BLOW MOLDING

Introduction

Blow molding is defined as a plastic process whereby a thermoplastic material is heated to its forming temperature, which is below that of the plastic materials being used; at its melting point it is made to form a hollow tube called a parison or preform. This heated homogeneous plastic material is then placed between two female molds that are cooled through some medium. The two female molds close on the heated parison or preform and a gas, usually air, enters via an open end of the parison via a blow pin or needle; the gas is blown into the closed female mold halves, taking the shape of the internal female closed mold, allow to cool, and is then sent out through an exhaust. The two female molds are then separated and the cooled, shaped hollow part is then ejected or allowed to drop out for the cycle to repeat.

In the first attempt over 100 years ago, to blow-mold hollow objects, two sheets of cellulose nitrate were clamped between two female mold halves. Steam injected between the sheets softened the material, sealed the edges, and expanded the heated sheets to form the inside shape of the two female mold halves. The high flammability of cellulose nitrate, however, limited the usefulness of this technique.

In the early 1930s, more suitable materials, such as cellulose acetate and polystyrene (PS), were developed; these led to the introduction, by Plax Corp. and Owens-Illinois, of automated equipment based on glass-blowing techniques. Unfortunately, the high cost and poor performance of these materials discouraged rapid development; they offered no advantage over the glass bottles. Finally, the introduction of low density polyethylene (LDPE) in the mid-1940s provided the advantage of squeezability, which glass could not match.

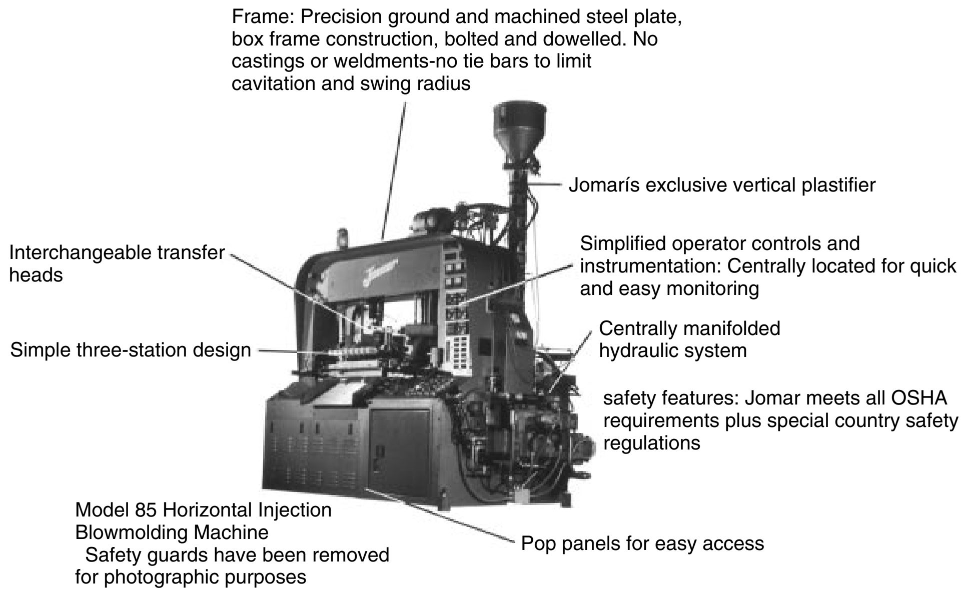

Fig. 1. Three-station injection blow-molding machine utilizing a vertical screw produced by Jomar, Pleasantville, N.J., U.S.A.

The first item to use LDPE was an underarm deodorant named Stoppette; the bottle was blow molded by the Plax Corp. In the first year, over 5 million units were sold and the blow-molding industry was born.

In the early 1950s, high density polyethylene (HDPE) was developed and today blow molding is the largest user of HDPE, which is the largest volume thermoplastic produced in the world, with over a billion pounds produced worldwide.

Blow molding, until the last few years, was the main plastic process utilized to produce a hollow object. In the past few years, other plastic processes, such as rotational molding and twin sheet thermoforming, have evolved with technical achievements and plastic raw materials improvements to where today, they can compete with blow molding for many uses as toys, gasoline tanks, holding tanks, etc.

The injection blow-molding (IBM) machines shown in Figures 1 and 2, even though produced by different injection blow-molding machinery manufacturers, can use tooling designed for either machine with slight mold design changes because of the bolt pattern or the platens used by each independent IBM machinery producer. There is no standard bolt pattern in the blow-molding industry for mounting the necessary tooling in the machines.

Resins

Most thermoplastic resins in use in the plastics industry can be blow-molded. Naturally, several resins are the leaders. HDPE is used in over 57% of the blow-molding market. In the year 2000, there was over 7021 million pounds of HDPE produced domestically. Poly(ethylene terephthalate) (PET) follows with over 33%

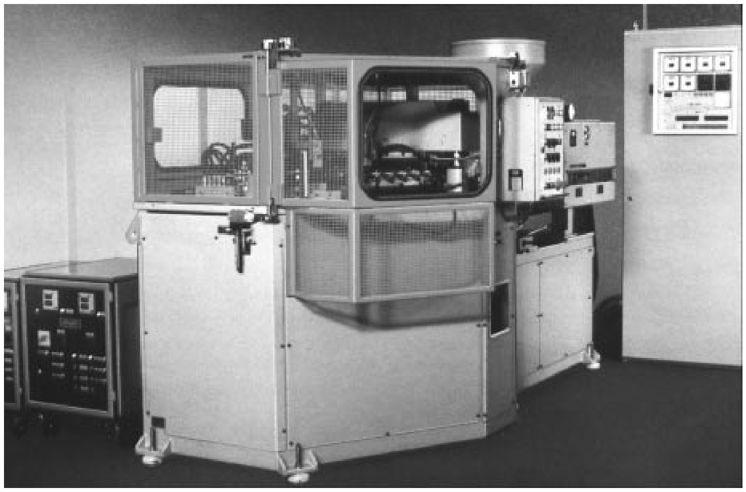

Fig. 2. Three-station injection blow-molding machine utilizing a horizontal reciprocating screw produced by Bekum, Berlin, Germany.

of the blow-molding market. In the year 2000, there was over 1720 million pounds of PET produced domestically.

Thus, these two plastic resins are used in slightly over 90% of the blow-molding industry. All the other thermoplastic resins such as polypropylene (PP), polystyrene (PS), poly(vinyl chloride) (PVC), acrylic–butadiene–styrene (ABS), acetal, polycarbonate (PC), low density polyethylene (LDPE), polysulfone, and others, all combine for the other uses in the approximate 10% blow-molded industry.

Examples would be gallon milk containers (HDPE), soft drinks (PET), gasoline tanks (HDPE), detergents, bleach, household chemicals (HDPE), automotive interiors (PP and ABS), mascara containers (ABS, PVC, HDPE), gas tanks for small yard mowers (nylon) to familiarize the reader with various markets. Naturally, the choice of resin used is based on performance, cost, barrier, availability, cleanliness, processing, transparency, and strength. The fastest growing markets at present are the automotive gasoline tanks, the 55-gallon drums (both HDPE) and the 20-oz soft drink products, the pint milk bottle (both PET). The beer market is just starting with specialty marketing.

Processes

There are three main processes used by the blow-molding industry to supply containers and hollow products to the blow-molding market: injection blow molding, extrusion blow molding, and stretch blow molding.

Generally, injection blow molding is used for small bottles and parts less than 500 mL in volume. The process is scrap-free, with extremely accurate control of weight and neck finish. However, part proportions are limited and the method is impractical for containers with handles and tooling costs are relatively high.

Extrusion blow molding, the most common process, is used for bottles or parts 250 mL in volume or larger. Tanks as large as 1040 L (275 gal) weighing

Table 1. Injection Blow Versus Extrusion Blow

Injection blow	Extrusion blow
Injection molded neck finish	Blown neck finish or calibrated neck finish
Scrap free	Must trim off tail and moilles
No pinch mark	Pinch mark which can be an area of the container for failure
Fast cycles for high output	Slower cycle
Tool cost relatively expensive	Tool cost relative low with use of aluminum molds
No handle ware	Handle ware of many sizes and shapes
Excellent surface finish or texture	Good surface area or texture
No die lines	Possible die lines due to extrusion of parison
Ease of automation for decorating and packing	Automation may be cumbersome and use large floor space
Small floor space	Greater floor space utilized

120 kg (265 lb) have been blow-molded; tooling is less expensive, and part proportions are not severely limited. Containers with handles and off-set necks are easily fabricated. On the other hand, flash or scrap resin must be trimmed from each part and recycled. Operator skill is more crucial to the control of part weight and quality. The two processes are compared in Table 1.

Stretch blow molding is used for bottles between 237 L (8 oz) and 2 L (67.6 oz) in size, and occasionally as large as 25 L (6.6 gal). The molecular biaxial orientation of certain resins enhances stiffness, impact, and barrier performance, and permits weight reduction.

Injection Blow Molding

In injection blow molding, melted plastic resin is injected into a parison cavity and around a core rod. This test-tube-shaped parison, while still hot, is transferred on the core rod to the bottle blow-mold cavity. Air is then passed through the core rod, expanding the parison against the cavity, which, in turn, cools the part.

Early injection blow-molding two-position techniques used adaptations of standard injection-molding equipment fitted with special tooling. The Piotrowski method used a 180° rotating arbor with two sets of core rods and one set of parison and bottle cavities. The Farkas, Moslo, and Gussoni methods used an alternating shuttle with two sets of core rods, one set of parison cavities, and two sets of bottle cavities. The difficulty with these methods was that the injection-mold and blow-mold stations stood idle while the finished parts were removed. In 1961 in Italy, Gussoni developed the three-position method, which used a horizontal 120° indexing head with split-mold parison and bottle cavities and three sets of core rods. The third station was intended for removal of the part, and the parison- and bottle-molding phases were completed simultaneously. A special machine was required, and by the late 1960s, this technique was perfected; it is the principal system used today. A layout of the standard three-station machine is seen in Figure 3.

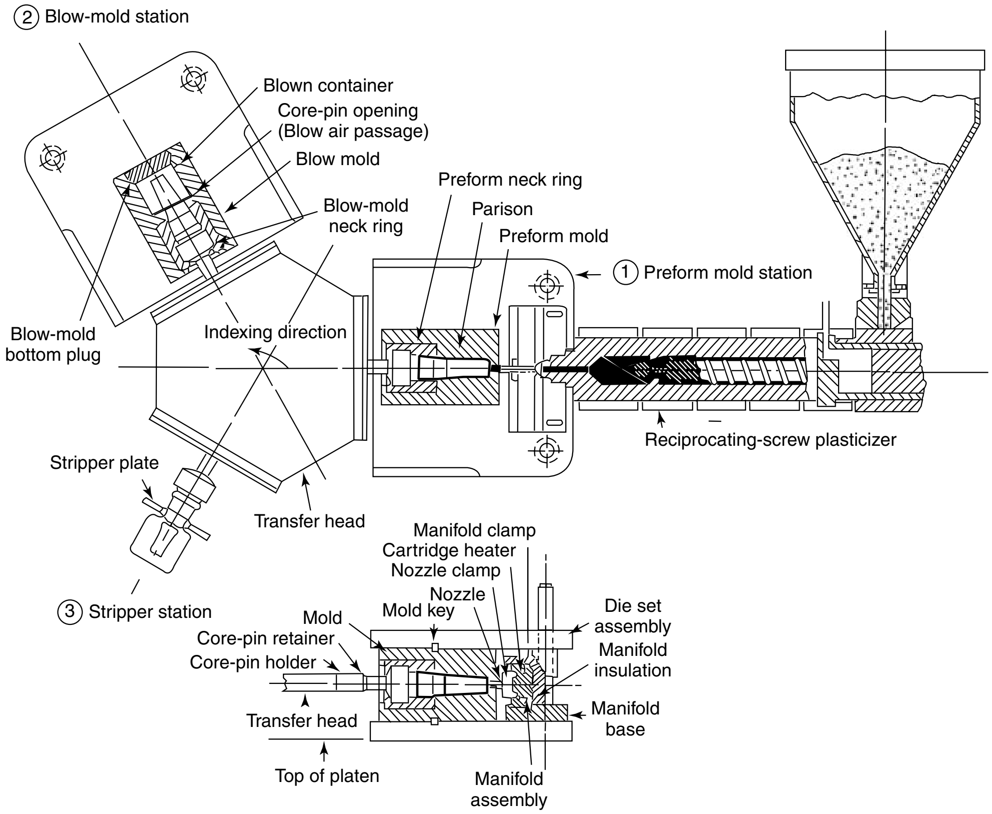

Fig. 3. A typical three-station injection blow-molding machine. Courtesy of Rainville Operation, Hoover Universal, Inc.

The three-position injection blow molding machine was upgraded to have four stations through companies as Larson Mardon Wheaton, Bekum, and Uniloy Milacron. The addition of the fourth station allowed for faster cycle times since the rotating table containing the core rods only indexed 90° instead of 120° as on the third station. The addition of fourth station was placed after the eject station and prior to the injection station. This additional station also could be used as a safety station to ensure the core rods were free of any debris. This station could also be used for in-mold decoration and also for conditioning the core rods prior to moving to the inject station to have a parison injection molding onto each core rod. The four-station machine is depicted in Figure 4.

