner, it should be mounted on a ring stand so that the flame hits the plate horizontally. As a safety precaution, the cleaning of the breaker plate should be done inside a vented hood behind a protective window. Burning a breaker plate clean takes about 20 minutes.

Use compressed air to blow out any carbon left in the breaker plate from the burned polymer. A spare breaker plate should always be available to be placed into service rather than waiting for the old one to be burned out and cleaned for reuse.

Cleaning the Die

Many different dies are available for blow molding, so there is no single rule for cleaning them. The heads of other dies may be left attached to the adapter which, in turn, may be left hinged to the extruder. After removing the die from the die head, clean the adapter with brass wool. Clean the attached die head with a brass or copper brush. Use other brass or wooden tools for cleaning these parts, if necessary. The die heater bands may be left connected, but the electricity must be turned off. To remove resin residue from parts of the die, put on your protective gloves. Simple brass or wooden tools and “knives,” brass or copper wool and silicone grease help to remove stubborn resin. Use a brass or copper wool cloth or brush to finish the cleaning job. Finally, use silicone grease for lubrication. Never use steel tools or steel wool for die cleaning. They may leave marks and scratches which can cause die lines in finished products.

Maintenance of Extrusion and Blow Molding Equipment

Regular checkups and maintenance of the blow molding equipment should be scheduled. A thorough maintenance program reduces downtime and operating costs as well as rejects. Often, the blow molding equipment manufacturer suggests the frequency of lubrication and what type of oil or grease to use. Such instructions should be followed. Read thoroughly and follow to the letter the service manuals for the various units that make up your extrusion blow molding equipment.

Monitor Lubricant

The oil should be changed in the gear box and transmission (if oil-driven) about every six months if the extruder is operated on one shift daily, and every three or four months if it is operated on two or more shifts daily (see manufacturers’ recommendations). In between, the lubrication of all bearings, gears, shaft seals, etc. must be checked regularly. Oil leaks may indicate the need to replace gaskets or seals, a clogged part or too much oil. In such cases, the part must be cleaned or the oil drained. A lack of oil in any equipment requiring lubrication can result in a great deal of damage. External parts such as hinges, clamps and swing bolts should be treated periodically with heat-resistant lubricants.

Checking of Band Heaters, Thermocouples and Instruments

Electric band heaters should be regularly examined for tightness. A loose heater does not do its job effectively or for very long. It must be tightened so it fits snugly around the barrel, adapter or die. If a burned-out band heater is suspected to be the cause of a drop in temperature, replace the heater.

Thermocouples in the barrel, adapter and die must also be checked periodically for tight contact. A loose or worn out thermocouple is unreliable. It is advisable to replace thermocouples with the same types and sizes as those currently in use, although bayonet-type locking mounts are preferred.

At regular intervals, check whether the set points for the various zone heater temperatures are accurately shown on the indicator dials on the temperature control board. Procedures for checking thermocouples, lead wires and instruments for calibration can be found in instrument manuals. If an alarm system for faulty operating heaters, blown fuses or breakers is provided, such as a flickering bulb, buzzer, horn or ammeters, react to the warning signals immediately. Determine, by means of the instruments on the temperature control board, which of the heaters is failing.

The alignment, level and, wherever necessary, placement of the various main parts of the extruder and blow molding equipment should be checked regularly and must be corrected when required. Check the die opening with a flexible gauge whenever the parison extrudes with non-uniform wall thickness, causing it to curve.

An adequate amount of clean oil must be kept in the hydraulic system. The equipment manufacturer usually recommends a specific type of oil in the maintenance manual. The air in the pneumatic system that operates valves, automatic stripping, the cut-off knife and other parts of the blowing equipment should be lightly oiled, provided the blow molding air is supplied by a separate system. This means the pneumatic system must contain an oiler and a water strainer to protect the oil from water contamination. The blowing air should not be oiled. The operator must constantly watch both the hydraulic and pneumatic systems for pressure changes caused by faulty valves and gauges or by leaks, as indicated on instruments.

A closed water circuit is frequently preferable to using tap water in the cooling system. Tap water requires a cleaning tower in the system. Well water is often “hard,” and mineral deposits might lessen the effectiveness of the heat exchanger for the oil in the hydraulic system. Watch the mold cooling water temperature either by means of instruments, such as thermocouples or pyrometers, or manually by occasionally touching the water line surfaces. Do not touch the mold surfaces for this purpose.

Cleanliness in the blow molding shop is a most important part of the maintenance job. Contamination of the resin by dust, dirt and especially, small metal parts make the production of good products impossible; it may also damage the screw, the die and other parts of the extruder. It is always advantageous to keep small sets of comparatively inexpensive spare parts in stock, such as thermocouples, heaters, fuses, die adjusting bolts, screen packs, a breakerplate, die pins, etc.

Prevent Hazards Harmful to You, Your Equipment and Your Product

Accidents to people and equipment, except for those caused by uncontrollable events, can be prevented. Most are caused by human error or negligence. Always keep in mind a few basic safety rules:

- Be accident-conscious; develop a “safety sense,” and follow safe working procedures
- At all times, keep all your equipment, machinery, tools or auxiliary parts well maintained and clean
- The “No Smoking” signs on the walls of a blow molding shop must be heeded; smoking is dangerous and can be a source of resin contamination.

