



**TECHNICAL TIPS FOR BLOW MOLDING
MILK, WATER AND JUICE BOTTLES**

***The Advantages and Disadvantages of
Ovalized Tooling in the Dairy Industry***



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ABSTRACT

Ovalized tooling can improve blown bottle quality and possibly reduce resin usage. However, it is important to realize that any innovation has limitations, and what may be good for one dairy may not be good for another. It is also important to know that using ovalized tooling requires precision alignment in the tools. Thus, the blow molding machine operator must be vigilant and constantly observant: Are the parisons dropping straight? Are the ovalized areas on the parisons in the proper positions? The operator has to monitor the process even more closely than with round tooling to make sure that acceptable containers are produced. All of these issues and others must be considered in making the decision to convert to ovalized tooling; obviously, the equation is more complicated than the cost of the tooling versus the payback in decreased resin use.

PART 1: THE ECONOMY OF OVALIZED HEAD TOOLING

The one-gallon polyethylene milk bottle has been significantly improved since its inception more than 20 years ago. Since that time, advances in bottle design, molding equipment, handling equipment and the polymers used to make the bottles themselves have enabled bottle weights to be reduced substantially, for example. When first introduced, the polyethylene milk bottle weighed about 100 grams. Today's typical milk bottle weighs between 60 and 65 grams. This weight reduction results in sizeable resin savings for the packager and gives the polyethylene bottle a competitive advantage in the marketplace.

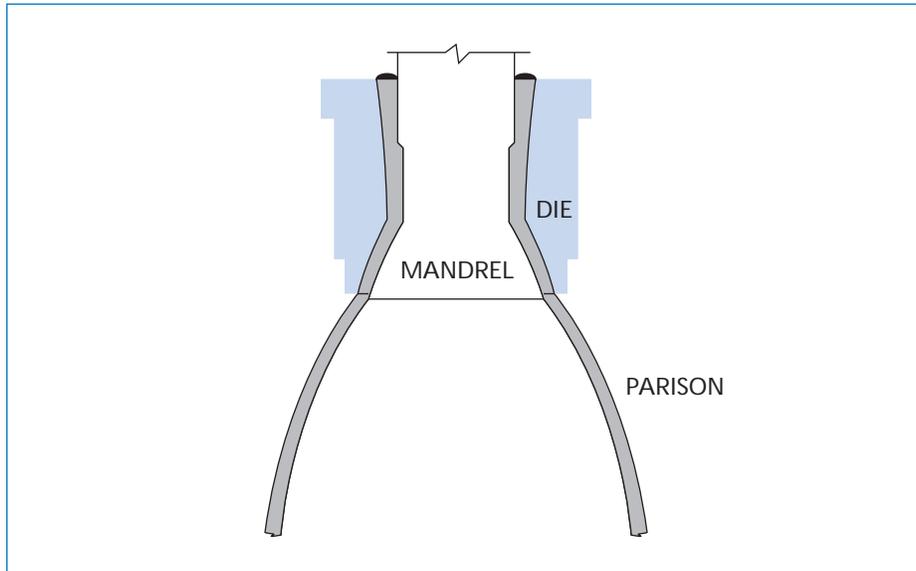
Dramatic reductions in package weight are not likely to continue. However, even very small additional weight reductions can mean significant savings today because of the tremendous number of bottles currently produced. One technique for achieving additional weight reduction while maintaining the performance standards of the bottle is by using ovalized head tooling. Bottles produced with ovalized tooling have a more uniform wall thickness than those produced with standard round tooling. Ovalized tooling has been available for many years, but to date has not been widely used in the dairy industry.

This article reviews the performance properties and economic advantages for one-gallon milk bottles produced with ovalized head tooling over those produced with standard round head tooling.

THE FUNCTION OF OVALIZED TOOLING

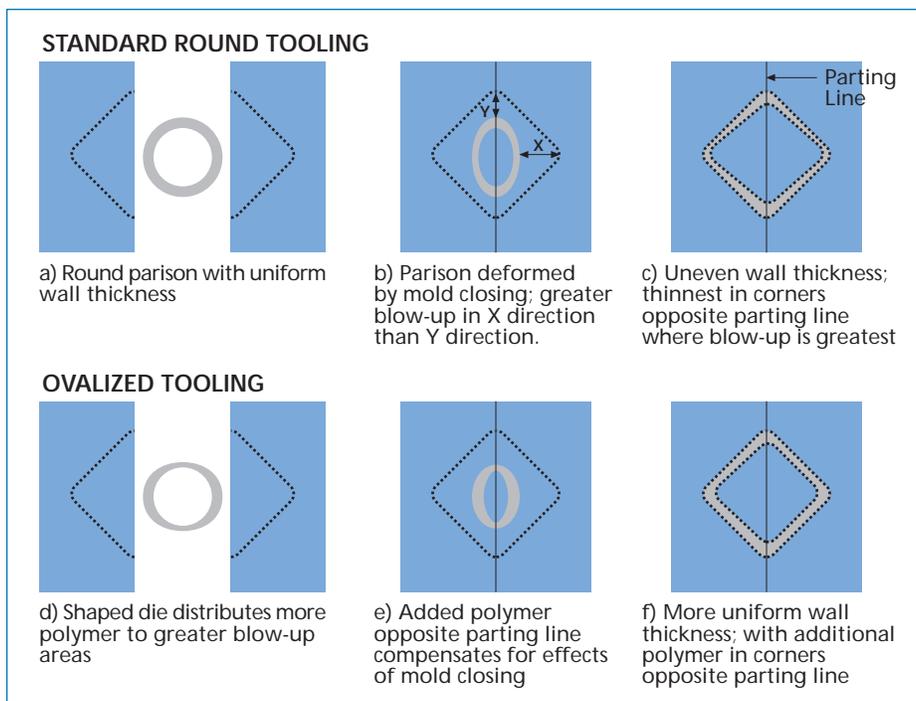
The parts of the head tooling which form the parison for blow molded bottles are the die and the mandrel. As shown in Figure 1, the die forms the outer surface of the parison, while the mandrel forms its inner surface.