One of the main features one should always be cognizant of is the dry cycle time of the machine. The *dry cycle time* is the time that it takes to open the clamp, raise the rotating table, index to the next station, drop the rotating table into position, and close the clamp or mold halves. There is no processing during the dry cycle. Processing time will add to the dry cycle time. Normally, on a three-station machine, the dry cycle time will vary from 2.8 to 3.5 s. On a four-station machine the dry cycle may range from 1.8 to 2.6. s. Larson Mardon Wheaton has taken this a step farther by designing and building their own all-electric machine. Their new all-electric four-station machine can dry cycle from 1.1 to 1.8 s depending

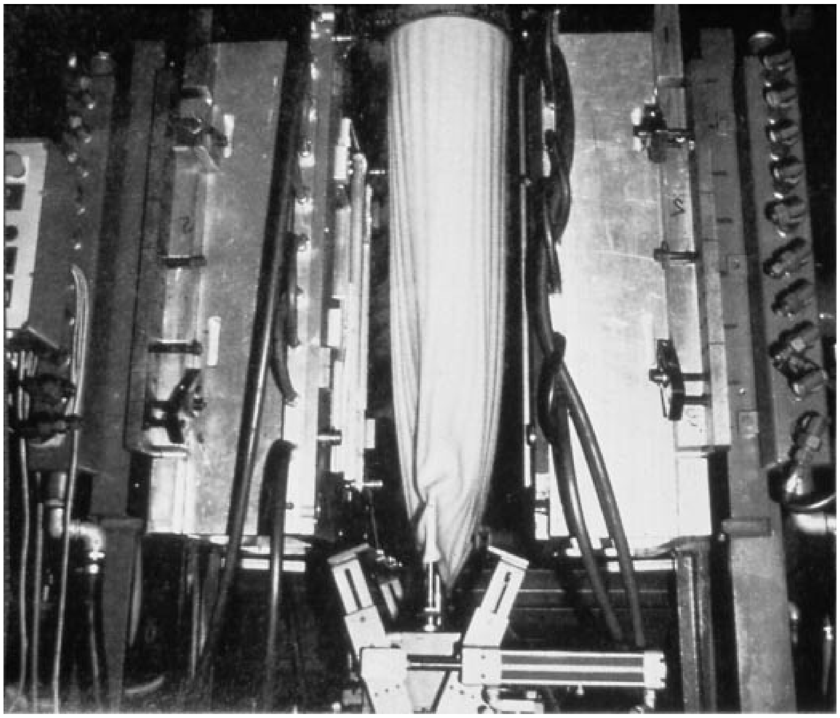

Fig. 4. Four-station layout.

on the size of the machine, whether it be a 15 or 180 ton. The tonnage relates to the clamp tonnage at the inject station plus the addition of the blow-mold clamp station. The injection station utilizes the greater tonnage. For example, a Larson Mardon Wheaton four-station may have 150 ton at the inject station and 30 ton at the blow-mold station. Together, the machine is rated at 180 ton. The Uniloy Rainville (85-3) three-station machine has 68-ton clamp at the injection station and 17-ton clamp at the blow-mold station, which added together to be the 85-ton machine. Figure 5 is a typical time or cycle sequence for an injection blow-molding machine.

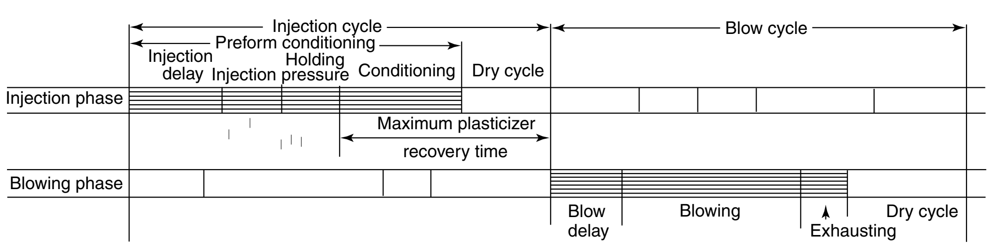

Fig. 5. Time sequence of injection blow molding. Courtesy of Rainville Operation, Hoover Universal, Inc.

Injection blow-molding machines are manufactured by Uniloy Milacron, JOMAR, Nissei, and Bekum for sale in the blow-molding industry. Several companies produce and use their own as Larson Mardon Wheaton and Captive Plastics and are not offered for sale. Injection blow-molding is normally considered when the container to be produced is 8 ounce (0.24 L) or under. The advantages and disadvantages of injection blow molding when compared to extrusion blow molding are listed in Table 1.

Injection Blow-Mold Tooling

Injection blow-molding requires two molds: one for molding the preform or parison, and the other for molding the bottle. The preform mold consists of the preform cavity, injection nozzle, neck-ring insert, and core-rod assembly. The blow mold consists of the bottle cavity, neck-ring insert, and bottom-plug insert (see Figs. 6–10).

The preform cavity design is governed by four basic rules or constraints. The first rule concerns the core-rod or cavity length-to-diameter ratio, which ideally approximates 10:1 or less. This ratio is frequently based on the overall height and the neck-finish diameter of the bottle. It ensures a minimum of core-rod deflection from injection pressures, which, in turn, provides uniform wall distribution and heat. Higher ratios have been used, but often require sliding pins to momentarily center the end of the core rod during the injection phase.

The second rule concerns the ratio of preform size to maximum bottle size, ie, blow-up ratio, which ideally is 3:1 or less. Most often, it is based on the maximum bottle diameter, width, or depth, and the neck-finish diameter. Maintaining this ratio provides uniform and consistent bottle cross-sectional wall distribution. If

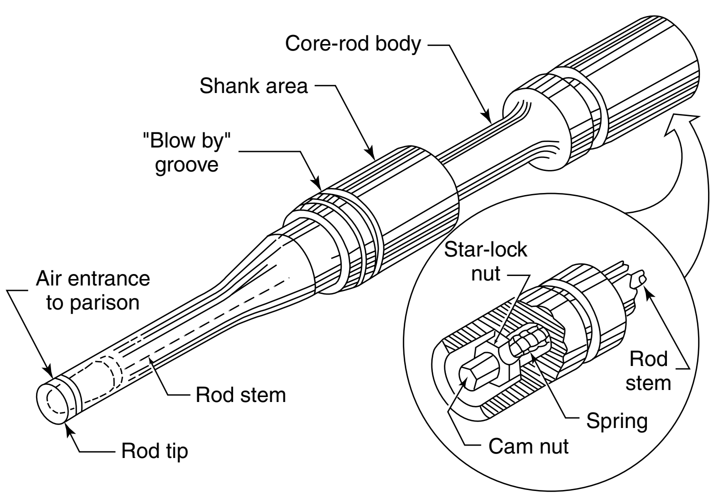

Fig. 6. Typical bottom-blow core rod and its principal elements. The core-rod tip mechanism that closes the air passage during the parison-injection cycle is shown enlarged at right (17). Courtesy of Plastic Engineering.

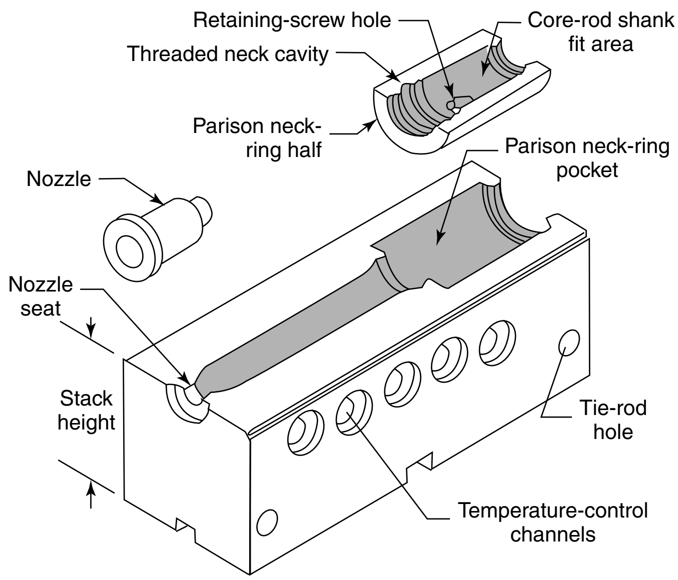

Fig. 7. Exploded view of one-half of a parison-mold cavity, with nozzle and neck-ring details.

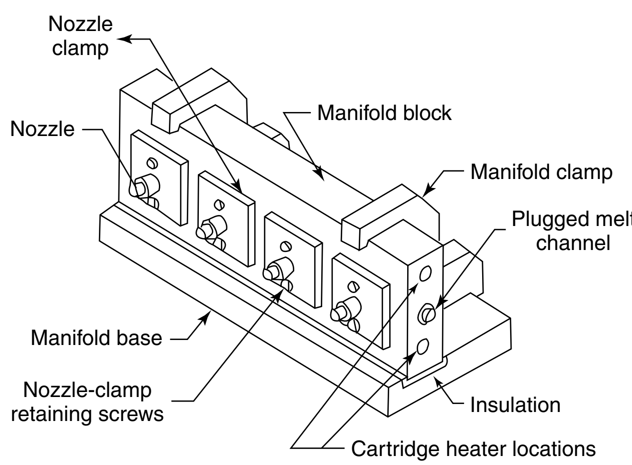

Fig. 8. Injection manifold for injection molding of parisons. Individual nozzles are clamped to the manifold block, which houses a hot runner for the melt.

the ratio is higher, the parison tends to float around during expansion, which therefore increases the chances of an eccentric wall distribution.

The third rule concerns the parison wall thickness, ideally between 2 and 5 mm. A wall thicker than 6 mm is difficult to temperature-condition and may act unpredictably during expansion. A wall less than 2-mm thick may also act unpredictably. For a given weight, a thin wall also increases the projected area, and thus possibly exceeds the capacity of the press.

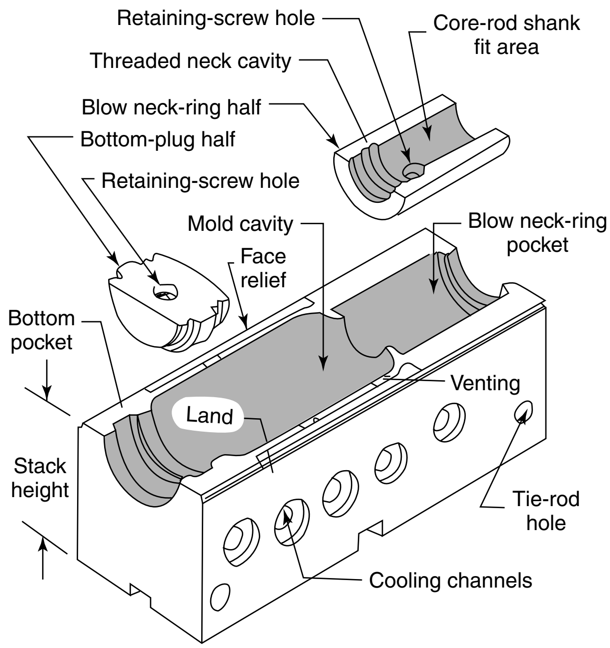

Fig. 9. Exploded view of one-half of an injection blow mold, with details of bottom plug and neck ring.

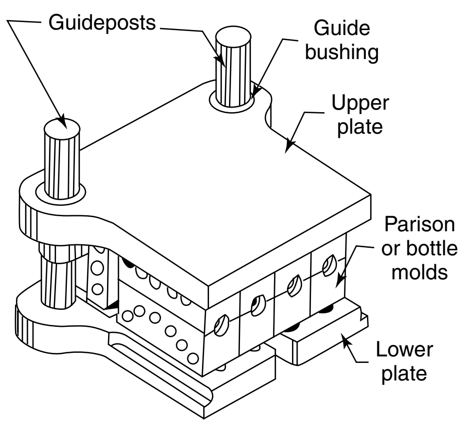

Fig. 10. Die set for manufacturing position and alignment of injection blow-mold cavities.

An important advantage of injection blow molding is the diametrical and longitudinal programming of the parison by shaping the parison mold cavity or core rod, or both. This is particularly important with oval bottles and leads to the fourth rule: in an annular cross-section, the heaviest area should not be more than 30% thicker than the lightest area. Generally, the shaping is done in the cavity and the core rod is round. With a higher ratio, the selective fill of material during the injection phase causes a vertical weld line in the bottle. Avoiding this condition, in turn, restricts the bottle ovality to 2:1, that is, the width should not exceed two times the depth.

In multiple-cavity arrangements, each parison cavity is fitted with an injection nozzle of decreasing sizes. Material flow through the injection manifold is balanced, thus allowing each cavity to be filled at an equal rate.

The neck-ring insert has four functions: (*1*) it forms the finish or threaded neck section of the bottle; (*2*) because it is an insert, it provides a relatively low cost, easy method to change the size or style of the finish; (*3*) it firmly centers and locates the core rod in the parison cavity; and (*4*) it provides venting and a thermal break.

During the process, the neck-finish area of the parison must be cooled to retain its shape; the remainder of the parison is kept hot for later expansion in the bottle cavity. Depending on the plastic molding material, the temperature of the parison is between 65 and 135°C. The neck-ring insert is at times cooled as low as 5°C. The water lines for both the cavity and the neck-ring are usually drilled as closely together as possible, perpendicular to the cavity axis. The water flows from one cavity to the next.

The core-rod assembly also have four functions: (*1*) it forms the interior of the preform; (*2*) it supports the parison or the bottle during transfer; (*3*) it supplies the valve where air enters to expand the parison (the valve is located in the shoulder area or the tip, depending on the shape of the bottle or the ratio of the core-rod length to diameter; wide-mouth bottles, ie, core rods with low length-to-diameter ratios, are usually equipped with a shoulder valve); and (*4*) it has a "blow by" groove. This annular groove, located near the seating shank, 0.1–0.25 mm deep, is needed to seal the parison to prevent excessive air loss during blowing and to eliminate elastic retraction of the parison during the transfer between cavities.

Various materials are used to construct the parison cavity and core rods. For nonrigid polyolefin resins, the parison cavity is made of prehardened P-20 tool steel with a hardness of 31–35 HRC. For rigid resins, the parison cavity is made of A-2 tool steel, air hardened to 52–54 HRC. The neck-ring insert for most resins is made of A-2 tool steel. The core rod, for greater strength, is made of L-6 tool steel, hardened to 52–54 HRC. In all cases, the cavity surfaces are highly polished and chromium-plated, except for the neck-ring insert for polyolefin resins, which is occasionally sandblasted with a No. 120 grit.

The cavity defines the final shape of the bottle. The only design constraint is that the cavity width should not exceed two times the depth. To compensate for resin shrinkage after molding, the cavity dimensions are slightly enlarged. Specific shrinkage rates vary with the resin type and process conditions. For nonrigid polyolefin resins, shrinkage is between 1.6 and 2.0%; for rigid resins, 0.5% shrinkage is added. Slightly higher rates are usually applied to the heavier neck-finish dimension than to the body.

Vents are placed along the mold-parting surface to allow the escape of trapped air between the expanding parison and the cavity. If these are too deep, an objectionable mark is left on the bottle. Because an air pressure of 1 MPa (145 psi) is used in injection blow molding, these vents are kept less than 0.05-mm deep.

