Marlex® POLYETHYLENE

Premium Extrusion and Rigid Packaging Resins

CPChem™

PE TIB-81 THERMOFORMING HDPE PARTS

INTRODUCTION

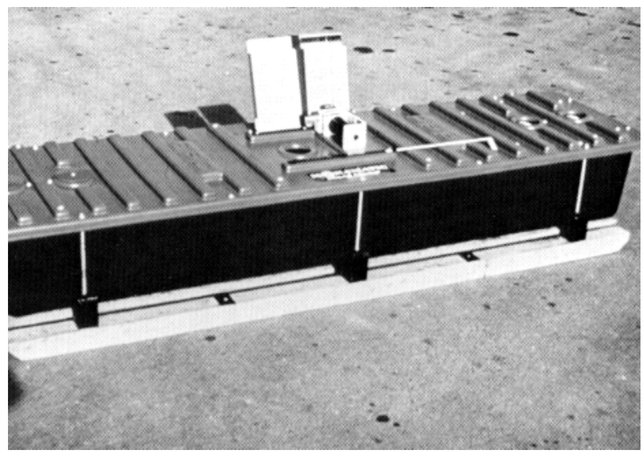
With improved resin technology and advanced thermoforming techniques, today's thermoformers can fabricate tougher and more attractive products. Marlex® high density polyethylene (HDPE) thermoforming resins undergo constant refinement in order to provide the best possible material for the job.

The wide acceptance of extra high molecular weight (EHMW) resin as an ideal thermoforming material, especially for shallow draw parts, is indicative of the progress made in resin technology. Principal benefits of the EHMW resins include high melt strength or minimum sag during forming and excellent toughness of the finished part.

Figure 1 shows an application for these resins that has utilized both of these properties. This cattle feeder is 9 ft. 4 in. x 26 in. x 16 in. deep. The top is formed from 350-mil sheet and the bottom from 400-mil stock. The large size of this part requires that the resin have very high melt strength during forming. If the sheet sags too much when forming the shallow-draw top, webbing will occur. During service, the feeder is bumped, kicked and scuffed at temperatures from -20 to 130°F. In addition to this external abuse, it is continually stressed from the inside by 150 gal. of liquid feed that weighs approximately 1500 lbs.

The cattle feeder is an excellent example of proper resin selection balanced with appropriate thermoforming technique. If the thermoforming technique is not compatible with the selected resin, problems such as poor wall distribution, part warpage or rough surface may result. Thermoforming techniques best suited to high density polyethylene sheet will be summarized in this bulletin. Sheet extrusion recommendations are detailed in separate Marlex technical information publications.

FIGURE 1



This bulletin stresses the importance of up-to-date and versatile thermoforming equipment. To help clarify some essential details of this equipment and the related forming techniques, several diagrams and figures are included. These diagrams are based on machines with upper and lower movable platens, fixed clamps and retractable sandwich heaters.

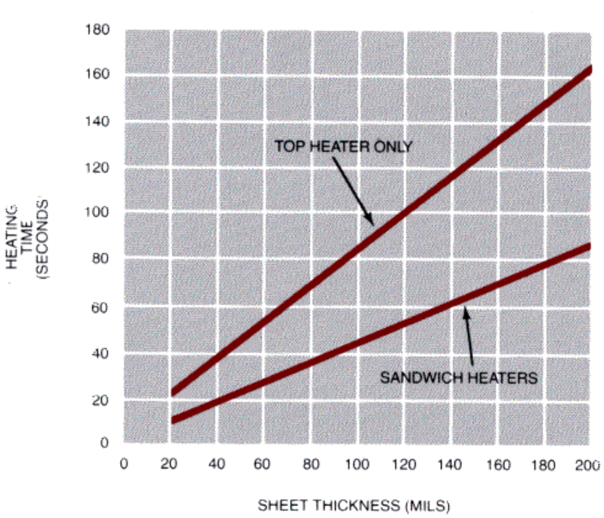
HEATING THE SHEET

Figure 2 shows why sandwich heaters are preferred for forming high density polyethylene sheet. The data for these curves were obtained with the heaters set at 1200°F - a typical operating temperature. Each individual heater had a watt density of 15 W/in^2, using heater rods 3 in. apart and 4 in. away from the sheet. Thus, when both the upper and lower heaters were employed to provide the sandwich effect, total projected watt density was 30 W/in^2. A high watt density, divided between the two sides of the sheet to avoid scorching, plus a short air gap between the heaters and the sheet are essential factors for the fastest heating cycles.

The advantage of sandwich heaters becomes especially evident with sheet that is over 100 mils thick. With this heavier sheet and only one heater bank (even with 22.6 W/in^2 available), it is necessary to preheat the sheet on one side and then reverse sides for the remainder of the heating period. Otherwise, the surface temperature becomes too high or the heating period gets unduly long. Sandwich heaters eliminate the need for this extra handling and reduce heating time as much as 50%.

Unpigmented (natural) high density polyethylene sheet becomes "clear" to translucent over the entire forming area when it is ready to form. At the time of forming, the sheet temperature is normally about 350°F, depending on gauge. For a given sheet thickness, dark colored sheet will heat somewhat faster than light colored sheet because its ability to absorb energy is greater. Regardless of sheet color, the behavior and appearance of the blank can be used to determine when the sheet is ready to form. The proper heating cycle can be judged quite easily with experience.

FIGURE 2
Heating Time vs. Sheet Thickness



When HDPE sheet is heated, it initially sags. At this stage, the sheet appears irregular or wavy. With thicker sheet, the weight may exceed internal forces and the sheet will continue to sag during the entire heating period. In either case, the sheet will go through a wavy stage, followed by a gradual smoothing out with increasing sag. Just as all the wrinkles disappear the sheet is ready to form.