Figure 1. Parts of the head tooling which form parison



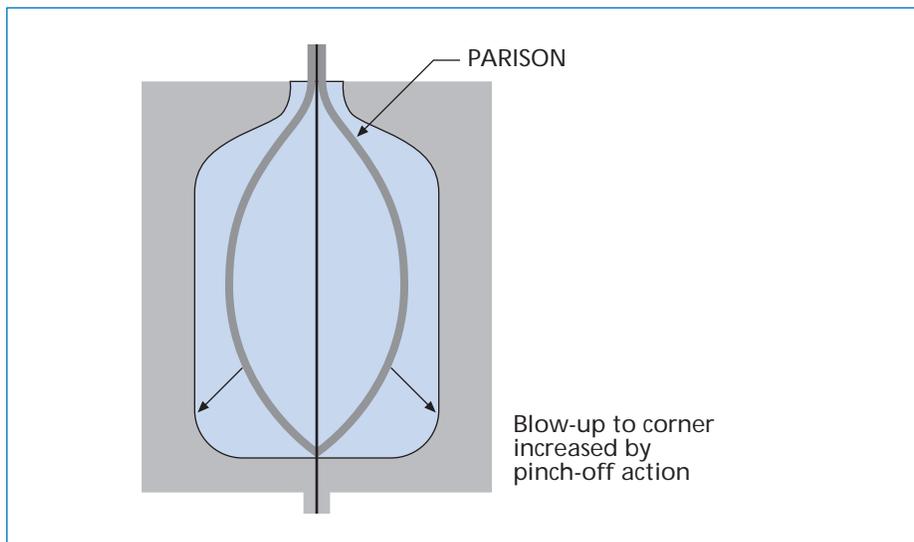
In standard tooling, both die and mandrel are round and concentric, forming a round parison of uniform wall thickness. As the mold halves close around the parison, they deform the parison, flattening it in the direction of the mold parting line. When air is introduced into the trapped parison, the parison expands out to contact the mold cavity surface. Because of the deformation caused by the mold closing, the parison has greater blow-up (expansion) 90 degrees from the parting line than along the parting line. Greater blow-up results in a bottle with thinner walls.

Figure 2. Effects of mold closing and expansion on parison



In ovalized tooling, the shape of the die or mandrel, and in some cases both, is modified by adding or removing metal in specific areas to selectively decrease or increase the die gap opening. This modification increased the thickness of the parison 90 degrees from the mold parting line and decreases the thickness along the parting halves closing around the parison and results in a bottle with more uniform wall thickness. Figure 2 shows, in an exaggerated way, how the parison is squeezed together by the mold when it closes, and how the parison expands when blown. The thinnest areas of a one-gallon milk bottle made by standard round tooling are the two lower corners opposite the parting line. This thinning occurs when the parison is pinched off: the bottom areas draw together, as shown in Figure 3, increasing the distance the parison must be blown to contact the mold surface.

Figure 3. Parison drawn together by pinch-off



To maintain sufficient thickness in these thin lower corners with standard round tooling, the overall bottle weight must be increased. This increase also results in excess polymer in all the areas along the parting line – and increased cost. Ovalized tooling distributes more polymer to the areas of the parison experiencing the greatest blow-up. More polymer is blown to the corners 90 degrees from the mold parting line than to other parts of the bottle. With optimized ovalized tooling, all four corners have equivalent thickness. The bottom line is that a bottle made with standard round tooling would have to be substantially heavier to match the performance properties of a bottle made with ovalized tooling.

EVALUATION METHOD

To evaluate the effects of ovalized tooling, one of the two central heads of a UNILOY* 350 R2 four-head blow molding machine was fitted with an ovalized die, while standard round tooling remained on the adjacent head. Molds and blowing mandrels were identical. The ovalized die used was a “shelf item” with 0.003 inch ovalization, available through UNILOY (Part number 865821).

A PETROTHENE® high density polyethylene resin (melt index = 0.65 g/10 min.; density = 0.959+ g/cm³), specifically designed for high speed production of thin-walled containers, was used in this evaluation. Bottles with target weights of 53, 55, 57, 59, 61, 63, and 65 grams were produced on each of the two blow molding heads. Bottles used for this evaluation fell within 0.2 grams of the target weight; bottles with handle webbing or resin folds were discarded; and parison swing was held to a minimum. Based on the parameters, ten bottles from each

*UNILOY is a registered trademark of Johnson Controls, Inc.

head were selected at each of the seven target weights. The 140 bottles accepted for the study were tested for top-load capacity and wall thickness uniformity.

