Makrolon® WB1239 – Water in Good Shape.

Technical Information Source

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Quench your thirst for knowledge. That little bit more with each chapter.

1 Basic Essentials

This technical brochure deals with the production of returnable water bottles in Makrolon®. For only those who have the right technology are capable of providing people with what they most need to stay alive: water.

1 Basic Essentials

Almost 70 % of the human body is made up of water. All the biological processes that take place in the human organism require the supply of water. Two liters of water per day are what the body requires to top up its reserves again.

In the ideal case (and the human body is a good example here) water ought to be transported in a perfectly closed circuit. In five-gallon returnable bottles made of Makrolon® high-tech polycarbonate.

These bottles are gaining ground worldwide. Because they guarantee reliable supplies in hygienically perfect conditions. And they are becoming increasingly important precisely for this reason in the developing and threshold countries of the Near and Middle East, Africa, Asia and Latin America. More than a billion people there still have no access to clean water. More than 2.2 million die every year as a result of illnesses attributable to contaminated water. In many of these countries, five-gallon bottles made of Makrolon® are already helping to supply the population with clean water. Particularly so in sparsely populated areas or regions without the appropriate infrastructure. And this development is set to become even more pronounced in future, since various organizations, including UNESCO, are predicting a dramatic worsening of water shortages. The reasons for this are environmental pollution, population growth and climate change.

Even in the industrial nations of the West, returnable polycarbonate bottles are experiencing above-average growth rates. They are now a standard feature in department stores, fitness studios and offices, where they reflect a new, healthconscious drinking culture. Used in water dispensers, popularly known as coolers, they supply chilled, non-carbonated water to quench people's thirst. In Western Europe, North America and the booming nations of Asia, this new form of refreshment is now an integral part of people's lifestyle.

Added value through multiple use

Covestro was quick to recognize the growth potential of "packaged water" and, with its high-viscosity Makrolon® grade WB1239, established a custom-tailored polycarbonate for the production of high-capacity bottles on the market. This high-tech material is ideal for packaging water on a number of counts. The bottles weigh just 750 grams, only 15 % of the weight of corresponding bottles in glass. And the key advantage of Makrolon® WB1239 compared with other plastics, such as polyethylene terephthalate (PET), polypropylene (PP) and polyvinyl chloride (PVC), is its combination of stiffness, toughness, break

Makrolon®
allows flexible processing – for high productivity and cost efficiency.

resistance and temperature resistance, which ensures that the high-capacity bottles are both robust and have a long service life. With the result that they can be cleaned and re-filled a hundred times or more. This allows drinking water to be distributed on an extremely efficient basis. A key advantage for the water-cooler sector.

Makrolon® WB1239 fulfills all the requirements placed on plastics for food contact applications worldwide. The bottles are highly transparent so as to highlight the quality of their contents. This also means that the amount of water still left in them can be readily checked. The blue color of the bottle together with its outstanding optical properties gives an immediate impression of chilled freshness.

A further major advantage of polycarbonate is its resistance to temperatures ranging from – 100 to +135 °C. The bottles will thus withstand both the hot summer temperatures of the southern hemisphere and the thermal stresses acting on them during cleaning. PET, for example, tends to suffer post-shrinkage, among other things, at the standard bottle cleaning temperatures.

Customized, cost-efficient processing

Five-gallon water bottles are produced by extrusion blowmolding or injection stretch blow molding. The high-molecular-weight and amorphous Makrolon® WB1239 polycarbonate resin is a customized grade offering the processor the full range of technical advantages thanks to its balanced property profile.

Makrolon® WB1239 can be processed by all the standard blow molding methods, ensuring a high level of productivity and flexibility for the bottle manufacturer. Semi-crystalline thermoplastics such as PET are, in contrast, not suitable for extrusion blowmolding and have to be injection stretch blow molded. Biaxial stretching and careful temperature control are essential for the production of amorphous bottles. Almost 70 % of the human body is made up of water. All the biological processes that take place in the human organism require the supply of water. Two liters of water per day are what the body requires to top up its reserves again.

2 Product Description: Makrolon® WB1239

Absolutely pure, crystal clear and indispensable: Makrolon® WB1239 has many features in common with water. Perhaps that's what makes it the ideal material for transporting water safely from A to B. On the following pages, you will discover other benefits that Makrolon® has to offer when it comes to protecting this vital element.

2 Product Description: Makrolon® WB1239

The Makrolon® family is so versatile that it even has a dedicated grade for the safe storage and transport of water without any loss of quality: Makrolon® WB1239 is a special food contact grade, developed specifically for the blow molding of bottles, which meets the requirements placed on containers to hold water – no wonder it's so successful.

Brief description

Global grade, MVR 2.3 cm3/10 min, high-viscosity, branched, food contact grade, for extrusion blow-molding and injection stretch blow molding, available in transparent colors only; special grade for water bottles.

Characterization

Makrolon® WB1239 is a high-viscosity, branched polycarbonate based on bisphenol-A. As a food contact grade, it meets the requirements of the EU and its member states, as well as the FDA Regulations governing materials in contact with foods. It also complies with the recommendations issued by the German Federal Institute for Risk Assessment (BfR) and is NSF-listed in the standard colors. Details of its food legislation status can be found in our conformity declaration which we will be pleased to supply to you.

Abbreviation to DIN EN ISO 1043-1: PC Designation to DIN EN ISO 7391-1: Thermoplastic ISO 7391-PC,B,(,,)-05-9

Delivery form

Granules, packed preferentially in FIBC (Flexible Intermediate Bulk Containers – 1000-kg Big Bags) or in silo trucks.

All batches of Makrolon® are homogenized after production.

Makrolon® WB1239 is only available in transparent colors.

The production plants for Makrolon® have been certificated to DIN ISO by the appropriate quality organizations. Details of this, together with conformity declarations on food legislation status, can be found on our website at www.plastics.covestro.com/Library/Certificates.aspx

Applications

The main application for Makrolon® WB1239 is high-capacity water bottles. Makrolon® WB1239 can also be used for the production of other blow-molded hollow-articles and for extruded or injectionmolded items.

Safety Data Sheet No. 112000021478 will be sent to you on request or can be called up by registered customers at www.productsafetyfirst.covestro.com

Properties

The key properties of molded articles made of Makrolon® WB1239 are:

- suitability for food contact applications
- high mechanical strength and impact strength
- high heat resistance
- dimensional stability, very small dimensional changes
- excellent light transmission
- outstanding electric and dielectric properties

Pre-treatment and processing

Drying

Makrolon® must be dried prior to processing. No more than 0.02 % residual moisture may be present in the granules for injection molding, and no more than 0.01 % for extrusion. Moisture in the melt leads to surface defects and a reduction in molecular weight. Makrolon® should be dried in suitable dryers at 120 °C. The drying time for moist granules is largely determined by the nature and type of the drying unit and can range from 2 to 12 hours depending on the drying capacity. Drying times of 2 to 4 hours are sufficient in modern dry-air (dehumidifying) dryers. One means of dispensing with pre-drying is for the moisture to be removed during melting with the aid of a degassing unit. This method is frequently employed in the extrusion of polycarbonate sheet.

Blow molding

The pseudoplasticity of Makrolon® WB1239 is based on a small number of chain branches and results in a high melt viscosity with low shear rates. This makes it particularly suitable for the blow molding of high-capacity water bottles (cf. Figs. 1 and 2).

Extrusion

Compared with linear polycarbonate grades, Makrolon® WB1239 offers the following advantages in the production of extruded articles:

- high melt viscosity under extrusion conditions
- no drawdown in the melt between the die opening and the calibrator
- reduced specific power consumption

Injection molding

The non-Newtonian behavior of the melt means that the melt viscosity of Makrolon® WB1239 under the conditions that prevail during injection molding is in the same range as the melt viscosity of conventional Makrolon® general-purpose grades (e. g. Makrolon® 31XX and Makrolon® 28XX). Makrolon® WB1239 can thus be processed by injection molding without any problems.

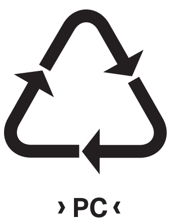
Recycling / Material disposal

Rejects and production waste can be reground, observing the drying and processing advice for virgin material, and made into new moldings providing that they have the same level of purity as the starting material, i. e. that they are not contaminated with foreign substances. It is essential to check the property level and the color of molding compounds that contain regrind in respect of the envisaged application. The permissible regrind content must be established on a case-by-case basis.

When using regrind, it should be borne in mind that the granule geometry, which differs from that of extrusion granules, will influence the feed and plastification behavior. For the same reason, physical mixtures of regrind and granules tend to segregate on account of the movement they experience during transport, conveying and metering operations.

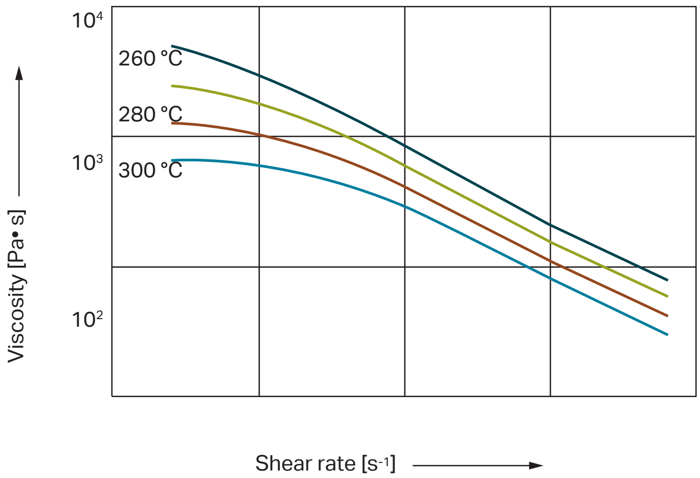
When Makrolon® is recycled, care should be taken to ensure that no foreign materials or dirt are incorporated. Contaminated and mixed waste can be chemically recycled or incinerated with energy recovery. Non-recyclable Makrolon® waste can be disposed of in an environmentally compatible manner through the correct form of incineration and subsequent dumping of the slag.

Parts are identified in accordance with DIN EN ISO 11469; the marking to be applied to parts made of Makrolon® WB1239 is as follows:



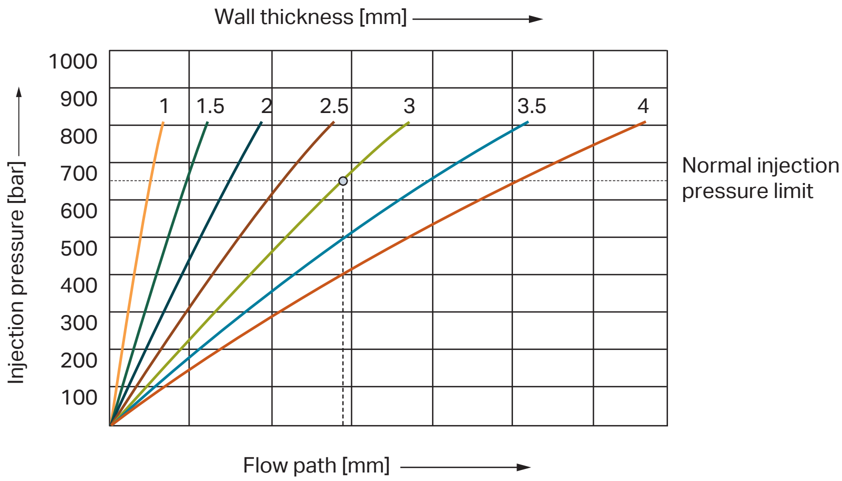
Details on this can be found in our Technical Information Sheet “Marking products made of technical thermoplastics” on our Product Center Plastics website at www.plastics.covestro.com/en/Library/White-papers.aspx

Fig. 1: Melt viscosity as a function of shear rate



Viscosity curves to ISO 11443
Curve fitting to Carreau WLF

Fig. 2: Flow behavior – calculated values

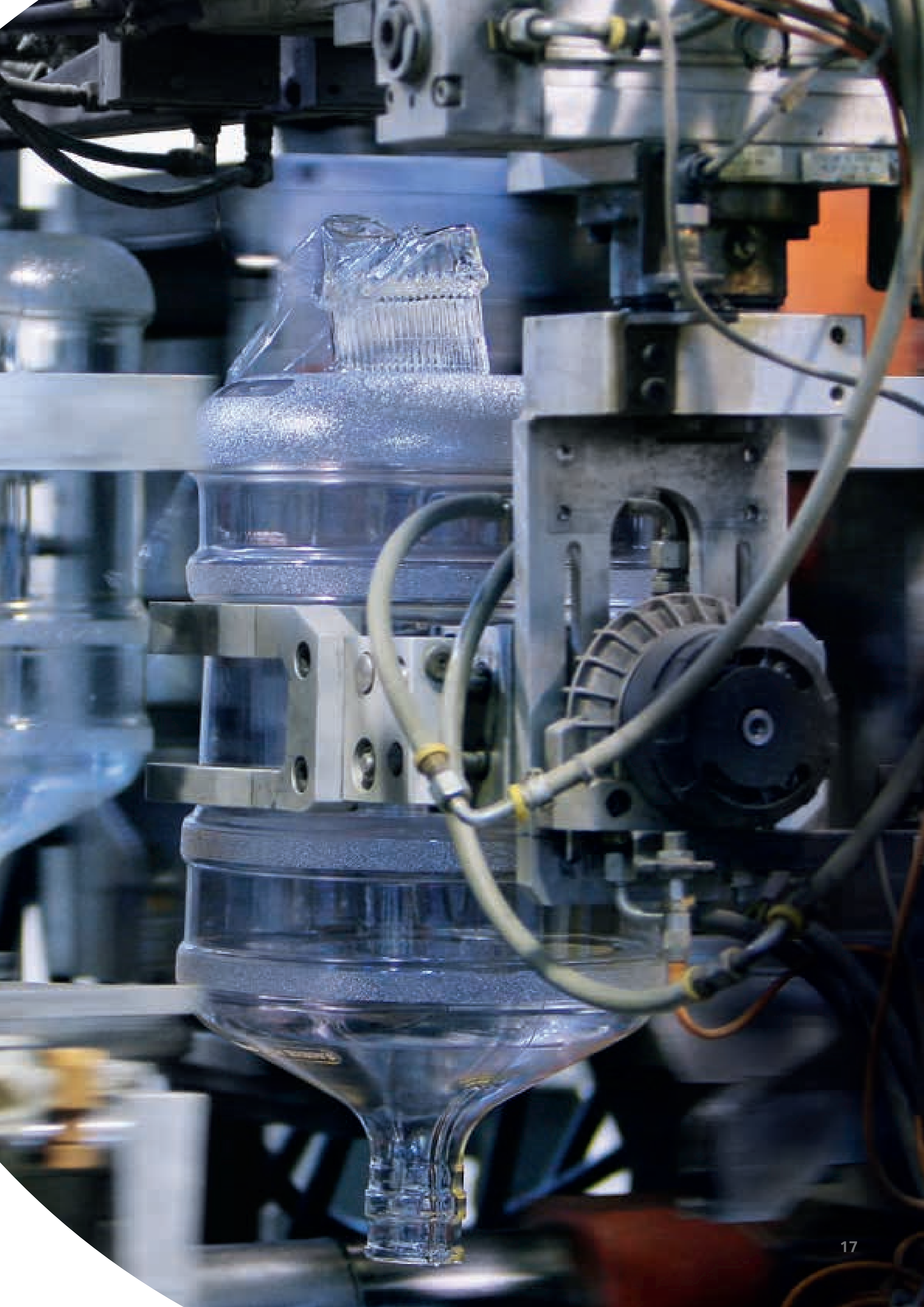


Melt temperature: 300 °C
Mold temperature: 80 °C

○ Example:
295 mm flow path for 3 mm at 650 bar filling pressure

3 Blow Molding Technologies for the Production of Water Bottles

Makrolon® has been an established product for the production of returnable water bottles for many years. With a property profile specially tailored to these requirements, it offers processors and bottlers all the advantages they need – from an economic angle too, since Makrolon® WB1239 is not only easy to produce but also particularly cost-efficient.



3 Blow Molding Technologies for the Production of Water Bottles

How is water best packaged? Five-gallon water bottles in Makrolon® WB1239 are ideally produced by either extrusion blow molding or injection stretch blow molding. This chapter sets out the advantages of the two technologies.

Water containers produced in Makrolon® WB1239 are noted especially for their:

- excellent dimensional stability
- high transparency
- extremely high mechanical strength
- high heat resistance
- extremely long service life, especially in returnable bottle applications

Water bottles with a capacity of anywhere between one and twenty liters to suit market requirements are produced either by extrusion blow molding or by injection stretch blow molding.

Extrusion blow molding

Two systems, based on different principles, are currently in standard use for supplying the quantity of polymer melt required to extrude the parison:

- with accumulator head systems, singleshaft extruders are virtually the only type of plasticating unit employed. The melt continuously conveyed by the extruder is diverted into the accumulator head and, once the head has been filled to a defined level, the melt is rapidly expelled by means of a hydraulic piston (cf. Fig. 1).
- in contrast to this, with the reciprocating screw system, the plasticating unit is displaced in the axial direction so that a melt cushion forms upstream of the screw, and this melt is then expelled by means of a rapid screw advance.

The tube produced in this way (the parison) is enclosed by a blow mold. A separator cuts the tube off just below the nozzle. At the same time, a blowing mandrel moves into the blow mold and inflates the tube on a discontinuous basis. Heat is dissipated via

Makrolon® WB1239
can easily be processed – by injection stretch blow molding or extrusion blow molding.

the blow mold so that the article attains a dimensionally stable state (cf. Fig. 2). As soon as the article has been moved from the molding zone (it is generally handled by a gripper system), the next cycle can commence. The parison waste that is left in the mold when the tube is pinched off at the neck, base and possibly handle, too, is removed in a subsequent step.