The neck-ring insert is used in the bottle cavity in a manner similar to its use in the parison cavity, although they are not identical. The thread diameter dimensions in the bottle cavity are 0.05–0.25 mm larger than in the parison cavity.

Unlike the parison neck-ring, the bottle neck-ring does not form the finish detail, but only secures the already-formed neck. The additional size provides clearance, reducing the change of distortion.

The bottom-plug insert forms the bottom or push-up area of the container; in some molds, this insert must be retractable. Generally, the push-up of polyolefin bottles can be stripped without side action if the height is less than 5 mm. With rigid resins, this height is reduced to 0.8 mm. When side action is required, an air cylinder, cam, or spring mechanism is used.

Aluminum, steel, or beryllium–copper is used for the bottle cavity and neck ring. For polyolefin resins, aluminum No. 7075, as well as QC-7, is used. The surface is usually finished with No. 120-grit sandblast, which increases the venting of trapped air. For rigid resins, A-2 tool steel air-hardened to 52–54 HRC is used. The surface finish is highly polished with chromium plating. Cast beryllium-copper is often used for minute detail. As with the parison cavity, water lines are drilled as closely together as possible, perpendicular to the cavity axis.

The parison and bottle molds are mounted onto a die set, which is then mounted to the platens of the injection blow molder. Keyways in two directions, on the upper and lower platens, are used to precisely position the cavities. Guideposts and bushings maintain precise alignment between the plates. To speed the operation, the entire die set or mold assembly is exchanged during a job change. It is considered false economy to reuse the die set with another mold set.

Injection blow-mold tooling must be designed for very precise tolerances, with dimensions often held to ± 0.015 mm, otherwise bottle quality will be inconsistent. For example, the core rods must be located closely fore and aft, and left and right of centerline of the parison and bottle cavities. If too tight, the mold could be damaged or the assembly might bind. If too loose, resin could flash around the shank area of the core rod, or the core rod could shift sideways, causing uneven wall distribution. In addition, many parts and sections of the mold setup must fit together and be interchangeable. Several core rods must fit the pocket of the parison or bottle cavities. These core rods are stacked alongside each other on a face bar. Clearly, the need for precision is the most crucial factor in the high cost of injection blow-mold tooling. However, once properly assembled, the injection blow-mold process can provide high yield and trouble-free production. Additional tooling for setup of the injection blow-molding machine would include the stripper plate (see Figs. 11 and 12) for stripping the formed containers from the core rods. The stripper consists of a stripper base and a stripper plate plus the screws and washers. On most machines the stripper is able to rotate 90° downward to

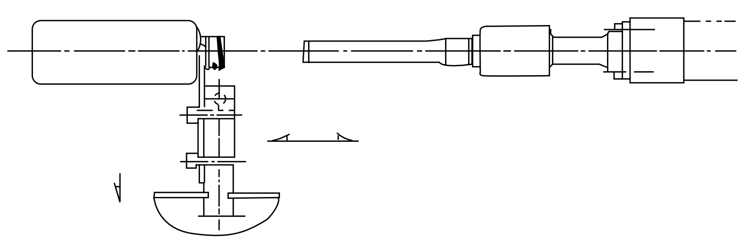

Fig. 11. Stripper action.

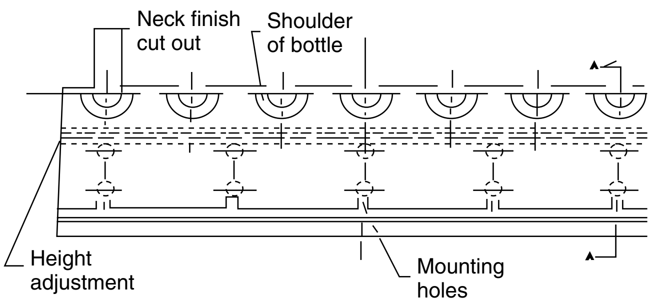

Fig. 12. Stripper plate.

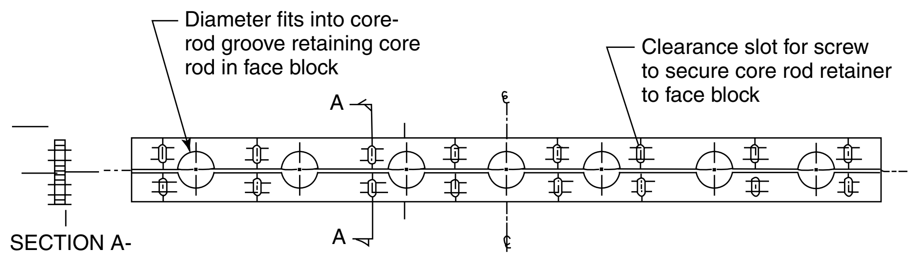

Fig. 13. Face bar.

deposit the product onto a conveyor, etc. We refer to this stripper as a stripper/tipper.

Figure 11 shows the blown bottle being ejected with the stripper moving out, and once the bottle is dropped into a container or on a conveyor belt, the stripper returns for the next cycle. Figure 13 shows a face bar which mounts to the rotating table (three-station machine requires three face bars and a four-station machine requires four face bars) to hold the core rods.

Figure 14 shows the retainers that fit over the rear shank of the core rod and hold the core rod in place on the face bar. In some instances, possibly because of core rod damage it may be necessary to use a face block plug. However, the manifold also has to be plugged for this same cavity.

By reviewing all the tooling essential for injection blow-molding, one can easily understand why it is more expensive than the extrusion blow-molding process. However, the injection blow-molding process yields a process that produces scrap-free, high volume containers that have the best neck finish dimensions and details in the blow-molding industry. Roll-on-deodorant containers are evidence of this statement.

Troubleshooting Injection Blow Molding. Injection blow-molding is no different than any other plastic process as to troubleshooting the process. One should first analyze as to what you feel is the problem and then approach the problem systematically. In approaching the problem, you should only make one change at a time and after the change, provide adequate time for the change you made to show its effect.

Below is a list of items or problems that are some-what common in the injection blow-molding process with possible solutions to the happening. The list is a

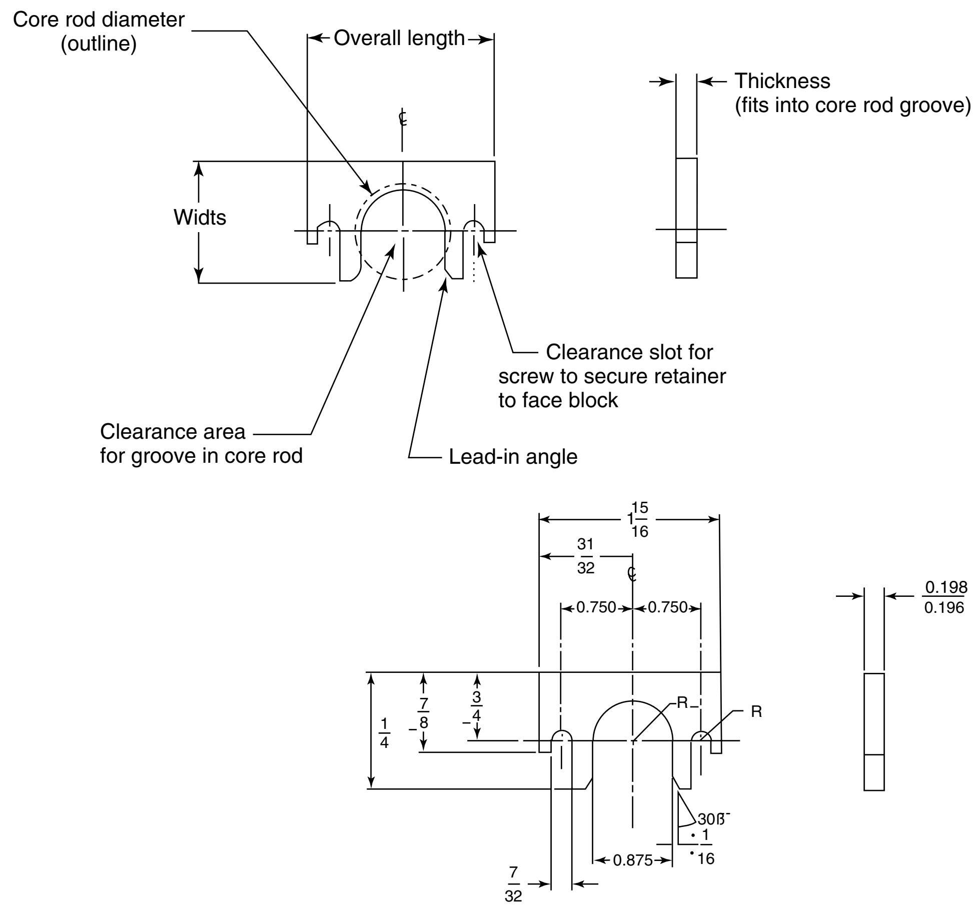

Fig. 14. Core-rod retainer.

guide and is not inclusive as machines and materials change along with controls. Always keep in mind, your injection-molding parisons and if you make a good parison, you should make a quality container.

Problem	Solution
Short shots	Out of material in the barrel
	Hopper out of material
	Material is budging
	Material slide not open
	Material too cold
	Secondary gates dirty or not large enough
	Inadequate venting
	Shot size not adequate
Sink marks in parison	Material not homogeneous
	Not adequate packing time or pressure
	Inadequate venting

Problem	Solution
Streaks in parison	Mold dirty
	Regrind or material fines
	Cavity damaged
	Melt not homogeneous
	Injection pressure too high or too fast
Stringing of gate of parison	Melt temperature is too high in secondary nozzle or manifold
	Secondary gate too large
Parison stuck to core rod	Melt temperature too hot
	Parison mold coolant not adequate or at proper temperature
	Core rod cooling not adequate
Parison tip too large to compress	Reduce land in secondary gate
	Move secondary nozzle in toward the parison
	Reduce land in end cap on spherical nozzles
Product torn	Lower gate temperature
	Check core rods
	Check nozzle seats
	Check parting line of parison and blow mold
	Add injection time
	Replace nozzle
Weak spot in center of product	Lower gate temperature
	Check parison body temperature
	Lower parison body temperature
	Add more injection time and pack time
	Lower injection pressure
	Decrease back pressure
Heavy section in product	Raise gate temperature
	Decrease core rod cooling
	Raise temperature in parison body
Push up not consistent	Increase blow time
	Increase blow pressure
	Increase bottom plug cooling
	Reduce gate temperature
	Add core rod tip cooling
	Lengthen cycle time
	Check vents
Rocker bottoms	Flash
	Vent
	Improper cooling
	Mold dirty
	Increase cycle time
	Check exhaust-possibly add exhaust time
	Check core rod openings
Bottom folds	Increase blow pressure
	Check core rod openings
	Reduce injection pressure
	Increase temperature in parison mold at fold location

Problem	Solution
Surface finish	Dirty molds
	Venting
	Material not homogeneous
	Temperature of parison too cold
	Increase blow pressure
	Increase cycle time
Dips in finish	Parison not packed
	Vents
	Neck rings too cold
	Increase pack time
Cracked necks	Raise melt temperature
	Increase parison neck ring temperature
	Retainer grooves on core rod too deep
Cocked necks	Increase blow pressure
	Increase blow time
	Check bottom plug movement
	Increase cooling on blow mold products body
Shrinkage	Increase blow time
	Decrease blow mold temperature
	Increase pack pressure
	Increase pack time
	Lower parison mold temperature
Flash	Melt too hot
	Injection pressure too high
	Molds not flat
	Vents too deep
	Clamp not adequate
	Platens not aligned
	Mold damaged
Parison sag (parison parting line and blow mold parting line do not overlap)	Decrease melt temperature
	Redo parison cooling lines for more balance
	Venting
	Add packing pressure
	Melt not homogeneous
	Check for nozzle uniform flow
Nozzle freeze-off	Contamination
	Damaged nozzle
	Temperature too low
	Manifold dirty
	Thermocouple malfunctioning
Stripping	Decrease blow time
	Retainer grooves too deep
	Increase pressure to stripper
	Lubricate stripper
	Check core rods for damage
Weld lines	Raise manifold temperature
	Raise parison mold temperature
	Raise injection pressure

Problem	Solution
	Increase pack time
	Increase secondary nozzle opening
Parting line	Molds damaged
	Molds not aligned
	Molds not flat
	Clamp pressure inadequate

Setup for Injection Blow Tooling. When doing a setup, whether it be for injection molding, blow molding, or extrusion, one should always strive to do the setup so that there are areas that can be used if needed in the process. Short cuts should not be taken in doing your setup.

In setting up the injection parison mold, a separate cooling line should be used for the neck rings, the parison end cap, and the zone immediately above the end cap. The temperature of the parison that is going to be blown needs to be controlled as uniformly as possible. If core-rod cooling is utilized, then a separate cooling unit should be utilized for the core rods.

In the blow mold, a separate cooling line should be used on the neck rings, the bottom plug, and the containers body.

It is recommended that all secondary nozzles from the manifold to the parison injection mold have a smooth bore so no material can be stagnant or hung up, nor be sheared. Each secondary nozzle should have its own heater band and thermocouple control. The manifold should have two deep well thermocouples that are averaged together to ensure that the manifold maintains an even melt temperature.

It is a good idea to have all the die sets nickel-coated plus the water lines. This will prevent rust within the die sets, which leads to pitting of the machine platen. This also prevents rust and mineral deposits from forming in the mold water lines.

The future of injection blow-molding will see a 3–5% growth. The machines will be redesigned to be all-electric based on the all-electric injection machines. The shortage of electrical power and its rising costs will force machine producers plus their customers to reduce energy use and costs. It is well documented that the all-electric injection machines reduce energy use by 30–35%, thus injection blow will follow the injection-molding machine lead into this industry.