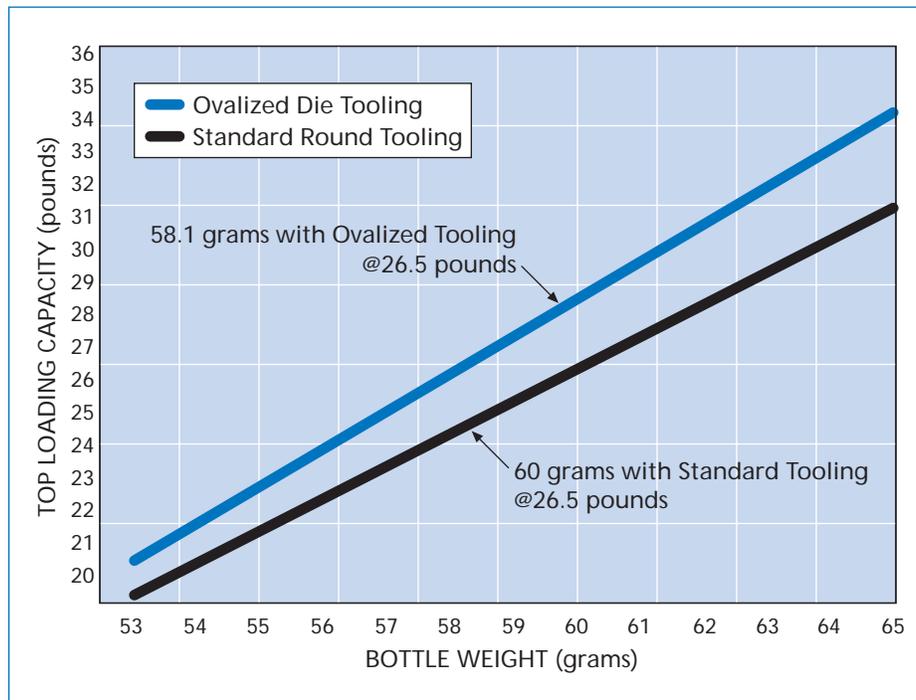
Top-load capacity is the maximum amount of force in pounds that can be applied to the top of a bottle without deforming the bottle. This capacity is important because similar stress is applied to the bottle during filling operations. Top-load failures usually occur at the weakest section of the bottle shoulder. In this study, the top-load capacities of the bottles were measured with a Model 51008 Testing Machines, Inc. Universal Tester and the results were statistically normalized.

EVALUATION RESULTS

Top-load Capacity

Figure 4 shows that a 60-gram bottle produced by standard round tooling has a top-load capacity of 26.5 pounds. The same load capacity is withstood by a 58.1-gram bottle produced by ovalized tooling. The performance of the two bottles is similar, but the use of ovalized tooling results in a savings of 1.9 grams per bottle. Additionally, since the curves in Figure 4 are divergent, bottles blown from standard round tooling must increase in weight at increasing rate to match the performance of bottles produced from ovalized tooling. Thus, as bottle weight and performance requirements increase, even greater savings can be realized by using ovalized tooling.

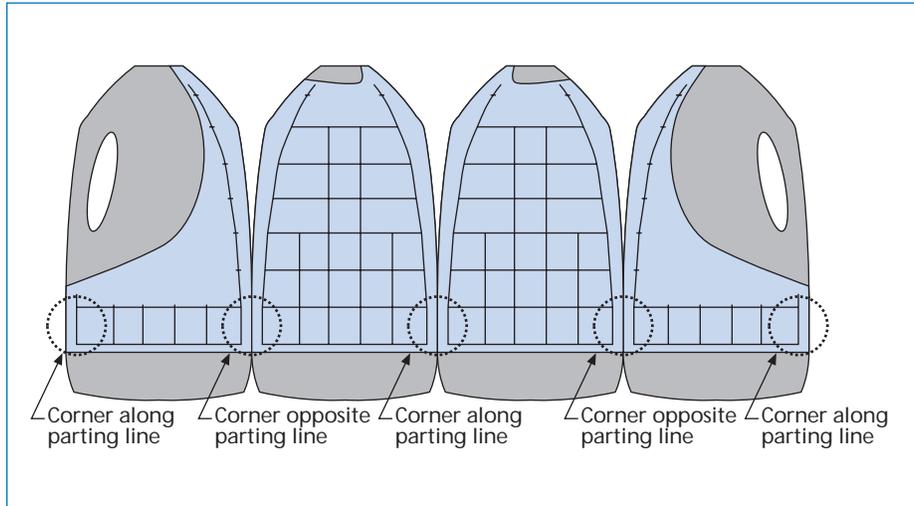
Figure 4. Top-load capacity of bottles



Thickness Uniformity

To analyze wall thickness uniformity, all the bottles were cut apart and marked with a grid pattern as shown in Figure 5. Wall thickness was measured at each intersection, resulting in 108 thickness values for each bottle in a series. These data were statistically analyzed and significant differences were noted between bottles made with standard and ovalized tooling. To avoid confusion, all the data are not presented. Instead, as the lower corner areas opposite the parting line are the thinnest areas of a bottle made with standard tooling, and therefore most susceptible to failure when dropped, the data provided focuses on these areas (circled in Figure 5). The parts of the bottles beneath the circled areas had textured surfaces, making accurate thickness measurements difficult.