FORMING STAGE

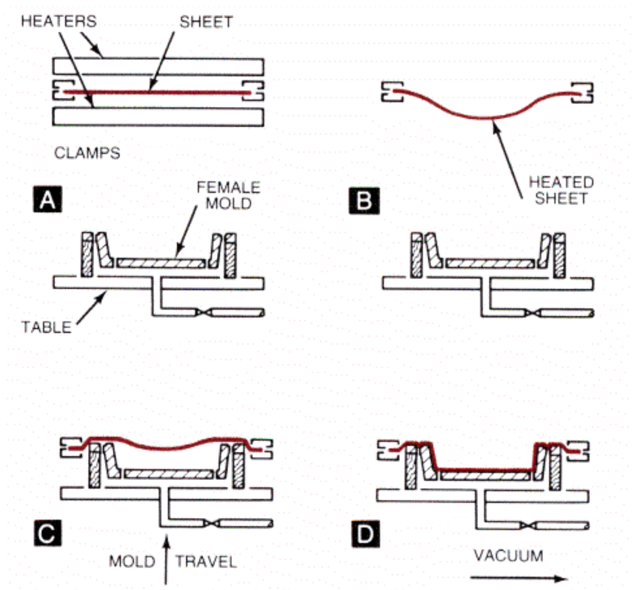
Once the sheet is properly heated and softened, any one of a number of forming techniques may be employed. One of the oldest techniques is straight vacuum forming; i.e. where the sheet is held against the top of a female mold at the start of the heating cycle. However, this technique is seldom feasible with high density polyethylene due to appreciable sag of the sheet while heating. Therefore, drape forming is the first practical technique using these materials.

FEMALE DRAPE FORMING

In female drape forming (Figure 3), the mold rises to meet the sheet, or the clamps may bring the sheet down over the edges of the mold to give the same effect. To remove the part, air is blown back through the vacuum holes after the part is sufficiently cool. This last air eject step is common to all of the techniques discussed in this bulletin.

Maximum thinning occurs where the vacuum pulls the sheet the greatest distance before the sheet contacts the mold. Conversely, the material is thickest where the sheet first contacts the mold, generally along the top edges. Because these differences in wall thickness may become excessive, this technique should be limited to parts with relatively low draw.

FIGURE 3
Female Drape Forming



a) Clamp and heat sheet, b) Retract heaters, c) Seal edges of sheet against mold, d) Apply vacuum.

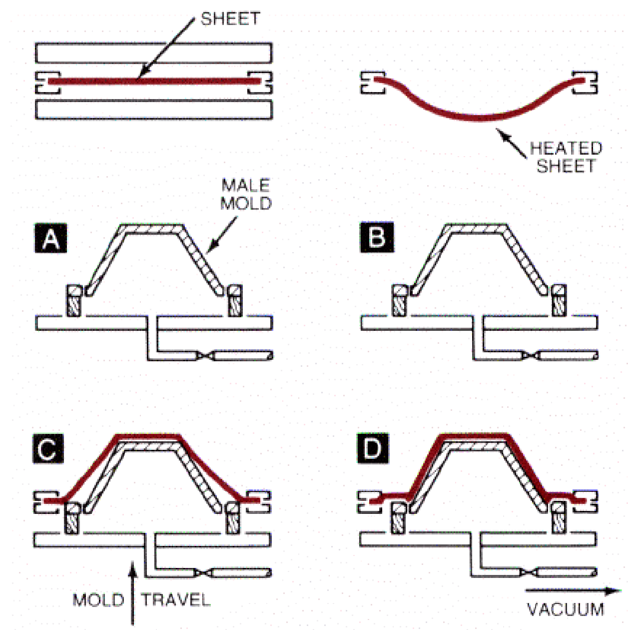
The "draw" or "draw ratio" of a female mold is defined as the ratio of maximum cavity depth to the minimum span across the top opening. For female drape forming, best results are achieved when this ratio is maintained below 0.7:1. Even below this limit, however, plug-assist forming should be considered to optimize part wall distribution.

MALE DRAPE FORMING

Male drape forming (Figure 4) is identical to female drape forming except a male mold is used. As before, either the mold table (platen) or the clamps may move (Step C).

Since some stretching or "preforming" of the sheet can occur before the vacuum is applied, the sidewalls are often more uniform than those obtained with a female mold. In addition, more material is utilized in male drape forming, other factors being equal. All of the sheet from the top of the mold to the edge of the mold base is available for forming. In comparison with a female mold, only the sheet within the top edges of the cavity is usable because little, if any, sheet slips over the edges into the cavity.

FIGURE 4
Male Drape Forming



a) Clamp and heat sheet, b) Retract heaters, c) Seal edges of sheet against mold, d) Apply vacuum

For these reasons, higher draw ratios are often possible with male molds than with their female counterparts. In fact, draw ratios up to 1:1 have been employed in the male drape forming of HDPE sheet. Draw ratio for a male mold is defined as the ratio of maximum form height to the minimum dimension at the base of the mold.

Following the general rule, maximum thinning will still occur at those points most remote from where the sheet first contacts the mold. So with a male mold, the parts will be thinnest around the base of the mold and thickest at its top. Where the top surface is flat, the final part thickness in that area may be almost equal to the thickness of the original sheet. This effect again confirms the non-slip characteristic of HDPE at elevated temperatures.

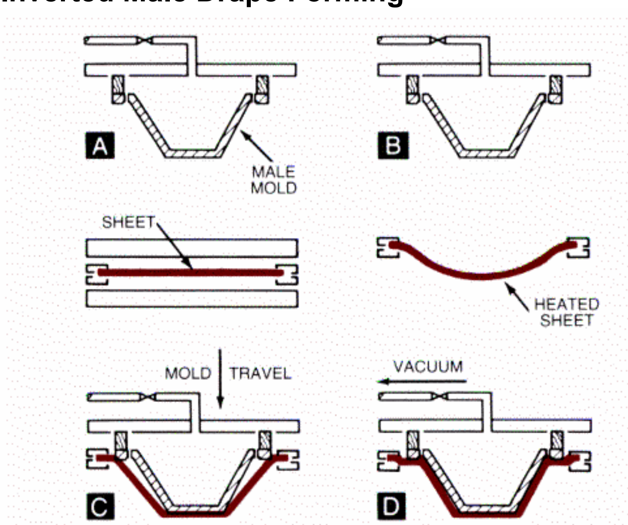
A problem encountered more frequently in the male drape technique than any other is "webbing," i.e., where the sheet folds over against itself while still hot. Proper mold spacing, web blocks and various ring assists may be used to eliminate this difficulty.