Extrusion Blow-Molding

In extrusion blow molding, homogeneous melted thermoplastic resin is extruded as a tube into the air. This tube, called a parison, is captured between two mold halves that are of the female type. Gas usually air, enters as the female molds are closed, either through a blow pin or needle, and expands the homogeneous melted thermoplastic into the female mold halves, taking design of whatever is cut into the two female mold halves, alllowed to cool, then the gas is exhausted, the molds

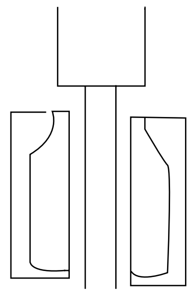

Fig. 15. Extrusion blow-molding process.

open, and exits the cooled desired product. Unlike injection blow molding, this process produces flash or trim off, that has to be trimmed and reclaimed. This excess is formed when the heated parison is pinched together at the bottom and top of this heated hollow tube. In some cases, there can be flash or trim on the entire periphera of the product to be formed (ie, automotive gasoline tanks) (See Fig. 15).

There are basically two different machines offered in the extrusion blow-molding industry. They are intermittent and continuous.

In continuous extrusion blow molding, the extruder or plastifier is running continuously and forming a parison continuously. The continuous extrusion provides the most homogeneous heated parison as the heated thermoplastic material is moving constantly with the least amount of residence time on the heated thermoplastic material. This method is employed to produce containers as on Bekum & Kautex; shuttle blow-molding machines such and on large industrial machines

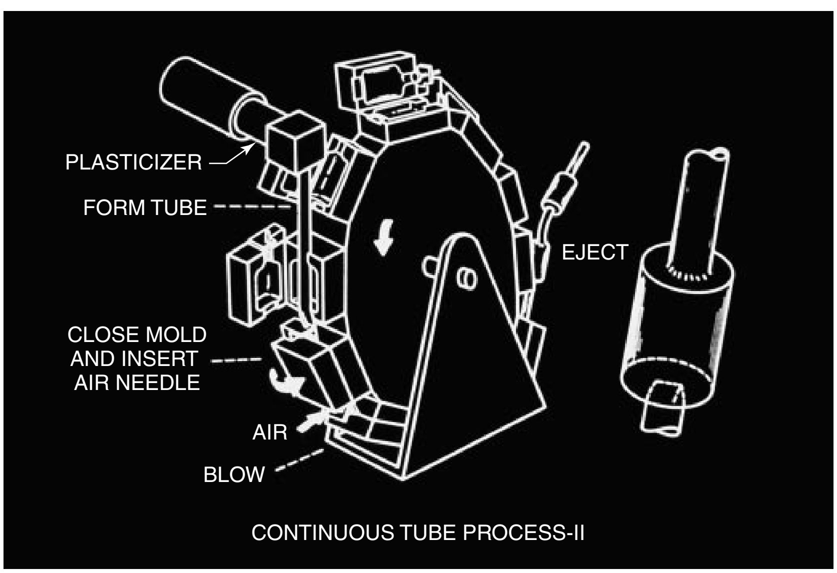

Fig. 16. Schematic of a rotary or wheel machine with continuous extrusion of the parison. Number of blow molds depends on size of wheel diameter and extruder size for output.

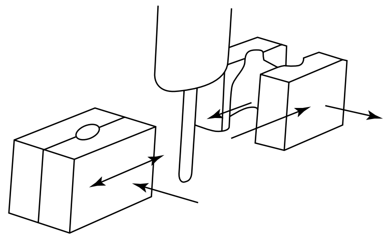

Fig. 17. Depicts a continuous extruded parison with blow molds that shuttle right or left, cut the parison, capture the cut parison in the closed blow mold and move right or left to blow the container.

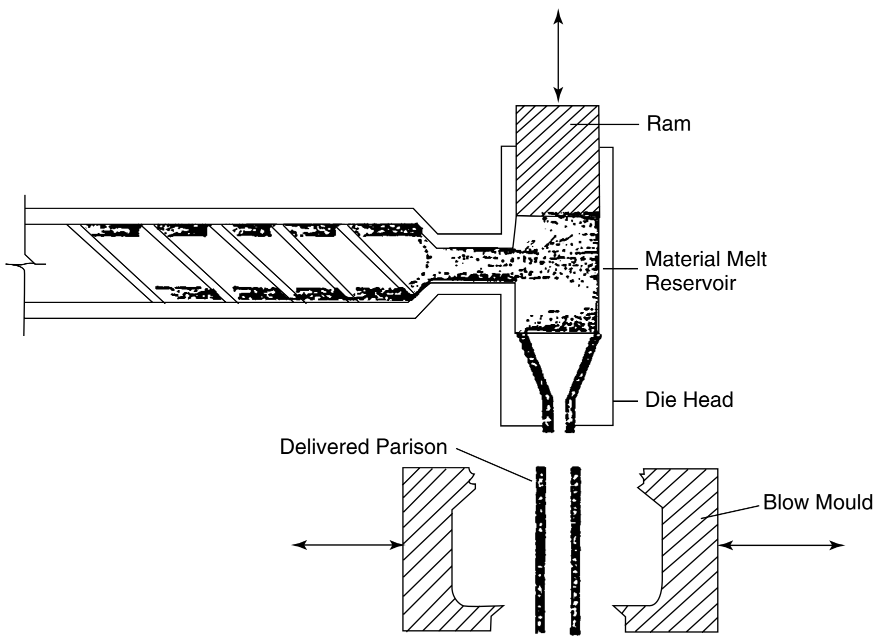

Fig. 18. Intermittent extrusion blow molding.

such as wheels produced by Uniloy Milacron, Plastipak, Graham & Owens Brockway. It is also used by Bekum, Kautex, Wilmington, Uniloy Milacron, Graham, Davis Standard, and Jackson Machinery to produce containers such as automotive gasoline tanks, holding tanks, 55-gal drums (see Figs. 16 and 17).

A reciprocating screw extrusion blow-molding machine sketch is shown in Figure 18. This is the process where the parison is extruded, then the blow molds cut the parisons and close, and the containers are then blown. Only after the blow molds open and the blown containers exit the machine is the parison once again extruded (see Fig. 18).

In intermittent extrusion blow molding, the parison is formed immediately after the blow-molded product is removed from the blow mold in most machines. In some large machines, the parison is cut and closed within the blow mold and then

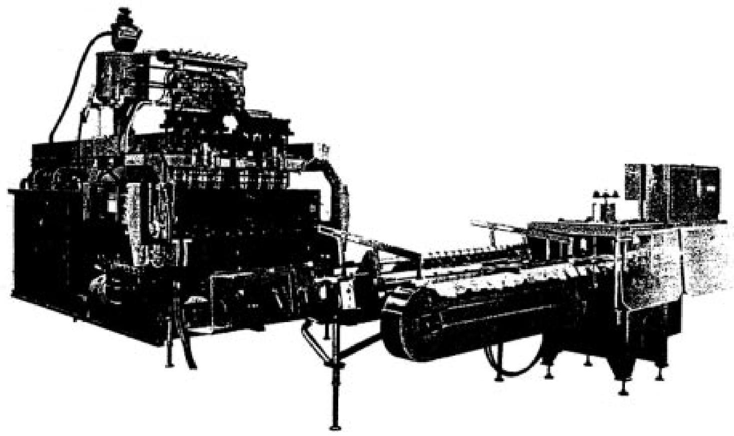

Fig. 19. Uniloy 350R2 8-head intermittent extrusion blow molder for the manufacture of 2-L (0.5-gal) milk bottles with handles. Production rates of over 65 bottles/min have been achieved; also shown is the flash trimmer. Courtesy of Hoover Universal, Inc..

the blow mold moves out from under the parison head tooling to allow another parison to be formed. Because of the stop and start of the parison, this method is normally not employed to use heat-sensitive materials, such as PVC. It is more suitable for heat-stable materials, such as HDPE, and ABS. Examples are gallon milk containers, automotive ducts, 5-gal water containers (polycarbonate).

The intermittent process utilizes a reciprocating-screw plastifier. After the parison is formed, the screw moves back (or recovers) accumulating new homogeneous melt in front of its tip. Once the blow mold exits the product, the signal is given for the plastifier to form a new parison. The screw will then move forward as a ram forcing the plastic melt through the extrusion head forming the next parison. At present, up to 12 parisons can be formed simultaneously. A reciprocating screw extrusion blow molder for a dairy bottle is shown in Figure 19.

Another modification is the ram-accumulator method, although no longer in widespread use. It is intended for parts weighing 2 kg or more. This system, much like the reciprocating-screw method, is used to extrude quickly heavy parisons that might sag or be deformed by their own weight. The accumulator is a reservoir mounted alongside the extruder. A piston or plunger pushes the melt through the extrusion head. In this method, unlike the reciprocating-screw process, melt that enters the reservoir first is last to leave. As a result, melt history of the resin is not uniform.

The accumulator head (see Fig. 20) has replaced the ram accumulator in its application for heavy parts. The tubular reservoir is a part of the extrusion head itself. Plastic melt that enters the head first is first to leave. A tubular plunger quickly extrudes the melt from the head annulus with a low, uniform pressure, which helps reduce the stresses found in other systems.

Related to extrusion blow molding is the extrusion-molded neck process (see Fig. 21). Still used by Owens-Illinois, this proprietary process can be traced to glass-blowing technology. In an unusual approach, the neck of the bottle is injection-molded and the bottle body is extrusion blow-molded. The two halves of

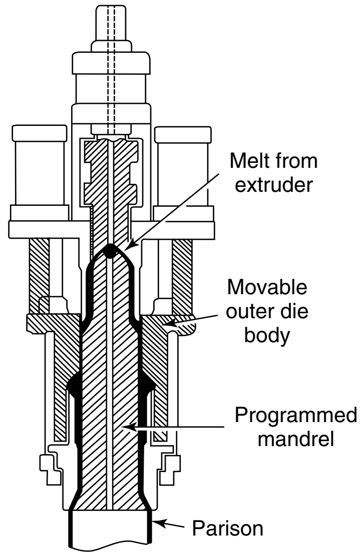

Fig. 20. Typical accumulator head.

the neck-finish cavity or neck ring are mounted to an actuating-head assembly, which intermeshes with the two halves of the blow-mold cavity. The process cycle begins with the main-body mold cavity open and the neck-ring cavity closed. The actuating-head assembly moves downward to contact the extrusion die head. When in position, extrusion pressure fills the neck section with plastic melt. After holding for 1–2 s, the head assembly moves upward while the parison is extruded. When the head assembly reaches the top of its stroke, the blow-mold cavity closes on the parison. The remaining steps of flash pinch-off, blowing, and part removal follow conventional techniques. Although the production cycle is somewhat slow, the process offers the advantages of an accurately molded neck and of a parison held at both ends. The other advantage is that only tail scrap is to be reground whereas in standard extrusion, both neck and tail scrap are to be reground.

Preference for a specific type and manufacturer of a blow-molding machine is based on experience, exposure to specific extrusion blow-molding methods, and different manufacturer equipment.

There are many blow-molding machine manufacturers, and choice should be based on the following criteria: cost, energy usage, floor space, reliability, output, service, manufacturer's reputation, controls–user friendly, cleanliness, world class design, height, maintenance, options available, dry cycle time, mold open and mold close time, and CFM usable per cycle with gauge and reservoir.

On any extrusion blow-molding machine, the buyer or user should know or test to have answers to the following:

(1) pound per hour output – actual
(2) plastifier – $\frac{L}{D}$ barrel

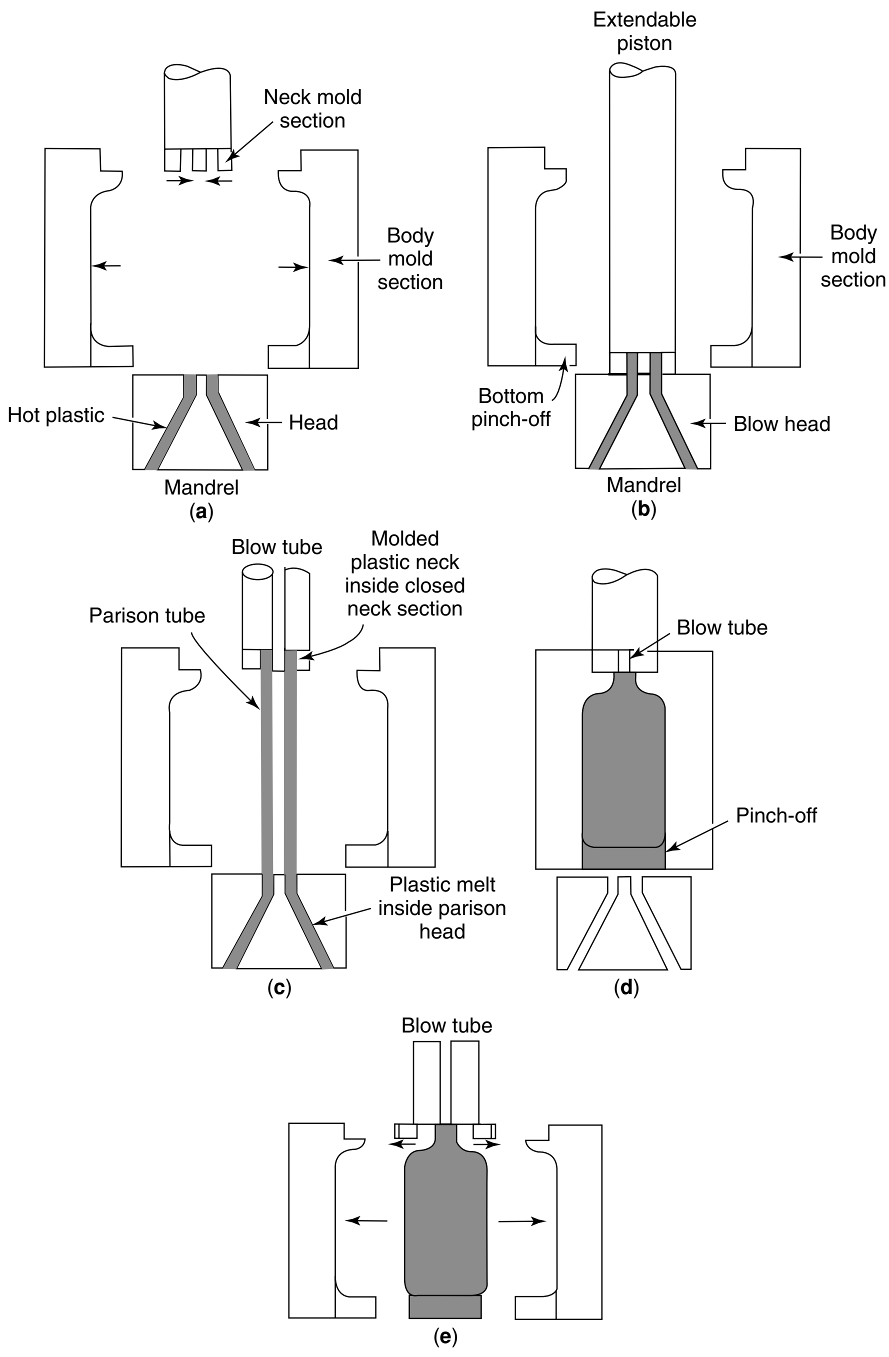

Fig. 21. Extrusion-molded neck blow-molding process. (a) Body section open, neck section closed, neck section retracted; (b) neck section extended to mate with parison nozzle (plastic fills neck section); (c) neck section retracted with parison tube attached; (d) body section closed, making pinch-off (parison blown to body sidewalls); (e) body molds open, neck molds open, bottle about to be ejected.