Figure 5. Locations of wall thickness measurements

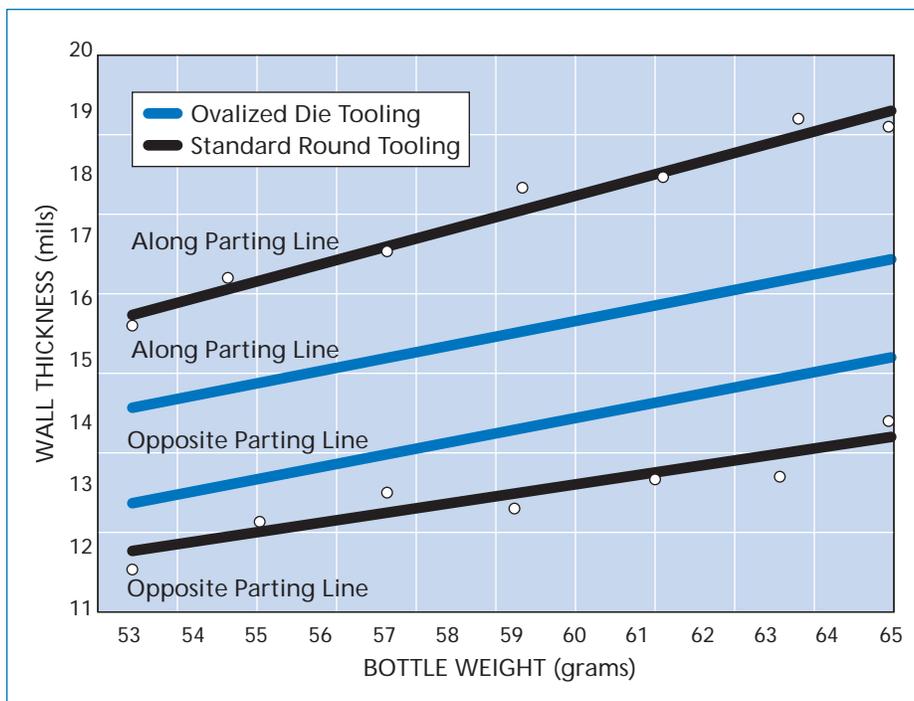


In each corner of the bottles, four thickness values were compiled. Then the opposing corner thicknesses were statistically normalized to give a single thickness value for opposing corner. The results are shown in Figure 6, with one set of values corresponding to the wall thickness of the corners along the parting line, and the other set of values indicating the wall thickness of the corners opposite the parting line.

Figure 6 clearly shows that ovalized tooling redistributes polyethylene from the corners along the parting line to the opposing corners. Bottles made with the ovalized tooling were consistently thinner along the parting line and thicker opposite the parting line than bottles made with standard tooling.

Based on the results shown in Figure 6 and the remaining wall thickness data that were analyzed during the evaluation, it is evident that ovalized tooling yields a stronger bottle with a more uniform wall thickness than standard round tooling.

Figure 6. Bottle corner wall thickness



ECONOMICS

Now that the theory of ovalized tooling has been translated in actual experimental results, it is time to discuss options and potential savings to the processor. There are two major options available:

1. To design, fabricate and develop optimized ovalized tooling
2. To purchase "off-the-shelf" ovalized tooling

Thoroughly optimized ovalized tooling enables the processor to make bottles with uniform corner wall thicknesses. However, the developmental cost of such a system can be high and design factors such as mold configuration, molding conditions and polymer properties have to be maintained within very close tolerances for best results.

On the other hand, off-the-shelf ovalized tooling, the type used in this study, is relatively inexpensive and quite flexible in terms of processing conditions and ability to produce high quality bottles with a wide range of polymers.

Based on our evaluation, even off-the-shelf ovalized tooling can yield bottle weight savings of 3-4% over production operation using standard round tooling to make 60-65- gram bottles without sacrifice in performance. Lighter weight means a savings of 1,200 to 1,600 pounds of polymer per truckload. A processor who uses a truckload of polyethylene per month can easily determine the dollar savings based upon current pricing. The cost of the ovalized die used in this study was about \$300 per head and the installation time was approximately two hours per head. The return on investment for this type of system is obviously quite high.

PART 2: IMPROVING PLASTIC BOTTLE PRODUCTION

Considerable attention has been given to the advantages of ovalized head tooling in the production of one gallon milk bottles. An initial study (*Dairy Foods* magazine, known at the time as *Diary Record* magazine, Nov. 1982) compared off-the-shelf ovalized tooling with standard round tooling, showing the improved top-load capacity and better resin distribution that ovalized tooling can offer at equivalent bottle weights. The *Dairy Foods* study emphasized however, that the primary benefit derived from ovalized tooling is a superior bottle without changing its weight. The trade magazine also noted that if reduction of bottle weight is desired, ovalized tooling can help maintain properties in the lighter bottle, but tighter control of the blow molding process is required. More recently, studies at LyondellBasell determined that 3 to 4% reductions in bottle weight are possible without sacrificing strength and quality by using available off-the-shelf ovalized tooling.