A few years ago, male and female drape forming techniques were widely utilized to thermoform high density polyethylene parts. This was due, primarily, to limitations of available equipment rather than to specific advantages of these techniques. Since then, numerous advances in process versatility have expanded the capabilities of the custom thermoformer. Among these are movable upper and lower platens, programmable ovens, fully automated forming systems and more sophisticated controls such as photoelectric eyes. These improved processing tools are responsible for the broadened range of today's thermoforming techniques and the increased complexity and better performance of thermoformed high density polyethylene products.

INVERTED MALE DRAPE FORMING

In certain instances, sag can be used to good advantage. Excellent parts have been produced from large male molds with inverted male drape forming. The only requirement is a vertically movable platen above the clamps for mounting the mold in an inverted position.

FIGURE 5
Inverted Male Drape Forming



a) Clamp and heat sheet, b) Retract heaters, c) Seal edges of sheet against mold, d) Apply vacuum

Inverted male drape forming is well suited for large-area molds, particularly when the HDPE sheet is over 125 mils in thickness. Nevertheless, it is limited to draw ratios of roughly 1:1 because the effect of gravity is slow and only time and sheet temperature can be used to control the resultant preforming.

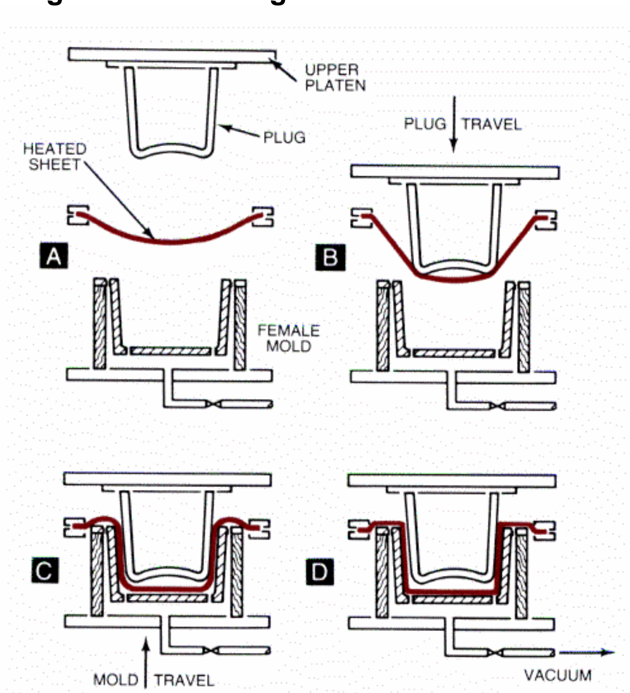
PLUG-ASSIST FORMING

Because a plug and female mold are employed in this technique, two variations are possible. Either the plug may move down before the mold moves up (plug-first variation) or the mold may move up before the plug moves down (drape-first variation). The plug-first technique is most used because it almost always provides best part wall distribution. Therefore, the following comments will pertain particularly to the plug-first procedure shown in Figure 6.

The plug should have low thermal conductivity and be capable of withstanding elevated temperatures of about 340°F at the surface for extended periods. Heated plugs cast or machined from aluminum are recommended. On the other hand, temperature control of the plug is not as critical as that which is required for the mold itself. Ordinary strip heaters with "on-off" thermostatic control will suffice.

Excellent results have been obtained by shaping the plug to conform to the shape of the mold cavity. In general, it should be about 10 to 20% smaller in length and width (or diameter) where these dimensions are on the order of 5 in. or more. For a smaller plug, dimensions should be reduced by more than 20%, allowing at least a 1/2 in. clearance where practical, because insufficient clearance can cause non-uniform thinning. In all cases, the effective height of the plug should be greater than the cavity depth to provide an adequate range of adjustment. Furthermore, all corners should be very generously radiused.

FIGURE 6
Plug-Assist Forming



a) After heaters are retracted, b) Move plug down to partially preform, c) Move mold up to complete preform and effect seal, d) Apply vacuum

Plug assist forming combines the principles of thinning discussed above for both male and female drape forming. That is, increased plug penetration tends to put more material at the bottom of the part. Reduced penetration thickens the top. By judiciously balancing these two effects, excellent wall uniformity can be obtained. For optimum results, the plug should penetrate to about 70-80% of the cavity depth.

To help avoid "mark-off" problems, the surface temperature of the plug should be maintained at about 340°F. This will be well above the crystalline melting point of the polyethylene resin, but probably just below the actual sheet temperature at the time of forming. If the plug draws too much heat from the sheet, a slight "mark-off" may occur. Contact time between the plug and the hot sheet should also be held to a minimum.

Another way to avoid "mark-off" problems is to cover the plug with felt. With a felt covered plug, the plug does not have to be heated, eliminating the need for temperature control. Felt also corrects any problems caused by molten sheet sticking to the plug.

Plugging speeds up to 22 in./sec. have been successfully used. The air pressure between the sheet and mold, however, may restrict mold speeds as the mold moves up around the plug. This pressure keeps the sheet away from the mold and against the plug, allowing more material to be drawn into the cavity for better material distribution. If this pressure gets too high due to excessive mold speeds and/or insufficient clearance, it can blow a hole in the sheet. For the 0.7:1 draw flower box illustrated in Figure 7, the mold speed was 8 in./sec. and the smallest clearance was 3/4 in. In this example, the air pressure between the sheet and the mold was easily controlled.