The following hazards also require constant attention:

Heat

You are working with hot resins in a heated machine. Unless required for cleaning or other purposes, do not remove protective covers or hoods from the extruder or blow molder. When working around hot machine parts, always use protective gloves. Clean up lumps of purge resin left on the floor near the machine. They present a safety hazard, easily became contaminated and, therefore are useless as regrind. The best procedure is to let purge drop into a tray in pieces small enough to be easily reground.

Physical injury

Never place your hands in hazardous areas such as near the moving platens or molds when starting up or adjusting the molding press. In fact, no machine should be run with gear guards removed. Never allow resin pellets or cubes to remain on the floor. If you step on them, they may roll like a ball or roller bearing with dangerous consequences. Do not start the extruder at too low a temperature. The inside pressure built up by the viscous or solid resin may break the equipment, “shoot” the die assembly off and cause injury as well as put the extruder out of operation for a long time.

Areas around moving equipment may be “injury traps,” particularly when you handle objects or use hand tools. Avoid wearing long neckties and loose-fitting clothing. Anything loose about you may be caught by moving equipment and pull you into contact with moving or hot machine parts, resulting in injury. Wear safety glasses and safety shoes while working around the extruder and blow molding equipment.

If there is a safety mechanism on your machine, such as a “panic button” for the protection of personnel and equipment, make sure all operators know how to use it. Never try to remove a safety device or make it inoperable while the machine is running. Most blow molding presses are equipped with pivoting or sliding safety shields, safety screens or gates for your protection. The machine stops whenever a shield is removed. Do not tamper with this safety device; some day it may save your hand or eye. Some blow molding machines have electronic safety devices replacing the safety screen.

Poor Ventilation and Uncleanliness

Dust and dirt are unhealthy for operators and can damage your products. Therefore, keep the shop clean. Do not permit waste to accumulate on the floor around the machine. Adequate ventilation is a must. Never tamper with the exhaust equipment. Keep it clean and in good order.

Electricity

Never forget high voltage can be dangerous. Damaged electrical insulation is a major safety hazard. Beware of the high voltage-carrying electrode bars of some types of electric heating equipment. Some moving parts of blow molding equipment are wired. Make sure these electric connections are good, safe and controlled. Keep water and oil lines away from them. Water vapor in the air may condense on cooling lines and on nearby electrical contacts.

Appendix 1:
Guide to Solving Polyolefin Extrusion Blow Molding Problems

Parison Extrusion Problems	Causes	Solutions
Bubbles	Moisture in resin	Keep resin dry and clean Reduce coolant flow to feed throat Raise feed section temperature Use indoor surge bins to allow resin to warm up after transferring from cold outside conditions (silo)
	Extrusion rate too slow	Increase back pressure Increase orifice size Use resin with higher MI
	Melt temperature too low	Increase feed section temperature Increase die lip temperature
	Misalignment of die/mandrel	Tighten die lip bolts Realign die/mandrel Repair die seal Lengthen land between mandrel and bushing
Rolling Up (Parison Curl)	Uneven extruder heating	Melt temperature too low Replace/repair heater bands Replace/repair melt thermocouples
	Die and mandrel misaligned	Tighten die tip bolts Realign mandrel and die Repair mandrel seal Lengthen land between bushing and channel Replace tooling
	Extrusion rate too low	Increase back pressure Increase orifice size Use resin with higher MI
	Resin contaminated	Keep resin and regrind clean
	Contaminants in die channel	Briefly open die gap and purge contaminate Clean die and resin channel
Excessive Stretching	Melt temperature too high	Lower feed section temperature Lower die tip temperature
	Extrusion rate too high	Reduce mold open time Lower back pressure Reduce orifice size Use resin with lower MI
Holes	Contaminated resin	Keep resin and regrind clean
	Contaminates in die channel	Briefly open die gap Clean die and resin channel
	Bridging or collaring	Drop scrap directly into feed throat

Parison Extrusion Problems	Causes	Solutions
Rough Surface	Extrusion rate too low	Increase back pressure Increase orifice size Use resin with higher MI
	Melt temperature too low	Raise feed section temperature Raise die tip temperature
Streaks	Contaminated resin	Keep resin and regrind clean
	Contaminants in die channel	Briefly open die gap to purge Clean die and resin channel
	Die and mandrel misaligned	Tighten die tip bolts Realign mandrel and die Repair mandrel seal Lengthen land between bushing and channel Replace tooling
	Uneven extruder heating	Melt temperature too low Replace/repair heater bands or rods Replace/repair melt thermocouples
	Extrusion rate too high	Reduce mold open time Lower back pressure Reduce orifice size Use resin with lower MI
Uneven Parison Thickness	Melt temperature too high	Lower feed section temperature Lower die tip temperature
	Extrusion rate too high	Reduce mold open time Lower back pressure Reduce orifice size Use resin with lower MI
	Contaminants in die channel	Briefly open die gap Clean die and resin channel
	Uneven extruder heating	Melt temperature too low Replace/repair heater bands Replace/repair melt thermocouples
	Die swell too high	Use lower die swell resin
	Die and mandrel misaligned	Tighten die tip bolts Realign mandrel and die Repair mandrel seal Lengthen land between bushing and channel Replace tooling