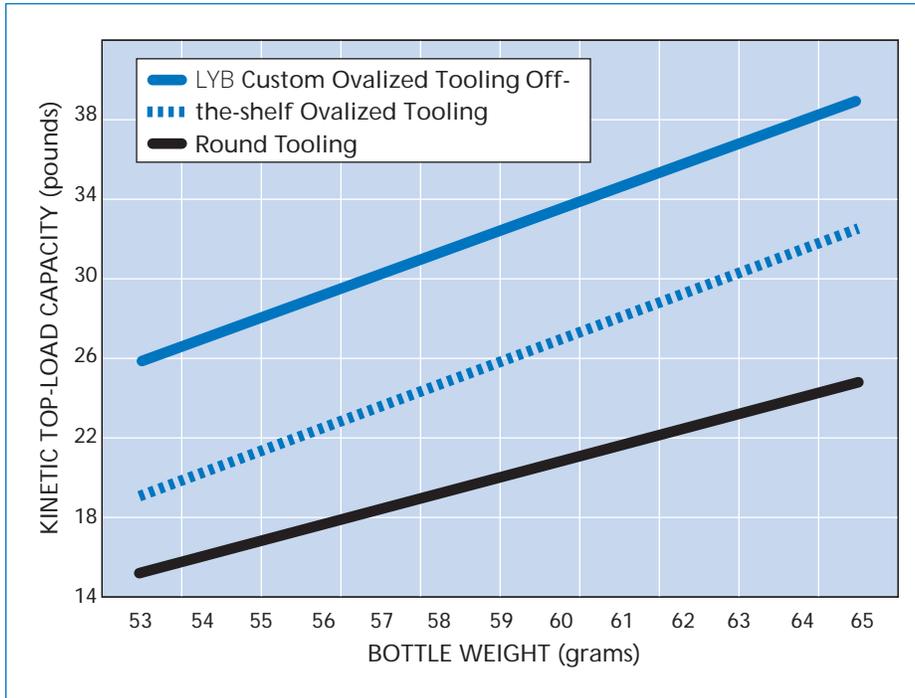
Although the off-the-shelf ovalized tooling produced a superior bottle compared to round tooling, analysis of the process and bottle design prompted LyondellBasell to design ovalized tooling to our own specifications. An evaluation of the resulting LyondellBasell ovalized tooling was conducted similarly to the study reported in Part 1 of this article. Overall, we found that custom-designed ovalized tooling resulted in potential weight reductions of up to 10 to 12% over bottles made with standard round tooling.

The same PETROTHENE high density polyethylene resin was used in the evaluation and bottles with target weights of 53, 55, 57, 59, 61, 63 and 65 grams were produced with each tooling. Acceptable bottles were within 0.2 grams of their target weight; bottles with handle webbing or resin folds were not acceptable for evaluation; and parison swing was held to a minimum. Based on these acceptability parameters, 15 bottles from each type of tooling were selected at each of the seven target weights. The resulting bottles were tested for kinetic top-load capacity and wall-thickness uniformity.

Kinetic Top-load Capacity

Testing for kinetic top-load capacity was performed with a Testing Machines, Inc. Universal Tester Model 51008 and the test results were statistically normalized. Figure 7 illustrates the kinetic top-load capacity (at various bottle weights) of the bottles produced. The results show the superior kinetic top-load characteristics ovalized tooling can provide. Bottles made with the LyondellBasell custom-designed ovalized tooling exhibited the best results, and the off-the-shelf ovalized tooling also performed substantially better than the round tooling.

Figure 7. Kinetic top-load capacity of bottles



Wall-thickness Uniformity

To analyze wall-thickness uniformity, the bottles used for the kinetic top-load testing were cut apart and measured in the locations shown in Figure 8. The wall-thickness values at the measurement points indicated in Figure 8 are plotted for 57-gram bottles in Figure 9. Figure 9 compares bottles from the round tooling to those from LyondellBasell custom-designed ovalized tooling and off-the-shelf ovalized tooling.