Fig. 1: Accumulator head unit

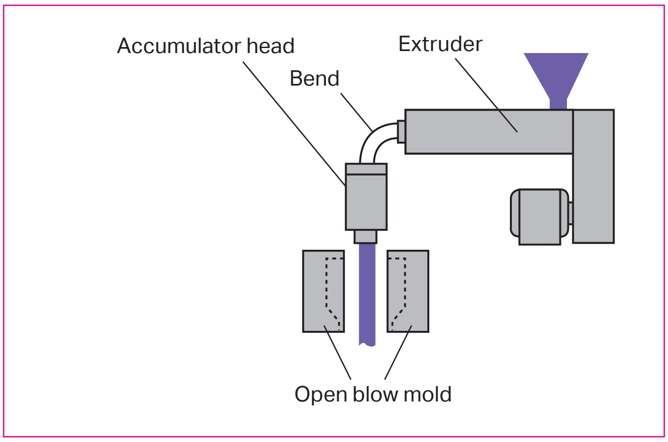


Fig. 2: The principle of the extrusion blow molding process

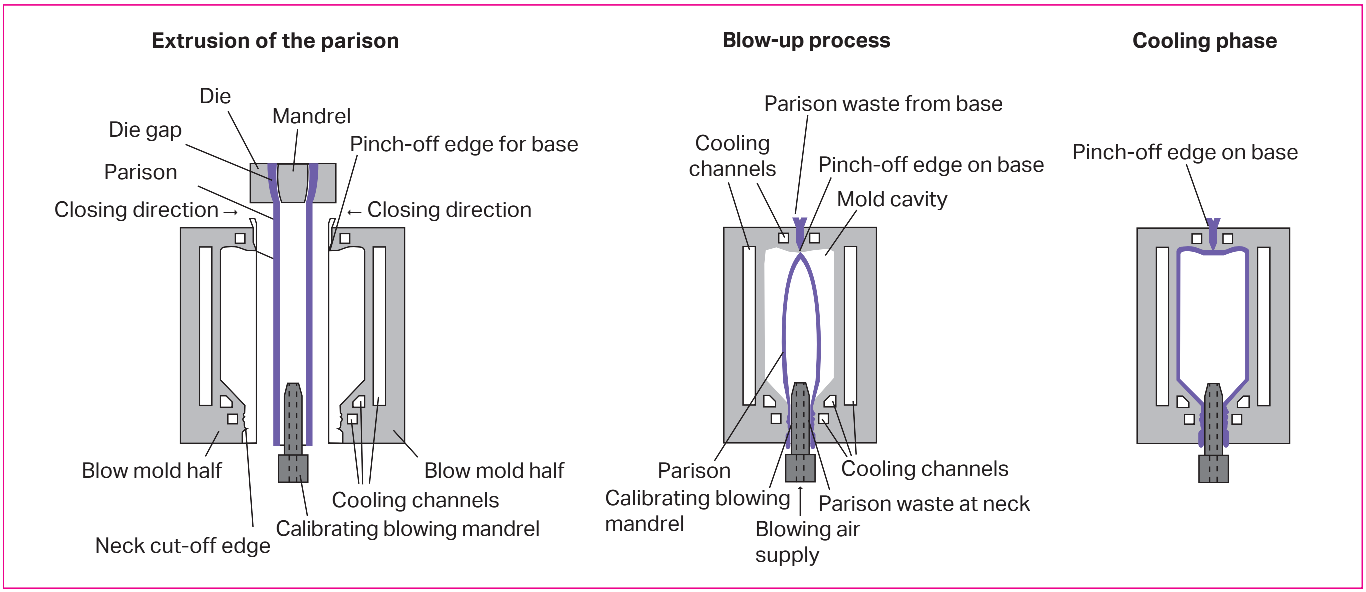


Fig. 3: Injection molding the preform

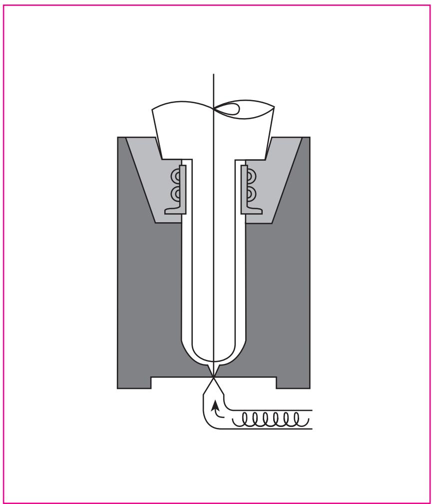


Fig. 4: Conditioning the preform (hotpot)

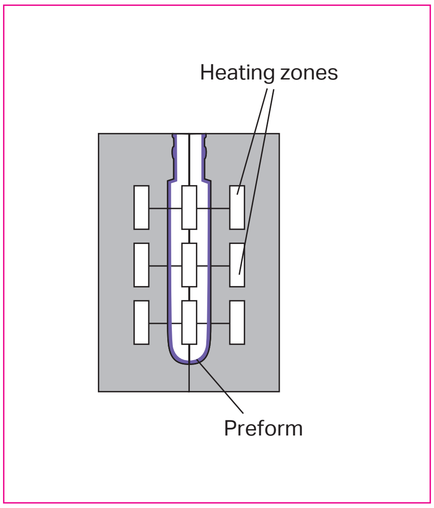
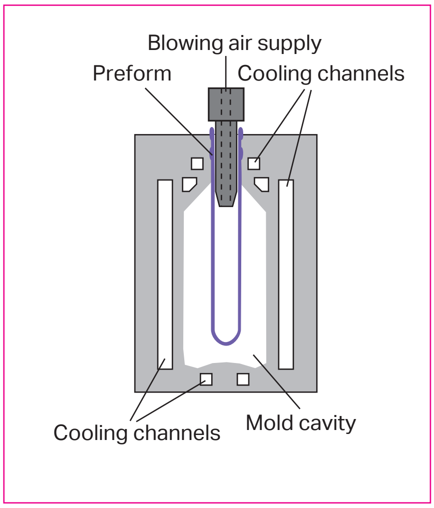


Fig. 5: The blowing process



Injection stretch blow molding

Polycarbonate water bottles are manufactured by injection stretch blow molding with a single heat process. The process starts with the production of the preforms by injection molding (cf. Fig. 3). Throughout the entire process, the preforms are transported through the individual stations on the machine with the opening pointing upwards. Once the preforms have been manufactured, they are conveyed directly to the conditioning station, where they are heated to the stretching temperature (cf. Fig. 4). The desired wall thickness distribution in the bottle is achieved through appropriate temperature control in the individual heating zones. In the following step, the conditioned preform is conveyed to the blowing station. Here, the preform first undergoes axial stretching and then, after a time lag, is inflated into the final bottle (cf. Fig. 5). This can take place in one or more stages. The final process step after shaping and cooling is the output of the article.

Technology comparison

If the two processes are compared in terms of the investment costs required for the machinery and the output, i. e. the number of articles produced per hour, extrusion blow molding has the edge. A further point in favor of extrusion blow molding is the freedom of design it offers in shaping the bottle. Bottles with a handle can be produced by extrusion blow molding without any problems, whereas injection stretch blow molding is more complex, requiring a prefabricated handle to be inserted into the blow mold. Key advantages of injection stretch blow molding are a precisely-shaped neck and a generally better surface finish.

Cycle times for injection stretch blowmolding are around 60 to 70 seconds. With extrusion blow molding, cycle times of 26 to 40 seconds are generally achieved. If a single-cavity mold is used, it is thus possible to produce 50 to 60, or 90 to 140 bottles per hour respectively. In many cases, injection stretch blow molding machines with two cavities are used, enabling the number of bottles produced per hour to be increased to around 100.

At the same time, however, having a second mold increases the overall purchase price. Leading manufacturers of such systems include Nissei ASB and AOKI.

Just a single cavity is generally employed in extrusion blow molding. Well-known manufacturers of extrusion blow molding systems include Kautex Maschinenbau, Graham Machinery and Bekum.

With its balanced property profile, Makrolon® WB1239 is equally suited to both processes. The processor enjoys maximum flexibility, since a single product fulfills all the requirements placed on the production of polycarbonate water bottles. This is because Makrolon® WB1239 has a high melt viscosity at low shear rates and a low melt viscosity at high shear rates. Low, or negligibly small, shear rates prevail during the inflation process and the extrusion of the parison, as well as during the conditioning of the preform, while high shear rates prevail during plastication in the extruder and during injection molding. This special behavior of Makrolon® WB1239 is attained through the selective branching of its polymeric molecular structure.

While the melt viscosity of linear polycarbonate remains virtually constant at low shear rates, branched polycarbonate displays an increase in its melt viscosity in this range. At high shear rates, by contrast, linear and branched polycarbonates display very similar behavior in terms of their melt viscosity.

In practical terms, this behavior results in greater melt stability at low shear rates, since the extruded parison, or conditioned preform, retains its structure and does not become elongated under its own weight.

Fig. 7: Makrolon® WB1239 polymer structure

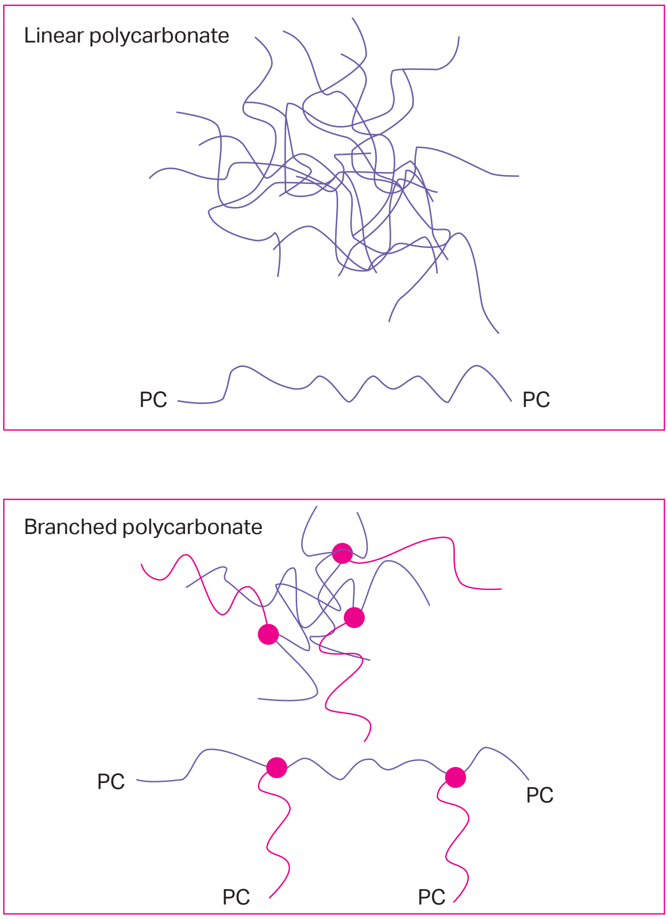
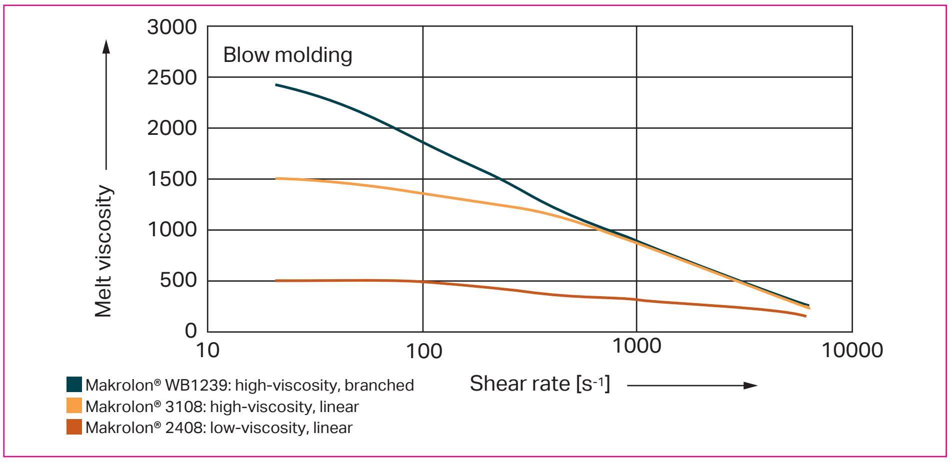
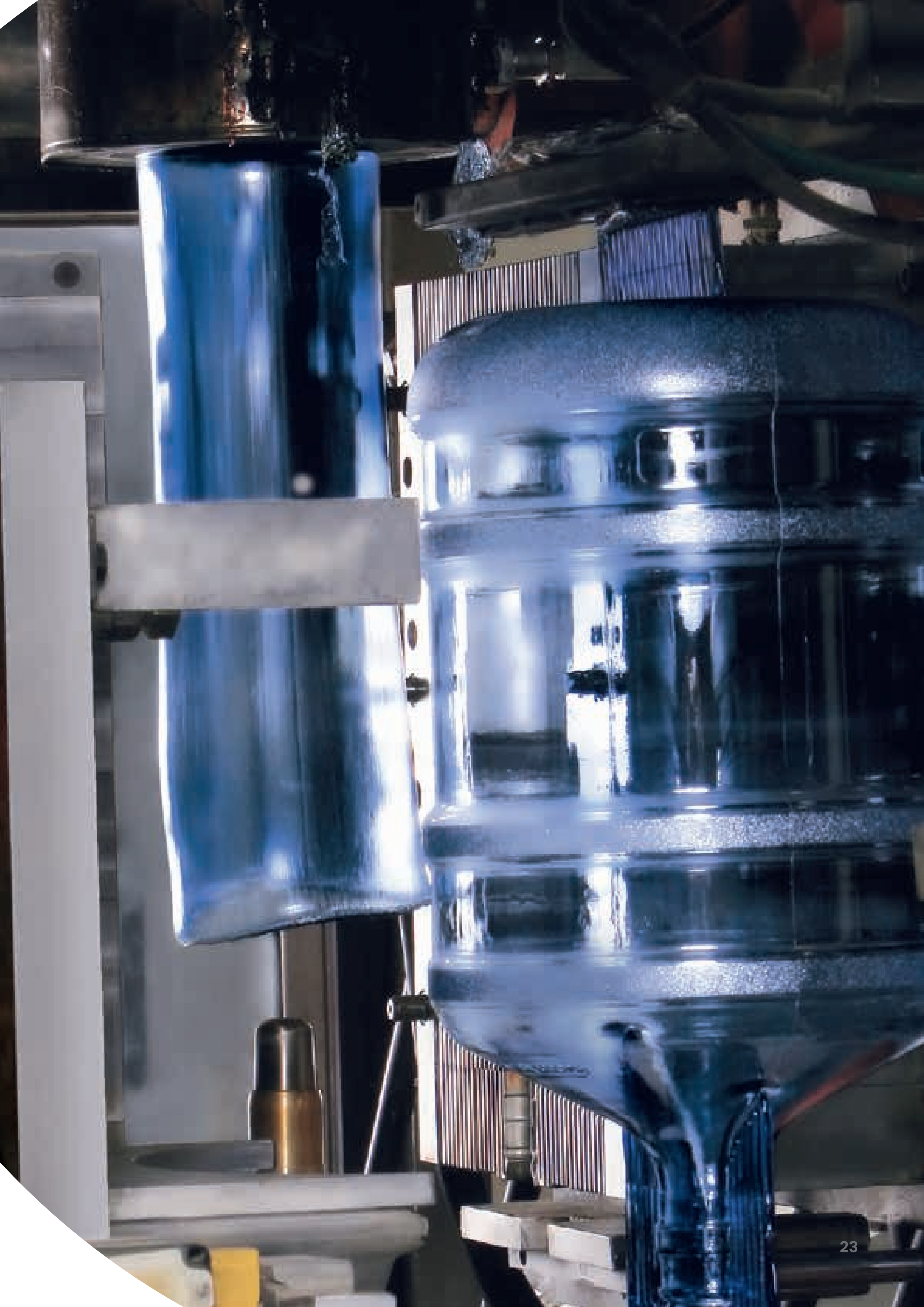


Fig. 6: Viscosity vs. shear rate



4 Extrusion Blow Molding of Bottles in Makrolon®

Extrusion blow molding has proved to be a successful method for manufacturing water bottles in Makrolon® WB1239, and is the most commonly used production process for these high-specification containers. Let us now follow Makrolon® on its journey from the granule form to a high-quality water bottle.



Makrolon®

4 Extrusion Blow Molding of Bottles in Makrolon®

Achieving a great deal for a low outlay – that is what extrusion blow molding with Makrolon® is all about. If care is taken with just a few things, like the preparation of the material, the machinery and equipment used and the machine settings, then this attention will ensure optimum processing and a perfect product.

Drying

Careful drying of the granules is crucial when it comes to ensuring problem-free production. Residual moisture in and on the granules can give rise to the following problems:

- At processing temperatures of around 250 °C, the water evaporates, leading to surface streaks or small bubbles on the finished water bottle.

- Water can cause hydrolytic degradation of the molecule chains in polycarbonate. This results in a reduction in the molecular weight, which can be accompanied by a deterioration in the mechanical properties of the plastic and the bottles produced.

Different types of drying equipment are available for drying the granules. Highspeed dryers and dry-air (dehumidifying) dryers are in particularly widespread use (cf. Figs. 1 and 2). Both types of dryers blow or suck pre-heated air through the granules. In the case of dry-air dryers, the air is also pre-dried with the aid of a drying agent before it comes into contact with the granules. This serves to speed up the drying process and, in very moist climates, a dry-air dryer may also be essential to ensure that the desired residual moisture content is in fact attained. The drying agent is regenerated in a second stage once it has attained a specific moisture content. It should be borne in mind that polycarbonate granules will very rapidly absorb moisture from the surrounding air again.