For deeper or otherwise more difficult parts, partial vacuum may become necessary to withdraw some of the air from under the sheet as the mold moves upward. The rate of evacuation should be sufficient to prevent excessive pressures, but less than the rate of displacement of the air by the plug.

FIGURE 7
Planter Boxes Formed by Plug-Assist Technique

The use of a plug will add to the initial tooling costs. These costs are often quickly regained in subsequent material savings. Plugging procedures provide a substantial improvement in wall uniformity and permit the use of lighter gauge sheet to form equivalent parts. To illustrate potential improvement, the flower box shown in Figure 7 was formed by both female drape and plug-assist techniques in the same mold.

Starting sheet gauge was 187 mil in both instances. With drape forming, the boxes exhibited a wall thickness variation at one cross-section of 0.120 in. This variation was held to 0.029 in. with plug-assist forming. Thus, plugging reduced the variation to only 25% of the best achieved with simple drape forming.

VACUUM SNAP-BACK FORMING

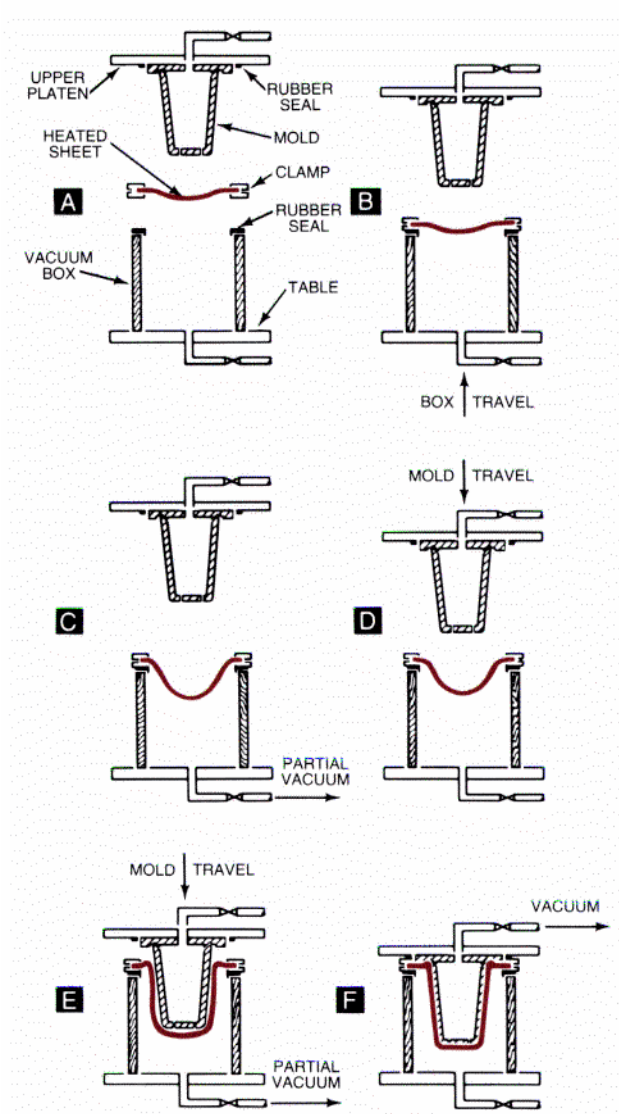
In this technique, the preforming step can be controlled without the mechanical contact inherent to plug-assist forming. Thus, the vacuum snap-back technique is ideal for producing many deep drawn HDPE items. Draw ratios greater than 1.5:1 have been demonstrated with excellent results.

Figure 8 shows the full procedure required for the highest draw ratios. Control of the partial vacuum in the vacuum box is exceedingly important. The vacuum is applied in two steps to accomplish two different results. The first-stage vacuum (Step C) draws the sheet into the box. This thins out the area that will become the bottom of the final part. The amount of thinning will depend, of course, on how far the sheet is drawn. As a general rule, the center will thin roughly 50% if the sheet is drawn to a depth equal to 50% of the minimum clamp opening. When the bottom of the mold contacts the sheet, very little additional thinning occurs in this area. The second-stage vacuum (Step E) then helps distribute the areas that will become the sidewalls of the finished item.

For draw ratios less than 1.5:1, the second-stage vacuum may not be needed. For larger and shallower draw parts, the vacuum box may not be required, and the inverted male drape forming technique can be used.

When the partial vacuum is applied in two stages, sufficient time must be allowed for controlling the second stage. Depending on the mold height, a mold speed of 8 in./sec. or less generally provides sufficient time if the timer for the solenoid-operated vacuum valve is capable of controlling to 1/60th of a second or less. If only one vacuum stage is necessary, faster mold speeds may be used simply to reduce the cycle time.

FIGURE 8
Vacuum Snap-Back Forming

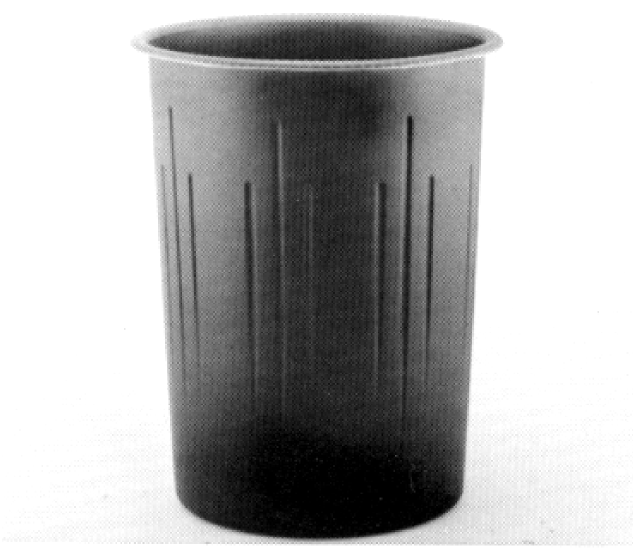


a) After heaters are retracted, b) Seal vacuum box against clamps, c) Apply partial vacuum to box, d) Turn vacuum "off" as mold descends, e) Reapply partial vacuum just before mold contacts sheet, f) Apply full vacuum to mold as mold seals against clamp

A vacuum box can be a simple, four-sided plywood box - open at top and bottom - which will withstand the low-pressure operation. It must seal on the clamp frame or sheet to prevent loss of vacuum. The front and back of the box may have clear sheet sections to allow observation of the sheet during the forming process. These clear sections also allow use of an electronic eye, if needed, to more accurately control preform depth.