Figure 8. Locations of wall-thickness measurements

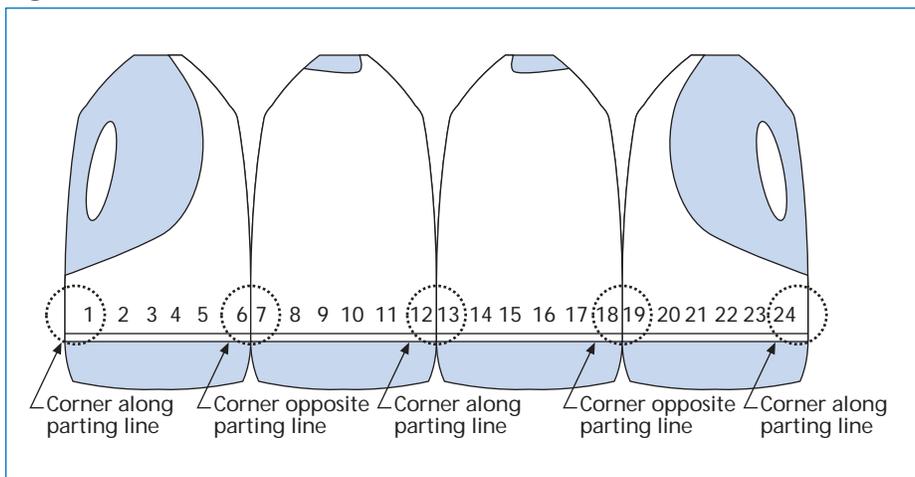
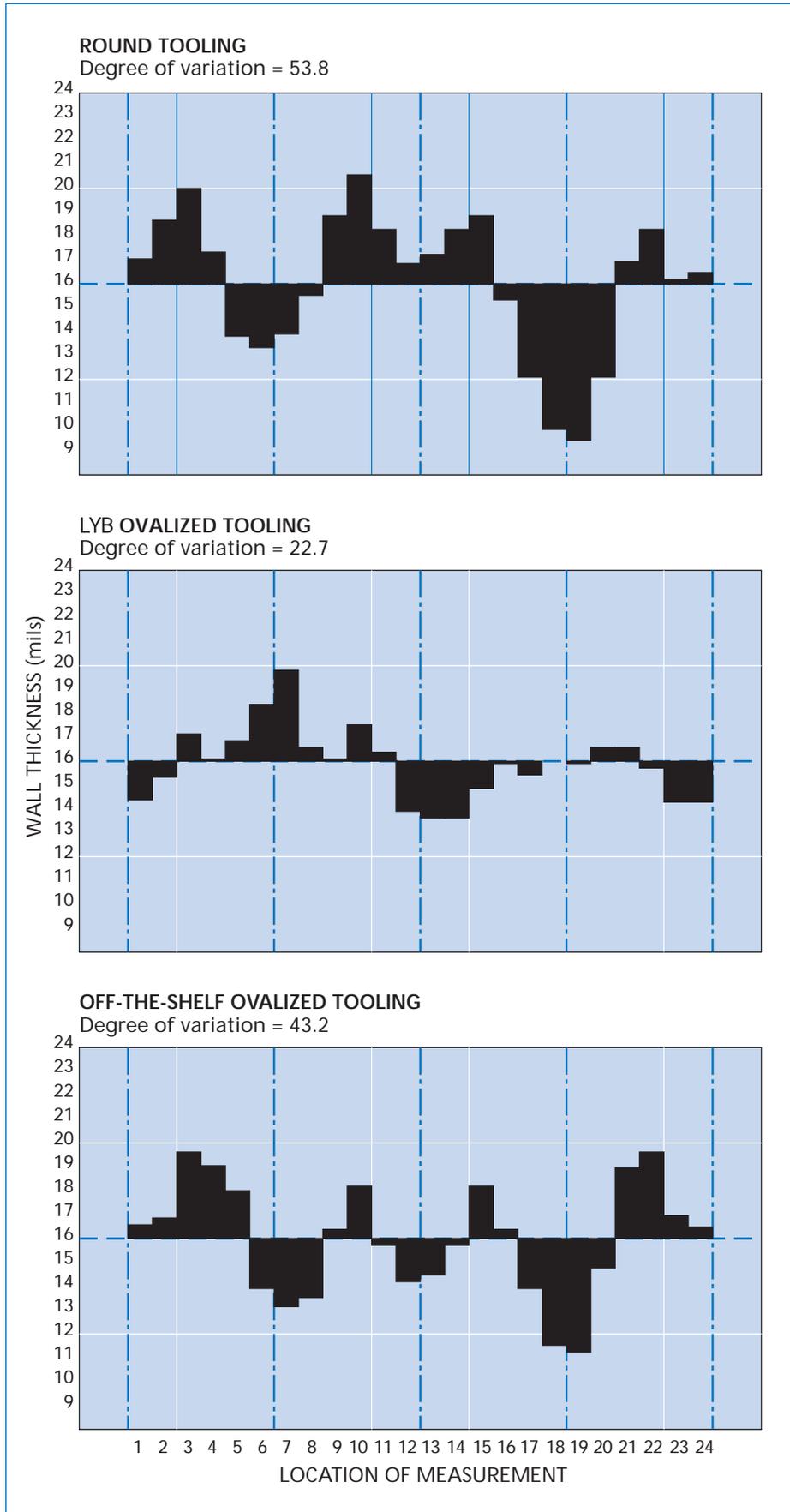


Figure 9. Wall-thickness uniformity of 57-gram bottles



As mentioned earlier, the main reason for ovalized tooling is to improve wall-thickness uniformity. With ovalized tooling, more resin is distributed to the corners opposite the mold parting line, the thinnest areas on a bottle made with round tooling. It is apparent in Figure 9 that the LyondellBasell customer-designed ovalized tooling increased the wall thickness in these corners. The increase in minimum wall thickness from 9.6 mils in bottles made with round tooling to 13.8 mils for bottles made with LyondellBasell ovalized tooling was a dramatic improvement.