Since the dryers circulate large quantities of air, there is a danger that dust from the surrounding air will make its way into the granules and cause defects in the product. This can be remedied by employing an intake filter, which should be cleaned at regular intervals. A clogged-up filter reduces the air throughput and thus prolongs the drying time. The air outlet should similarly be equipped with a filter so as to prevent dust from the plastic from entering the surrounding air.

The Makrolon® WB1239 used for the production of five-gallon water bottles must have a residual moisture content of no more than 0.01 %. A drying temperature of 120 °C is recommended, with a drying time of 2 – 4 h for high-speed dryers and 2 – 3 h for dry-air dryers. Lower temperatures do not ensure a sufficient level of drying and, at higher temperatures, there is a danger of the granules sticking together and no longer being suitable for processing.

Fig. 1: High-speed dryer

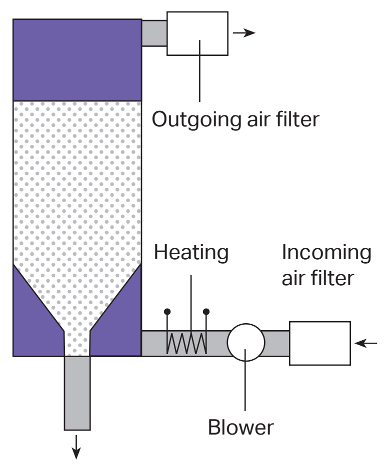
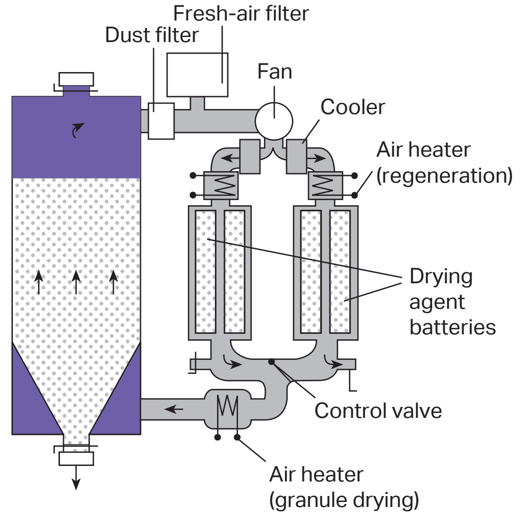


Fig. 2: Dry-air dryer



Makrolon®

Fig. 3: Three-section screw

Machinery

Plasticating unit

Two different designs of extrusion blow molding machine can be used for producing five-gallon water bottles. These are, firstly, discontinuously-operating, reciprocating-screw extruders and, secondly, extrusion blow molding units with accumulator heads. In the case of reciprocating screw extruders, the screw can be moved in the axial direction, in the same way as on injection molding machines. As the screw retracts, the space in front of it fills up with the necessary amount of melt. The material is then output by the piston principle as the screw moves forward. Extrusion units with accumulator heads, by contrast, operate with the continuous delivery of material into the accumulator head, which can be heated and cooled separately. This permits the output rates, the melt temperature and the degree of swelling in the parison to be controlled very accurately.

Makrolon® WB1239 is generally processed on extruders with a smooth feed section. Grooved feed sections may also be employed, providing that the grooved section is not too long, the grooves are not cut too deep, and the feed zone is heated to around 130–140 °C. Apart from this, it is recommended that the area beneath the hopper be fitted with thermal insulation or be cooled so as to prevent the granules from sticking together and disrupting production.

The universal three-section screws and barrier screws used for processing engineering thermoplastics are suitable (cf. Fig. 3). These are divided up into a feed section with a deeper flight depth to take up the granules, followed by a compression section in which the flight depth or width is reduced and where the material is degassed. In the final section, the metering section, the flight depth and width are uniform once again. It is here that the plasticated material is output.

Shearing sections often heat up the melt to such an extent that an unsatisfactory melt stiffness is achieved, particularly with extrusion blow molding. Mixing elements have a positive impact on melt homogeneity, but are not generally necessary if no specific demands are placed on the mixing effect.

Screws with a diameter of 90 to 100 mm are recommended for the production of five-gallon bottles. The length of the screw should be at least 24 D if possible. Screw geometries of this type are particularly suitable for achieving low shear rates at low speeds. A high level of melt homogeneity is then achieved at low melt temperatures. This also ensures gentle processing of the material in terms of the temperatures acting on it, thus allowing the processor to produce high-grade bottles.

The plasticating capacity of the units described is generally in the range of 120 to 180 kg/h, although higher performance can sometimes be attained. To avoid excessively high shear stressing and damage to the resin, the screw speed should be selected such that the circumferential speed is between 0.05 and 0.2 m/s and does not exceed 0.3 m/s under any circumstances.

Parison die

The parison die serves to convert the solid strand of melt emerging from the extruder into the tubular form required for the parison. This also involves the horizontally oriented flow of melt from the plasticating unit being converted into a vertical flow. Makrolon® WB1239 can be processed on the standard designs of parison die (center-fed die, spider die, spiral mandrel die, single or overlapping cardioid die). Spiral mandrel dies and overlapping cardioid dies in particular have become increasingly popular of late, since they permit optimum melt homogeneity and hence a narrower wall thickness distribution.

The flow channels should not have any dead spots where the melt can stagnate and possibly suffer thermal damage. Chrome-plated flow channels have proved successful and are not prone to chipping as a result of cooling polycarbonate melts sticking to them. They also have a reduced tendency to boundary layer formation (specks, discoloration).

In the case of accumulator heads, the parison die has a reservoir which initially fills up with molten plastic from the continuously operating extruder. A piston then outputs the melt via the nozzle. The capacity of the reservoir can be up to three liters depending on the make, the design of the head and the size of the article. The reservoir should be an appropriate size in relation to the quantity of plastic melt required for a bottle. If the stored volume is excessively high, a residual amount of melt will always remain in the accumulator, which is then subjected to additional thermal stressing. Modern accumulator heads work on the first-in, first-out principle, ensuring only minimal thermal stressing of the melt.

Reciprocating screw plasticating units are fitted with a crosshead which deflects the horizontal strand of melt emerging from the extruder into the vertical direction. The parison dies used here are essentially of the same design as those used in continuous extrusion.

Points at which streams of melt flow together (weld lines) downstream of the spider legs on a center-fed die, for instance, are visible as “flow lines” in both the parison and the finished article and result in optical flaws and reduced strength. This can be countered by implementing the appropriate design measures in the parison die beforehand (spiral mandrel, overlapping cardioid) or by raising the temperature of the melt during processing.

Die, die diameter and swelling behavior

The extruders available on the market are equipped with either diverging or converging die geometries (cf. Fig. 4). Both types are essentially suitable for processing Makrolon® WB1239. The flow behavior of the melt differs, however, due to the physics of polymers.

The orientation of the molecule chains in a melt is influenced, among other things, by the geometry of the die and the flow channels behind it. When polymers are extruded through a die, they not only experience shear at the die walls but also undergo extensional deformation of the melt, which is brought about by reversible molecule orientations. Some of this orientation is eliminated again through relaxation as the melt flows through the die, where the molecules once again return to a more favorable state in energy terms. The orientation that is still left after this, together with the elastic shear caused by the die, leads to swelling of the parison. This so-called die swell is all the more pronounced, the higher the extrusion velocity and the shorter the die. Under these circumstances, there is insufficient time for the molecule chains to relax. The extent of the swelling falls, by contrast, as the temperature rises.

More pronounced die swelling is also seen as a function of the die geometry, however. Convergent dies, for example, lead to greater die swell than divergent ones, although, over the years, divergent dies have been seen to have advantages for processing polycarbonate. This is probably due to the fact that non-crosslinked, high-molecular polymers such as Makrolon® WB1239 have a memory effect. In other words, following deformation in the visco-elastic range (at above the glass transition temperature), they attempt to revert to their original shape again. The cross-sections of the flow channels upstream of the die are a decisive factor which needs to be taken into consideration. Like all other thermoplastics, Makrolon®WB1239 also displays this typical swelling of the parison after it has emerged from the die.

The swelling behavior is also influenced by the polymer architecture and molecular weight, with the entanglement density being of decisive importance here, and the length of the molecular chains playing a key role too. With Makrolon® WB1239, the entanglement density is adjusted through the selective branching of the molecule chains. In the starting state, the molecule chains are highly entangled and display a pronounced level of interpenetration. The force of deformation that acts during processing serves to extend the entangled polymer ball, forcing it into a less favorable state in energy terms. The polymer chains then try to counteract this by sliding off each other. If the deformation is so short that the entangled points have not come undone and hence the chains have not yet been able to slide off each other, then the polymer will resume its initial shape as soon as the force of deformation no longer acts upon it (memory effect). If the force of deformation acts for a sufficiently long time, however, the chains will slide off each other, and the entanglement will come undone. This allows the melt to relax and leads to a more favorable state in energy terms, with the memory effect no longer being in evidence.

On the basis of what has been said above, the swelling behavior cannot be precisely predicted in advance. Instead, it must be established empirically. Experience has shown that, with the standard processing conditions for 20-liter water bottles, swelling of between 15 and 20 % can be expected. In other words, the diameter of the parison is 15 to 20 % greater than the diameter of the die. The die diameter is determined as a function of the article size and geometry. Particular attention must be paid here as to whether the bottles to be produced have handles or not. Larger die diameters should be selected for bottles with handles as a matter of principle so as to ensure an optimum wall thickness distribution in the area around the handle. The standard die diameters are in a range between 90 and 130 mm.

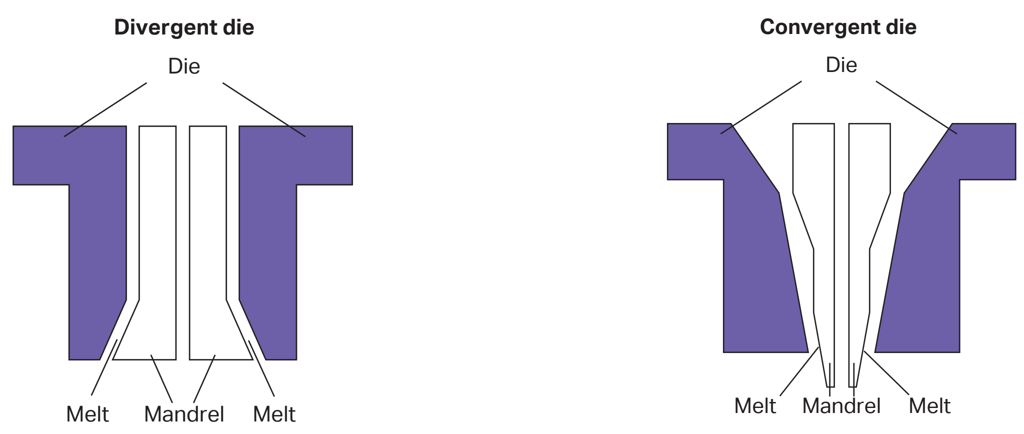
Like all other parts that come into contact with the melt, extrusion dies should be made of alloyed, non-oxidizing steels. High-alloy chrome steels are recommended because they offer a combination of abrasion resistance and protection against corrosion and have a lower tendency to boundary layer formation. Unalloyed steels can form oxide layers at the processing temperatures employed for Makrolon®, which are then picked up by the melt and become visible as black "flecks".

High-gloss surfaces can only be achieved on Makrolon® water bottles if the parison already has an excellent surface. This requires the surface of the extruder die (mandrel and die) to be polished to a high gloss, or at least to be finely ground. Chrome plating has proved successful here too. Under no circumstances should there be cracks, grinding grooves or other damage (generally caused by inappropriate cleaning or handling) running in the axial direction. These will cause streaks on the parison, which will then be visible on the blow molded part, considerably impairing the optical quality of the bottles.

Wall thickness control

All extrusion blow molding machines in current use are equipped with axial wall thickness control. The width of the die gap is varied during tube extrusion by means of a relative axial movement between the mandrel and the die. This allows axial profiling of the parison, permitting it to be tailored to the specific bottle design and making it possible to achieve the wall thicknesses required at different points of the bottle. The die gap width is generally controlled by a hydraulic or electric system and adjusted by means of individually programmable software. A control system of this type

Fig. 4: Divergent and convergent dies



does not allow the wall thickness distribution to be influenced in the radial direction. Axial wall thickness control systems are currently state-of-the-art for achieving optimum results in terms of wall thickness distribution, cycle time and material consumption.

Mold

The blow mold is made up of two movable halves having the negative form of the bottle that is to be produced. Once the parison has emerged from the die head, the mold is closed and any protruding material pinched off. In parallel to this, the blowing mandrel moves into the mold and thus into the parison. This serves to form and calibrate the bottle neck, while blowing air is still being fed continuously to the parison. The parison comes into contact with the mold wall, and the cooling process via the mold commences. Blowing air continues to be fed in until the definitive bottle shape and the requisite demolding temperature have been attained. The blowing pressure is generally between about 6 and 8 bar, with the blowing process frequently taking place in two stages. For the mold closing movement, the system is first operated with supporting air and a pressure of approximately 2 bar. Once the mold is fully closed, the actual blowing process for shaping the bottle is started. The use of supporting air prevents the extruded tube from collapsing. To shorten the cooling time, the heated blowing air is eliminated via holes in the blowing mandrel. Air is generally used as the blowing medium. Once the demolding temperature has been reached (in the case of Makrolon® WB1239 this is approximately 130 °C), the bottle is sufficiently strong for the mold to be opened and the finished bottle to be removed. Use is made of both aluminum molds with steel cutting edges and all-steel molds. Steel molds have a longer service life than aluminum ones on account of their higher strength, but they cost more to buy. Aluminum molds with aluminum cutting edges are not recommended because of their lack of strength.

The requisite clamping force depends on a series of influencing factors, including the melt temperature, the closing speed, the parison wall thickness and the shape of the pinch-off edge. It is thus not possible to give a precise value. It can, however, be assumed that the clamping force will be some 1000 to 1500 N per centimeter of pinch-off seam.

The blow mold should not just be cooled but should also have its temperature maintained at around 60 to 90 °C so as to ensure a brilliant and high-grade part surface. Uniform temperature control of the mold and effective cooling are prerequisites for low-stress bottles. To this end the temperature of the base, body and neck areas should be separately controllable. The recommended temperatures are 60–80 °C for the body and 80 to 90 °C for the neck and base zones.

In many cases, the recommended guide temperatures for the mold are not observed. Processors prefer to work at lower temperatures to save on cycle time, forgetting that this can impair the quality of the molded article. To improve the quality of the molded bottle and shorten the production time, it is essential to have a basic understanding of the rules governing heat exchange in the mold. Whether the mold is an efficient or a poor heat exchanger will have a decisive influence on the cost-efficiency of production. Molds that are well-designed from the thermal point of view help to make production more cost-efficient and more reliable. Designers currently have a large number of aids, as well as practical and theoretical study results at their disposal, which they can use to establish the thermal design of a mold. To achieve the aims of thermal mold design as set out above, i.e. precise observation of the target mold temperature, uniform temperature distribution and short cycle times, while still producing a high-quality article, the designer must be familiar with the temperature conditions prevailing in the mold and positively influence these through the position of the heating/cooling channels. Apart from favorably-positioned heating/cooling channels, it is then equally important to establish the pressure losses in these channels and to select a heating/cooling unit with the corresponding performance. Only if the necessary flow of cooling agent is available will the heat in the mold be effectively eliminated.

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It is possible for stresses to become frozen in the bottles precisely as a result of the molding operation and subsequent cooling. In other words, the polymer chains are fixed in an unfavorable state in energy terms. The level of frozen-in stress will depend very much on the different wall thicknesses that occur in a bottle and on the associated material distribution over the bottle as a whole. By the very nature of the process, extrusion blow molded bottles display accumulations of material or thicker walls in the base areas (pinch-off seam) and at the neck and shoulder.

Processors will endeavor to work with the lowest possible mold temperature in a bid to increase cost efficiency (by reducing cycle time). Excessively low temperatures always result in a poorer surface quality and a less favorable stress relationship. Higher mold temperatures ensure better reproduction of the cavity surface, leading to higher gloss levels and more precise textures on the surface of the blown bottles. At the same time, the stresses introduced in the course of processing are reduced, since the material has been able to relax in the mold as a result of an intelligent and balanced temperature control. Apart from impairing the mechanical properties, excessively high internal stresses can also lead to stress cracking as soon as polycarbonate bottles come into contact with the cleaning and disinfecting agents used in industrial plants. To produce bottles with a long service life and a high value in use, the stress level in the parts should be kept as low as possible through optimum process control and mold cooling.

In addition to a suitable heating/cooling channel configuration in the mold, it is also important to choose the right heating/cooling unit. A key requirement for attaining the mold temperature rapidly and then controlling it on a reliable basis is a sufficient heating and cooling capacity in the temperature control units employed.

To achieve efficient mold venting and hence high-grade article surfaces, the cavity surface should not be polished but slightly roughened. This does, however, result in slightly reduced transparency. To counter this, venting holes and slits should, if possible, be placed at appropriate points.

Machine settings	
Screw diameter	90 to 100 mm
Die diameter	90 to 130 mm
Temperature setting (smooth feed-section)	
Extruder	260–255–250 °C
Accumulator head	250 °C
Die	250 °C
Mold temperature	
Base	80 to 90 °C
Body	60 to 80 °C
Neck	80 to 90 °C
Screw speed	10 to 60 1/min
Tube length	600 to 700 mm
Gross weight	940 to 1400 g
Net weight	700 to 800 g
Supporting air pressure	0,5 to 1 bar
Blowing pressure	6 to 10 bar
Blowing time	25 to 35 s

Machine settings

The standard melt temperature for processing Makrolon® WB1239 is between 250 and 270 °C. Achieving the appropriate melt temperature will depend to a major extent on the screw geometry employed, the arrangement of the individual heating zones and the accuracy of the temperature controls. These temperature values can thus only be taken as a guide for a basic setting. Once the system has been run in, the temperature must be optimized on the basis of the resultant melt properties.

