WHITE PAPER

UNDERSTANDING DAIRY BOTTLE SHRINKAGE

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Find out about how to maintain consistent bottle capacity during manufacturing, storage and filling

WITH GROWING PRESSURE ON PRICES, MILK PRODUCERS ARE FOCUSSED ON CONTROLLING PRODUCTION COSTS, INVESTING IN NEW TECHNOLOGY AND/OR INCREASING THE SCALE OF THEIR OPERATIONS. MINIMISING PRODUCT LOSSES IS ALSO ESSENTIAL TO PROFITABILITY.

The decline in the wholesale price of milk over recent years has driven an increase in efficiency at all stages of production from the farm to the supermarket shelf. Reducing wastage is a key objective within the industry.

Plastic milk bottles are typically manufactured at a dairy blow moulding plant from high grade HDPE resins. These bottles tend to shrink over time causing the volume capacity of the bottle to change.

Bottle shrinkage is an important consideration for the industry as subsequent under or over filling of bottles may have costly ramifications.

Most milk and dairy products are packaged in containers made from high density polyethylene (HDPE). The familiar milk bottles are typically manufactured at a dairy blow moulding plant from food-grade HDPE resins. Developments in resin technology have allowed bottle manufacturers to reduce costs through lighter, lower cost milk bottle design, while maintaining critical properties such as top load strength, stiffness and impact resistance.

Producing a bottle of the required capacity is critical as milk is sold by volume. Any reduction in the volume of a bottle may result in underfilling which can lead to waste or the risk of action from the weights and measures authorities.

MAGNITUDE OF BOTTLE CAPACITY REDUCTION

Blow moulding process conditions directly influence bottle capacity. Figure 1 shows the extent of the capacity change for unannealed 2 L bottles over a 20-day period. There was about 10 g reduction in capacity between day 1 and day 12. The first data point at 2103 g was measured 6 hours after blow moulding the bottle. The capacity measured immediately after manufacture would be significantly higher than 2103 g. Typically, the capacity reduction for unannealed 3 L bottles between day 1 and day 12 is around 15 g.

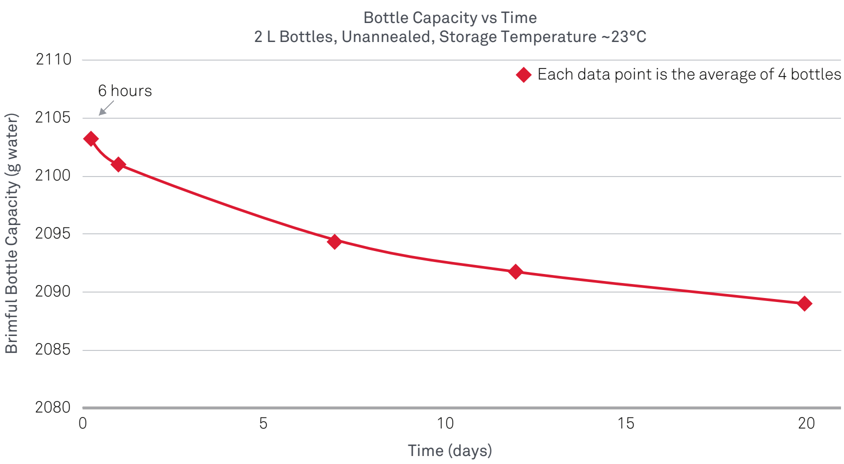

Figure 1. **Capacity of unannealed 2 L bottles measured over a 12-day period and stored at 23°C**

> **POLYMERS MANUFACTURED FROM RESINS THAT EXHIBIT LOW SHRINKAGE OFFER MANY ADVANTAGES TO DAIRY BOTTLE MANUFACTURERS**

HOW IS BOTTLE SHRINKAGE TESTED?

Test description

Bottle capacity is defined as the volume of a HDPE bottle measured under specific test conditions. The objective of the test is to determine the bottle capacity by measuring the mass of water required to fill the bottle. The method is based on ASTM D2911-10 Standard Specification for Dimensions and Tolerances for Plastic Bottles.

Procedure

First the empty bottle is weighed. The bottle is then filled with water at 23°C within 60 seconds. The bottle should be carefully topped up using a wash bottle or pipette within 10 seconds. The bottle is then reweighed to the nearest gram. This test is typically repeated 1, 2, 5 and 10 days after manufacture using a minimum of 4 sample bottles, preferably taken from different mould cavities. Note that the volume that 1 gram of liquid water occupies at standard temperature and pressure (0°C and 1 bar) is 1 ml.

Treatment of results

The results of 'brimful bottle capacity' versus 'days after manufacture' are plotted on a graph, similar to the one shown in Figure 1.

