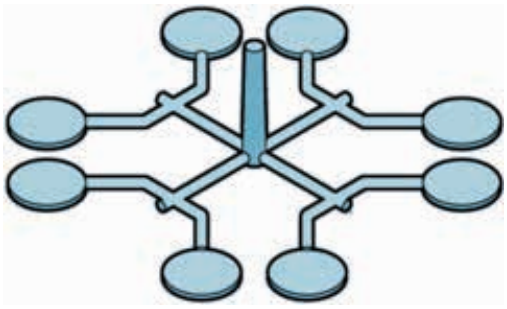
Balanced Filling in Thermoplastic Medical Molding

If molten plastic behaved like a simple fluid, there would be little need to worry about balanced filling during molding. The melt would fill the cavities like water, and the way the mold filled would have little or no influence on the properties of the molded parts. In reality, molten plastics are complex, viscous, and highly compressible fluids. How the mold fills can affect physical characteristics of the part such as size, strength, and appearance. Balanced filling can reduce part variations and improve part quality, both important in medical molding.

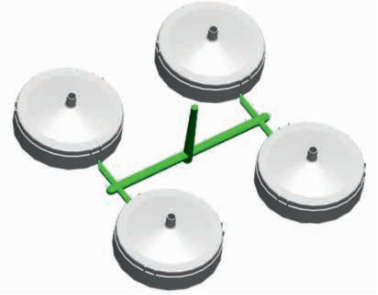
Multi-Cavity Balancing

Balanced filling in plastic molding can refer to filling in multi-cavity molds or filling within a single part cavity. Balanced filling in multi-cavity molds typically involves designing the runner system (hot or cold) so each cavity fills at the same time and at about the same temperature. When they fill at the same time and temperature, cavities tend to pack to the same density. Parts packed to the same density are likely to shrink to the same size as the material solidifies. Packing can also influence mechanical properties, so balanced filling can also produce more consistent mechanical performance. The runner below is just one example of a balanced runner. Note the large runner volume in this example i.e. everything excluding the round parts.

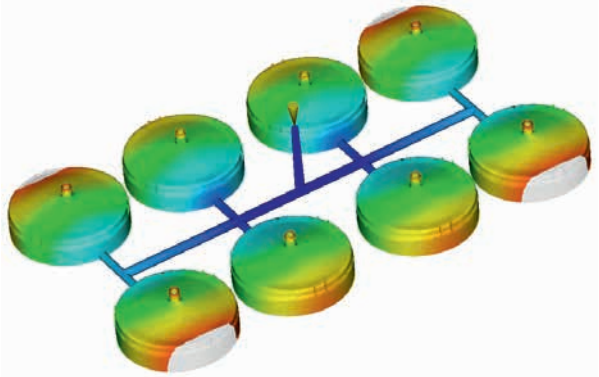


In unbalanced multi-cavity molds, the ideal processing conditions for the early-filling cavities may be different than for late-filling cavities. The processing settings on the press end up being a compromise. This narrows the processing window and makes quality control more difficult. Cavities that fill first are more prone to flash and core deflection while late filling cavities can exhibit non-fill, sink and voids. Texture and gloss can also appear different between the early and late filling parts. Processing conditions that fix problems in late-filling cavities can cause problems in the early-filling cavities. Balanced filling can reduce these problems.

Most geometrically balanced runners attempt to balance filling by providing the same flow distance to each of the cavities. In the example below, the distance from where the plastic enters the mold at the tip of the sprue to each of the four part gates is the same. The parts should all fill at the same time.

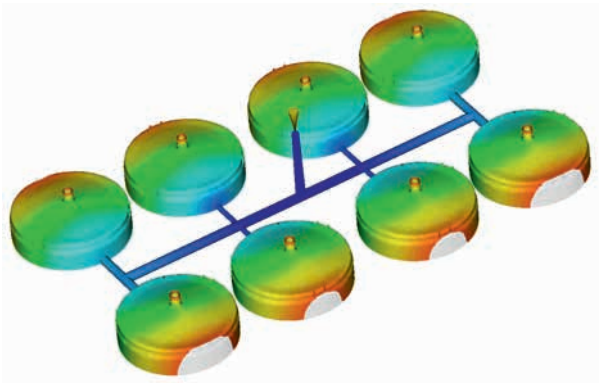


When this runner design is extended to accommodate four more cavities as shown below, an imbalance occurs.