The temperatures given in the table can be taken as a guide for the settings to be employed when starting up production of 20-liter bottles. These values are not universally valid, however, and the precise setting can only be established empirically on the blow molding unit in question.

Breaks in production

During brief interruptions to production, the processing equipment can be maintained at the processing temperature. When production is started up again, the system should be briefly purged before blow molding commences.

In the case of longer stoppages (such as overnight), the barrel should be run until it is empty and the system temperature reduced to approximately 180 °C if parts that convey melt are surface-hardened or chrome-plated. Polycarbonate adheres so strongly to the metal surface that, when it cools to room temperature, the hard surface layer can become detached through thermal contraction. During the next production cycle, this layer is then delivered together with the melt and is visible as black contamination.

If the blow molding unit is to be fully shut down for a prolonged period of time, the barrel should be run until it is empty and the temperature of the unit reduced to approximately 180 °C. The unit should then be dismantled and the polycarbonate cleaned off the parts that convey melt.

Processing regrind

Production rejects and waste can be regranulated, observing the drying and processing advice for virgin material, and processed into new moldings. In all cases, the property level and the color of molding compounds that contain regrind must be checked with respect to the intended application. The permitted content of regrind must be established in each individual case.

When using recycled material, be mindful that the different geometry of the recyclate compared with extrusion granules influences the feed and plastication behavior. This applies both to regrind with an excessively large particle size and to dust, which frequently leads to surface flaws on the bottles. For this same reason, physical mixtures of regrind and granules tend to segregate as a result of the movement they experience during transport, conveying and metering.

When using reground Makrolon®, it is important to ensure that no foreign substances and no dust are introduced with the regrind. Waste containing contaminants or mixed waste can be chemically recycled or incinerated with energy recovery.

Release agents

As a rule, it is not necessary to use release agents with Makrolon®. Before starting up the production unit, however, it is advisable to spray underneath the bottom edge of the die with release agent. This will prevent any melt that comes into contact with the bottom of the die as a result of a not-yet-optimized machine setting from sticking to the die and hampering melt delivery or negatively affecting the parison surface during subsequent cycles.

Not all release agents are suitable for use with Makrolon®. First of all, the release agent's general compatibility with polycarbonate must be assessed on the basis of its chemical composition. In unfavorable cases, the mechanical properties or surface finish of the bottle can be impaired. Secondly, it must be remembered that water bottles made from polycarbonate are food packaging. Any contamination with substances that could impair the quality of the bottled water must be avoided. The suitability of a release agent for this application must be checked with the manufacturer beforehand.

If the articles are to be subsequently printed, then release agents containing silicone should be avoided, since traces of these release agents on the article surface can lead to problems during printing.

Material changeover

Polycarbonate exhibits molecular compatibility with only a very few other thermoplastics. It is completely incompatible with polyethylene and polypropylene. Even slight traces of these polyolefins will have a highly disruptive effect, especially if a high-quality surface with uniform gloss is required in the blow molding. After a change of material, therefore, such as a switch from polyethylene to polycarbonate, it will take a long time before clean polycarbonate is extruded. Even then, quality impairments can still occur at times.

In general, therefore, it is advisable not to purge the unit when switching between two materials. Instead the unit should be dismantled, and all the melt-conveying parts cleaned mechanically.

Troubleshooting – Quality of the parison

Problem	Cause	Remedy
Stripes on the surface	• mandrel/die damaged	• grind or polish mandrel/die
	• melt too cold	• increase the temperature
	• deposits on the die	• clean the melt delivery point
	• foreign material in the melt channel	• dismantle the system and clean it mechanically
Matt surface	• excessively high shearing	• reduce the output rate • increase the melt temperature • considerably increase the die temperature
Streaks	• inhomogeneous melt	• check temperature setting • avoid extreme temperature changes between neighboring heating zones • increase the counter pressure on the output piston during plastification
	• foreign material	• purge • dismantle the system and clean
	• excessively high moisture	• dry the material
Specks	• contamination	• check dryer, clean if necessary • check pelletizer, clean if necessary • check parison waste
	• dust from neighboring machines	• cover over the material hopper
Dark particles in the melt	• cracked material	• purge the system before resuming blow molding. Possibly increase the output briefly
	• oxide layer flaking off	• use high-alloyed steels
	• chromium/nitride layer flaking off	• check parts conveying melt and the extruder
Gas bubbles in the melt	• excessive moisture	• dry the material
	• pellets melt prematurely	• reduce extruder temperature in the first heating sections
	• support-air leak in head	• seal support-air duct
	• excessive changes in wall thickness	• set wall thickness program to run more slowly

Parison extrusion

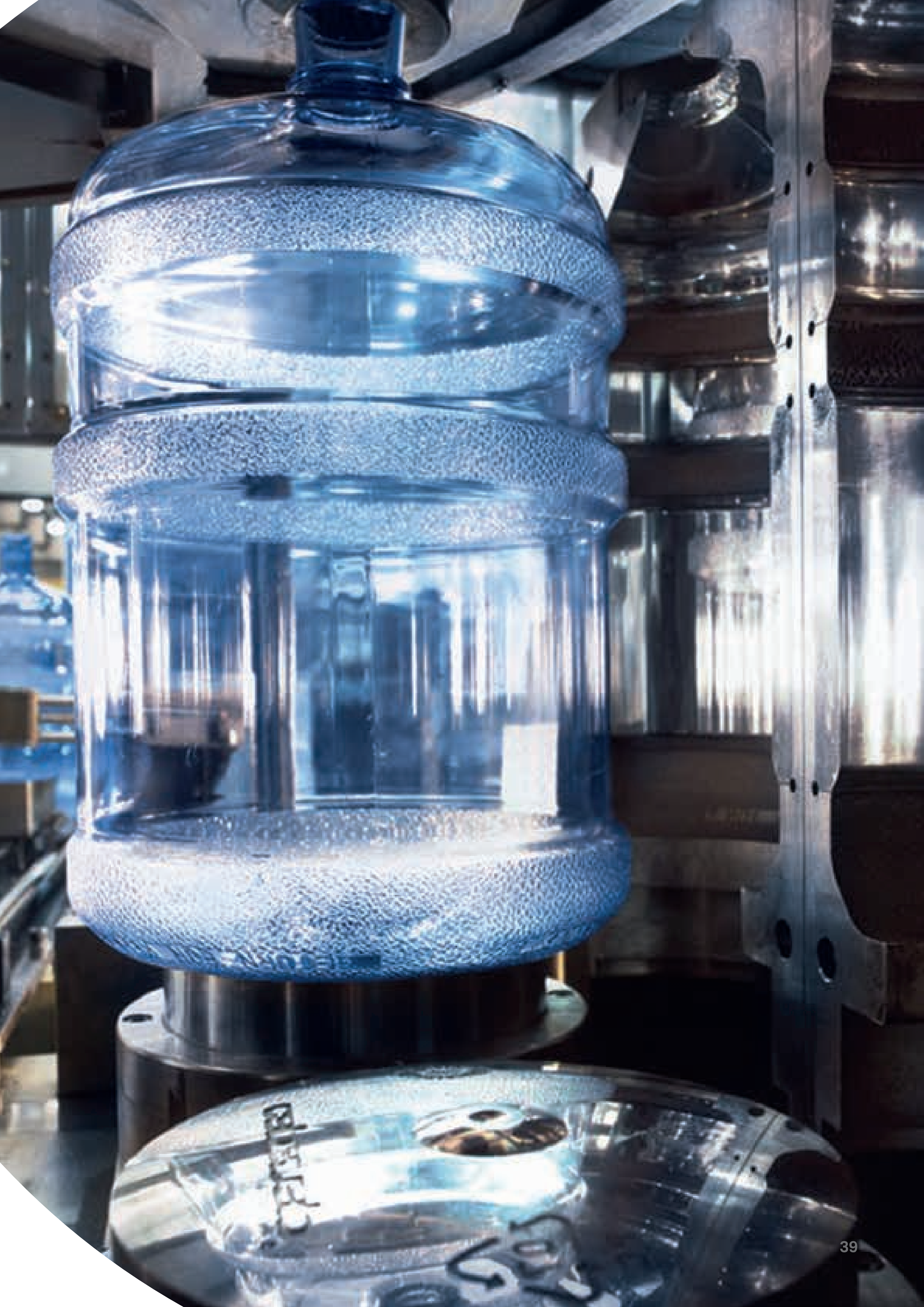
Problem	Cause	Remedy
Parison collapses during extrusion (Venturi effect)	• support-air flow too strong	• reduce support-air flow (pressure)
	• blowing pressure starts prematurely	• delay start of inflation
Parison rolls up	• excessive temperature differential between the mandrel and the die	• switch off mandrel heating • increase die temperature setting
	• mandrel protruding too far out of the die when output commences	• reduce gap width at the start of output • use a smaller mandrel • speed up the output • apply release agent to underneath of die • reduce the melt temperature
Parison curls up towards the inside	• excessive temperature differential between mandrel and die	• wait until the mandrel has heated up sufficiently • increase mandrel temperature setting
	• mandrel is too far inside the die when output commences	• increase gap width at start of output • use a bigger mandrel • reduce the output speed • apply release agent to underneath of mandrel • reduce the melt temperature
Excessive parison drawdown	• melt temperature too high	• reduce melt temperature
	• excessively slow output	• increase output rate
	• blowing commences too late	• speed up transfer to blow mold • speed up mold closing • set inflation to start earlier
Parison not straight	• mandrel and die are not centered	• center mandrel and die
	• non-uniform temperature distribution in the parison die	• wait until a uniform temperature distribution has developed • check and correct the functioning

Article

Problem	Cause	Remedy
Article weight too high/ too low	• incorrect parison thickness profile	• correct wall thickness distribution setting
Article not fully shaped	• melt too stiff	• increase melt temperature
	• insufficient blowing pressure	• increase blowing pressure
	• insufficient mold venting	• improve mold venting
	• inflation time too short	• increase inflation time
Demolded article is deformed	• insufficient cooling	• increase cooling/blowing time • reduce mold temperature • increase blowing pressure
Surface texture of bottle insufficiently clear	• bottle not fully shaped	• improve mold venting • increase blowing pressure • increase melt temperature • increase mold temperature
Uneven outer surface	• insufficient mold venting	• slightly matt the cavity • incorporate venting slits or holes
	• release agent or condensation water in mold	• clean cavity
Sticking at the pinch-off edges	• pinch-off edges too hot	• improve cooling of pinch-off edges
Parison collapses in the mold (Venturi effect)	• blowing pressure too high	• reduce blowing pressure
	• parison too soft	• reduce melt temperature
Matt article	• parison is matt • mold temperature too low • mold surface too rough	• see “Quality of the parison” • increase mold temperature • reduce mold temperature • smooth mold surface
Parison waste difficult to pinch off	• pinch-off edges not sharp enough	• alter pinch-off edges
	• clamping force too low	• precisely set the mold height (toggle clamping unit) • increase the closing pressure (hydraulic clamping unit) • select a bigger machine
	• pinch-off seam too long	• use a smaller extrusion die
	• pinch-off edges not in contact with each other	• rework parting plane/pinch-off edges
	• melt too stiff	• increase melt temperature • increase mold temperature
Flash/too much material squeezed out, particularly at bottle neck	• one-sided flash: parison not correctly centered	• center position of die over the mold
	• parison too big	• reduce output speed • increase melt temperature • select a smaller extrusion die • increase the pinch-off edge zone in the blow mold • increase the time lag prior to mold closing • reduce the mold closing speed

5 Injection Stretch Blow Molding of Bottles in Makrolon®

From the granules through to the finished bottle – alongside extrusion blow molding, Makrolon® WB1239 is also eminently suited to processing by injection stretch blow molding. It makes no difference whether the process is run with three or four stations.



Makrolon®

5 Injection Stretch Blow Molding of Bottles in Makrolon®

The previous chapter described the extrusion blow molding process for high-grade water bottles in Makrolon®. Even if your company works with injection stretch blow molding systems, however, you can still benefit from the outstanding properties of Makrolon® WB1239. This chapter shows you precisely how this is done.

Basic process engineering

As the designation “injection stretch blow molding” already suggests, this is a combination of the familiar processes of “injection molding” and “blow molding”. With today’s technologies, a distinction is drawn between the single-stage and the two-stage process. This refers to the temperature configuration after injection molding, which involves either a “single heat” or a “dual heat” approach.

In the single-stage or “single-heat” process, the preform is conditioned directly after manufacture and blown up into the finished article in the blowing station. This ensures that optimum use can be made of the residual heat from the injection molding process.

With the two-stage or “dual heat” process, the injection molding of the preform is carried out independently of the stretch blow molding process in which the finished article is created from the preform. In the two-stage process, the preforms are generally placed in intermediate storage after injection molding and have to be reheated prior to stretch blow molding. It is thus not possible to make use of the residual heat from the injection molding process. This process is widely used for the production of PET bottles.

The single-stage process is the preferred method for the production of five-gallon water bottles in Makrolon®. The two-stage process has not made any real inroads here to date. Only the single-stage process will thus be described in what follows.

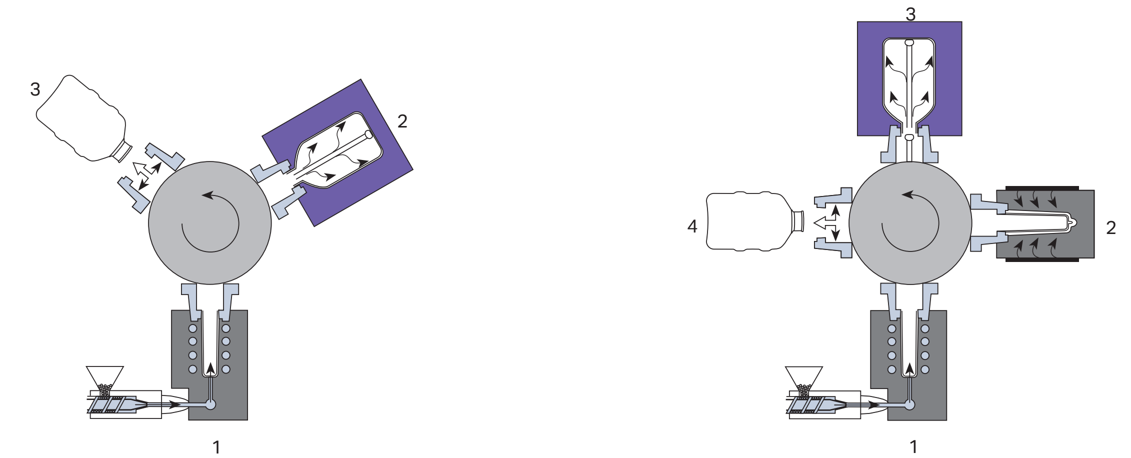
The process sequence

An injection stretch blow molding process can be schematically divided up into the process steps of preform production by injection molding, the conditioning (heating) of the preform and the blow molding process proper. Throughout the process, the preforms are conveyed through the individual stations of the machine on a rotating carousel with their opening pointing upwards. Once the preforms have been produced, they are transported directly to the conditioning station where they are heated to the stretching temperature. The desired wall thickness distribution in the bottle is achieved through appropriate temperature control in the individual heating zones.

As the next step, the conditioned preform is conveyed to the blowing station. Here, the preform first undergoes axial stretching and then, after a certain time lag, is inflated into the final bottle.

The standard machines available on the market today are equipped with either three or four stations, with the injection molding and blow molding always being conducted in two separate stations. A distinction is drawn here between a separate conditioning station (four-station principle) and a conditioning station that is integrated in the blow molding station (three-station principle, cf. Fig. 1).

Fig. 1: Operating mode of injection stretch blow molding systems with three stations (left) and four stations (right)



1. Injection molding of the preform
2. Conditioning and blow molding of the bottle
3. Demolding and output of the finished bottle

1. Injection molding of the preform
2. Conditioning of the preform in the hotpot
3. Stretch blow molding of the preform into the finished bottle

Various machine types are available which differ according to the number of injection molding units and/or cavities they offer. Machines can be supplied with up to two cavities and with two separate injection molding units. Well-known manufacturers of three and four-station machines include AOKI and Nissei ASB.

Preparation of the material and production of the preforms

When it comes to material preparation and drying, the advice given in the preceding chapter for extrusion blow molding also applies here.

Universal three-section screws and barrier screws can be used for processing Makrolon® WB1239. In contrast to extrusion blow molding, however, the processing temperatures are approximately 300 °C. The mold and core temperature for the injection molding of the preform will depend on the machine concept (three or four stations) and the design of the injection molding unit and will be between 40 and 60 °C (four stations) or 80 and 100 °C (three stations). The cycle times and cooling times will be 50 to 60 seconds depending on the preform and mold design. The overall cycle will take between 60 and 70 seconds, which corresponds to 50 to 60 bottles per hour for a single-cavity machine.

One key advantage of preform production by injection molding is the precise shaping of the neck, which makes it possible to get by without the finishing work that is required on extrusion blow molded bottles. In addition, the weight of the finished bottle is precisely defined by the preform. The higher processing temperatures employed for injection molding and the improved reproduction accuracy in the mold mean that articles with optimum transparency and an outstanding surface finish are obtained.