Blow Molding Problems	Causes	Solutions
Bad Pinch-Off	Melt temperature too low	Lower feed section temperature Lower die tip temperature
	Pinch-off too thin	Widen pinch-off land Eliminate knife edges and burrs on mold Repair damaged mold
	Molds misaligned	Realign molds Use pre-blow cushions and slam Replace or repair mold
	Flash volume too great	Reduce flash size
Blowout	Melt temperature too high	Lower feed section temperature Lower die tip temperature
	Extrusion rate too high	Reduce mold open time Lower back pressure Reduce orifice size Use resin with lower MI
	Blow pressure too high	Lower blowing pressure Delay air start time
	Pinch-off too wide	Reduce pinch-off
	Mold temperature too high	Increase mold cooling Clean cooling channels Increase mold close time
	Parison too short	Increase mold open time Increase extrusion rate
	Mandrel/die misaligned	Tighten die tip bolts Realign mandrel/die Repair mandrel seal Lengthen land between mandrel and bushing Replace tooling
	Contaminated resin	Keep resin and scrap clean
	Contaminants in die channel	Briefly open die gap Clean channel and die
	Poor parison clamping	Increase clamp pressure
	Blow up ratio too high	Use larger diameter die Eliminate mold hang-ups
Breakage at Part Line	Poor parison clamping	Increase clamp pressure
	Molds misaligned	Realign molds Increase pre-blow cushion time Replace or repair mold
	Melt temperature too high	Lower feed section temperature Lower die tip temperature

Problems	Causes	Solutions
Ejection From Mold	Melt temperature too high	Lower feed section temperature Lower die tip temperature
	Mold temperature too high	Increase mold cooling Clean cooling channels Increase mold close time
	Not enough draft in mold	Clean blow pins Eliminate mold hang-ups Align blow pins Redesign molds (increase draft)
Flash	Pinch-off too wide	Reduce pinch-off
Weak Weld Line	Melt temperature too high	Lower feed section temperature Lower die tip temperature
	Mold temperature too high	Increase mold cooling Clean cooling channels Increase mold close time
	Pinch-off too thin	Widen pinch-off land Eliminate knife edges and burrs

Finished Product Problems	**Cause**	**Solutions**
Bubbles	Moisture in resin	Keep resin dry Reduce coolant flow to feed throat Raise feed section temperature
	Moisture in mold	Increase mold temperature Vent molds Eliminate cooling water leaks Dehumidity molding area Wipe mold surface
	Extrusion rate too low	Raise back pressure Increase orifice size Use resin with higher MI
	Misaligned die/mandrel	Tighten die tip bolts Realign die/mandrel Repair mandrel seal Lengthen land between mandrel and die Replace tooling
Flashing on Product	Melt temperature too high	Lower feed section temperature Lower die tip temperature
	Mold Misaligned	Realign mold Use pre-blow cushion and slam repair or replace mold

Problems	Causes	Solutions
Product Breaks Weld Line	Poor parison clamping	Increase clamp pressure Check pinch-off areas
	Mold misaligned	Realign mold Use pre-blow cushion and slam Repair or replace mold
	Melt temperature too low	Lower feed section temperature Lower die tip temperature Reduce cycle time
Shrinkage	Melt temperature too High	Lower feed section temperature Clean cooling channels Increase mold close time
	Blow pressure too low	Increase blowing pressure Increase blowing time Increase blow pin size Eliminate air leaks
	Extrusion rate too high	Reduce mold open time Lower back pressure Reduce orifice size Use resin with lower MI
Specks	Resin contamination	Keep resin and regrind clean
	Die/mandrel contaminated	Briefly open die gap Clean channel and die
Surface Roughness	Moisture in mold	Increase mold temperature Vent molds Eliminate cooling water leaks Dehumidify molding area Wipe mold surface
	Blow pressure too low	Increase blowing pressure Increase blowing time Increase blow pin size Eliminate air leaks
	Incomplete melting	Do not use resins/regrind with different MIs
	Misaligned mold	Realign mold Raise preblow cushion Repair or replace mold

Courtesy of Society of the Plastics Industry, Inc.