When using a vacuum box, the bottom of the formed part can be made thicker by decreasing depth of the preform draw. Conversely, preforming to a greater depth will make the bottom of the part thinner. At the extremes, excessive preforming causes webbing and inadequate preforming can result in tearing of the sheet as the mold descends. Generally, the sheet should be preformed to a depth equal to about 50% of the mold height.

FIGURE 9
Vacuum snap-back formed container
(5-gal. capacity) with 1.5:1 draw ratio



In the vacuum snap-back technique, the mold might appear to function like a plug assist. Its temperature, however, should be accurately controlled with circulating water held in the vicinity of 190°F. A vacuum snap-back mold requires the same temperature control as any other mold suitable for HDPE. Plugs and molds should not be confused with respect to operating temperatures. Figure 9 illustrates a 5-gal. container with 1.7:1 draw ratio.

BILLOW-PLUG FORMING

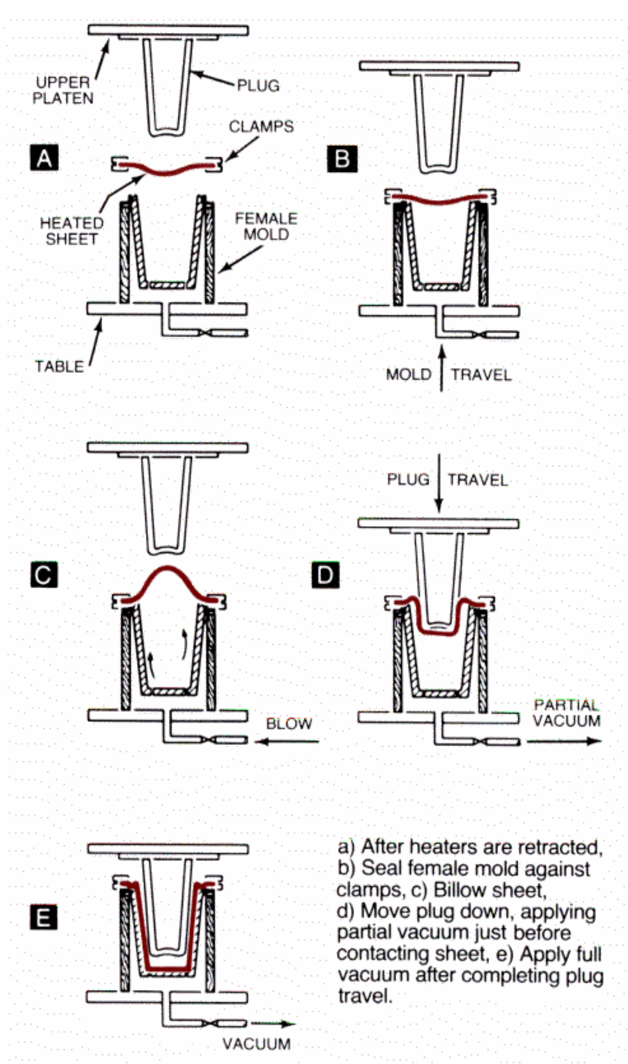
The billow-plug technique (Figure 10) has been used to form parts with draw ratios up to 1.5:1. The two most important variables are billow height and plug penetration. Billow height is the height to which the sheet is blown. Plug penetration is the maximum distance the plug travels into the cavity. The wall distribution is largely controlled by these two factors.

The bottom of the parts can be made thicker, or the sidewalls thinner, by increasing the penetration of the plug or by decreasing the height of the billow. Optimum results have been obtained by billowing to a height equal to 50-75% of the mold depth. Billowing too high will produce excess material and cause webbing. On the other hand, the plug may tear the sheet if the billow is low.

A billow pressure of about 3 psig (6 in. Hg) under the mold has proved to be adequate. These relatively low pressures allow more time to complete the billowing action and permit better control over the billow height.

In many cases, it is essential to provide some means for controlling the pressure under the sheet as the plug descends. The air between the sheet and the mold should be evacuated more slowly than the plug displaces it. Enough pressure should be maintained to keep the sheet off the sides and edges of the mold, allowing more material to be drawn into the cavity. Excessive pressures may blow a hole in the sheet. Since very small vacuum holes are required with HDPE, venting through these holes to atmosphere is generally not adequate. Instead, it is best to evacuate the mold directly into the vacuum tank. To control pressure during this critical phase of the operation, plug speeds should not exceed 8 in./sec. In addition, the timer controlling the solenoid-operated vacuum valve should be adjustable to 1/60th of a second or less.

FIGURE 10
Billow-Plug Forming



This technique is suitable for essentially the same products as those that can be formed by the vacuum snap-back process. However, since the billow-plug technique involves a female mold, certain top lip or edge configurations may be easier to form. On the other hand, billow techniques are difficult to control unless the sheet is held to close tolerances.