The length of the preform corresponds almost exactly to the length of the finished bottle. The amorphous structure of Makrolon® means it is possible to dispense with the pronounced biaxial stretching that is required to improve the mechanical and optical properties of semi-crystalline thermoplastics. A minimal amount of stretching is called for on account of the slight shrinkage that takes place after conditioning (memory effect). The quality of the finished bottle is determined to a large extent by the quality of the injection molded preform. In addition to the optical properties, particular care must be taken to ensure that the preform has a uniform wall thickness in the axial and radial directions. The wall thickness is influenced by the dimensions of the gap between the mold and the core and also by the position of the core. From time to time, it will also be necessary to precisely center the core and check its position. The wall thickness will generally be between 10 and 13 mm.

Conditioning the preform

The conditioning of the preform in the hotpot constitutes the key process step in the production of five-gallon bottles. Not only is the preform heated to the temperatures necessary for the blowing process here, but the wall thickness distribution, or profiling, of the bottle is also determined (cf. Figs. 2 + 3).

The conditioning station is divided up into a number of different heating zones that operate independently of one another, allowing the preform to be heated to differing degrees in the axial direction. The selective heating of individual segments ensures an optimum wall thickness distribution in the finished article and prevents material from accumulating in critical areas. The wall thickness control works by influencing the flowability of the plastic through the precise control of its temperature, thus not only ensuring material savings but also determining the stress regimen inside the bottle and hence the bottle's mechanical properties. The stress regimen and the mechanical properties correlate directly with each other and are dealt with in detail in the chapter on "Annealing Blow Molded Bottles". Material orientation, which is brought about by tensile stresses, should be avoided on principle.

On most of the conventional machines available on the market, the heat is introduced via electric strip heaters arranged in the longitudinal direction. The transfer of heat then takes place solely via the outer wall of the preform. To support heat transfer and achieve a better distribution of the heat over the wall thickness, the preform is additionally heated from the inside via a heated lance or by hot air.

The transfer of heat between the preform and the hotpot wall is influenced by the gap between them and can be improved by employing air at a low pressure. The standard surface temperatures after conditioning are in the region of 160 to 200 °C. Since the neck of the preform has already received its definitive shape during the injection molding process, this remains unchanged during the blowing stage. No conditioning

Fig. 2: Hotpot with electric heating elements

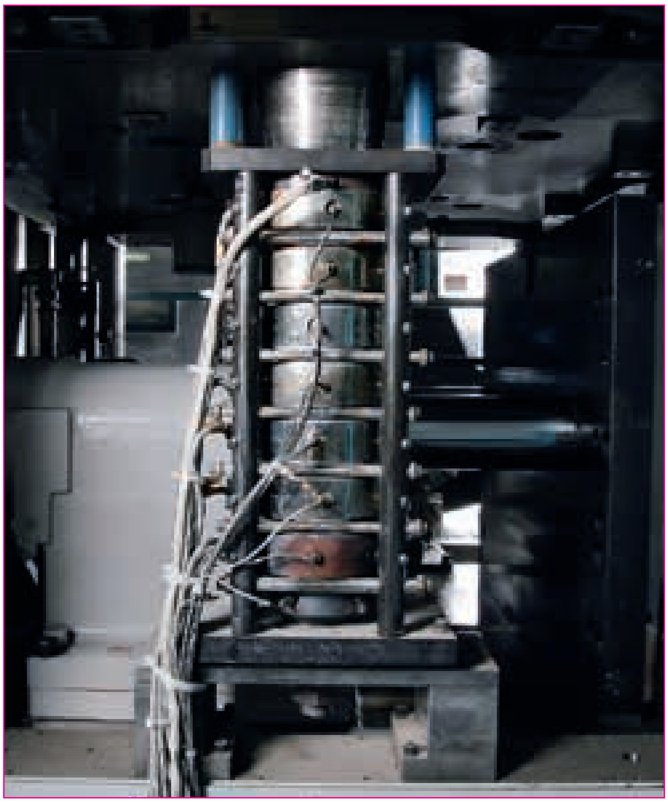
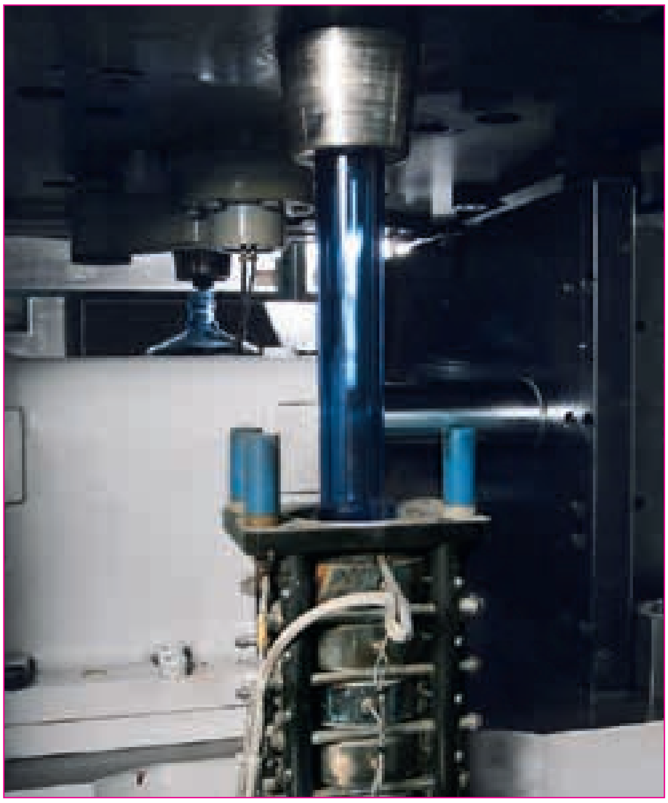


Fig. 3: Preform after conditioning in the hotpot



is therefore required for the neck. One accompanying effect can be a reduction in the length of the preform after conditioning (memory effect). This is due to the partial relaxation of the molecule chains, since the injection molding process has caused material orientation and hence given rise to stresses too.

The maximum preform temperature should be selected in such a way that the material is sufficiently softened for the blowing process (i. e. is above its glass transition temperature). At the same time, it is essential to avoid excessive drawdown due to temperatures that are too high. Apart from the temperature, the inherent weight of the preform and the transfer to the blowing station also affect dimensional stability. When the preform is handed over by the rotating carousel, the kinetic energy that acts can similarly cause deformation and hence changes in dimensions. This places particularly stringent requirements on both the material and the process.

Makrolon® WB1239 counteracts deformation on account of its polymer architecture and its resultant high melt stiffness. If the temperature is too high, however, not even the special molecular structure of Makrolon® can guarantee dimensional stability.

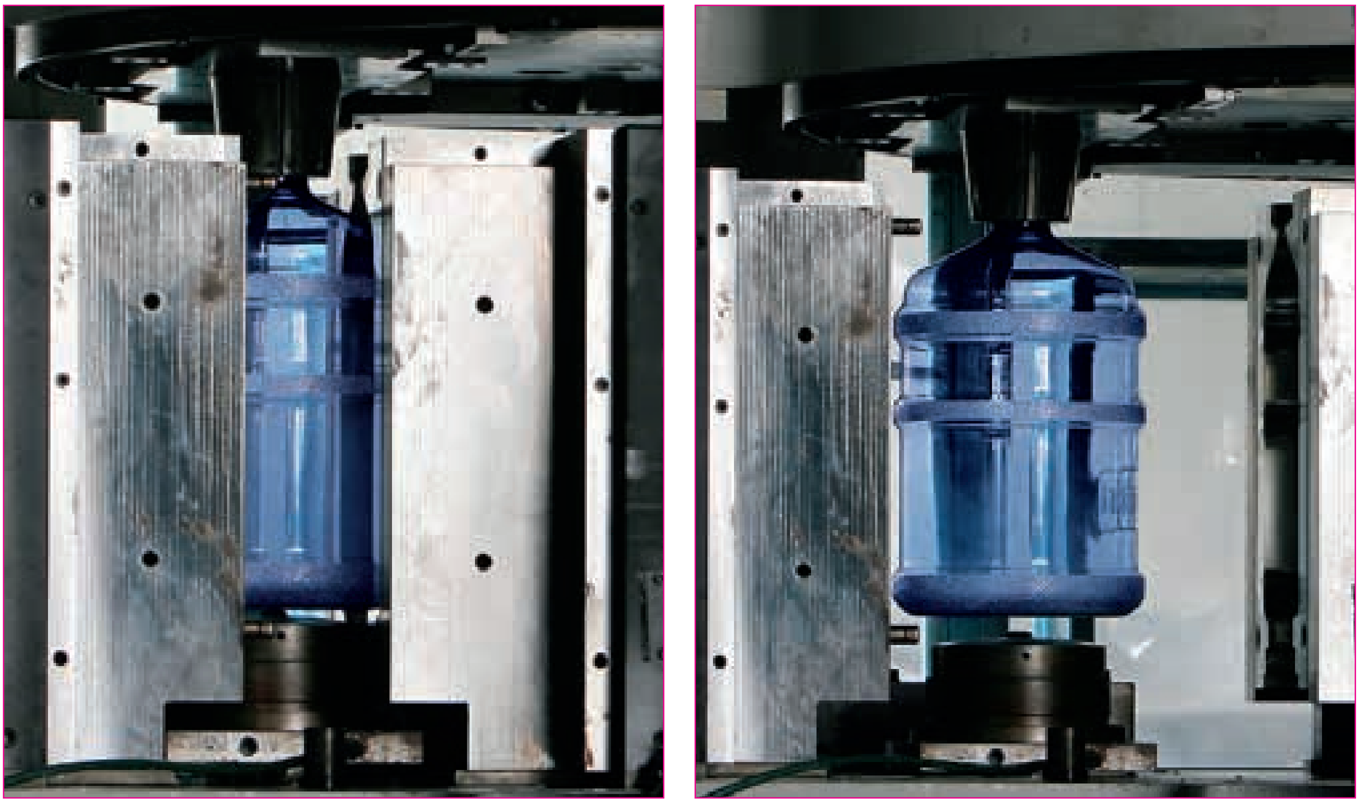
The blowing stage

Inside the blow mold, the preform is stretched to its definitive length in the axial direction by means of the blowing mandrel. At the same time, it is pre-blown in the radial direction with a blowing pressure of 1 to 2 bar. The bottle receives its definitive shape in a second stage once the mold has closed.

For this second stage, the blowing pressure is some 8 to 12 bar, depending on the mold geometry or the surface structure. The mold can be custom-designed and contains all the contours required on the bottle. The mold temperature will be between 60 and 80 °C. Care should be taken to ensure sufficient ventilation so as to ensure that no optical defects are visible.

With injection stretch blow molding, it is not generally possible to achieve a blown handle in the same way as in extrusion blow molding. It is, however, possible to place a prefabricated handle in the mold wall – although this does make the process more complicated.

Fig. 4: Bottles immediately prior to demolding



6 Annealing Blow Molded Bottles

Makrolon® is the ideal material for the production of high-grade water bottles. But the process isn't finished once the bottles have been molded. What comes next is equally important. Correct annealing and relaxation of the material is essential in order to achieve the desired quality.

6 Annealing Blow Molded Bottles

Water bottles need to relax too. Annealing blow molded bottles in Makrolon® constitutes a small but important step in the production of high-grade polycarbonate water bottles. The following pages show you how to achieve optimum results.

Introduction

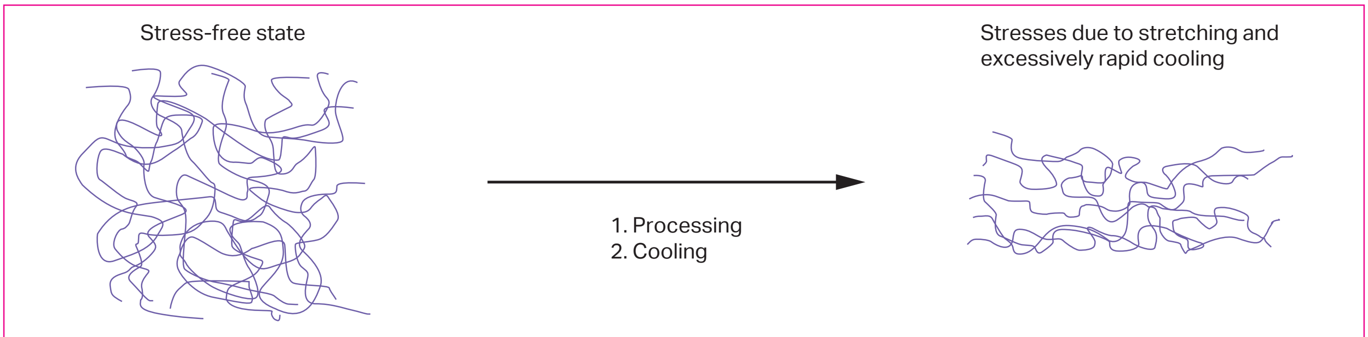
The very nature of the production process means that extrusion blow molded bottles display dissimilar wall thicknesses in the region of the pinch-off seams in their base, shoulder and handle areas, and these may contain frozen-in stresses brought about by cooling.

Although injection stretch blow molded bottles have no pinch-off seams resulting from the manufacturing process, they may similarly contain frozen-in stresses on account of the different wall thicknesses present in the bottle. These stresses are caused by the different cooling behavior in the individual zones of the bottle, because the speed at which heat is dissipated varies according to the wall thickness and the mold temperature.

Frozen-in stresses mean that the polymer chains are in an unfavorable state in energy terms – something which is also promoted by the stretching of the preform during the blowing process. Some of the molecule chains undergo disproportionately high stretching during this process, and, if the material is subsequently cooled too rapidly, extreme tensile stresses may result (cf. Fig. 1).

In order to avoid this, heat should be eliminated as uniformly as possible, making allowance for the wall thickness. Frozen-in stresses can be made visible with the aid of polarized light. They then appear as a colored pattern, whose intensity and spectrum is determined by the stress in the article (cf. Fig. 2).

Fig. 1



Plastics that undergo a high level of relaxation can eliminate these frozen-in stresses in the course of time, while plastics that experience only a low level of relaxation are less capable of doing this. Amorphous plastics, such as polycarbonate, also belong to this latter category on account of their low tendency to creep under load. The internal stresses are largely retained here and can take the form of both compressive and tensile stresses. These stresses can then lead to stress cracking as soon as the bottles are rinsed with hot and aggressive cleaning agents in industrial plants. Reduced mechanical stability may also result.

Therefore, prior to the bottles' use, these stresses should be reduced and largely eliminated through annealing. To produce bottles with a favorable stress level and hence a high value in use, it is necessary to carefully select the processing conditions beforehand.

This applies particularly with regard to the
- cooling process and
- correct annealing.

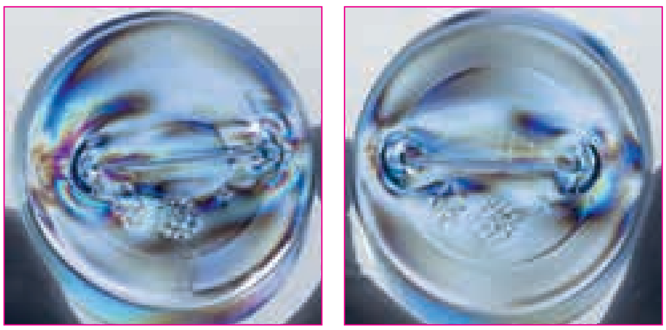
Cooling

If the material is to eliminate the stresses through relaxation as it cools, then the optimum balance must be achieved between the mold temperature and the cycle time. It is not just a matter of simply ensuring cooling but of achieving a balanced and uniform temperature control of the bottle throughout the cooling process as a whole.

Recommended mold temperatures

Neck, shoulder area	80 °C – 90 °C
Body	60 °C – 80 °C
Base area	80 °C – 90 °C

Fig. 2: Stresses under polarized light



Before annealing **After annealing**

Annealing

The machine settings should be selected to ensure that the stress level which develops in the bottle is as favorable as possible.

Annealing reduces the frozen-in stresses, since the temperature of the bottles is increased to the point where the molecule chains can reconfigure themselves into a more favorable lower energy position. However, not all of the quality deficiencies in the bottle that result from unfavorable processing parameters can be offset through annealing.

The speed and degree of stress relaxation increase as the annealing temperature rises. The temperature should not, however, be increased to the point where the bottles deform. Annealing at a temperature of around 130 °C (± 3 °C) has proved suitable in practice.

Checking the bottle temperature

To check the temperature of the bottles, we recommend using not only the standard IR temperature measurement devices but also “thermo-strips”. These are self-adhesive thermometers that indicate the temperature through an irreversible color change. Their advantage is that they permit precise measurement of the bottle surface temperature. They have proved especially successful in critical areas that are difficult to access with IR temperature measurement devices (i. e. the neck and base of the bottle).

Annealing can be performed through
• heating with hot air in suitable ovens or
• heating with the aid of infrared radiation.

Annealing with hot air

Annealing ovens can be designed for either batch or continuous operation. They should permit a temperature of approximately 130 °C (± 3 °C) to be maintained. Appropriate measures must be taken to ensure that the hot air reaches all the finished bottles in the oven and heats them uniformly. This eliminates the risk of some bottles suffering local overheating (deformation) and others not being sufficiently heated (annealed). The oven manufacturer should be consulted for advice where necessary.

Experience has shown that an annealing time of around 30 min is sufficient, regardless of the wall thickness of the bottles. The precise annealing time required, however, will be determined by the stress level and hence the production parameters of the bottles. It should be remembered that the mechanical strength of the finished articles decreases as annealing time increases. Thus it is advisable to perform a preliminary check to establish how annealing affects the service properties of the bottles.

When working out the bottle geometry, allowance must be made for the fact that annealing with hot air will cause a volume reduction of around 0.5% in the bottle.

Annealing with infrared radiation

In contrast to the conventional form of annealing in a hot-air oven where a pure annealing time of some 30 min is required, annealing with the aid of IR radiation takes just a few minutes. Heat transfer takes place through absorption of the radiation, rather than through conduction. Because of the increased danger of deformation, care must also be taken during IR annealing to ensure that the surface temperature of the bottle does not significantly exceed 130 °C.