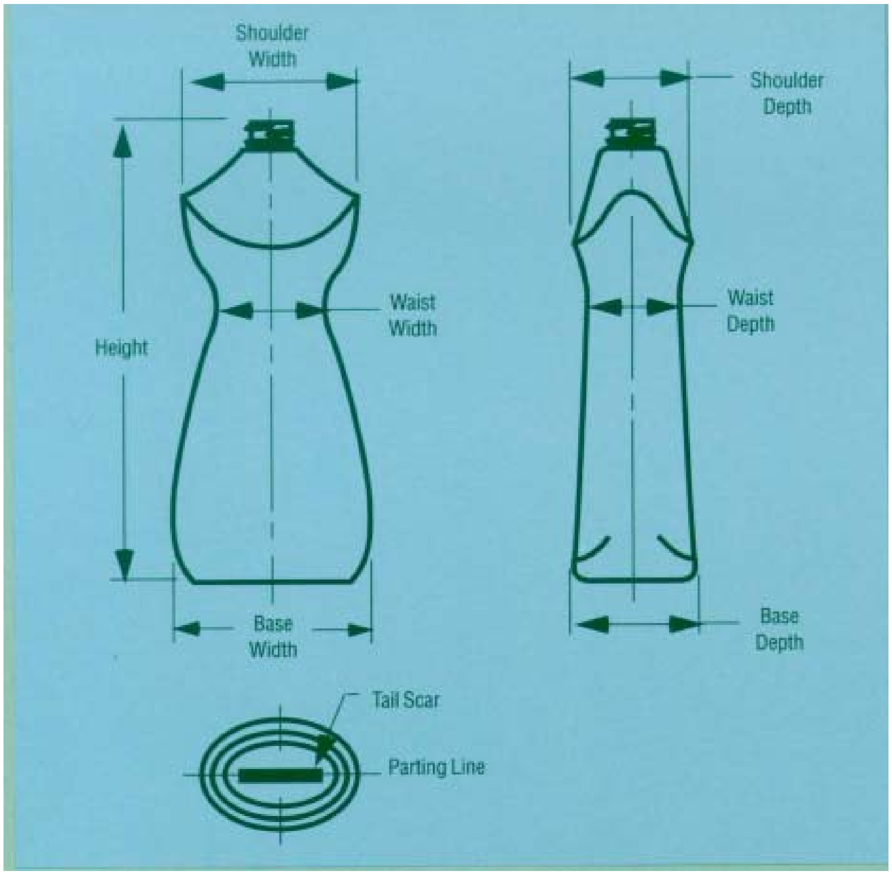


Figure 62. Plastic Bottle Terminology

Problems	Causes	Solutions
Uneven Wall Thickness	Extruder heating uneven	Repair/replace heater bands Clean/replace thermocouples Set melt temperature not reached
	Extrusion rate too low	Raise back pressure Increase orifice size Use resin with higher MI
	Melt temperature too high	Lower feed section temperature Reduce die tip temperature
	Poor product design	Redesign mold Use parison die tip temperature
Warpage	Melt temperature too high	Lower feed section temperature Reduce die tip temperature
	Mold temperature too high	Increase mold cooling Clean cooling channels Increase mold close time
	Poor product design	Redesign mold Use parison programmer

Appendix 2:
Blow Molding Terms

Courtesy of Society of the Plastics Industry, Inc.

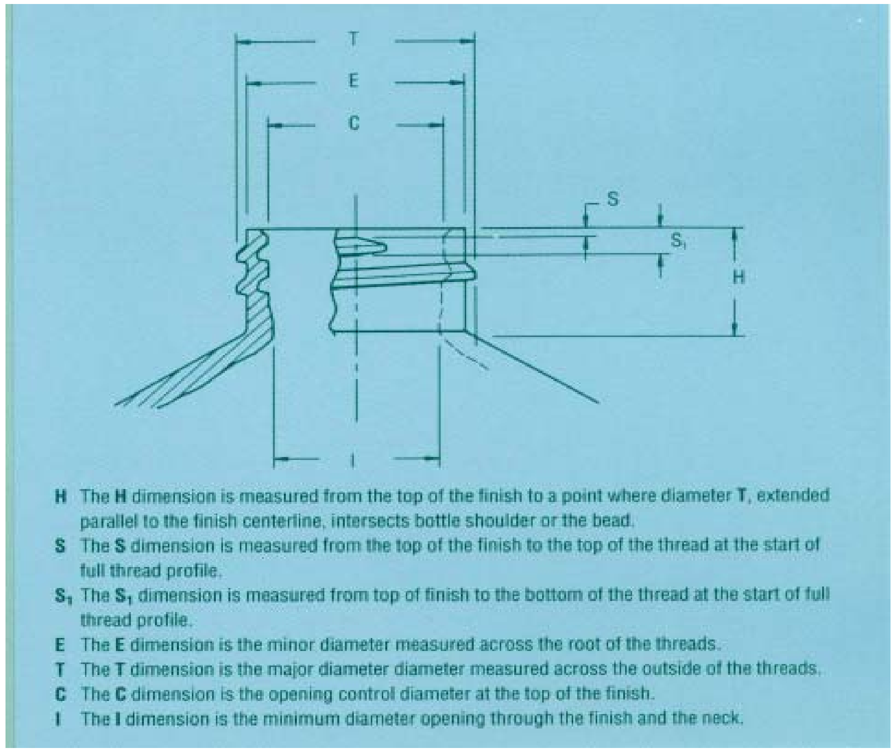


Figure 63. Bottle finish dimensions.

Accumulator: A cylindrical reservoir that is fed melted resin from the extruder. The accumulator accepts a predetermined quantity of resin and then delivers this stored material to the die opening as required by a hydraulic ram pushed forward to deliver the parison as needed.
Alligatoring: See melt fracture.
Annealing: A heating process used to relieve material stresses incorporated in the blown article.
Backing Plate: A plate used as a support for the molds and for fastening to the platens.
Barrel: See extruder.
Base Depth: See Fig. 62.
Base Width: See Fig. 62.
Blow Holes: Also called fisheyes. Holes or blisters evident in the wall surfaces of blown containers caused by entrapped air or water, decomposition gases, contamination or unplasticized resin.
Blow Pin: Part of the tooling used to form hollow objects in blow molding applications. The hollow pin is inserted or made to contact the blowing mold so the blowing media can be introduced into the parison or hollow form. Then the parison expands to conform to the mold cavity.
Blow Pressure: The pressure of the air or blowing media necessary to expand the resin or material to be blown to conform to the cavity of the blowing mold.
Blow Rate: The speed or rate the blowing air or media enters or the time required to expand the parison (tube) or form during the blow molding cycle.
Blow-Up Ratio: The ratio of the mold cavity diameter to the diameter of the parison or hollow form to be blown up.
Blowing Mandrel: See mandrel and blow pin.
Blowout: Blowing air rupture of parison or preform.
Blush: A whitening effect that can occur in the trim areas of blown pieces. Ban: Protuberance on a plastic part designed to add strength, facilitate alignment, provide fastening, etc.,
Bottle Finish: see Fig. 63.
Breaker Plate: Support for screen pack at end of extruder barrel.