(3) compression ratio of the screw
(4) what type of screw—general-purpose, barrier screw or specific to one type resin
(5) barrel heating or cooling
(6) number of zones for heating the barrel
(7) location of the thermocouples
(8) Is there an extrudate temperature readout? Where is it located?
(9) Does it have a grooved feed throat on the barrel?
(10) Are the heater bands rotated so there is not an area on the barrel or head tooling that could have a cold area due to all the heater band endings aligned?
(11) Is accumulator type first in, first out or first in, last out.
(12) Is the tooling converging or diverging
(13) Is the head tooling center-fed or side-fed?
(14) How many points can be programmed rising the parison programmer?
(15) Can the blow molds be mounted safely and quickly?
(16) Can the clamp tonnage be adjusted for large or small blow molds?
(17) How is the parison cut?
(18) Is coextrusion possible?

In any extrusion blow-molding process, there is off-fall or trim that has to be reclaimed. How a production plant handles their off-fall or trim can make a difference as to profit or loss. Use of regrind, as well as the use of color additives and lubricants, will have a major effect on parisons repeatability.

The screw of the plastifier is designed to pick-up pellets (virgin pellets), not chopped and screened chop of the resin. In grinding, a uniform ground chop is not achieved. You and up with strings, fines, and various chopped sizes of plastic. Thus, the feed hopper of the machine is being fed a different bulk density because of the grinding, the virgin, and the colorant additive, all being of different sizes. The plastifier is nothing more than a pump and with a different bulk density being fed to the screw, the plastic melt has a differential of pressures within its melt stream causing short and long parisons, excessive sag, black specks, streaks, gels, and different die smells, and the result is poor efficiency.

Fines are in the virgin resin as received. Fines are generated when any plastic is ground in a grinder. Fines do not melt at the same melting temperature as the virgin resin nor the regrind. Their molecular weight is different. Fines should always be eliminated. They can clog the dryers, cause streaks, black specks, star bursts, and tear drops in the parison and in the blown product. A separating type grinder should be used in the regrind area. It is also good practice to pass your virgin plastic material through a fine eliminator system as it is being fed to the machine hopper.

Any blender should be checked for accuracy of delivery. Weigh blenders are preferred in today's blow-molding plants.

Formulas. In extrusion blow-molding, there are some definite formulas you should be aware of and use.

The blow up ratio (BUR) is defined as the blow mold diameter (product) divided by the parison outer diameter.

$$\mathrm{BUR} = \frac{\text{Inside largest diameter inside blow mold}}{\text{parison outer diameter}}$$

Generally, this value is between 1.5 and 3; however, it can be up to 7 in unusual cases.

The amount of stretching a parison is subjected to is a function of the part size and configuration in relation to the parison size and orientation. In general, this can be expressed as follows:

$$\text{Average part thickness} = \frac{\text{parison surface area} \times \text{parison thickness}}{\text{product surface area}}$$

High blow pressure, greater than 60 psi, is necessary to achieve a good surface finish on the product, to pick up the mold detail, and to ensure the material is against the blow-mold surface to be cooled. Low blow pressure will increase the shrinkage of the product and will increase the cycle time since the mold cooling is not being utilized effectively. With some resins, such as polypropylene, a pressure of 100 psi has been found to be very satisfactory. However, the new procedure is to use low pressure of 80–120 psi and once the product is formed, then use high pressure of air (220–250 psi). Lower cycle times are achieved and an improved product is formed.

In PET stretch blow molding, single-stage machines, such as the Nissei, use a maximum pressure of 300 psi. In the two-stage method for PET, two-stage blow air is used. The low blow pressure would be approximately 220–250 psi and high blow pressure as high as 650 psi is used. Thus, the back plates and the blow mold must withstand these blow pressures and clamp closing forces.

Clamp Tonnage Required.

The required clamp tonnage is the sum of the blow pressure tonnage and pinch-off tonnage required with a 25% safety factor calculated as follows:

Production part projected area (IN^2) $\times$ Blow pressure $\times$ 1.25 $\div$ 2000 lb/ton = Blow pressure tonnage required with a 25% safety factor.

Pinch-off area (IN^2) (length $\times$ width) $\times$ pressure ($\mathrm{lb/IN}^2$) $\times$ 1.25 $\div$ 20,000 lb/ton = Pinch-off tonnage required with a 25% safety factor.

Approximate pinch-off pounds per inch (ppi) for specific resins: PVC, 400/500; HDPE, 600–700; PP, 700–800; and PC, 1000.

Units. There is no uniform rating by the machinery manufacturers for clamp tonnage units nor is there a uniform use of nomenclature. One might see U.S. tons listed followed by KN and both are listed. Sometimes the multiplier is 10, so a 42 ton clamp will also show as 420KN. Other times a clamp will show 67 tons and 600KN which means a multiplier of 8.95 was used. Also, sometimes the U.S. tons are also given in metric eg, Cincinnati Milacron does this. The best conversion would be to rate in U.S. and metric tons with the U.S. tons being divided by 1.1 to yield metric tons.

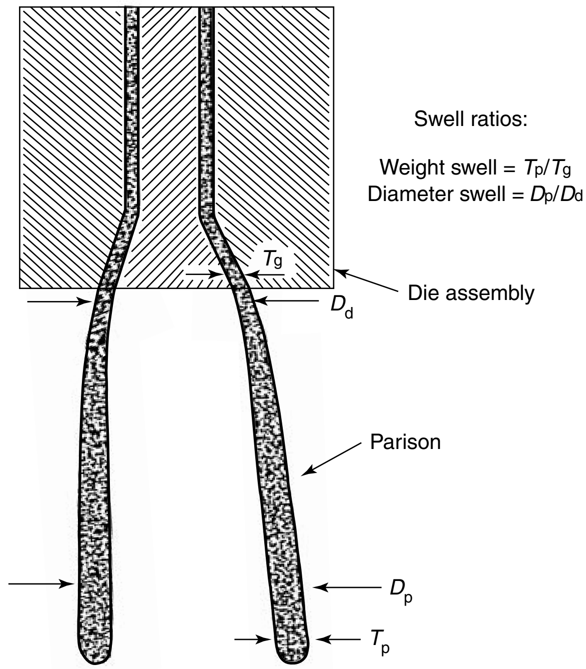

Fig. 22. Swelling behavior of viscoelastic material in parison formation.

Die/Weight Swell. The extrudate will swell as it exits the die. The swelling behavior is a result of the elastic component of the resin's flow. It is quite possible to measure the resins swell as it exits the die and to use this to ascertain the tooling sizes, and to determine if the resins can be used in producing the product.

There is also a weight swell of the resin and this is a result of the temperature, length of parison, speed of parison, drop, hang time of the parison, and the hot melt strength of the resin to be used. Swell ratios are defined in Figure 22.

Heat Extraction Load. The heat extraction load or the amount of heat to be removed from the product must be determined. This is important, as the amount of heat taken out by the blow mold must be known if the process is to be economically predictable. The amount of heat to be removed, Q, is determined by the material's temperature and the amount of plastic being delivered to the mold. It is calculated as follows:

$$Q = Cm\Delta t$$

where, Q is the total change desired during molding (J), C is the specific heat (J/g·°C) of the plastic material being processed, m is the amount (g) of plastic per hour to be cooled, and $\Delta t = (T_0 - T_f)$ is the initial plastic parison temperature into the mold minus final (demolding) temperature of the plastic (°C). As an example, for determining the heat load for a typical mold, the following data are used:

(1) C, specific heat for polyethylene = 2.5 J/g·°C.
(2) m, amount of PE to be cooled = 32 shots/h × 8.5 kg/shot × 0.80 shot reduction length = 218 kg/h

(3) T_0, parison temperature = 215.6°C (420°F).
(4) T_f, demolding temperature = 37.8°C (100°F).
(5) Δt, material temperature change = $T_0 - T_\mathrm{f} = 215.6 - 37.8 = 177.8$°C

Thus,

$$\begin{aligned} Q &= Cm\Delta t \\ &= (2.3)(218{,}000)(177.8) \\ &= 89\,\mathrm{MJ}(84{,}440\,\mathrm{BTU/h\ per\ mold,\ avg}) \end{aligned}$$

Assume 75% efficiency for heat transfer between chilled water and PE. Then,

$$\text{Cooling required} = \frac{119\,\mathrm{MJ}}{0.75}(112{,}600\mathrm{BTU/h})$$

With polyolefins, it is frequently desirable to run the molds as cold as possible, 4.5–15.5°C or lower. Condensation or moisture on the mold can cause outside surface defects when mold cooling temperatures are below dew point. To reduce or eliminate these, either the mold heat transfer fluid temperature can be increased, or it is possible with recently developed techniques to dehumidify the immediate blowing area to eliminate the condensation and maintain good surface appearance at a fast cycle. Effective dehumidification systems can be installed on existing equipment very satisfactorily, permitting ready access to the blow area while providing the dehumidification necessary to prevent condensation. Savings of 20–30 % have been reported through the use of this system.

Utilization of existing water temperatures in plants can be supplemented to improve cooling conditions through the use of turbulent flow of fluid through the mold channels. Depending upon the channel sizes, the greater the volume and the higher the pressure of the fluid put through the channels, the greater is the heat transfer. A turbulent flow wipes the side walls of the channels, permitting better heat transfer than that obtained with laminar flow of the fluid through the channels. This laminar flow characteristic tends to have reduced heat transfer at the channel circumference, whereas a turbulent flow enables more heat to be removed quicker with higher fluid temperatures, which also reduces the possibility of condensation.

A large-capacity temperature control unit (eg, with 2–7.5 HP pumping capacity, depending on the mold and channel sizes) can not only provide the desire turbulent flow, but can also assist in maintaining uniformity of control throughout the mold on an automatic basis. Production reports indicate that temperature variations of no more than 0.6–1.1°C are readily obtained with this approach, even with intricate molds.

To determine the proper flow for each mold, the Reynolds number should be determined. The Reynolds number ($N = DVP/M$, where D is pipe diameter, V is fluid velocity, P is fluid density, and M is fluid viscosity) is a nondimensional parameter used to determine the nature of the flow along surfaces. Numbers between 2100 represent laminar flow, numbers from 2100 to 3000 represent transitional flow, and numbers above 5000 represent turbulent flow.

The cooling time of parts is related to the wall thickness of the part. Tests on HDPE bottles have shown that wall thickness increases of 50% can increase the required cooling time as much as 200%. This increase of time is necessary to prevent warpage and to control shrinkage of the final product outside the molding cycle.

Because of the broad range of material, and part sizes, specific sizes and location of channels can be subjected to debate. To avoid this it would be better to state that channels should be as large as possible to provide high velocity flow for good heat transfer. They should be located approximately 0.5 in. from mold surface, depending upon mold size. These factors are highly desirable to ensure proper circulation through the work area to heat and cool the mold as rapidly as possible.

A roughened cavity surface is very helpful in blow-molding PE to assist in the movement of trapped air to the mold vents and to improve heat transfer rates.

Water, with its excellent heat transfer characteristics, is used primarily as the heat transfer medium for polyolefin blow-molding, but for the newer engineering resins a synthetic heat transfer fluid that operates up to temperatures of 121–149°C or more at low pressure is highly desirable because of the safety factor. Because the heat transfer characteristics of the synthetic fluid are not as effective as water, care must be exercised to use proper fluids in a safe manner to obtain as efficient production cycles as possible. Compromises sometimes are necessary, depending upon the required temperatures.

The most common material used for blow molds is aluminum. Aluminum has good conductivity, is lightweight, and has low mold costs. In considering the thermal conductivity, as measured in calories per square centimeter per centimeter per degree centigrade per second (cal/cm^2·cm·C·s) [or collecting terms, calories/(s·cm·°C)], aluminum has a thermoconductivity of 0.37, beryllium–copper 0.21 to 0.61, Kirksite 0.25, and steel 0.12–0.14. (In SI units of W/m·K the values are Al, 155; Be–Cu 88–255; Kirlisite, 105; and steel, 50–59). Aluminum is soft, however, and to protect against wear to specific points in the molds, steel or beryllium–copper inserts are used in production applications. The introduction of dissimilar materials, no matter how closely they are machined and mated, affects the heat transfer characteristic of the molds. Kirksite is less frequently used for inserts because of its weight and mass.

Metals Used in Blow Molds

Predominately, the choice of raw material for the main body of a blow mold is a high grade aluminum such as QC-7 or Alumnel 89.

With today's CADAM and CNC equipment, the blow-mold industry is producing large blow molds via machining rather than cast aluminum (Table 2). However, there are some industries that because of the blow-mold cost and short run volumes rely solely on cast aluminum blow molds. They also live with the problem of aluminum pinch-offs, rather than insert steel or beryllium–copper.

Aluminum is approximately eight times better in conductivity than steel. In some cases, blow molds are (for PVC or for inserts or cams) made of stainless steel (420,430).

Table 2. Some Metal Properties

Metal	Cast/cut	Upper cm^3	Durability	Resistance to PVC	Heat conductivity
Zinc	Cast	4.24	Fair	None	0.0017
Aluminum 70/75T6	Cut	1.60	Good	Fair	0.002
Aluminum	Cast	[a]	Fair (−)	Fair (−)	[a]
Brass	Cut	4.98	Good	Fair (+)	0.0015
Beryllium-copper	Cut	5.24	Very good	Very good	0.004
Beryllium-copper	Cast	5.24	Very good	Very good	0.004
Stainless steel 300	Cut	4.75	Fair	Very good	0.0006
Stainless steel 400	H.T. cut	4.75	Good	Fair	0.0003

[a]Depends on density of casting.