Short-wave IR heaters with a maximum wavelength of 1.0 to 2.0 µm or mediumwave heaters with a maximum value of between 2.0 and 3.6 µm can be used. The optimum heater for Makrolon® is one with a wavelength of approximately 2.5 µm. The short annealing times mean there is no risk of any reduction in notched impact strength as a result of this annealing process.

Quality assessment of annealed bottles

The success of the annealing operation in eliminating stress is best evaluated under conditions similar to those encountered in practice, or in a short test with media that trigger stress cracking, such as propylene carbonate or a mixture of methanol and ethyl acetate in a volume ratio of 1:1. When the stress cracking tests are performed, it is essential to comply with all the existing regulations governing the chemicals used.

After the bottles have been immersed in these media, visible cracks will appear at points where specific stress threshold values have been exceeded (cf. Fig. 3).

To check the pinch-off seam on the base, the Makrolon® bottle is immersed in the test medium at room temperature in such a way that it is in contact with the test medium on both sides. To make this easier, it is recommended that one or two holes (of approximately 10 mm in diameter) be made in the side of the bottle, directly above the base. While the bottle is in contact with the test medium it should not have any external loads applied to it which could cause additional stresses and thus affect the result. After a previously-defined immersion time, the bottle is emptied and thoroughly rinsed with water. The base of the bottle should not exhibit any stress cracks after this testing (cf. Fig. 4).

Experience has shown that the bottle will meet the standard market requirements with respect to stress corrosion cracking if no stress cracks occur after three minutes' immersion in propylene carbonate or ten minutes' immersion in methanol/ethyl acetate.

Fig. 3: Base of bottle, not annealed, after cleaning

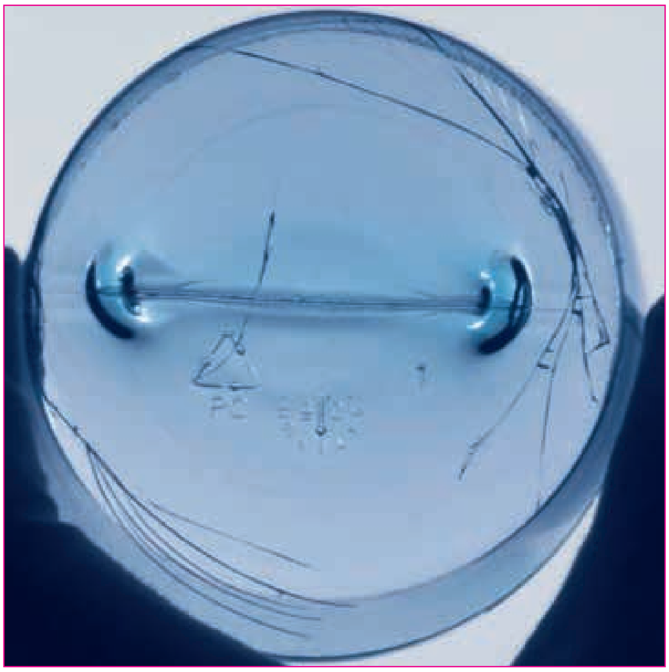


Fig. 4: Base of bottle, annealed after cleaning

Makrolon®

7 Quality Testing of Blow Molded Bottles

As a food, water has to go through a large number of tests before being filled into bottles. And the bottles themselves have to pass a fair number of tests too. After all, this refreshing beverage must reach the final consumer in the same perfect state as it was in when it was first put in the bottle.

7 Quality Testing of Blow Molded Bottles

To ensure that the bottles are of a consistently high quality, it is important to implement the correct quality testing and quality assurance measures, such as a top-load test, drop test or leakage test. Performed in the correct manner, these tests will ensure a first-rate product for optimum transportation of water which complies fully with food legislation over a prolonged period of time.

Water cannot be stored, sold or reliably conveyed to the final consumer without the appropriate packaging. The packaging assumes key functions in this process chain. Its prime task is to protect the food from the time it is packed right through to the point when it is consumed. During this time, the quality of the food must not be impaired by either the packaging itself or external influences. As a protective shell, bottles in Makrolon® protect the water inside them from environmental influences and contaminants, such as dust and micro-organisms. The exceptional stability of Makrolon® WB1239 means that this function is guaranteed even under extreme loading. Makrolon® thus makes it possible to supply a product that is in perfect hygienic condition even after a prolonged period of time.

Harmlessness to health and a neutral odor and taste are particularly important requirements for a sensitive product such as non-carbonated water. Makrolon® WB1239 fulfils these requirements along with all the relevant food-legislation provisions, such as those issued by the EU and the US FDA (see chapter 2).

In addition to this, the high transparency and brilliant surface finish of a water bottle in Makrolon® WB1239 highlights the freshness of the product inside it. Combined with the label, this produces an unmistakable message reminding us that water, as the elixir of life, is the most important food we have.

Quality testing

To ensure that water bottles in Makrolon® can meet these requirements, they must exhibit perfect quality in terms of their mechanical and optical properties. The following tests are recommended for assessing the quality of the bottles.

Top-load test

The strength of the side walls and the shoulder region can be checked by loading the tops of the bottles with a weight of 40 to 50 kg (top-load test). This simulates the stacking of bottles on pallets and the handling of the bottles by a robot once the bottles have been filled.

Leakage test

In the leakage test, the water bottles are filled with an overpressure of 1.07 bar and observed for leakage over a defined period.

Makrolon® WB1239
Only the right tests will ensure perfect quality bottles.

Bottle weight

The bottle weight is a key indicator of the wall thickness distribution achieved. Considerable deviations or extreme fluctuations from the target weight in extrusion blow molding point to process fluctuations. This can result in an unfavorable level of stress in the bottles produced, a consequent reduction in mechanical strength, or even an insufficient resistance to stress corrosion cracking during cleaning. In injection stretch blow molding, the bottle weight is defined by the injection molding process and is subject to considerably lower fluctuations than with extrusion blow molding.

Drop test

In the drop test, the filled water bottles are dropped from a specified height under defined conditions. This test provides information on the mechanical stability and the stresses prevailing in the bottles. If the bottles have an unfavorable stress level, they will display glasslike fracture behavior. They then no longer satisfy the market requirements in terms of mechanical load-bearing capacity. The precise configuration of the drop test depends on the demands of the individual bottle producers and the requirements of the fillers. The stability of the base or the side walls of a bottle, for instance, can be verified by deliberately dropping the bottles onto these areas (cf. Fig. 1). Experience has shown that a bottle should withstand at least three falls from a height of about two meters without suffering any damage if it is to achieve a long service life under the conditions prevailing in practice. A height of two meters was chosen because this is the typical height of the loading surface of a truck and is also the appropriate height when delivery personnel are carrying the bottles on their shoulders.

Fig. 1: Drop test

Wall thickness profile

The wall thickness distribution of a polycarbonate bottle is the key criterion for its stability and ought therefore to be as uniform as possible. For this reason, it is important to avoid both extremely thin points and material accumulations, as well as sudden changes in wall thickness. Thin points can be identified rapidly and easily by means of manual loading at different points of the bottles. The precise measurement of the wall thickness can be performed with the aid of an ultrasonic measuring head or a unit with magnetic steel balls. Our experience is that the wall thickness ought to be at least 0.8 mm in order to ensure sufficient stability of the bottle. At the same time, the walls should not be thicker than 3.2 mm, since the plastic deformation capacity of polycarbonate is limited at higher wall thicknesses.

Visual bottle assessment

Visual final inspections of the bottles have similarly proved successful for detecting surface defects. These defects can be due to an insufficient melt homogeneity, inadequate mold venting, degraded material, or abrasion from the metal surface of the machine. Frequently-occurring defects include brown or black specks, entrapped air bubbles, and streaks, which are generally attributable to the preparation of the material or problems with the machine.

It is also possible to detect deformation or inadequate shaping in certain areas of the bottle, such as in the handle zone. The transparency of the bottle can be established by comparison with an internal standard, or by viewing a sheet of different-sized letters or numbers through the bottle from a defined distance (lettering test, see page 57).

Bottle necks

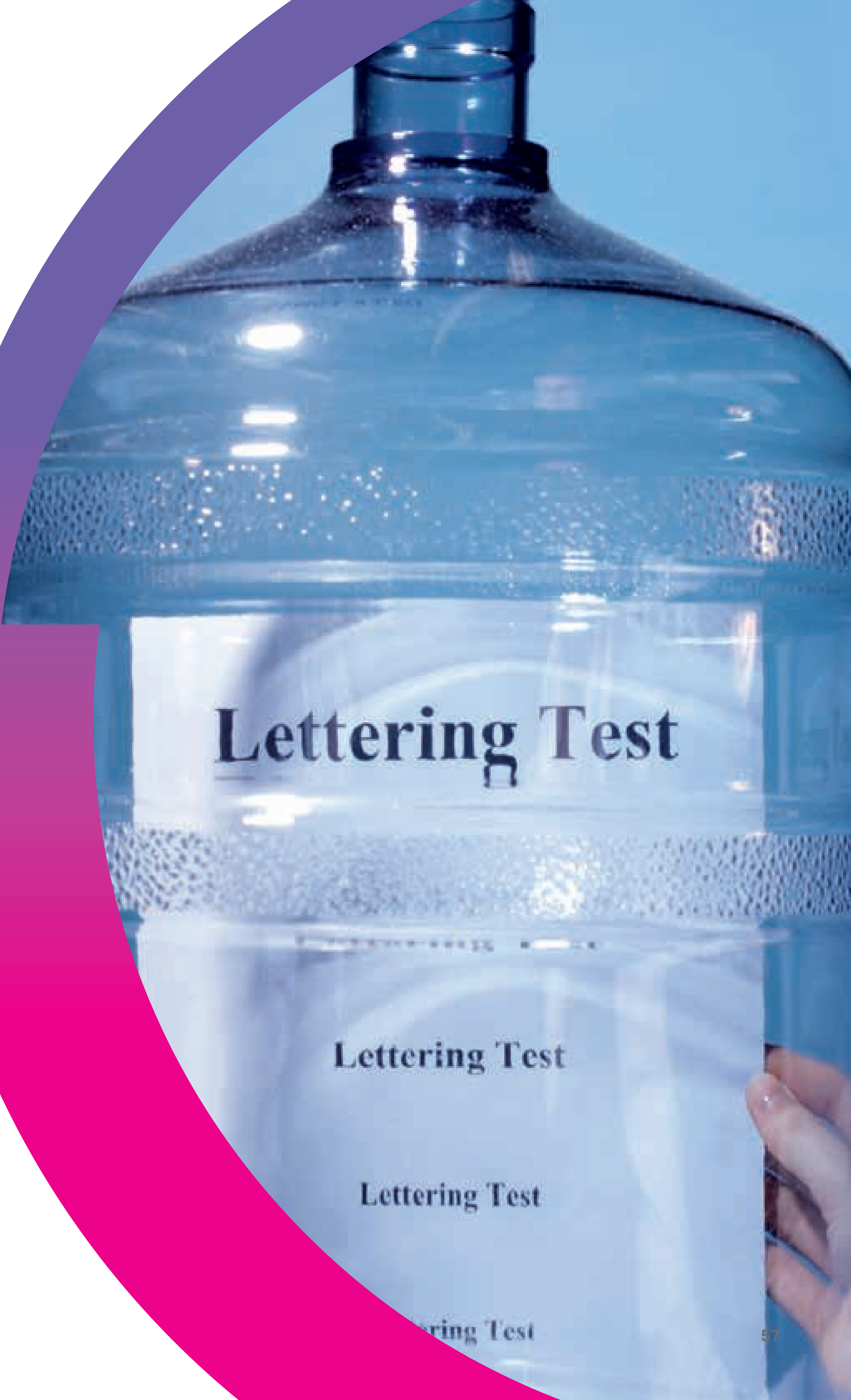
In the case of extrusion blow molding, problems can be encountered with the shaping of the bottle neck under certain circumstances. Sharp edges, undercuts or other irregularities can lead to leakage points in the closed bottle and hence to contamination with microorganisms. Manual finishing work may be required on the neck, or the blowing mandrel may need to be modified accordingly.

Other information

All quality tests should be performed under defined conditions at regular intervals so as to ensure that an overview of the process conditions is retained at all times and consistent bottle quality is assured. One approach that has proved successful is that of defining an internal bottle standard, together with specifications for relevant quality characteristics, which can then be used as a guide by the bottle manufacturers.

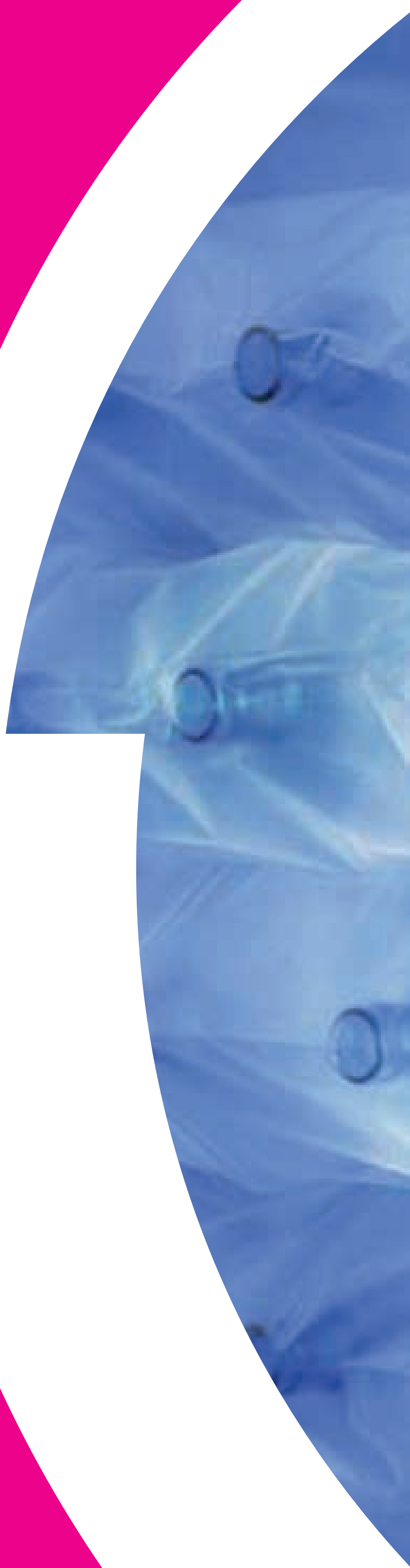
In addition to regular quality tests on the finished bottles, it is also advisable to record the associated processing and material data. Key settings and data for the blow molding machine and the peripheral units, such as dryers and annealing ovens, should be documented, together with data for the raw material batches. Samples should be retained of each batch used and, additionally, samples should also be taken of the bottles at regular intervals. This will permit statements to be made on the entire processing chain at a later date – from the material employed through to the finished bottle.

The quality of the water bottles is influenced not only by the Makrolon® WB1239 resin employed and the processing conditions but also by the properties of the in-house waste used. This material is subject to thermal and mechanical stressing each time it is processed and this can damage the polymer and reduce its molecular weight. Regular checks should therefore be performed on the suitability of the in-house waste for the production of water bottles. This can be done by verifying the rheological properties, for example. Measuring the Melt Volume Flow Rate (MVR) is a particularly suitable method.


Lettering Test
Lettering Test
Lettering Test

8 Labeling, Packaging, Transport and Storage of Bottles

Bottles made of Makrolon® are used to transport water over long distances and to store it for long periods without any loss of quality. But how are the bottles themselves to be transported? And how should they be stored? How can they be labeled? This chapter tells you everything you need to know on this subject.



Makrolon®

8 Labeling, Packaging, Transport and Storage of Bottles

What good is even the most attractive packaging if the consumer doesn't know what is inside it? Fortunately, bottles made of Makrolon® can be readily labeled and inscribed in a variety of ways. And the correct packaging, transport and storage of the bottles couldn't be easier either.

Labeling

The label on a five-gallon water bottle fulfills several different functions. First of all, it serves as an advertising medium so that people can immediately see the brand under which the water is marketed. This end-consumer brand perception can be further enhanced by employing a special design or color for the bottle. The bottle and the label are thus an unmistakable duo, conveying the desired advertising and image message in an optimum manner. Apart from this, the label generally also contains details of the quantity of water in the bottle, the composition of the water, instructions for use, and further information on the company. Labeling is carried out either directly by the bottle manufacturer or at the filling plant, depending on the water distributor's requirements.

The labels used are made either of semigloss paper which is protected against moisture, or from PVC, PE or PC. PVC labels can be readily printed, are resistant to solvents and lubricants and offer outstanding weathering resistance. If water-based printing inks are used for PVC labels, prolonged exposure to sunlight can cause the labels to fade.

Five-gallon polycarbonate bottles made of Makrolon® WB1239 are refillable and can be used up to one hundred times or more thanks to their high strength. The service life of a bottle can thus certainly run into several years, with the label being exposed to aggressive cleaning and disinfection conditions after each use cycle. Added to this comes additional stressing due to fluctuating temperatures or humidity. The labels must therefore retain their color for as long as possible and display good permanent adhesion. Use is made of acrylic polymer-based contact adhesives. These can be applied dissolved in an appropriate solvent, or with an emulsion. Casein adhesives are not recommended, since these readily dissolve in water.

Self-adhesive labels have a multilayer structure. They are made up of the label proper, an adhesive to ensure bonding, and the protective covering material. Self-adhesive labels are generally supplied on rolls, with the adhesive side of the labels being protected by a covering material, which is generally a specialty paper. The adhesives used for the labels are pressure-sensitive contact adhesives. They develop their maximum effect when the label is mechanically pressed onto the bottle surface. A siliconized protective covering material ensures that the label can be readily detached.