RESIN PARAMETERS AFFECTING BOTTLE CAPACITY

Typically, the peak melting temperature range of HDPE resins is 130°C to 138°C. Above the melting temperature, the polymer is an amorphous mass which behaves both as a viscous and an elastic fluid. As the amorphous molten HDPE cools, it begins to crystallise about nuclei in the polymer. This process occurs over a range of temperatures. The level to which the polymer is able to crystallise depends primarily on the degree of branching and the rate of cooling. It is also influenced by the polymer's molecular weight.

In the case of a reciprocating blow moulder system, the process of rapidly extruding a parison and then immediately inflating it with high pressure air as soon as the moulds have closed, followed by fast cooling, results in a significant level of frozen-in molecular orientation. It is the frozen-in stress which is likely to be the driving force for any subsequent shrinkage. Batch-to-batch changes in resin parameters such as melt index, density and swell, within the specification range, will have no measurable effect on bottle shrinkage.

EXTRUSION PARAMETERS AFFECTING BOTTLE CAPACITY

Factors that affect HDPE bottle shrinkage include:

- **Bottle weight:** the weight of a HDPE bottle is dependent on the thickness of the wall - and wall thickness affects the volume of the container. As more HDPE material is used, the bottle weight increases and the bottle's internal volume decreases. As heavier bottles with thicker walls retain more heat, they take longer to cool, which results in greater shrinkage. A heavier bottle is less likely to bulge when filled with milk, therefore reducing the fill volume at a given filler speed.
- **Cycle time:** manufacturing cycle time affects the temperature of the bottle as it exits the mould. The faster the cycle time, the less time the bottle spends in the mould cooling down and the greater the shrinkage. Also, a faster cycle time may elevate the parison temperature due to greater shear heat generated at higher extruder screw speeds. The hotter the bottle is when it exits the mould, the greater the shrinkage.
- **Bottle inflation air pressure:** the high-pressure blow setting used to inflate the HDPE bottles should be maintained at a constant value (typically 550-585kPa, or 80-85 psi). This control ensures consistent and intimate contact of the parison with the mould surface and allows efficient cooling of the container.
- **Extruder temperature profile:** a high stock or melt temperature produces a hot parison. The temperature of the bottles coming out of the mould will depend on the temperature of the parison. It is normally recommended that the stock temperature should be maintained in the range 170-200°C (350-400°F) to minimise shrinkage.
- **Mould design:** the mould cavity is always slightly larger than the finished container to allow for natural shrinkage that occurs after manufacture. Ideally moulds should be sized for the most extreme ambient operating conditions i.e. summer temperatures as bottles stored at higher temperatures will exhibit accelerated shrinkage. The chill water used to cool the moulds is normally in the range 1-6°C. Higher coolant temperatures will lead to warmer bottles coming out of the moulds and greater shrinkage. Blocked mould vents will cause inadequate venting, resulting in trapped air on the bottle surface and reduced bottle capacity.
- **Mould volume inserts:** mould volumes can be adjusted using volume inserts in the side of the mould body. Inserts allow for seasonal adjustment of container volume or when switching bottle production, such as bottles going directly to the filler to bottles being packed off for storage.
- **Annealing:** the annealing process "pre-shrinks" the bottles, moving them significantly down the capacity vs time curve, so that the extent of subsequent shrinkage will be much less and the potential for capacity variation will be reduced.

  Bottles on a conveyor pass through the annealing oven soon after they have been blow moulded. Typical oven temperatures can be 450-540°C with belt speeds of 7 to 15 m/min.

  The time between bottle manufacture and filling typically determines the requirement for annealing ovens. Where bottles are manufactured just prior to filling, annealing is necessary.

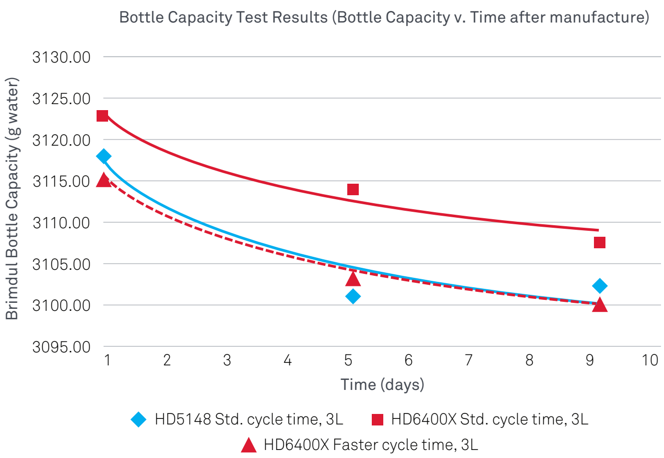

Figure 2. **Capacity of unannealed 3 L bottles made from two resins measured over a 9-day period and stored at 23°C.**