Pinch-offs can be produced from BeCu, Ampcoloy 940, or steel. S-7 are preferred for pinch-offs and 54–56 Rc for long life.

Shrinkage

Because molding is executed with a melt which is then solidified, shrinkage and warpage are experienced with most materials. Higher crystallinity polymers have higher shrinkage values (Table 3). Shrinkage is dependent upon the wall thickness because of the different cooling rates. The cycle time to cure the product will be what it takes to cool the thickest wall section. Cooling of a plastic part consists of three separate transfer mechanisms:

(1) Conduction of heat in wall of part
(2) Conduction of heat in mold wall
(3) Convective transfer of heat in cooling fluid

Step 1 is dependent upon resin type, temperature, and wall thickness. Step 2 depends upon the mold material's thermal properties, porosity, and mold/cooling

Table 3. Shrinkage and Other Properties of Some Common Blow-Molding Materials

Polymer	Shrinkage,[a] %	Linear coefficient of thermal expansion, (10^{-4} K^{-1})	Specific Volume, cm^3/g (at 20°C)
LDPE	1.2–2	2.3 (20°C)	1.09
HDPE	1.5–3	2.0 (20°C)	1.05
Polyacetal	1–3	1.3	0.7–0.71
PP	1.2–2.2	1.6	1.10
PS	0.5–0.7	0.7–0.8	0.89–0.95
PVC	0.5–0.7	0.8	0.81

[a]Measured on an axially symmetrical test bottle with an average wall thickness of 0.7–1 mm, by method of R. Holzmann, Kautex-Werke, Hangelar.

layout geometry. Some thermal properties of selected resins are shown in Table 3. Step 3 can be optimized with regard to temperature, fluid flow rate, and prevention of scale formation on the liquid side. The cooling rate of most processes is limited more by the rate of conduction within the plastic than by the rate of conduction in the mold. The cycle time of a part is usually strongly dependent on its wall thickness.

Venting

All blow molds have to be vented. The air that first occupied the product area must escape more rapidly than the rate at which the hot plastic is blown to fill the product area within the closed blow mold. This is known as venting.

In some cases it is very hard to ascertain that improper venting is the production problem that is keeping consistent quality parts from being produced in each cycle. Olefins will show burn signs and in some cases, carbon residue on the blown product, if the venting is really insufficient. There may be no burning of the plastic evident; however, the part produced just does not totally reproduce the blow-molding surface. In blow molding styrene and particularly PET, the resin will cool and just quit stretching since the compressed air, due to it being trapped, results in higher pressure than what is inside the heated parison or preform.

Well-designed molds are vented, as entrapped air in the mold prevents good contact between the parison and the mold cavity surface. When air entrapment occurs, the surface of the blown part is rough and pitted in appearance. A rough surface on a shampoo bottle, for example, is undesirable because it can interfere with the quality of decoration and can detract from the overall appearance. Molds are easily vented by means of their parting line, with face vents and with small holes. A typical mold parting line venting system is shown in Figure 23.

The venting is incorporated only in one mold half. This type of venting can be used on all sizes of molds. When certain areas of the mold cavity are prone to trap air, core vents as shown in Figure 24 can be used.

Venting in the mold cavity should be anticipated in the mold design and layout of the cooling channels so that provisions can be made for their locations.

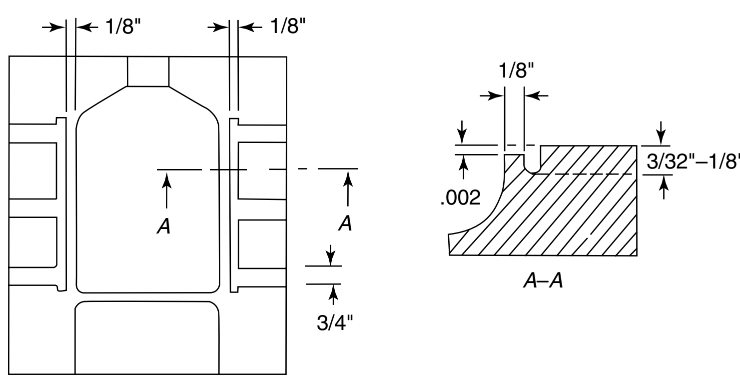

Fig. 23. Parting line venting.

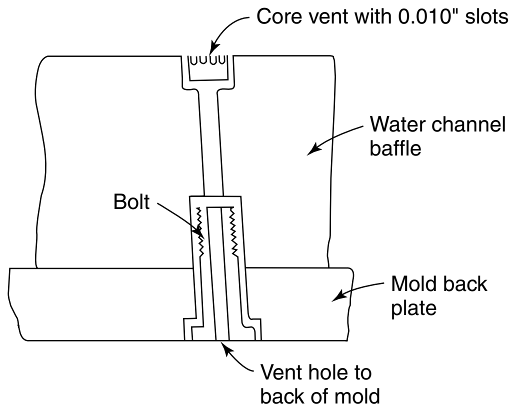

Fig. 24. Core venting.

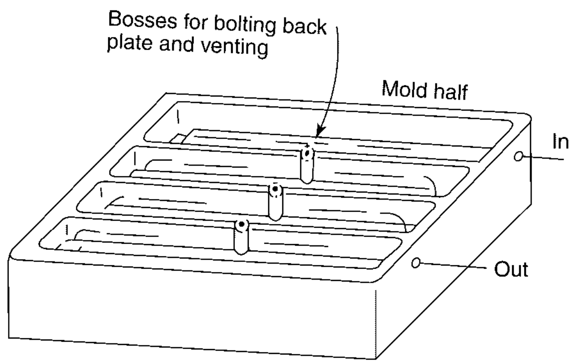

Fig. 25. Location of vents in baffles.

For the cast mold, the cooling channel baffles can be located over areas to be vented, as shown in Figure 25.

The vent opening will pass through a boss in the baffle to the back or outside of the mold. In machined molds, care must be taken so that vents miss the drilled cooling channels. When core vents cannot be used because the slots mark on the blown part will show, small drilled holes can be used. The effect of the size of hole on the surface of the part is shown in Figure 26.

If the hole is too large, a protrusion will be formed; if it is too small, a dimple will be formed on the part. Venting also can be incorporated in molds that are made in sections. A 76–250 μm (3–10-mil) gap between the two sections with venting to the outside of the mold is a very effective vent. For small containers, a 5–7.6 μm (0.2- to 0.3-mil) opening is used, and up to a 250μm (10-mil) opening has been used on large parts such as a 20-gal garbage container.

The mold cavity surface has an important bearing on mold venting and on the surface of the molded part. For PEs and PPs, a roughened mold-cavity surface is necessary for the smoothest surface. Grit blasting with 0.25–0.17 mm (60–80 mesh) grit for bottle molds and 0.59–0.42 mm (30–40 mesh) grit for larger molds is

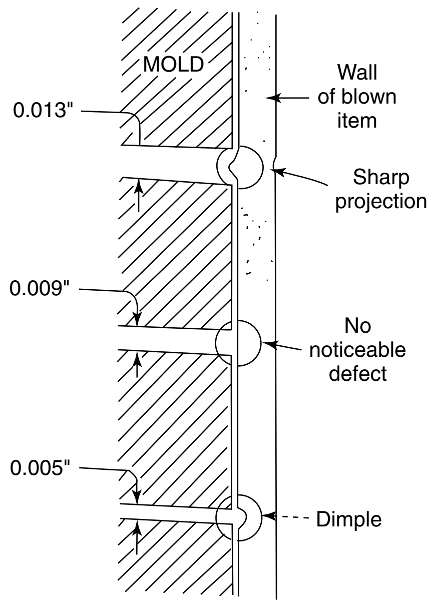

Fig. 26. Effect of vent hole size on part surface.

a common practice. The clear plastics such as PVC and styrene require a polished mold cavity for the best surface. A grit-blasted surface will reproduce on some clear plastics, an effect that is not normally desirable.

The pinch-off areas pinch the ends of the plastic parison and seal the edges together when the mold closes. These surfaces are subject to more wear than any other part of the mold. The high-heat-conductive metals preferred for blowing molds, such as aluminum and copper alloys, generally are less wear-resistant than steel. Steel inserts often are used for the pinch-off areas of the molds. An additional advantage of pinch-off inserts is that they can be made replaceable in the event of wear or damage. A neck pinch-off insert is sketched in Figure 27.

Generally, in volume production, pinch-off inserts are made of hard steel with the other portions of the blow mold produced from a nonferrous metal. The

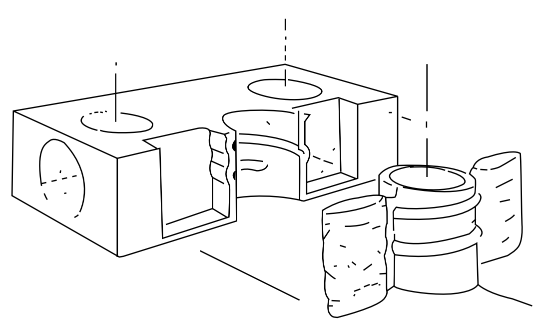

Fig. 27. Replaceable neck insert pinch-off.

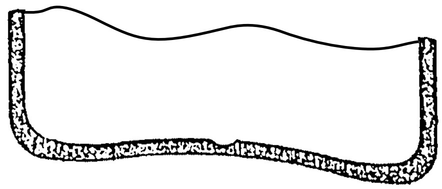

Fig. 28. Poor weld line (weak) pinch-off had knife edge; relief angle was either too large or too small.

pinch-off edge should not be similar to a knife edge, or it will tend to act as a cutter and will yield a "V" groove where the tail or pinch-off area of the parison is forced to bond (See Fig. 28).

The parts of the mold that weld the ends, and sometimes the interior portions, of the parison together, and also cut it or facilitate its removal are called the pinch-offs. Pinch-offs design has an important effect on the success of a blow-molding product because the weld seams are usually the weakest parts of the container. The pinch-off must be designed to maximize the strength of the blown product in this area. The results of a pinch-off optimization study for various grades of olefins are listed in Table 4 and also in Figure 29. A quality type pinch-off is depicted in Figure 30.

In bottle blow molds, there will be a hardened steel insert with a land of 0.076–0.13 mm (0.003–0.005 in.), a relief angle of 20° with a total depth of 0.76 mm (0.030 in.) measured from the inside bottom of the blow mold, and then a 45° cut to the bottom of the relief section in the pinch-off area. Normally, the total of this relief section will be 90% of the parison wall thickness to be pinched (see Fig. 31). This design will also minimize residual flash. It is best to design the pinch land at 0.25–0.4 mm (0.010–0.015 in.) and have metal to remove, if the pinch is not adequate.

Many different designs have been used in the pinch-relief sections. Two typical ones are shown in Figure 32. Design A is probably the one most widely used. In some instances, however, where the mold must pinch on a relatively thin portion of the parison and next to this pinching edge the parison must expand a large amount, the plastic will thin down and may even leave a hole on the parting line. This defect is sometimes seen near the finger hole on containers having handles. To prevent thin sections and holes, Design B is sometimes employed. The shallower angle of 20° has a tendency to force plastic to the inside of the blown

Table 4. Optimization Study Results for Various Grades of Olefins

Container volume (V), L	Pocket Opening Angel, (a), deg	Welding edge width b, mm	Pocket Width, (c), mm
≤1	30	0.6–1	2d
1–30	30	1–3	2d
30–250	30	3–5	1d–1.5d
250–2000	30	5–7	1d–1.5d

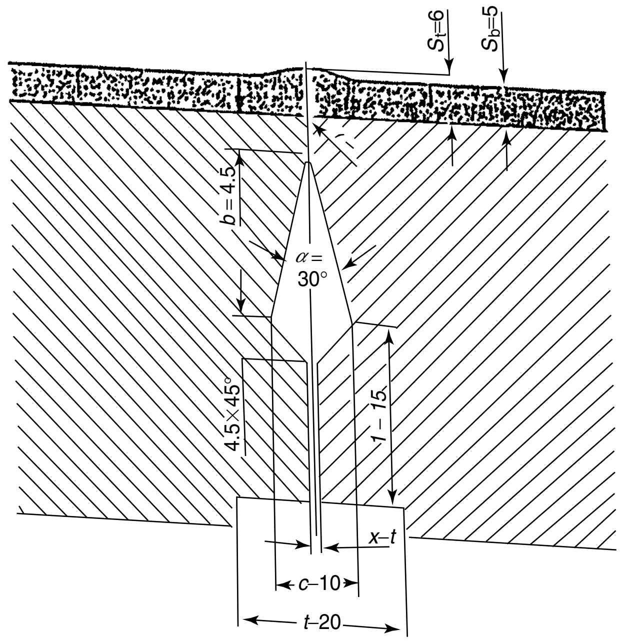

Fig. 29. Optimized mold base for a 60-L can be made from HMW-HDPE. Dimensions are defined in Table 4. Courtesy of Hoechst AG.

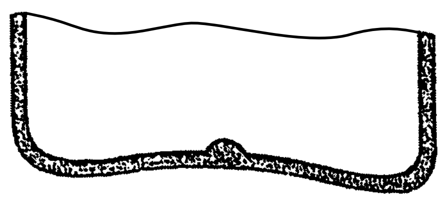

Fig. 30. Good weld line.

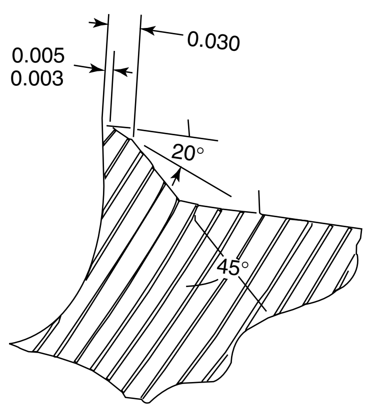

Fig. 31. Design often used to minimize residual flash.