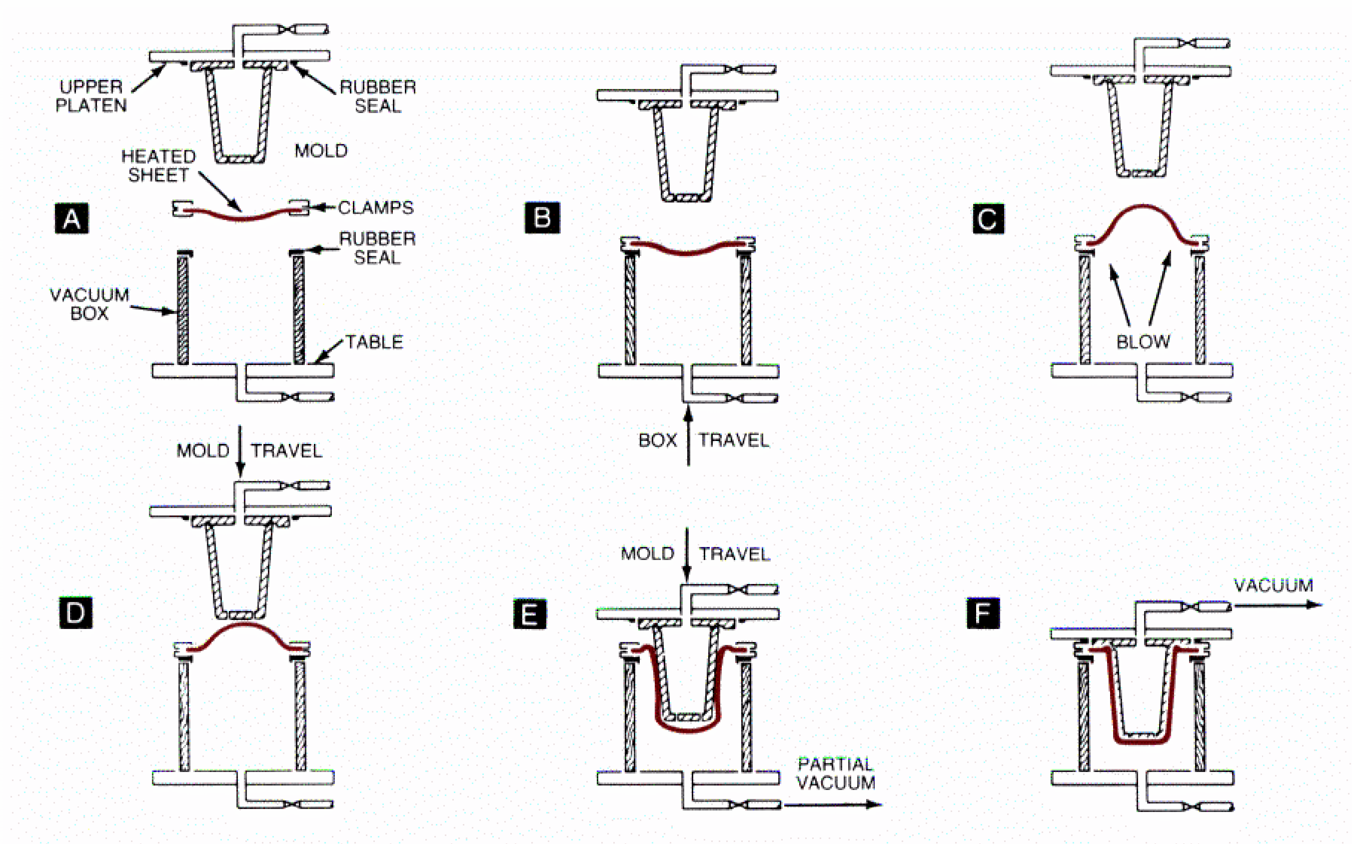
BILLOW SNAP-BACK FORMING

Billow snap-back forming, also known as reverse-draw forming, is almost identical to vacuum snap-back forming. The only difference is that the hot sheet is preformed by billowing (Figure 11) prior to drawing it into a vacuum box.

Wall uniformity of the finished part is governed largely by the billow height (height to which the sheet is blown upward). The bottom of the part becomes thinner as the billow height is increased. Billowing too high will cause webbing. With insufficient billow, the mold may tear the sheet as it travels into the vacuum box. For most purposes, optimum billow height is between 50 and 75% of the mold height. Strict control of the partial vacuum operation is extremely critical. Therefore, slow mold speeds are preferred with the billow snap-back forming method.

FIGURE 11
Billow Snap-Back Forming

a) After heaters are retracted, b) Seal box against clamps, c) Billow to desired height, d) Turn off air and start mold down, e) Just before contacting sheet, apply partial vacuum to box, f) Switch to full vacuum on mold as mold seals against clamps

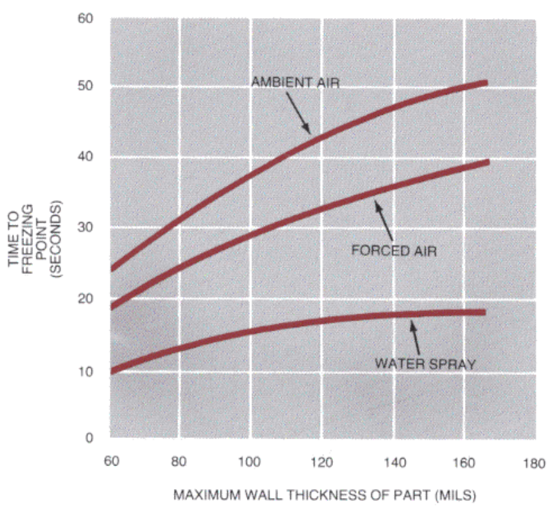


COOLING STAGE

Part cooling procedures are extremely important because, in many cases, cooling time on the mold constitutes a major portion of the overall cycle. Obviously, this stage deserves careful consideration. The effectiveness of ambient air, forced air and water spray cooling are compared graphically in Figure 12.