- **Bottle storage:** the ambient temperature can have a significant effect on bottle capacity during storage. The rate of shrinkage is greater at higher ambient temperatures, so in an uncontrolled environment, shrinkage will be much higher in summer than in winter. Bottles stored in a warehouse close to a hot roof are likely to shrink more than those stored closer to ground level. Empty bottles that are transported by truck during the summer period are likely to experience additional shrinkage. The longer the storage time, the more the bottles will shrink, although the rate of shrinkage reduces after 10-12 days, as indicated in Figure 1.
- **Filling operation:** the filler bowl height and filler speed affect the filled volume. To achieve a constant filled volume, it is important to maintain a consistent filler speed. Once the bottle is filled and stored at standard refrigeration temperatures, further bottle shrinkage is negligible.

BOTTLE SHRINKAGE IN DIFFERENT RESINS

Polymers manufactured from resins that exhibit low shrinkage are more desirable for bottle manufacturers. New generation catalyst technologies have now been developed to produce HDPE with broader molecular weight distribution (MWD) as indicated by higher Melt Flow Ratio (MFR). A broader MWD results in lower shear heating and a lower stock temperature which in turn results in a cooler bottle exiting the mould and less shrinkage. This advance in material technology is exemplified when comparing resins such as HD6400 (new generation catalyst dairy HDPE) to HD5148 (older generation catalyst dairy HDPE).

Performance testing HD6400 and HD5148

The bottle shrinkage characteristics of Alkatane HD6400 resin were compared to Alkatane HD5148 under the same blow moulding process conditions.

The bottle capacity tests were performed over a 9-day period. The plot in Figure 2 shows that bottles made from the HD6400 resin have a higher initial volume than HD5148. Subsequently, the capacity versus time curves for HD5148 and HD6400 bottles are essentially parallel. In both cases, the capacity reduction for unannealed 3 L bottles between day 1 and day 9 is about 6 ml.

Figure 2 shows that bottle capacity performance characteristics of Alkatane HD6400 at a 10% faster cycle time which is achieved through a faster drop time and a reduction in the blow time. As the cycle time is reduced the starting capacity also reduces as the bottles exit the mould at a higher temperature. The use of a lower shrinkage resin allows faster cycle times without a net reduction in bottle capacity, improving productivity and reducing production costs.

Comparison of resin properties

Table 1: Material properties and product performance characteristics of HD5148 and HD6400

	Alkatane HD5148	Alkatane HD6400
Material properties		
Melt index (MI_2) (g/10 min, 190°C, 2.16 kg)	0.83	0.72
Density (g/cm^3)	0.962	0.964
Parison swell (strand weight, mg)	86.0	92.0
Flexural modulus (1% secant, MPa)	1230	1500
Melt index (MI_{21})	49	56
Melt flow index ratio (MI_{21}/ MI_2)	59	78
3 L bottle top load (load at peak – kgf)	10.1	10.8
Product performance		
Top load	✓	✓✓
Cycle time	✓	✓✓
Surface finish	✓	✓✓

Typical material property values of HD5148 and HD6400 resins are shown in Table 1.

- HD6400 has a higher MFR than HD5148 indicating a broader molecular weight distribution (MWD) of the polymer and easier processing.
- HD6400 exhibits less shear heating, a lower parison or stock temperature, a cooler bottle exiting the mould and less shrinkage.
- HD6400 has higher elasticity and higher melt strength and less parison sag than HD5148, as shown by the rheology chart in Figure 3.

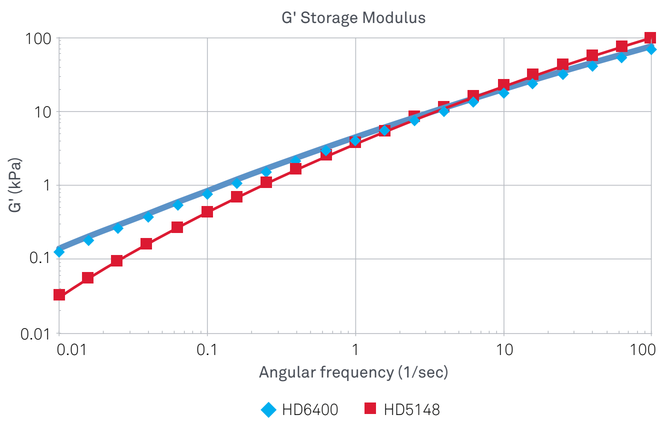

Figure 3. Rheology chart for HD6400 and HD5148 resins

REFERENCES

1. Australian Dairy, 2017, http://www.dairyaustralia.com.au/Industry-information/About-the-industry/About-the-Australian-dairy-industry.aspx

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