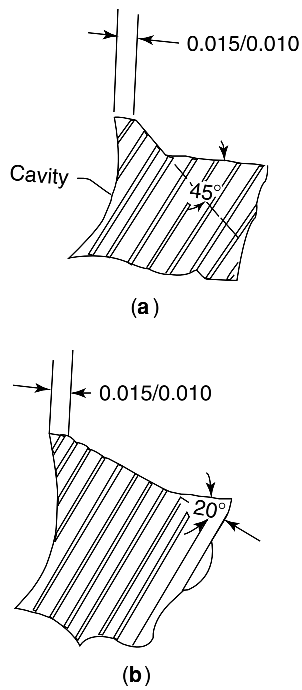

Fig. 32. Pinch-relief section designs.

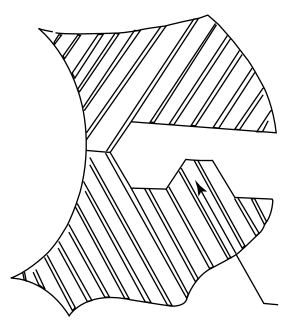

Fig. 33. Dam or restriction used to increase wall thickness on some designs. Arrow points to restriction.

part and increase the wall thickness at the parting line rather than pushing the excess material back into the pinch relief. Another method used for increasing the wall thickness at the parting line employs a restriction or dam in the pinch relief similar to that shown in Figure 33. The pinch-off must be designed to maximize the strength of the weld. Some different types of pinch-off designs are shown in Figure 34.

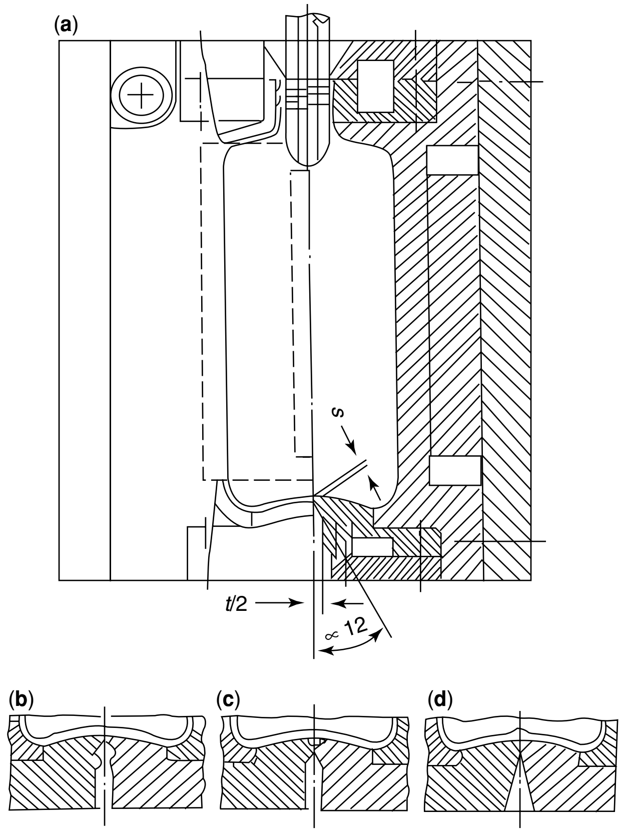

Fig. 34. Design of welding edges and pinch-off pockets. *s*, welding edge width;, opening angle of pinch-off pocket; *t*, width of pinch-off pocket. Courtesy of Hoechst AG.

Troubleshooting Extrusion Blow Molding

Problem	Suggested solution
Low gloss	Increase material temperature
	Increase mold temperature
	Improve mold venting
	Increase air pressure
	Increase air blowing rate
Excessive cycle	Decrease material temperature
	Decrease mold temperature
	Decrease part wall thickness
	Improve mold coring
	Increase material density
	Increase air pressure
	Increase melt index (with decreased stock temperature)

Problem	Suggested solution
Die lines	Clean the die
	Smooth and polish the die
	Increase mold temperature
	Increase air pressure
	Increase air blowing rate
	Increase purge time when changing materials
	Improve die streamlining
Low bottle weight	Increase due to mandrel clearance
	Decrease material temperature
	Increase extrusion speed
	Decrease extrusion die temperature
Surface roughness	Increase stock temperature
	Decrease extrusion speed
	Increase die temperature
	Improve die streamlining
Weak pinch	Adjust material temperature
	Increase pinch blade land width
	Decrease rate of mold closing
Parison curl	Adjust and center die-parison curls toward thin area
	Improve die and head heat uniformity
	Dirty die head
Wall thickness non-uniform	
vertically sag	Decrease material temperature
	Increase extrusion speed or accumulator ram pressure
	Lower melt index
	Increase material density
circumferentially	Decrease blow-up ratio
	Improve head and die heat uniformity
	Adjust and center the die
Excessive thinning at parting line	Decrease wall thickness, or make more uniform
	Decrease mold temperature
	Increase air pressure
	Decrease material temperature
	Decrease density
	Improve mold coring
Excessive shrinkage	Increase material temperature
	Decrease mold temperature
	Increase air pressure
	Decrease material temperature
	Decrease density
	Improve mold coring
Excessive parison swell	Increase material temperature
	Increase die temperature
	Decrease extrusion speed
	Increase melt index
	Reduce die size
Doughnut formation	Wait for mandrel temperature to reach die temperature
	Clean the lower surface of the die

Problem	Suggested solution
Warped top and bottom	Slow the cycle
	Decrease mold temperature
	Decrease stock temperature
	Decrease part weight
	Improve mold coringJ
Variable bottle weight	Finer extruder screen pack
	Increase screw cooling
	Raise rear extruder heats
	Decrease extruder rate

Coextrusion

A growing trend in extrusion blow molding is to coextrude parisons that contain up to seven layers of different materials. However, as of this time, coextrusion is limited to machines that only use one (1) parison as on a wheel and the continuous-type machine. Since the different materials combine in the head tooling (see Fig. 35), the use of manifolds for multiple cavity is not feasible, nor are accumulator machines (see COEXTRUSION).

Coextrusion blow-molding machines are very expensive and demand skilled operators. Coextrusion is used to produce containers having a view stripe and more recently for 55-gal drums and the plastic gasoline tanks that are in passenger cars, sport utility vehicles, or pick-up trucks. The plastic gasoline tanks are produced from a coextruded parison that contains six layers of different resins. For example, HDPE/adhesive/EVOH/adhesive/regrind/HDPE (see Fig. 35).

Major companies are finding that they can coextrude parisons that not only make use of their regrind, but also use less color additive. It is very feasible to extrude a virgin layer with no color additive on the inside of the

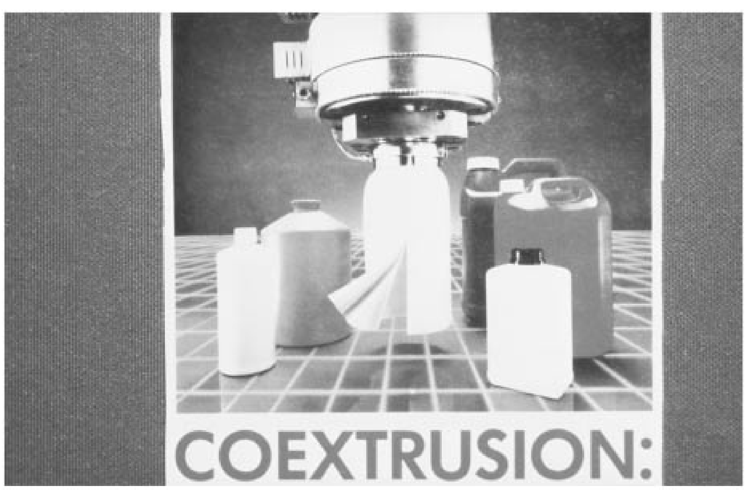

Fig. 35. Coextrusion head.

parison that is against the product to be packaged. The second layer is for the off-fall or regrind. The outer layer would be virgin with color additive, which would make up a three-layer coextruded parison. A six- or seven- layer coextruded parison may be HDPE/adhesive/EVOH/adhesive/regrind/virgin or HDPE/regrind/adhesive/EVOH/adhesive/regrind/virgin as examples.

Stretch Blow Molding

For stretch blow molding, mainly PET, PVC, PP, and PAN are used. In this process, based on the crystallization behavior of the resin, a parison or preform is temperature-conditioned and then rapidly stretched and cooled. For best results, the resin must be conditioned, stretched, and oriented just above the glass-transition temperature. At this point, the resin can be moved without the risk of crystallization (see Figs. 36 and 37).

Stretch blow molding is the most significant development since the development of the two piece can. This process improves produce performance, such as bottle-impact strength, cold strength, transparency, surface gloss, stiffness, and gas barrier. The bottles are lighter and less costly, and products that otherwise would not be suitable can be packaged. The process uses injection-molded, extruded, or extrusion blow-molded parisons in one or two steps.

In the one-step method, parison production, stretching, and blowing take place in the same machine. In the two-step method, the parison is produced separately from stretching and blowing. The main advantage of the one-step approach

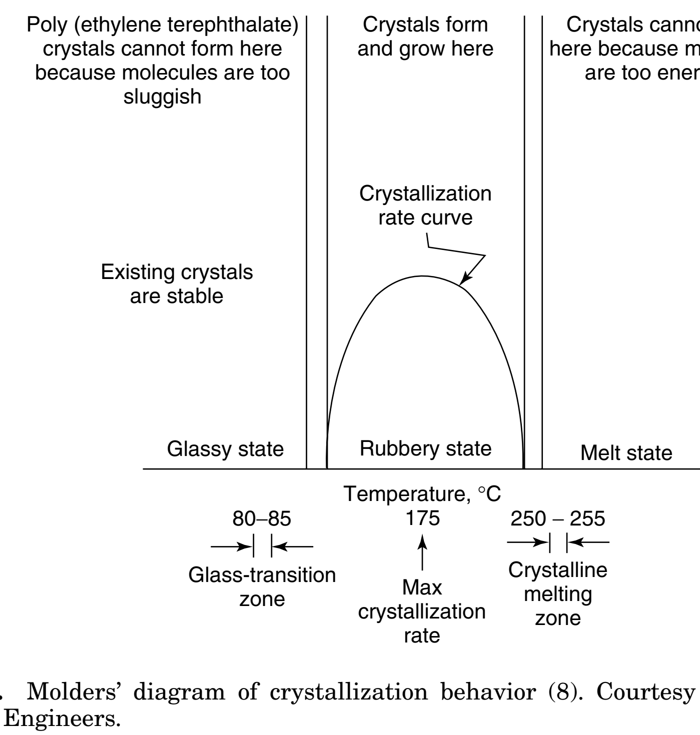

Fig. 36. Molders' diagram of crystallization behavior (8). Courtesy of the Society of Plastics Engineers.

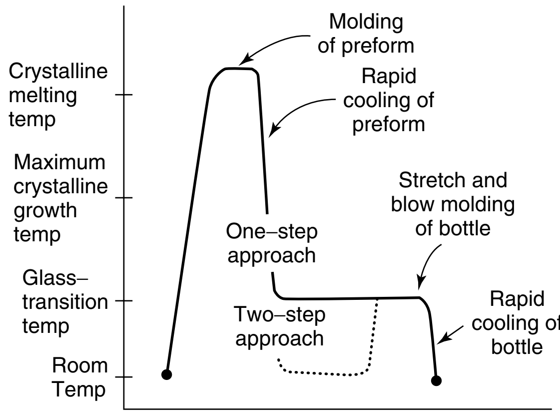

Fig. 37. Basic stretch blow mold process. Courtesy of Jerome S. Schaul.

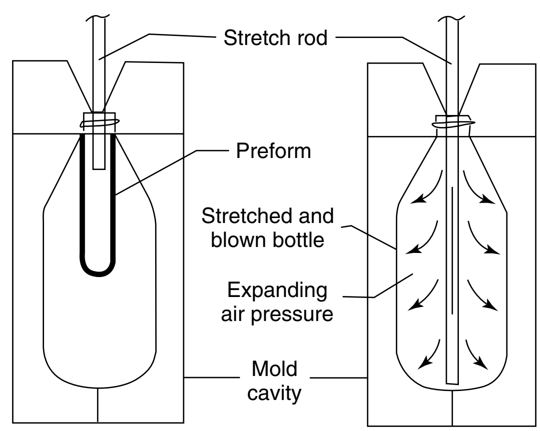

Fig. 38. A temperature-conditioned preform is inserted into the blow-mold cavity and is rapidly stretched. A rod is often used to stretch the preform in the axial direction, and air pressure to stretch the preform in the radial direction.

is the savings in energy as the parison is rapidly cooled to the stretch temperature. In the two-step approach, the parison is cooled to room temperature and reheated to the stretch temperature (see Fig. 38). On the other hand, production in the two-step method is more efficient, and a minor breakdown in one of the steps does not stop the other. The optimum balance of design vs output is also easier to achieve with the two-step approach. Limits on parison production, for example, do not force a compromise in parison design to achieve higher bottle production. For optimum performance, each bottle design has a unique parison-design and temperature-conditioning requirement which may or may not fit, for optimum productivity, the assumptions used in the design of the one-step equipment, which are virtually the same.

In the two-step method, the parison is injection-molded in a separate machine, sorted, and placed in an oven for temperature conditioning and blow molding. A rod is used inside the parison, in combination with high air pressure,

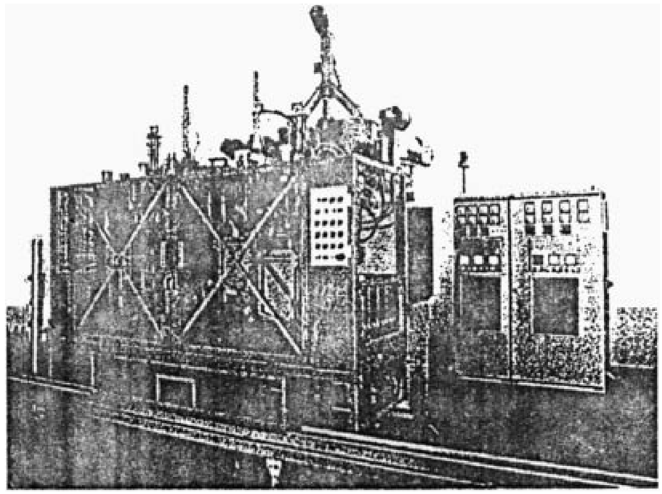

Fig. 39. Bekum BM04D continuous extrusion blow molder for the manufacture of biaxially oriented PVC bottles. Production rate for 1-L bottle is 2000 per h; maximum bottle size is 2 L. Courtesy of Bekum Plastic Machinery, Inc.

to complete the stretch (see Fig. 38). Injection stretch blow molding is commonly used for PET resin.