To provide a reference point, the data are plotted against the time required to reach the crystallizing (freezing) point of the polymer. The crystallizing point occurs when natural sheet goes from "clear" to semi-translucent white. "Ambient Air" represents an environment of about 68°F (20°C) without drafts or other accelerated cooling conditions. By directing air via fans on the parts immediately after forming, cooling time may be reduced by more than 20% as shown. A fine water mist can lower cooling requirements as much as 70%; however, water spray may produce "pock marks" on a molten polyethylene surface. To eliminate pock marks, forced air is used to "set" the surface, and water mist is used for final cooling. Since uneven cooling can cause part warpage, water mist cooling is not recommended for most operations. It is hard to direct uniformly over the part and can be messy to handle. Water mist sprays, however, can be quite useful in selected large part applications.

FIGURE 12
Comparison Of Various Cooling Procedures.



SUMMARY

Seven basic techniques can be utilized to thermoform high quality parts from Marlex high density polyethylene sheet. The relative merits of these techniques are outlined in the appended Selection Chart. Using these forming methods, innovative thermoformers are developing and marketing an impressive array of products. Some of these products are aimed at industrial applications such as cattle feeders, tote boxes, automotive dunnage trays and shipping containers. A wide variety of thermoformed products are also designed for home and play. A few of these include; grass catchers, storage bins, canoes, snow sleds and pickup truck bed liners.

In addition to the more conventional forming techniques, several specialized methods have been developed. Among these are solid phase pressure forming, twin-sheet thermoforming and continuous forming on vertical rotary machines. These sophisticated thermoforming techniques, along with advances such as robot trimming with programmed water jets or lasers, are rapidly expanding HDPE market potential for the custom thermoformer.

TROUBLESHOOTING GUIDE

To help answer questions and find solutions to various thermoforming problems, the following Troubleshooting Guide has been prepared. The problems illustrated in that guide have been keyed to situations common to several types of machines. Although it is impossible to cover all problems that may arise in a thermoforming operation, every effort has been made to make this guide as helpful as possible. For each problem listed, typical causes and solutions are shown in the order of their likelihood.

We have also included a Forming Technique Selection Guide on the following page for HDPE sheet.

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FORMING TECHNIQUE SELECTION GUIDE FOR HIGH DENSITY POLYETHYLENE SHEET

					Tooling Required				Equip. Required (3)		
Type of Forming	Maximum Draw Ratio (1)	Glossy Surface	Means of Texturing (2)	Uniformity of Walls at Max. Draw	Male Mold	Female Mold	Plug	Vac. Box	Lower Platen	Upper Platen	Comments
Female Drape	0.7:1	Inside	Mold	Fair		X			X		Only for shallower, simpler items. Permits closest spacing of multiple molds.
Male Drape	1:1	Outside	Sheet	Fair to Good	X				X		Only for smaller, simpler items. Somewhat less thinning than with female molds.
Inverted Male Drape	1:1	Outside	Sheet	Good	X					X	For large-area male molds where sag might be a problem.
Plug Assist	1:1	Inside	Mold	Excellent		X	X		X	X	Best for most tote boxes and similar products.
Vacuum Snap-Back	1.5:1	Outside	Sheet	Very Good	X			X	X	X	Best for deep draw items except where lip also requires severe draw, e.g. 1:2 in that area.
Billow-Plug	1.5:1	Inside	Mold	Fair to Good		X	X		X	X	Used for deep draw items where heavier wall is needed in certain lip configurations.
Billow Snap-Back	1.7:1	Outside	Sheet	Good	X			X	X	X	Uses generally the same as for Vacuum Snap-Back forming.

* Airslip and pressure forming are not included in this table. The free forming techniques have also been deleted because high density polyethylene sheet will not yield the transparent canopies usually produced by this procedure. Also, certain proprietary techniques are not covered for obvious reasons.

(1) Based on experience to date
(2) Assumes exterior surface to be textured
(3) Sandwich heaters recommended for all sheet thicknesses over 100 mils

If we may be of further assistance, please contact our Polyethylene Sales and Marketing team. Contact information is available at this web site http://www.cpchem.com/pe/index.asp, along with links to our polyethylene resins and MSDS sheets.

Last revised September 2002

THERMOFORMING TROUBLESHOOTING GUIDE

Observation	Probable Causes	Suggested Solutions
Part Sticking To Mold	A. Part temperature too high	1. Increase the cooling cycle. 2. Slightly lower mold temperature, not departing drastically from 170ºF minimum.
	B. Inadequate draft in mold	1. Increase taper on the mold. 2. Use a female mold.
	C. Mold has undercuts which prevent release of the part	1. Use a stripping frame. 2. Increase the air-eject pressure. 3. Remove the part from the mold as early as possible after forming.
Sheet Sticking to Plug Assist	A. Improper metal plug assist temperature	1. Change the plug assist temperature so it's closer to the resin's melting point. A good, lower-end starting point for HDPE is 300ºF. 2. Coat the plug assist with a release material like Teflon, or cover it with wool felt. Use a mold release compound as a last resort, because it may cause marks on the surface of the sheet.
	B. Wooden plug assist	1. For prototypes, use baby powder or talc as a release agent. 2. In production, cover the plug with wool felt.

THERMOFORMING TROUBLESHOOTING GUIDE

Observation	Probable Causes	Suggested Solutions
Chill Marks or "Mark-Off" on the Part	A. Plug assist temperature too low	1. Increase the metal plug assist temperature to the 300-350ºF range. 2. Cover the plug with wool felt.
	B. Mold temperature too low	1. Increase the mold temperature as needed. The maximum mold temperature setting is about 200ºF for HDPE.
	C. Inadequate mold temperature control	1. Increase the number and/or size of the cooling channels. 2. Check the mold for plugged cooling channels or low water pressure.
Inadequate Conformity of the Sheet to the Mold	A. The sheet is not hot enough to form properly	1. Increase the oven settings and/or heating cycle. The sheet should be wrinkle-free to the clamp frames when it's ready to form. 2. Eliminate air drafts or other causes of uneven heating.
	B. The vacuum is too low – should not drop below 20 in. Hg at the start of the cooling cycle and should rapidly recover to at least 25" Hg to ensure good contact between the sheet and the mold	1. Check the vacuum system for leaks. 2. Add more vacuum holes in the areas of deepest draw. 3. Slightly enlarge the size of existing vacuum holes. 4. Increase the size of the vacuum pump.