Calibration: The neck finishing of a container to a specific inside diameter.
Cavity: A depression in a mold made by casting, machinery or hobbing.
Charge: The measurement or weight of material necessary to form a useable parison to produce a complete blow molded item.
Clamping Plate: A plate fitted to the mold and used to fasten the mold to the molding platen.
Clamping Pressure: The pressure which is applied to the mold to keep it closed during a cycle.
Cold Flow: See creep.
Compression Ratio: A term used to define an extrusion screw, denoting the ratio of the compression section length to the screw diameter.
Cooling Channels: Channels located within the body of a mold through which a cooling medium is circulated to control the mold surface temperature.
Cooling Fixture: A jig or block to hold the shape of a molded part after it has been removed from the mold until it is cool enough to retain its shape without distortion.
Core Pin: Either the core, as described above, or an extension of the core that is called a mandrel.
Core: In blow molding ‘ this is the center portion of the blowing head and controls the inside diameter of the parison.
Crazing: Fine cracks which may extend in a network on or under the surface or through a layer of resin on a molded part.
Creep: The dimensional change with time of a material under load following the initial elastic deformation. Also called cold flow.
Crosshead: In blow molding, a head tooling design to facilitate extruding resin at an angle different from the extruder, usually 90 degrees.
Curling: A condition where the parison curls upwards and sticks to the outer face of the die. Adjustment of mandrel and die face levels or temperature usually corrects this problem. Also called “doughnutting.”
Curtaining: Draping or folding caused by extruding an off-center parison or excessive die swell characteristics.
Cut Off: Mold pinch-off areas. These lines (top and bottom) on a blown container are where the mold pinch-off areas have cut through the parision when it closed on the parison for blowing.

Cycle: The complete sequence of operations in a process to complete one set of parts. The cycle starts at a point in the operation and ends when this point is again reached.
Daylight Opening: The clearance between two mold halves or platens of a clamping press in the open position.
Deflashing: A finishing operation for removing flash on a plastic molding such as tails, handle plugs and material around thread areas.
Delamination: The surface of the finished part separates or appears to be composed of layers of solidified resin. Strata or fish scale-type appearance where the layers may be separated.
Density: Weight per unit volume of a resin usually expressed in grams per cubic centimeter.
Die Gap: In blow molding, the distance between the mandrel and die in the blowing head. This clearance governs the thickness of the extruded parison and thus the thickness of the walls of the finished part.
Die Land: See Land.
Die Lines: Lines that are evident in the finished molded part caused by the meeting or remeeting of the molten resin as it flows around the core or die pin to form the parison or extruded tube.
Die Swell Ratio: The ratio) of the outer parison diameter (or parison thickness) to the outer diameter (or die gap).
Die: Any tool or arrangement of tools designed to shape or form materials to a desired configuration.
Dispersion Aid: The breaker plate, screen pack or other device in the melt stream that allows uniform mixing and forces the suspended materials to be uniformly dispersed in the melt stream'
Dispersion: The suspension of a material (color) in the resin.
Draft: The degree of taper of a side wall or the angle of clearance designed to facilitate removal of parts from a mold.
Ejection: In blow molding, the removal of the finished item from the mold cavity and away from the blowing area.
Elongation: The increase in length of a molded piece of resin stressed in tension.
Extrudate Melt: The product or parison materials delivered by an extruder.
Extruder: The part of the blow molding machine in which the polyolefin resin is melted and pushed forward toward the die. It consists of a barrel enclosing a constantly turning screw, heaters, thermocouples to measure melt temperature and a screen pack.
Flame Treating: See Surface treating.
Flash: Excess plastic attached to the molded item that is formed by the pinchoff areas of the mold as it closes on the parison.
Flow Line: Visible marks on the finished item that indicate where the melt has joined or remet in the die head as it flowed around the core or mandrel to form the parison; also called weld line, flow line and die line.
Flow: A qualitative description of the fluidity of a plastic material during the process of molding. A measure of its processability.
Gear Pumps: See Melt pumps. Gel: In polyethylene, a small amorphous particle which differs from others because of its high molecular weight and/or crosslinking. Its processing characteristics are different and more difficult to homogenize into the resin melt.
Gloss: The shine or luster of the surface of a finished object.
Gravimetric Feeders: Feeders that measure the weight of materials fed to the extruder from a special weigh hopper and determine the rate at which the material is consumed.
Grit Blasted: See Sand blasting.
Guide Pins: Pins in the face of the mold to assure proper alignment when they are closed.
Handleware: Containers with handles.
Head: In blow molding, the end section of the molding machine that consists of the core, die, mandrel and other parts necessary to form the resin into a hollow tube (parison) with the correct dimensions and thickness. The head delivers this parison to the area where it can be picked up and transferred to the blowing mold.
Heel: The part of a container between the bottom bearing surface and the side wall.
High-Load Melt Index: The designation commonly used for high molecular weight resins, a measure of the resin's ability to flow through an orifice of a melt indexer with a heavier weight applying the pressure (21,600 gram weight). See also Melt Index.
Impact Resistance: The susceptibility of a resin or object molded from a resin to fracture by shock such as dropping. Injection ram: The ram or screw which applies pressure to the molten resin to force it through the tooling.
Injection Stretch Blow Molding: Process in which hot preforms are stretched before being blow molded. Stretching improves clarity and side wall stiffness.
Insert: An integral part of a plastic molding consisting of plastic, metal or other materials that has been preformed and inserted into the blowing mold so it becomes an integral part of the finished item. Jig: See Cooling fixture.
Knit Lines: See Flow Lines.
L/D Ratio: A term used to define an extrusion screw, denoting the ratio of the screw length to the screw diameter. Land: The bearing surface along the top of the flights of a screw; also the working area near the tooling opening of a die and mandrel that maintains a constant or controlled volume of resin prior to its leaving the tooling in the form of a parison. Also called die land.
Lightweighting: Design process to reduce weight of containers.
Lubricant: Additive to resin designed to facilitate part removal from mold cavity.
Mandrel: The central portion or "core" of the tooling at the opening where the parison is formed.
Manifold: The configuration of piping that takes a single channel flow of resin from an extruder and divides it into various flow channels to feed more than one head or one head in more than one place.
Melt Flow Rate: An indication of the fluidity of polypropylene resins. It is a measure of the amount of material that can be forced through a given orifice when subjected to a given weight in a given time. See ASTM D 1238-65T for further information.
Melt Fracture: Also called alligatoring, sharkskin or herringbone. This is a shearing effect or instability in the melt flow through a die clearance. This instability of flow causes irregular rough surfaces on the finished container. Adjustment of tooling, heat, extrusion rate or improved resin flow is required to correct this problem.
Melt Index: An indication of the fluidity of polyethylene resins. It is a measure of the amount of material that can be forced through a given orifice when subjected to a given weight in a given time. See ASTM D 1238-65T for further information.
Melt Pumps: Units at end of barrel and before the die head that greatly increase melt quality, by eliminating any surging resulting from the screw action.