While analyzing the data, it was found that the mean wall thickness at the points measured was 16 mils for a 57-gram bottle, independent of the tooling used. This mean thickness is represented by the broken horizontal lines in Figure 9. The degree of wall thickness variation can be visualized by comparing the magnitudes of the black bar graphs. Bottles from the LyondellBasell ovalized tooling appear to be the most uniform (i.e., their bars in Figure 9 are smaller, indicating less variation), while the round tooling produces the least uniform products.

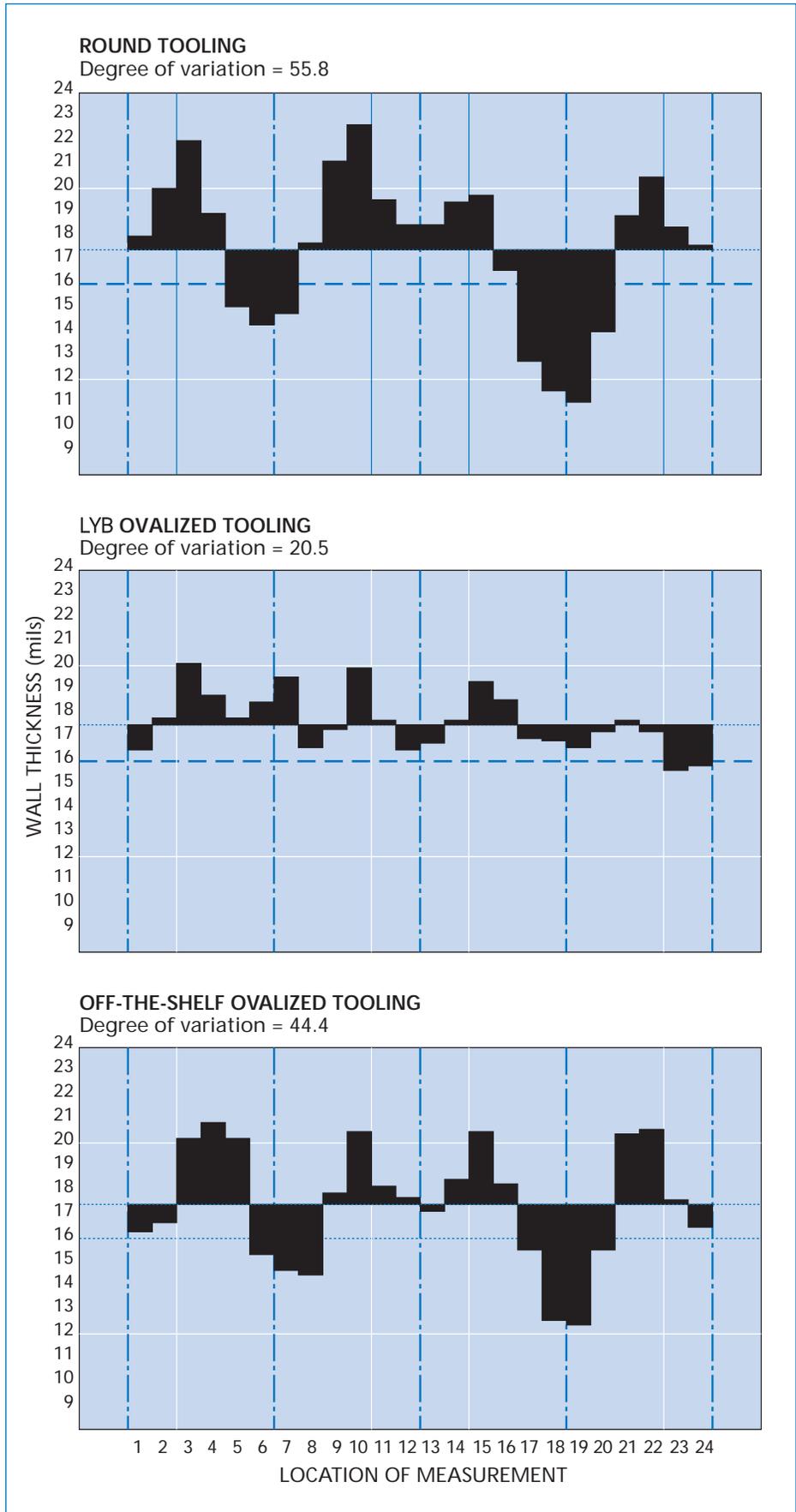
This visual comparison can be quantitatively confirmed by adding up the deviation from the mean at each of the 25 measuring points. In a 57-gram bottle, the mean wall thickness is 16 mils. If at a particular point the actual wall thickness is 19 mils, the deviation at that point is 3 mils. Similarly, if the wall thickness is 12 mils, the deviation is 4 mils. Adding all 24 deviation values gives the “degree of variation.” With a perfectly uniform bottle, the degree of variation would be zero, and the plot would consist of a straight line. The more the wall thickness varies from the mean, the larger the number and the heavier the bar. Results of these calculations are also presented in Figures 9 and 10.

The degree of variation for 57-gram bottles made with round tooling is 53.8 for standard round tooling; 43.2 for off-the-shelf ovalized tooling and only 22.7 for LyondellBasell ovalized tooling. This finding confirmed the visual observation that the LyondellBasell tooling produced the most uniform bottles.