With the so-called no-label look, colorless transparent or translucent labels are used, giving the impression that the printing has been performed directly on the bottle. The label is then more discreet, with the water and the bottle design featured more prominently.

Screen printing is a further versatile process that can be used to print a single color label on a bottle (cf. Fig. 1). It offers a range of design options, allowing wafer-thin to extremely thick ink application with translucent or highly opaque printing inks, which display a matt or gloss finish, and have particularly lightfast or weatherproof properties.

One risk with this process is that the polycarbonate may come into contact with the thinning and cleaning agents contained in the screen printing inks, such as toluene, xylene, petrol ether, methyl ethyl ketone, butyl acetate and others. Many screen printing inks contain up to 50% organic solvents. Inks for poster printing can include toluene, xylene and fairly large quantities of petrol ether, for example. Inks for printing PVC surfaces can contain large quantities of other solvents, such as isophorone.

The printing form used for screen printing is a frame that generally has a polyester fabric stretched over it. A stencil is applied to the fabric, usually by photographic means, which prevents ink from being applied to areas of the image that are not to be printed. The printing form is placed in a printing machine above the bottle that is to be printed. Following this, the printing ink is applied to the fabric and then spread on the print substrate through the open areas in the stencil using a squeegee (rubber blade). The ink is pressed through the pores of the fabric and applied to the bottle surface. Once the printing operation is over, the bottle is taken out of the machine to dry.

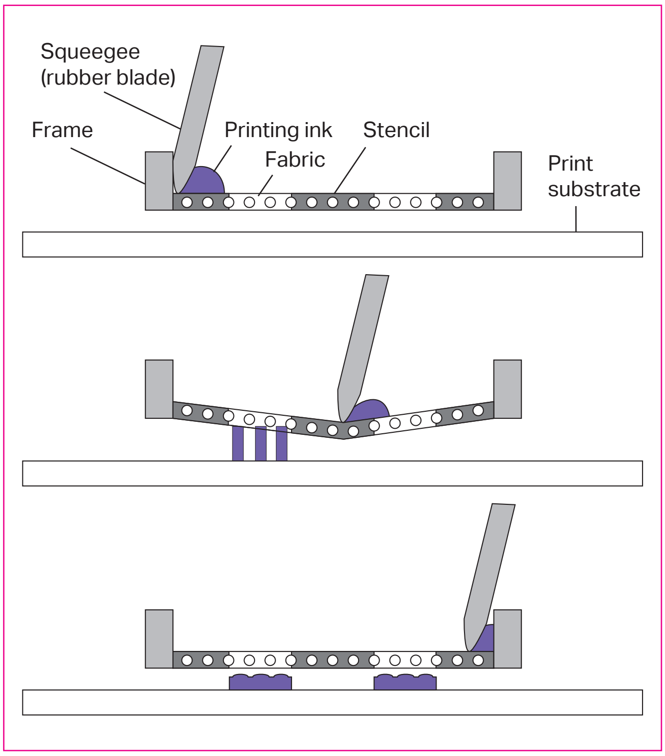
The labels, inks, adhesives and, where appropriate, protective films or lacquers must always be of a quality that is suitable for marking food packaging and must not release any substances that have a detrimental effect on the water quality. It must also be ensured that the labels, adhesives and ink formulations are compatible with polycarbonate. A large number of solvents can attack the polycarbonate or cause it to swell and could also diffuse into the polycarbonate.

A further means of applying an identification marking to a bottle is by embossing. The company name or company logo, for example, can be embossed on the bottle surface, with the inscription either being raised above the bottle surface or recessed. Embossing is also used to mark the bottle with the manufacturer's name and date of manufacture on its base.

Packaging

After production and labeling (where required), five-gallon bottles are generally packed in film for transport to the end customer. This packaging is designed to prevent damage to the bottle during transportation and storage. Four or eight bottles are generally packed together, but bottles are also packaged individually in some cases. Polyethylene has proved successful as a packaging material, although it is essential to use film that is suitable for food contact. Under no circumstances should substances be released from the packaging film which could then migrate into the packaged bottles and impair the quality of the water inside. Since different thermoplastics are in contact at this point and it is not generally possible to exclude substance transport, the use of perforated PE films has become established. The small air holes in the film permit a constant exchange of air, ensuring that the air between the packaged bottles is continually replaced, while the bottles are still protected against soiling. Bottles should always be cooled to room temperature prior to packaging, otherwise the packaging film will be heated up by the still-hot bottle. This could potentially lead to the release of substances from inside the film which could migrate into the bottle material (mass exchange). It is also not advisable to heat the packaged bottles in an oven to shrink the film onto the bottles.

Fig. 1: The screen printing process



Storage

The correct storage of both empty and full bottles made of Makrolon® WB1239 has a major influence on the quality of the water inside them. Unfavorable storage conditions can also have a negative impact on the service life of the bottles.

- The bottles should not be exposed to direct sunlight without protection. This not only promotes the growth of algae, but can also cause the polycarbonate to become brittle or discolored.
- Empty bottles should be stored in a place where they are protected from dust. Algae spores can enter the bottles along with dust, leading to algae growth.
- The bottles should not be stored in the vicinity of chemicals, solvents, cleaning agents or substances with a strong odor. Like any other thermoplastic, polycarbonate can absorb substances of this kind, which are then gradually released into the water inside the bottles and can cause irritation due to their odor or taste. Impairments of this kind in the water quality are generally very difficult to establish afterwards, since it is frequently only extremely low product concentrations that are involved.
- As far as possible, it is important to avoid storing filled bottles in places where they are exposed to temperature extremes. Different types of pallets and racks are available for the space-saving storage of five-gallon bottles (cf. Figs. 2 and 3).

Fig. 2: "Crate Plus" rack

Fig. 3: Stackable racks

- Wooden or plastic pallets are the least expensive means of storing and transporting bottles. These, however, have the drawback that if pallets of filled bottles are stacked on top of each other, the load acting on the lower bottles increases with the stacking height and can lead to damage and a subsequent reduction in the service life of the bottles. Wooden pallets should not have been treated with preservatives or insecticides. Compounds of this type can migrate through the polycarbonate into the water inside the bottle and can bring about a change in taste even in extremely small concentrations. Heat-treated pallets have proved a successful alternative here.

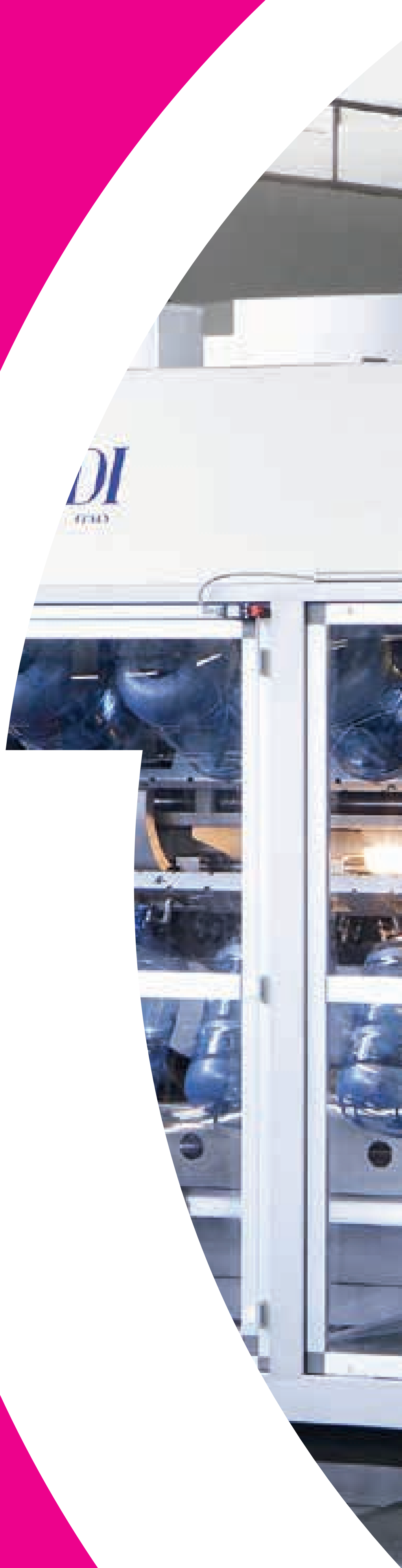
- Besides wooden or plastic pallets, different plastic or metal rack systems are available where bottles are not subjected to stressing by the bottles above them and cannot therefore suffer damage. Many of these are modular systems that can be stacked to virtually any height, ensuring that optimum use is made of the available space.

Transport

The filled bottles are best transported on the type of pallets referred to above, or on racks. They should be fixed in position during transport. Empty bottles are generally packed in film or placed in layers on the vehicle. In any case, it is important to ensure that the bottles, whether full or empty, do not become soiled, contaminated or damaged during transport. For this reason, the transport vehicle should be checked for contaminants before the bottles are loaded onto it. These include dirt, cleaning agents, greases and solvents, gasoline or diesel fuel and also any prior consignment that has been transported, if the vehicle is not used exclusively for the transportation of water bottles. For example, if products with a strong odor have been transported previously, this can, under some circumstances, subsequently impair the quality of the water.

9 Cleaning and Disinfection of Bottles

To ensure that the water which is pure and fresh when it is put in the bottles is still clear when it is poured out again, there are two key points to be borne in mind: correct cleaning and disinfection of the bottles. Only a clean bottle in perfect condition will guarantee that its contents remain fresh and clear.



9 Cleaning and Disinfection of Bottles

Makrolon® WB1239 has been designed to ensure the longest possible service life for bottles. Bottles made of Makrolon® can be cleaned and disinfected without any problems. Despite this, it is necessary to be mindful of a number of points to ensure that the bottles can be re-filled as frequently as possible in a manner that is eco-friendly and helps to conserve resources.

The chemical make-up of polycarbonate means it can react sensitively to certain cleaning and disinfecting agents. The agents employed must therefore be carefully selected so as to avoid damage in the form of stress cracking when the bottles come into contact with these media.

In addition to this, other effects, such as swelling or chemical degradation of the polymer can occur, which can also considerably impair the performance characteristics of the bottles. This incompatibility may be manifested by cloudiness in the material, for example, but is not always visible.

Bottles in Makrolon®, however, can generally be cleaned and disinfected in typical plants without any problems if the above criteria are taken into account.

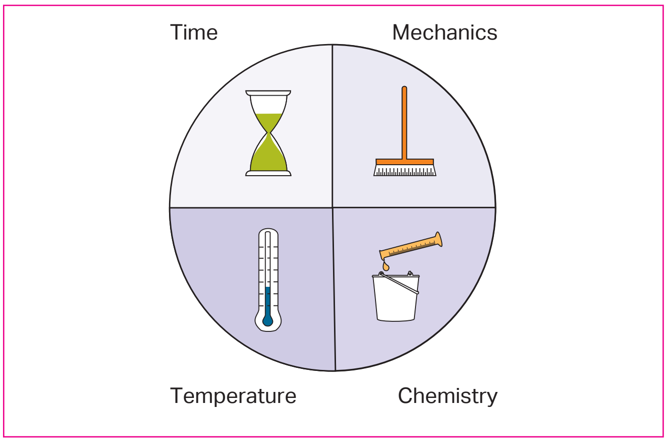
Fundamental aspects

The bottles are normally washed at elevated temperatures in automatically controlled plants employing a highly efficient cleaning fluid. The cleaning effect rests on a balanced combination of the four parameters of cleaning time, cleaning agent (chemistry), temperature and mechanics. The interplay of these parameters can be depicted in the cleaning circle according to Sinner, which highlights the principle behind effective cleaning (cf. Fig. 1).

According to this circle, complete cleaning is only ensured if all the parameters together add up to 100 % and if the area of the circle is completely filled out. All four factors are dependent on each other, but their relative proportions can be modified, with the parameters of the cleaning plant and the bottle material generally being the limiting factors. As is shown in the following diagrams (cf. Fig. 2), a restriction on one or more sectors can be offset by an increase in other parameters, thus ensuring that an optimum cleaning effect can be achieved.

Cleaning times and the mechanical cleaning action are determined by the design of the bottle cleaning plant in most cases, which means that the temperature and the type and concentration of cleaning agent are the only factors that can be varied. Alongside the specific properties of the polycarbonate referred to above, allowance must also be made for the corrosion resistance of the cleaning plant when selecting the cleaning and disinfecting agent.

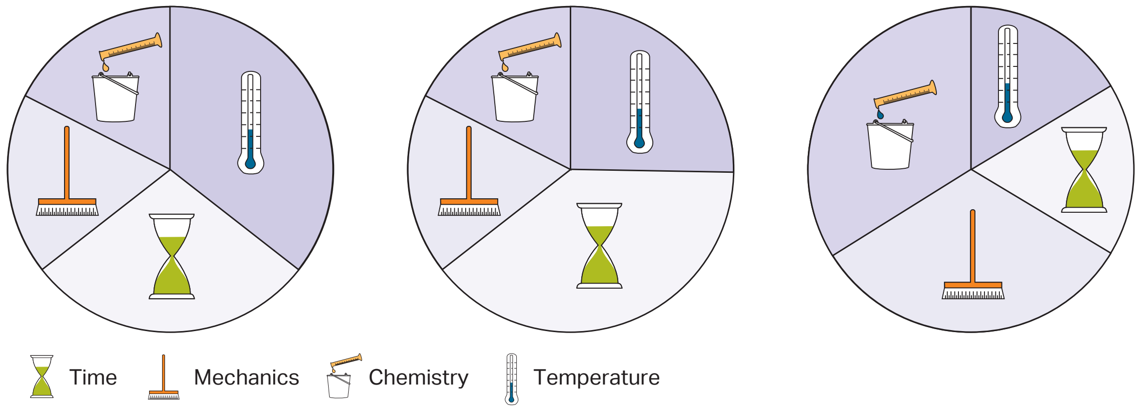
Fig. 1: The cleaning circle according to Sinner



Special products for cleaning Makrolon® bottles are available from a number of manufacturers. The cleaning agents are specially tailored to the specific properties of polycarbonate and are noted for their high efficacy. Only cleaning agents specially developed for polycarbonate should be used.

Reference is frequently made in publications to polycarbonate's sensitive reaction to tensides and strong alkaline solutions. This generally means the occurrence of stress cracking. While these statements are basically correct, they normally only apply to bottles with unfavorable stress levels. This is because a low stress level generally ensures improved compatibility with the cleaning agent and hence a longer service life for the bottle. It is therefore standard practice to clean Makrolon® bottles with strong alkaline solutions. Additives are employed to reinforce the cleaning effect and avoid alkali-specific problems such as lime scale deposits.

Fig. 2: The interdependence of the cleaning parameters



Cleaning and disinfection

When cleaning and disinfecting bottles in Makrolon®, a distinction must first be made on the basis of the residues that can be expected in the bottles and the cleaning plant that is to be used. Five-gallon bottles, for example, are cleaned in special-purpose units on account of their size.

Besides minerals from the water, water bottles chiefly contain residues that have accumulated during the storage of the bottles. These are essentially dust, dirt and micro-organisms, with organic substances accounting for the bulk of the contamination. It is also necessary to expect soiling as a result of the bottles being used for other than their intended purpose. This too will generally involve organic substances, such as solvents, lubricants, fuels and oil.

Figure 3 shows a schematic diagram of the cleaning unit. The cleaning process can be divided up into the following stages:

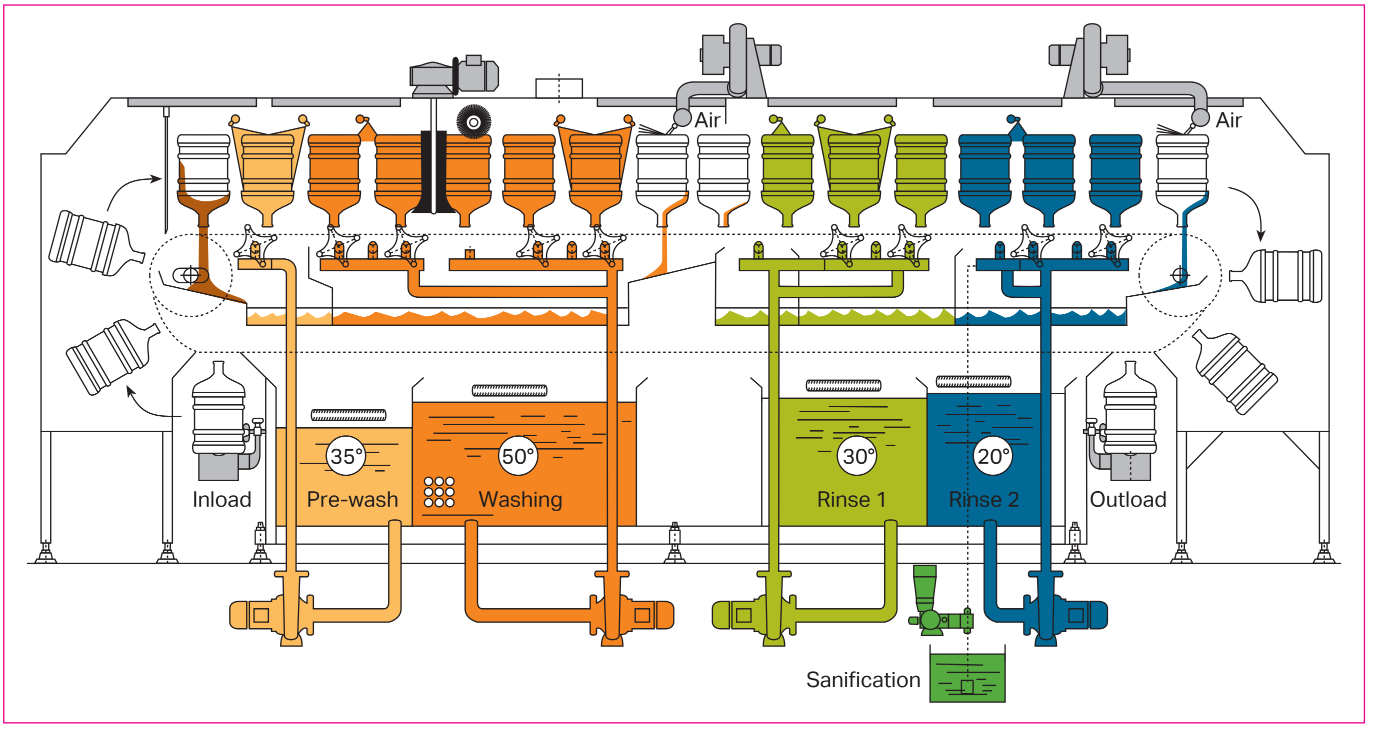
- optical and sensory inspection to assess bottle quality
- emptying of any residual contents
- pre-washing
- multi-stage washing on the inside and outside at a minimum of 60 °C
- rinsing of bottles on the inside and outside with clean water
- disinfection of bottles
- re-rinsing
- bottle filling

The water bottles are cleaned using just water, a cleaning agent and a disinfectant. No additional detergents or ancillaries such as rinsing agents and antifoaming agents are employed as a rule, since the cleaning agent normally contains all the necessary additives.