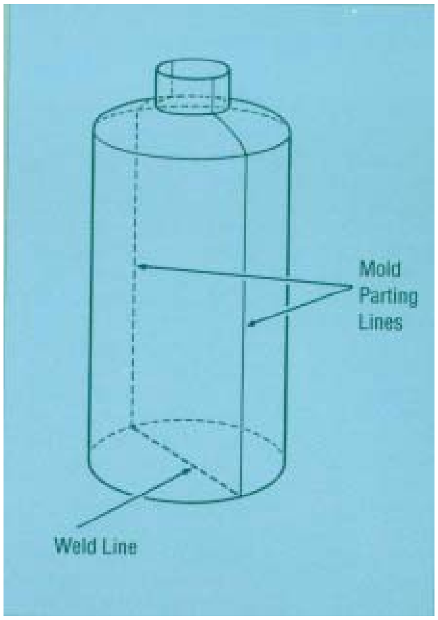


Figure 64

Melt Strength: The strength of the plastic while in the molten state. The ability to resist deformation or parison sag by the weight of the parison. This is usually a function of the flow of the resin and can be estimated by the melt index. The lower the melt index, the better the melt strength.
Metering Screw: An extrusion screw that has a shallow constant depth and pitch section usually over the last three or four flights.
Mold Seam: The vertical lines that may be visible on the molded item that shows where the mold separates to allow removal of the blown article **(See Fig. 64).**
Molding Cycle: See Cycle.
Molding Shrinkage: See Shrinkage.
Movable Platen: The platen for holding the blowing mold, moved by a hydraulic ram or toggle mechanism.
Multi-Cavity Mold: A mold having more than one cavity or impression for forming finished items at one machine cycle.
Neck Finish: Threads in the neck of containers and the neck opening.
Needle Blow: A sharp, rather small in diameter, blow pin that is forced through the parison as the mold closes around it or after the mold has closed. This area has to be trimmed from the container after the part is blown as there is a hole where the needle punctures the parison.
No Blow: Failure of air inflation of a parison or preform.
Off-Set Neck: Neck set to either side of the center of a container.
Orange Peel: A surface finish defect on a molded part that is rough and splotchy. Usually caused by moisture in the mold cavity. Sometimes melt fracture is erroneously referred to as orange peel.
Ovalization: Altering of the parison shape to ensure uniform wall thickness.
Parison Swell: An increase in parison diameter and wall thickness that occurs after the parison exits the parison die.
Parison: The hollow plastic tube that is extruded from the head from which blown objects are made.
Parting Line: See Mold seam.
Permeability: Degree to which oxygen or moisture vapor can pass through a material. See ASTM F372 and ASTM D3985.
Pinch-Off: On the blowing mold this is a raised edge which seals off the object and separates the excess material of the parison from it.
Pinhole: A very small hole in the finished object.
Pitch: The distance from any point of the flight of a screw line to the corresponding point on an adjacent flight, measured parallel to the axis of the crew line or threading.
Plastic: A synthetic or natural product excluding rubber) that at some stage of working under heat and pressure is capable of flowing and being formed and held in a desired shape when cooled.
Plasticate: To soften by heating and mixing.
Platens: Steel plates on which mold halves are mounted in the blow molding clamp.
Plunger: See Ram.
Pock Marks: Irregular indentations on the surface of a blown container caused by insufficient contact of the blown parison with the mold surface.
Pre-Blow: An initial expansion of a parison before it is fully expanded to a products final size and shape.
Programming: A system of altering the die gap opening while the parison is being extruded so that the wall thickness of the extruded parison may be varied to control the wall thickness or resin distribution in the finished blow molded article.
Punch-Out: A finishing technique generally used to remove the material from inside a handle on a blown container.
Purging: The elimination of one color by another, or one type of resin by another, from an extruder or cylinder prior to molding the new color or resin.
Ram: The portion of an extrusion system that pushes or forces molten resin from an accumulator or feed area through a set of tooling to form a parison for blow molding into a container.