The extruded parison stretch process can use either the one- or two-step method. In the former, a parison is extruded and fed directly into an oven for conditioning. After conditioning, the parison is cut into lengths. Mechanical fingers grab both ends and stretch the parison. The two mold halves close, whereupon air pressure expands the stretched parison against the mold cavity. In the two-step method, the extruded tube is cooled and cut to length. Later, the cut tubes are placed in an oven for conditioning. This technique is used mainly for PP, and occasionally for PVC.

With the extrusion blow stretch process, the parison is shaped and temperature-conditioned in a preform cavity in the same way a bottle is extrusion blow-molded. From this preform cavity, the parison is transferred to the bottle cavity where a rod and air pressure combine to stretch and expand the resin. PVC is most often stretch blow-molded with this process. Although the one-step method is the most common (see Fig. 39), a two-step technique, in the same fashion as the others, is feasible.

PET is the second largest volume resin used in the blow-molding industry. HDPE is first, with a 57% share of the blow-molding market today. PET has 33% of the blow-molding market and is growing. Thus, all the other resins combine for 10% of the blow-molding market.

As stated previously, stretch blow molding impacts clarity, top load strength, drop impact resistance, improved barrier, and will allow approximately 15% or greater reduction in material usage for the same size container.

In stretch blow molding, there are two ratios that multiply together to provide the blow up ratio BUR. In extrusion blow molding, there is only the hoop ratio (that is the blow-up ratio). In stretch blow molding there is the hoop that is multiplied by the axial ratio. Thus, BUR = Hoop ratio $\times$ axial ratio.

The hoop ratio is the most important. If the product to be packaged is pressurized as soft drinks, carbonated water, and beer, the hoop ratio should be at least 10 or higher. The *hoop ratio* is defined as the ratio of the largest inside diameter (D_1) of the blown article to the inside diameter (D_2) of the parison or preform.

The *axial ratio* is also very important as this provides vertical strength, material distribution, improved barrier, and allows for raw material savings. Usually, the axial ratio should be at least 1.7 with greater than 2 preferred. The *axial ratio* is defined as the axial length (A_1) where the actual axial stretch is initiated in the preform measured to the inside bottom of the bottle to be produced divided by the axial length (A_2) of the preform as it is measured from the point where stretching is initiated to the inside bottom of the preform.

The BUR is used to determine the wall thickness that would be necessary in the precursor or preform. If the BUR is 10, and the desired minimum wall thickness is 0.38 mm, then the BUR $\times$ the desired wall thickness, would indicate that the minimum wall thickness in the preform should be 3.8 mm since the thickness will be expanding 10 times. The total BUR is equal to the hoop ratio times the axial ratio.

To check if the orientation is correct, a dog bone can be cut from the stretch blow-molded PET container and a tensile test conducted on an Instron or similar machine. A dog bone shape is cut in the hoop direction and one is cut in the axial direction. PET has a base strength of approximately 46 MPa (6700 psi). If the hoop ratio is 5, then in the container in the hoop direction, the tensile strength should be approximately 231 MPa (33,500 psi). If the axial ratio is 2, then the tensile strength in the vertical direction would approximately be 92 MPa (13,400 psi).

In order to achieve these results, the stretch blow molding has to be performed when the heated preform's body is within the orientation window for the polymer that is to be stretch blow-molded. A list of the orientation temperatures for specific polymers follows:

Material	Orientation temperature, °C
PP	128
PAN	124
POM	160
PVC	100
PET	95
PS	150

It is important to note that each polymer listed has specific stretch ratios and if exceeded the polymer will fail.

Material	Stretch ratio	Orientation temperature range, °C
PET	16/1	90–115
PVC	7/1	99–110
PAN or AN	12/1	115–127
PP	6/1	127–138
PS (Crystal)	12/1	143–160

Table 5. Gas and Water Vapor Barrier Properties of Glass-Clear Resins

Polymer	O_2[a]	CO_2[b]	Water[c]
Oriented PVC via extrusion blow molding (high impact)	9.0	16.5	0.7
Oriented PET	11.1	22.2	1.5
Oriented PVC via extrusion blow molding (normal impact)	9.6	5.2	1.1
Nonoriented PVC via extrusion blow molding (high impact)	12.2	35.7	1.5
Nitrile	1.1	1.3	4.4
PC	215.0	400.0	9.0

[a]cc/mL/24 h/atm/100 in.^{2}/73°F.
[b]g/mL/24 h/atm/100 in.^{2}/100°F, 90% RH.
[c]Test results provided by Occidental Chemical Corp.

Stretch blow-molded containers of AN, PVC, and PET may have an average wall thickness of 0.23–0.64 mm (0.009–0.025 in.) Normal blow molding would call for an average wall thickness of 0.46–0.5 mm (0.018–0.020 in).

As noted, each polymer has a temperature at which the heated preform or parison should be stretch blow-molded to achieve maximum orientation properties. Each polymer exhibits its own natural stretch ratio. Orientation of polymers is a study by itself, and there are references to in-depth study of specific polymers (13) (see also, FILMS, ORIENTATION).

Table 5 depicts barrier properties of several stretch orientable polymers and their barrier improvements obtainable through stretch blow molding (see BARRIER POLYMERS).

PET has grown in its use because of several properties possessed by this polymer which no other stretch blow-molded polymer possesses. PET has what is referred to as self-leveling. Since PET work hardens similar to a metal, as it stretches out, the material stretching becomes stronger than the material next to it and so it waits until the material next to it stretches and becomes stronger. Thus, the term *self-leveling*. No other polymer possesses this feature. All the other polymers behave as bubble gum when they are being blow-molded.

Another unique property of PET is that it can be heat set. Heat set is achieved by either of two methods. Normally, a PET stretch blow-molded container cannot be subjected to heat above approximately 54°C (130°F) because of distortion. This relates to the fact that the glass transition of PET is approximately 68–71°C (155–160°F).

However, this can be altered by inducing the PET stretch blow-molded container to become more crystalline. A quality 2-L PET soda container will have approximately 14–22% crystallinity. This crystallinity is induced by heating the preform and through the orientation. To increase the crystallinity within the wall of the container, the container may be blow-molded in a hot blow mold in the range of 124–155°C, with the bottom plug or push up at approximately 68–88°C. When produced in a hot blow mold, the crystallinity with in the wall of the stretch blow-molded container can be increased to be in the range of 28–32%. There is a loss in orientation because of blowing in a hot blow mold. The heat set stretch blow-molded container is tested fresh. It is filled with hot water to the top of the finish at a temperature of 90°C. It cannot distort nor shrink greater than 2% when dimensions are checked before and after the hot fill test. This ensures the container will pack a 85°C hot fill product such as juice and sport drinks. An aged container over 24 hours is checked using 85°C hot water. There are many other quality assurance tests performed and produces such as Schmalbach Lubeca, Graham, Ball Corp, and Crown Cork & Seal have their own test procedures.

Other Blow-Molding Operations

Many related operations have been used to improve blow molding, eg, in-mold labeling, fluorination of surface, and internal cooling.

In-Mold Labeling. A label with a heat-activated adhesive is automatically placed into the mold cavity and held by a vacuum. The expanding hot parison activates the adhesive to create a strong bond.

Some of the advantages of the process include a stiffer, stronger structure, bottle-weight reduction, improved label appearance, elimination of high speed complex labeling equipment, and varied package opportunities. Bottle weight is often reduced without impairing performance. The strong bond improves label appearance by eliminating blisters and wrinkles. The pick-and-place mechanism used to place the label into the mold cavity, although somewhat complex, is often simpler than using high speed equipment for labeling on the filling line. New package-design opportunities are created with the possibility of placing the label closer to or around the bottle edges, which could further increase strength.

However, with in-mold labeling, production efficiency can suffer from the slower cycle and the complexities of the process. The scrap is more valuable and costly to reclaim. Very high production runs are required to justify the investment.

Fluorination. Fluorination surface treatment improves the resistance of PE to nonpolar solvents. A barrier is created by the chemical reaction of the fluorine and the PE, which forms a thin (20–40 mm) fluorocarbon layer on the bottle surface. Two systems are available. The in-process system uses fluorine as a part of the parison expand gas in the blowing operation. A barrier layer is created only on the inside. In the post-treatment system, bottles are placed in a chamber filled with fluorine, and a barrier layer forms on both inside and outside surfaces.

This surface treatment allows low cost blow-molded PE bottles to be used for paint, paint thinner, lighter fluid, polishes, cleaning solvents, cosmetics, toiletries, etc, and higher cost resins or coextrusion processes are not always necessary. For floorination to be effective, the parison temperature must be greater than 195°C.

Internal Cooling. Normally, a blow-molded part is cooled externally by the mold cavity, forcing heat to travel through the entire wall thickness. With the poor thermal conductivity of plastic resins, molding-cycle times of heavy parts can be lengthy. Internal cooling systems are designed to speed mold cooling, thus reducing costs by removing some heat from the inside. Three basic systems have been developed: liquefied gas, supercold air with water vapor, and air-exchange methods.

In the liquefied-gas system, liquid carbon dioxide or nitrogen is atomized through a nozzle in the blow pint into the bottle immediately after the parison has been expanded. The liquid quickly vaporizes, removing heat, and exhausts at the end of the cycle. This method has increased production rates by 25–35%. A disadvantage is the cost of the liquefied gas. If consumption is not precisely controlled, the cost saving is small.

The supercold-air system with water vapor is similar. A stream of very dry, subzero air expands the parison, circulating through the bottle and exhaust.

Immediately after the parison has expanded, a fine mist of water is injected into the cold air stream and turns into snow. As the snow circulates through the container, it melts and vaporizes. At the end of the molding cycle, the water mist is stopped, permitting the circulating air to dry the interior before the mold is opened and the article is removed. Production rates can be improved as much as 50%.

The air-exchange system is far simpler. Here, plant air, after the parison has been expanded, is circulated through the bottle and is exhausted continuously. Differential pressure inside the bottle is maintained at 550 kPa (80 psi) to keep the parison in contact with the mold cavity. Production rates, however, are increased by only 10–15%.

More expensive internal cooling systems are often not justifiable with today's equipment because most blow-molding machines do not have the additional extruder capacity to support the high production rate. This is particularly true for the heavier bottles that would benefit most. As a result, only the low cost air-exchange systems have been accepted.

With the exception of larger industrial blow molds cast from aluminum (typically No. A356), most extrusion blow molds today are cut from No. 7075 or No. 6061 aluminum or from No. 165 or No. 25 beryllium-copper. The latter is corrosion-resistant and very hard, making it the choice for PVC blow molding. However, compared with aluminum, it weighs about three times as much, costs about six times as much per cubic centimeter, and requires about one-third more time to machine. In addition, thermal conductivity is slightly lower (see Table 6). For polyolefin blow molding, some mold makers combine the materials by inserting beryllium-copper into the pinch-off area of an aluminum cavity, thus gaining a lightweight, easy-to-manufacture mold with excellent thermal conductivity and hard pinch-off areas.

Table 6. Blow-Mold Tool Materials

Material	Hardness[a]	Tensile strength, MPa[b]	Thermal conductivity, W/m·K
Aluminum			
No. A356	BHN-80	255	151
No. 6061	BHN-95	275	168
No. 7075	BHN-150	460	105
Beryllium-copper			
No. 25 and 165	HRC-30 BHN-285	930	105
Steel			
No. O-1 and A-2	HRC-52-60 BHN-530-650	2000	35
No. P-20	HRC-32 BHN-298	1000	37

[a]HRC: Rockwell hardness (C scale); BHN: Brinell.
[b]To convert Mpa to psi, multiply by 145.

Unlike injection blow molds, which are mounted onto a die set, extrusion blow molds are fitted with hardened-steel guide pins and bushings to ensure that the two mold halves are perfectly matched. Dies, mandrels, blow-pin cutting sleeves, and neck-ring striker plates are made from tool steel hardened to 56–58 HRC.

Guidelines. Guidelines have been mentioned throughout this article in the form of process and tooling limitations, such as parison blow-up ratios, ovality ratios, tooling sizes, and so forth. Product design begins with a clear understanding of process.

Most blow-molded articles perform better with rounded, slanted, and tapered surfaces. Square or flat surfaces with sharp corners are undesirable. Wall thickness can vary considerably from side panels to corners. Corners become thin and weak, heavy side panels thick and distorted. Flat panels are not uniform and flat shoulders offer little strength. Highlight accent lines should be "dull" with a radius of 1.5 mm or more. If they are sharper, the parison does not penetrate, and trapped air marks result along the edge.

The blow-up ratio of 4:1 for extrusion blow-molded bottles or parts is considered a maximum. This applies overall and to separate sections as well. For example, bottle handles that are deeper than they are wide across the mold-parting face are difficult to mold and are often thin and weak.

Ribs do not always stiffen. Blow-molded ribs often increase surface area and reduce wall thickness, creating a flexible-bellow or accordion effect. Flexing may affect "hinge" points. Proper design prevents this.

Designers must be familiar with bottle-performance tests. The Society of the Plastics Industry has recommended 21 standard practices; the most important are vertical compression or top-load strength, drop-impact resistance, product compatibility and permeability, closure torque, and top-load stress-crack resistance.

Blow-molding process conditions can influence not only bottle dimensions, but also bottle volume. HDPE bottles shrink, with 80–90% of the shrinkage taking place in the first 24 h. Lighter-weight bottles use less plastic for a given capacity and bulge more. A 4-L bottle weighing 5 g less increases about 12 mL in volume—5 mL for the plastic and 7 mL for bulge. Shorter cycle times, lower parison-expansion air pressure, and lower melt and mold temperatures reduce bottle volume. Storage temperature is very important. After 10 days, bottles stored at 60°C change more than bottles stored at 20°C.

The guidelines will continue to change with the use of the computer with CAD flow analysis, blow simulation, and new talent in the industry. The future is bright.

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