Figure 10 shows comparable results for 63-gram bottles. The main difference between the results shown in Figures 9 and 10 is the mean wall thickness of 17.5 mils for the 63-gram bottles. Again, the LyondellBasell custom-designed ovalized tooling showed the least variation in the mean wall thickness among the samples tested. Table 1 lists the results obtained for all the bottle weights tested; the LyondellBasell tooling produced bottles with consistently more uniform wall thickness than did the other two tooling alternatives. Also indicated on Table 1: for every two gram increase in bottle weight, there is only a 0.5 mil increase in mean wall thickness. This fact demonstrated the usefulness of ovalized tooling for producing more uniform bottles, particularly since bottles produced from round tooling may vary more than 10 mils in wall thickness.

Bottle Weight (grams)	Mean Wall Thickness (mils)	Standard Round Tooling	Off-the-shelf Ovalized Tooling	Custom LYB Ovalized Tooling
53	15.0	53.0	43.0	20.2
55	15.5	51.1	42.7	18.7
57	16.0	53.8	43.2	22.7
59	16.5	55.4	46.9	24.1
61	17.0	57.5	46.6	35.0
63	17.5	55.8	44.4	20.5
65	18.0	59.9	50.7	21.6
Average degree of variation		55.2	45.4	23.3

Figure 10. Wall-thickness uniformity of 63-gram bottles



This study has shown that custom-designed LyondellBasell ovalized tooling is an effective means for reducing the weight of one-gallon polyethylene bottles used to package milk, juice and water. The bottles made with this tooling were superior in both kinetic top-load capacity and wall-thickness uniformity. The off-the-shelf ovalized tooling proved to be somewhat less effective, but offered improvement over standard round tooling and was less expensive than the custom-designed alternative.

LIMITATIONS

The LyondellBasell studies have described the potential benefits of converting standard round tooling to ovalized tooling. However, before making the decision to convert, dairies should optimize their current molding procedures and resin combination to improve their bottle performance. If further improvements are desired, the ovalized tooling should be considered as a possible method for producing stronger, lighter bottles. Ovalized tooling is not for everyone; for some processors, round tooling may still be the best option.

Ovalized tooling can produce lower-weight containers without sacrifices in strength. Of course, when a container is produced with less material without mold changes, its volume increases and the pinch-off and flash areas may not cool properly. The mold cavities must be altered to correct for volume and the flash pockets reduced so the smaller volume of pinched-off resin can cool properly. Also, when containers are made lighter and molding cycles faster, more processing problems can occur.

Ovalized tooling produces a parison with a different shape from that produced by round tooling. The thicker sections of parison extrude less smoothly from the die and mandrel opening. These heavier sections flow toward one another and cause the parison to “lip,” or close, at the bottom. This “lipping” can cause the parison to collapse. If this happens, it may be necessary to feed air into the parison as it extrudes. Additionally, with ovalized tooling, the parison must extrude as straight as possible, because any curving of the parison can produce finished containers with very thin wall areas.

Parisons extruded from ovalized tooling to produce lighter weight containers are thinner than those produced from round tooling and have less hot melt strength. Since the mandrel is raised, the tooling opening is reduced and more frictional heat is generated because of higher shear. This increased shear and temperature may increase resin die swell, causing the melt to hang up on the die bushing face or stripper bar.

Also, with the higher temperature and lower melt strength, the thinner parison has more tendency to curtain, drape and sag. When these problems occur, more folds and laps in the parison can be expected. In the finished container, these folds appear as heavy areas. Lower melt strength and sag tendencies may also reduce the effective die swell properties of the resin, leading to potential problems in catching the bottle handles, intermittent handle loss and bridging in several areas of the handle from shot to shot.

If reground resin is used, it is necessary to maintain a constant blend to keep the parison stable. To improve the melt strength of the resin so the parison does not sag or drape, it may be necessary to switch to a resin with a lower melt index. However, a lower MI resin may require an increase in parison drop time and a corresponding increase in cycle time. The lower MI resin also may have a narrower operating range, exhibiting less processing latitude than a higher MI resin.

SUMMARY

The decision to convert to ovalized tooling is not a simple one and depends upon a great many factors. Some of the technical ones are listed in Table 2. There are others, including the availability of training for blow molding machine operators and the troubleshooting ability of your resin supplier. Equistar's technical service department has been providing training and support to blow molding resin customers for many years and has extensive experience in handling the transition to ovalized tooling. You can contact us through the sales office listed on the back of this booklet.

Table 2: Factors to consider with ovalized tooling

LIGHT WEIGHTING WITH OVALIZED TOOLING

Advantages

Improved resin distribution
Improved bottle strength
(top-load, drop, crush)
Substantial resin savings
possible

Disadvantages

Smaller operating window
Increased need for straight parison

Increased need for operator
awareness and skill
Tooling must be properly aligned
Slightly less flash in pinch-off areas
Thinner handle area
Change in volume
Increased resin sensitivity
Amplified blow molding difficulties

If bottles are improperly molded:

Lipping – folds in pinch-off area
Swinging – handle webbing,
wall-thickness variation
Rotating – uneven wall thickness
Possible increased spillage
Possible increased down time
Possible increased scrap



LyondellBasell Industries
P.O. Box 3646
Houston, TX 77252-3646
United States

www.LYB.com

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