Reciprocating Screw: Screw inside extruder barrel that moves backward as melt is produced in front of screw tip. When desired melt volume is reached, the screw is pushed forward ejecting the melt into a parison die head or into an injection blow mold.
Regrind: Plastic scrap from finishing blown parts that has been granulated into small pieces for blending with virgin resin pellets.
Rocker: A plastic container having a bulged bottom that causes it to rock when in an upright position.
Sag: Stretching of parison wall thickness caused by weight of melt pulling downward.
Sand Blasting or Grit Blasting: A surface cleaning and roughening system in which sand or grit is blown under pressure against the mold cavity. The pinchoff areas must be taped so they do not get blasted and worn down. The resultant rough surface allows entrapped air in the mold to have a place to go and let the blown plastic contact the mold surface. Generally, an 80 grit sand is used for this roughening.
Sharkskin: See Melt fracture.
Shot: The completed resin used in a molding cycle to produce the finished object
Shoulder depth: See Fig. 62.
Shoulder width: See Fig. 62.
Shrinkage: The difference found on a molded part as compared to the actual mold cavity dimension. The resin is a factor in the shrinkage level; however, the main factors are melt temperature, mold design, part thickness, part design and temperature of the part when removed from the mold.
Snap-Back: The shrinkage in length and/or diameter of the open end of a parison as it is being extruded or while it is hanging on the tooling prior to the mold closing on it.
Spin Welding: A process of fusing two objects by forcing them together while

one of the two is spinning until frictional heat melts the interface.

Stress Cracking: The phenomenon causing plastic material to fail after it has been processed into finished objects and placed in contact with certain chemical reagents. Normally, the finished objects are stressed during production or are under stress during use. When these stressed parts are placed in contact with a wetting agent, they tend to fail.

Stripper: A plate or ejection device that removes the finished molded part from the tooling or mold at the end of the cycle.

Suck-Back: See Snap-back.

Surface Treating: A system of treating the surface of the finished container so it accepts ink, lacquers, paints, adhesives, etc. This treating is usually done by an oxidizing flame. However, electronic treating by a "corona" discharge or a chemical treatment in hot dichromate and sulfuric acid may be used to accomplish the same task.

Swell: Expansion of parison as its exits the parison die.

Tail Scar: See Fig. 62.

Tensile Strength: The pulling stress in psi required to break a given specimen.

Throughput: Amount of melt that can be processed by a plasticating unit in an hour, e.g. XX lbs./hr. Also the number of blown products that can be made in an hour, e,g., XX 8-oz. bottles/hr.

Toggle: A mechanism that exerts pressure developed by applying force on a knee joint. It is used to close and exert pressure on a molding press.

Undercut: Having a protuberance or indentation that impedes withdrawal from a two-piece rigid mold.

Vent: A shallow channel or opening cut in the cavity to allow air or gases to escape from the mold as the parison is expanded to fill the cavity.

Viscosity: Internal friction or resistance to flow of a liquid. The constant ratio of shearing stress to rate of shear. In liquids for which this ratio is a function of stress, the term "apparent viscosity" is defined as this ratio.

Volumetric Feeders: Units that feed resin based on the volume of resin needed to fill the hopper.

Waist Depth: See Fig. 62.

Waist Width: See Fig. 62.

Warpage: Dimensional distortion in a molded object.

Weld Line: See Fig. 64.