Contact times with the cleaning solution are relatively short – in the region of one to two minutes. The cleaning effect is reinforced in mechanical terms through the use of special spray nozzles. Since the bottles are not submerged for cleaning, there is a risk of the cleaning solution drying on the bottle between the different treatment stages. Depending on the particular cleaning agent selected, this can impose limits on the cleaning temperature. When designing the plant, particular attention must be paid to ensuring that a complete film of liquid forms over the entire bottle during the spraying operations. If this is not the case, "channeling" will prevent the bottle from being fully cleaned.

In view of the expected type of soiling, preference is given to alkaline cleaning agents, which can have different pH values. Heavy soiling requires a higher degree of alkalinity, while mildly alkaline products can be sufficient for bottles that remain within a more or less closed distribution circuit with no major possibility for soiling.

Fig. 3: Basic layout of a cleaning plant



If extensive mineral residues remain, as can happen with water that has a fairly high mineral content, then acidic cleaning agents should additionally be used, which will completely remove mineral specks without stressing the material excessively. In most cases, the combination of the chemical and mechanical cleaning action and the prevailing cleaning temperature will ensure that the bottles are hygienically clean. A disinfection agent should also be added in the rinsing zones in order to prevent renewed contamination with micro-organisms. The final spray-rinsing of the bottles will generally be performed using the same water as that which is to be bottled.

One problem that may occur with incorrectly stored five-gallon bottles is algae growth, which takes the form of a green deposit. Algae grow in water and on moist surfaces and can be found almost everywhere in nature. If a surface covered in algae dries out, the algae can spread through the air in the form of spores. Thus any type of dirt or dust in the environment constitutes a potential source of contamination by algae.

For algae to grow, they require light in addition to water. Bottles can thus only be affected by algae growth if they contain algae spores and have been exposed to sunlight or bright artificial light for a prolonged period of time. Therefore, to reduce the risk of algae growth, the following recommendations should be followed:

- Do not store filled or returned bottles in an exposed place outdoors.
- Check bottles carefully for soiling before they are put in the cleaning plant.
- Never put bottles with algae growth through the normal cleaning process.
- Avoid contamination of the cleaning plant and other bottles.
- Segregate highly soiled bottles and, where appropriate, pre-wash them before putting them in the standard cleaning plant.
- Avoid any contamination of the filling plant and the holding tank.
- Ensure effective washing and disinfecting conditions.

When bottles are filled with water, care should be taken to ensure that the disinfectants used do not affect the water in terms of taste or smell. Disinfectants with a strong oxidizing effect in particular frequently promote the formation of sensorially active compounds that can impair the taste of the water in the bottle. These include, for example, AOX (AOX = adsorbable organically bound halogens, i. e. the sum of the organic halogen compounds that are adsorbable on activated charcoal) and haloforms. If these are used in high concentrations, they may also damage the bottle material.

Disinfectants containing peracetic acid are thus especially recommended. They do not generally cause sensorially active compounds to develop, and products of this type display particularly good compatibility with polycarbonate. Disinfection is generally carried out by rinsing the bottles with the appropriate disinfection solution.

As a general rule, the instructions provided by the cleaning and disinfecting agent manufacturers should be observed. Companies producing appropriate cleaning agents include:

- Ecolab (www.de.ecolab.eu)
- Sealed Air Diversey Care (www.diverseysolutions.com)

Special thanks go to Mr. Wershofen of Ecolab Germany for his invaluable assistance with this chapter.

10 Information on Bottle Design

Good design is something that you can see – even if it is not immediately obvious. This is because it is not just the external appearance of a bottle that determines how good its design is, but first and foremost its internal values.

10 Information on Bottle Design

Apart from its external appearance, a well-designed bottle in Makrolon® WB1239 requires a correctly coordinated wall thickness and wall thickness profile, since this has a major influence on the mechanical properties and service life of the bottle.

Design recommendations for five-gallon water bottles

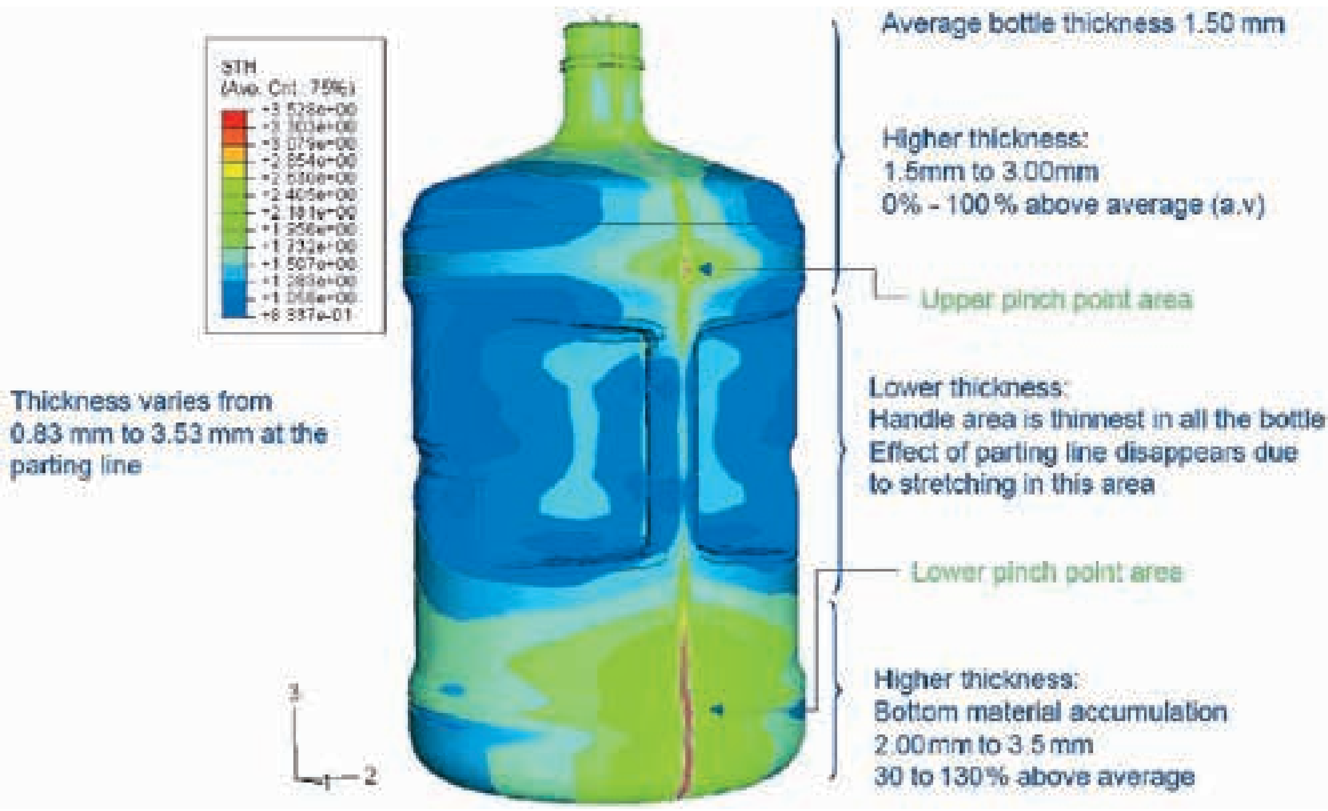
Makrolon® WB1239 can be used to produce a wide range of designs for returnable five-gallon water bottles. The high brilliancy and transparency of Makrolon® WB1239make the bottles visually attractive. Besides aesthetic considerations, there are also a large number of productivity and safety aspects that need to be taken into account and reconciled with the optical factors.

The companies that fill the bottles with water are interested in their returnable bottles having as long a service life as possible. During each individual cycle, a bottle is exposed to many different types of stress during filling, storage, transportation, use by the customer and cleaning. A key requirement for high strength in a bottle is a carefully-coordinated production process. In addition to this, the bottle design is also a determining factor for strength, and hence for productivity too.

In general terms, it is important to avoid sharp edges and corners on the body of the bottle, since high stresses can prevail at these points and lead to premature failure of the bottles during use. For this same reason, areas that are rounded should always have the largest possible radius.

The wall thickness should be at least 0.8 mm to ensure sufficient stability in the bottle (cf. Fig. 1). Points that are exposed to greater mechanical stressing, such as the shoulder and base areas, should have thicker walls than the sides of the bottle. The wall thickness should not exceed 3.2 mm, however, since thicker walls would restrict the plastic deformation behavior of the polycarbonate and could lead to premature failure of the bottle in the event of an impact. The wall thickness profile should essentially be as uniform as possible. It is important to avoid abrupt changes in wall thickness, since this is where stresses become frozen in during cooling, and this can subsequently lead to stress cracking under mechanical stressing or during cleaning.

Fig. 1: Example of a wall thickness study



Extrusion blow molded five-gallon water bottles have different wall thicknesses at the pinch-off seams on account of the production process. When bottles with a handle are produced, there are also obvious changes in wall thickness in the handle zone, which can cause stresses to develop (cf. Fig. 3). Generally, it can be said that bottles with a handle display higher stresses than those without a handle as a result of the production process. However, stresses of this type can largely be eliminated by annealing, thus ensuring a sufficient level of stability.

Bottle design also plays a key role in facilitating the cleaning and disinfection of the bottles. The cleaning agent must be able to wet the entire surface of the bottle and then run off the surface completely. There should not be any dead spots that the cleaning agent does not reach or where liquid accumulates without flowing off. Particularly in the case of bottles with a handle, the additional complexity means that extra care is required.

Covestro can advise its customers on wall thickness distribution, as well as on design, geometry optimization and other issues, employing a range of different methods. We offer qualitative assessments of our customers' design proposals with respect to stability and stress levels and can also advise on the optimization of bottle designs (Fig. 2).

Fig. 2: Capturing the bottle geometry and preparing it for analysis

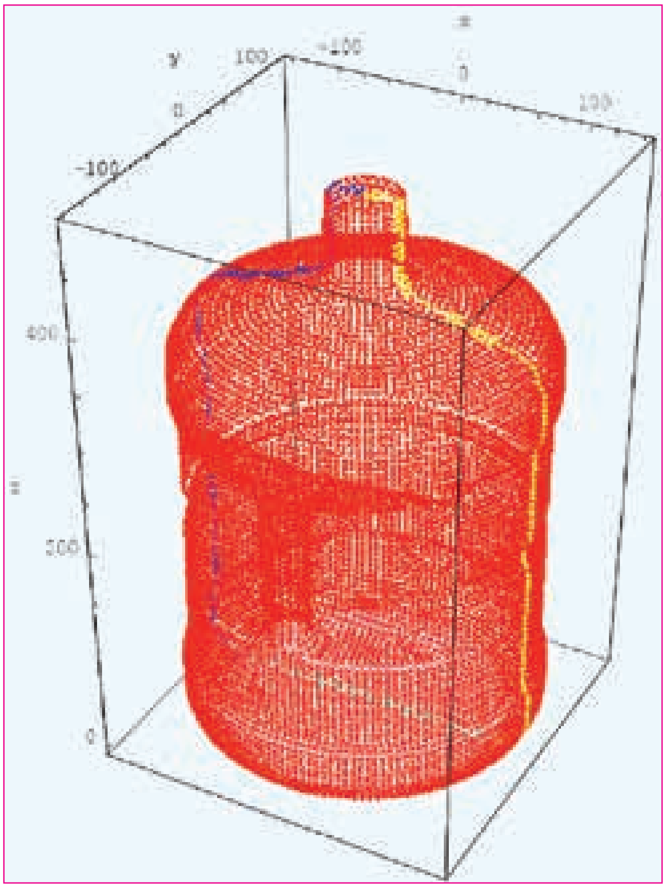
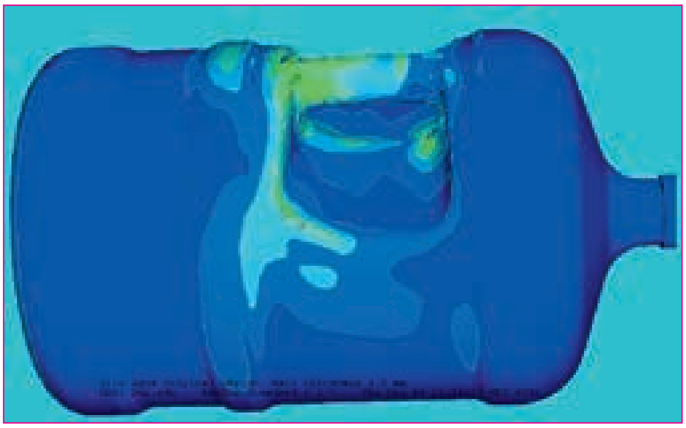
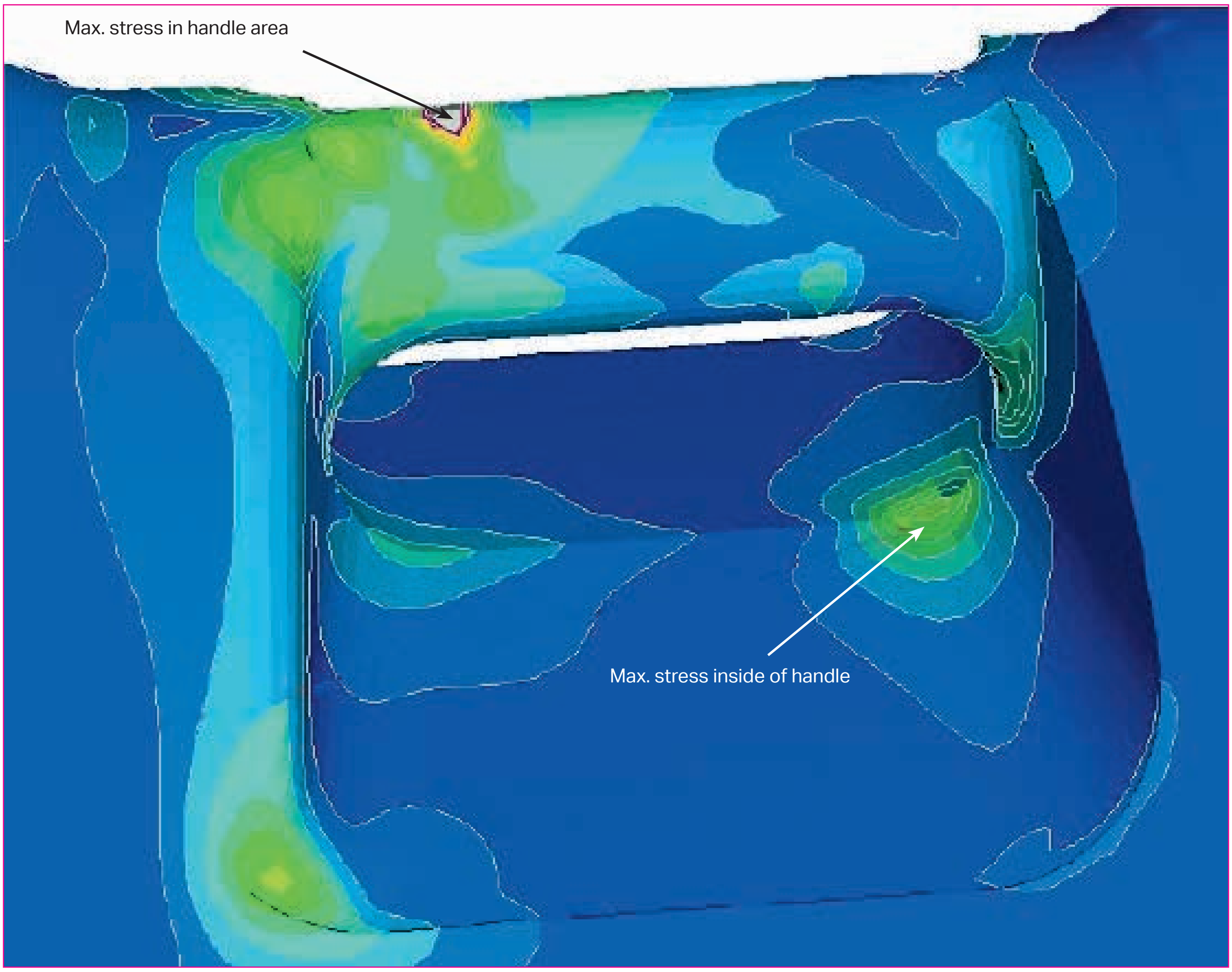


Fig. 3: Analyzing stress levels





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