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THERMOFORMING TROUBLESHOOTING GUIDE

Observation	Probable Causes	Suggested Solutions
Part Warpage	A. Uneven part cooling	1. Add more water channels to the mold, or increase their size.
		2. Check for plugged water channels or vacuum holes.
	B. Poor wall distribution in the part	1. Change the forming technique according to the information provided in the Selection Guide.
		2. Resolve any problems with uneven heat in the sheet.
		3. Check for sheet gauge variation or non-uniform sheet orientation problems.
	C. Poor mold design	1. Add vacuum holes to the mold.
		2. Add a moat to the mold at, or close to, the trim line.
	D. Improper part design	1. Break up large, flat surfaces with ribs where practical.
	E. The mold temperature is too low	1. Raise the mold temperature to within the normal 165 to 200ºF range, with higher temperatures used for thicker sheet.
Pock Marks on the Part Due to Air Entrapment	A. The mold surface is too smooth, which promotes air entrapment between the sheet and mold	1. Grit blast the surface of the mold so the air can move to the vacuum holes without becoming trapped.
	B. The vacuum is too low	1. Add vacuum holes to the mold – especially in the female radii and deep draw areas.
		2. If the pock marks are in an isolated area, add vacuum to this area or check for plugged vacuum holes. Also ensure the moat is fully sealed around its perimeter.

THERMOFORMING TROUBLESHOOTING GUIDE

Observation	Probable Causes	Suggested Solutions
Shiny Streaks on the Part	A. The sheet was overheated in this area, either during sheet extrusion or when the sheet was heated for forming	1. Lower the oven temperature in the scorched area. 2. Shield the heater with screen wire to reduce heat in the problem area. 3. Extend the heating cycle by reducing overall oven temperature settings. 4. Increase the distance between the heaters and sheet. The minimum allowable distance for HDPE is typically about 8 in. – more for thicker sheet.
Nipples on the Mold Side of the Formed Part	A. The sheet is too hot, and forms into the vacuum holes	1. Reduce the heating cycle and/or oven temperature settings so the wrinkles just barely disappear in the corners of the sheet when forming starts.
	B. The vacuum holes are too large	1. Plug the vacuum holes and redrill them with a smaller bit
Sheet Sag is Excessive	A. The sheet is too hot	1. Reduce the heating cycle as needed. 2. Increase the oven temperature to reduce the sheet's "hang time" in the oven. This action minimizes the effect of gravity on the sheet.
	B. The sheet's melt index value is too high	1. Use a lower melt index resin. 2. Always select extra high molecular weight (EHMW) resins when web problems are expected – i.e. large, flat parts like portable toilet doors.

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THERMOFORMING TROUBLESHOOTING GUIDE

Observation	Probable Causes	Suggested Solutions
Poor Wall Distribution in the Formed Part	A. Improper sheet sag	1. Use a different technique from the Forming Guidelines chart.
		2. Select a resin with the right melt index for the application.
	B. Poor sheet gauge control	1. Ensure the sheet gauge variation meets specifications.
	C. Hot or cold spots in the sheet	1. Improve sheet-heating procedures to achieve uniform sheet temperature.
	D. Too much sag in the center of the sheet	1. Use screen wire to reduce oven heat to the center of the sheet.
		2. Change to a resin with a lower melt index value to improve the sheet's melt strength.
The Sheet Sag Varies Between Blanks	A. The sheet temperature varies between blanks when removed from the oven	1. Eliminate air drafts through the oven by shielding the open sides. Also close open building doors and power vents to minimize air flow through the building.
	B. The sheet properties are not uniform	1. Ensure the sheet has proper regrind levels. Also prevent contamination with incompatible resins.

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Observation	Probable Causes	Suggested Solutions
Shrink Marks are Observed on the Part – Especially in Corner Areas (inside radii of the mold)	A. The mold's vacuum is low	1. The vacuum system may be improperly sized. Increase pump size as needed. 2. Check for vacuum leaks or plugged vacuum holes.
	B. The mold surface is too smooth	1. Grit blast the mold surface with #30 to #60 grit to help air move to the vacuum holes.
	C. The part is shrinking away from the mold during the cooling cycle	1. Increase the mold temperature (up to 200ºF maximum). 2. Add vacuum holes and increase vacuum pump size as needed. In rare cases, you may need to add air pressure to the part opposite the mold surface to ensure good contact between the sheet and mold.
Distortion of the Part After it is Removed from the Mold	A. The part was removed from the mold while it was too hot	1. Increase the cooling cycle. Part temperature should be close to the mold's temperature when it is removed from the mold. 2. Use fans or water mist to improve cooling while the part is on the mold. Note – if water mist is utilized, the mist must be fine enough to evaporate before it hits the sheet. Also, water mist cannot be applied at the very start of the cooling cycle, or pock marks will result. 3. Use cooling fixtures.

THERMOFORMING TROUBLESHOOTING GUIDE

Observation	Probable Causes	Suggested Solutions
Webbing	A. The sheet is too hot when formed	1. Reduce the heating cycle and/or oven temperatures.
		2. Increase the distance from the heating elements to the sheet.
	B. The melt strength of the resin is too low, so sheet sag is excessive	1. Select a lower melt index resin for the application.
		2. Raise oven heats and shorten the heating cycle to minimize the effects of gravity.
	C. The draw ratio is too high where the webs form	1. Redesign the mold to reduce areas of deep draw.
		2. Use a mechanical assist to “push” the sheet into the deepest draw areas.
		3. Change the orientation of the sheet so the direction of extrusion is in-line with the ribs.
	D. Poor vacuum	1. Add vacuum holes to the mold, and ensure that no air leaks past the moat.