Appendix 3:
Metric Conversion Guide

To Convert From	To	Multiply By
Area		
square inches	square meters	645.16
square millimeters	square inches	0.0016
square inches	square centimeters	6.4516
square centimeters	square inches	0.155
square feet	square meters	0.0929
square meters	square feet	10.7639
Density		
pounds/cubic inch	grams/cubic centimeter	7.68
grams/cubic centimeter	pounds/cubic inch	0.000036
pounds/cubic toot	grams/cubic centimeter	0.016
grams/cubic centimeter	pounds/cubic foot	62.43
Energy		
foot-pounds	Joules	1.3558
Joules	foot-pounds	0,7376
inch-pound	Joules	0.113
Joules	inch-pounds	8.85
foot-pounds/inch	Joules/meter	53.4
Joules/meter	foot-pounds/inch	0.0187
foot-pounds/inch	Joules/centimeter	0.534
Joules/centimeter	foot-pounds/inch	1.87
foot-pounds/square inch	kilo Joules/square meter	2.103
kilo Joules/square meter	foot-pounds/square inch	0.41
Length		
Mil	millimeter	0.0254
millimeter	mil	39.37
inch	millimeter	25.4
millimeter	inch	0.0394
Output		
pounds/minute	grams/second	7.56
grams/second	pounds/minute	0.1323
pounds/hour	kilograms/hour	0.4536
kilograms/hour	pounds/hour	2.2046
Power		
kilowatts	horsepower(metric)	1.3596
horsepower (metric)	kilowatts	0.7376
voltage/mil	millivolts/meter	0.0394
millivolts/meter	voltage/mil	25.4

To Convert From	To	Multiply By
Pressure		
pounds/square inch (psi)	kilopascals (kPa)	6.8948
kilopascals (kPa)	pounds/square inch (psi)	0.145
pounds/square inch (psi)	bar	0.0689
bar	pounds/square inch (psi)	14.51
Temperature		
°F	°C	(°F-32)/1.8)
°C	°F	1.8°C+32
inches/inch	F meters/meter,C	1.8
meters/meter,C	inches/inch,F	0.556
Thermal Conductivity		
Btu-in/hr, sq. ft.,°F	W/(m-°K)	0.1442
W / (m-°K)	Btu-in/hr,sq ft, °F	6.933
Thermal Expansion		
inches/inch,°F	meters/meter,°C	I . 8
meters/meter, °C	inches/inch, °F	0.556
Viscosity		
poise	Pa-sec.	0.1
Pa-sec	poise	10
Volume		
cubic inch	cubic centimeter	16.3871
cubic centimeter	cubic inch	0.061
cubic foot	cubic decimeter	28.3169
cubic decimeter	cubic foot	0.0353
Weight		
ounce	gram	28.3495
kilogram	ounce	0.03527
pound	kilogram	0.4536
kilogram	pound	2.2046
ton (US)	ton (metric)	0.972
ton (metric)	ton (US)	1.1023

Appendix 4:

ASTM Methods for Polyolefins and Blow Molding

Property	ASTM Method
1 % Secant modulus	D 638
Density	D 1505 or D 792
Elongation	D 882
Environmental stress cracking resistance	D 1693
Flexural modulus	D 790
Flow rates using extrusion rheometer	D 1238
Gloss	D 523
Hardness, Rockwell	D 785
Hardness, Shore	D 2240
Haze	D 1003
Impact strength, drop dart	D 1709/A
Low temperature brittleness	D 746
Melt index	D 1238
Oxygen permeability	D 3985
Rheological properties using capillary rheometer	D 3835
Specific gravity	D 792
Tensile strength	D 882
Thermal conductivity	C 177
Vicat softening point	D 1525
Volume resistivity	D 257
Water absorption	D 570

Appendix 5:

Abbreviations

ASTM	American Society for Testing and Materials
Btu	British thermal unit
cyl	Cylinder
deg	Degree (angle)
E	Modulus of elasticity
elong	Elongation
ESCR	Environmental stress cracking resistance
EVA	Ethylene vinyl acetate copolymer
EVOH	Ethylene vinyl alcohol copolymer
FDA	Food and Drug Administration
fl	Fluid
flex	Flexural
g	Gram
HDPE	High density polyethylene
HIC	Household and industrial chemicals
HMW	High molecular weight
htr	Heater
hyd	Hydraulic
imp	Impact
J	Joule
K	Kelvin
kpsi	1000 pounds per square inch
L/D	Length to diameter ratio of screw
lbf	Pound-force
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
MD	Machine direction
MDPE	Medium density polyethylene
MFR	Melt flow rate
MI	Melt index
mod	Modulus
mol%	Mole percent
MW	Molecular weight
N	Newton
PE	Polyethylene
PP	Polypropylene
pphr	Parts per hundred resin
ppm	Parts per million
psi	Pounds per square inch
RH	Relative humidity
rpm	Revolutions per minute
sp gr	Specific gravity
SPE	Society of Plastics Engineers
SPI	The Society of the Plastics Industry
TD	Transdirectional
ten	Tensile
T_g	Glass transition temperature (crystalline polymers)
T_m	Melt temperature (amorphous polymers)
ult	Ultimate
UV	Ultraviolet
VA	Vinyl acetate
WVTR	Water vapor transmission rate
yld	Yield

Appendix 5:

Alathon®	**HDPE Polyethylene Resins**
Aquathene®	**Ethylene vinylsilane compounds for wire and cable**
Flexathene®	**Thermoplastic Polyolefin Resins**
Integrate™	**Functionalized Polyolefins**
Microthene®	**Powdered polyethylene resins**
Petrothene®	**Polyethylene and polypropylene resins**
Plexar®	**Tie-layer resins**
Ultrathene®	**Ethylene vinly acetate (EVA) copolymer resins**
Vynathene®	**Vinyl acetate ethylene (VAE) copolymer resins**

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