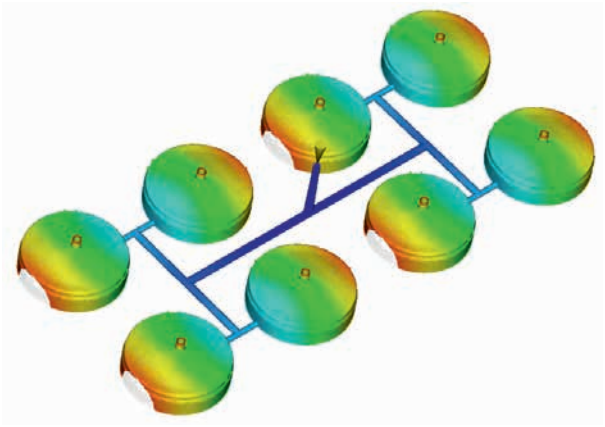
The runner distance to the outer four parts is longer than to the inner four parts. The flow simulation shows the inner parts completely filled while the outer parts still have the grey area yet to fill. The inner parts will be more prone to flash and will likely shrink less than the outer parts.

One solution is to use filling simulation to adjust the runner diameters to balance the filling to all cavities. In the example below, the diameters of the short runner segments feeding the inner four parts were reduced to restrict filling. Just before filling, all of the parts have about the same amount left to fill, but the inner parts are still slightly ahead. In this example, the runner adjustments were limited to standard cutter sizes. A better balance could be achieved with custom cutters.



This method of balancing runners, often called artificial balancing, has been used successfully for many years. It generates compact runner layouts (reducing regrind generation) and corrects many of the problems associated with unbalanced runners. Problems can occur when the restricted runners become too small to deliver adequate packing to the inner parts. Artificially balanced runners are designed for a specific set of processing conditions. Changes to the filling speed or melt temperature can throw off the balance. Some molders attempt to balance flow by adjusting the gate size. This is not recommended. Differences in gate sizes can lead to variations in packing, material shrinkage and part cosmetics. Balancing by varying gate size is also much more sensitive to changes in processing conditions than runner balancing.

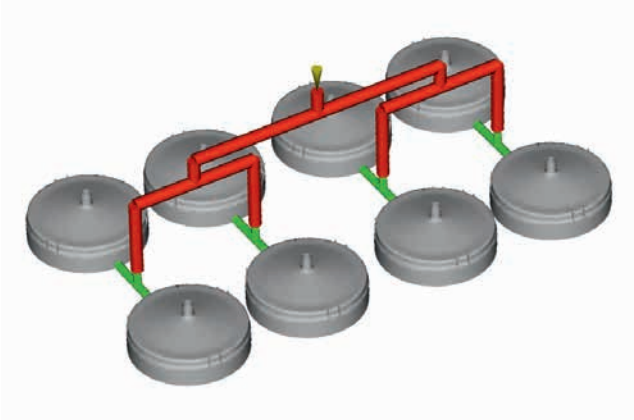
An alternative 8-cavity runner option branches the runner segments to produce a geometrically balanced runner system as shown below. This design maintains an equal distance from the tip of the sprue to each part cavity. The predicted filling pattern for this runner system shows the flow fronts in the inner and outer cavities progressing in a balanced fashion. In reality, this configuration usually fills the inner cavities ahead of the outer cavities despite the runner distances all being the same. This effect is not picked up by conventional mold filling simulations. This phenomenon becomes a major issue in runners that branch more than once.



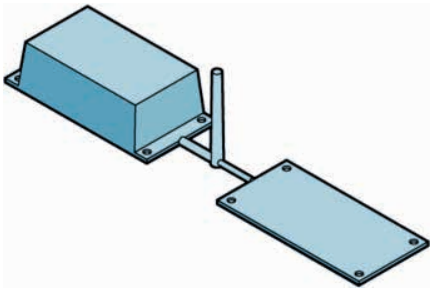
Dr. Beaumont of Beaumont Technologies, Inc. discovered that as flow in the runner splits at the first runner branch, the hotter shear layer near the runner wall remains on the inside-corner side of the runner. The cooler core material goes to the opposite side. After the split, the melt flowing within the runner then has a hot side and a cool side. When the flow splits again at the second runner branch, the melt on the hot side fills the runner going one way and the melt on the cooler side fills the runner going the other way. The hotter material follows the inside corners, feeding the inner cavities in this runner layout. Because the melt viscosity is temperature-dependent, this temperature difference within the runners creates a filling imbalance.

To remedy this, Dr. Beaumont devised inserts that modify the runner branch intersections and rotate the hot and cool sides 90 degrees, so equal amounts of hot and cool material enter each part cavity. This MeltFlipper® technology can be purchased and licensed from Beaumont Technologies, Inc. Contact them for more information on this technology.

Hot runner systems also require flow balancing. The figure below represents an 8-cavity mold with a hot runner system (red) feeding molten plastic to four short cold runners (green) which each fill two parts. The hot runner system is geometrically balanced to provide balanced filling.



Family molds (molds producing different parts at the same time) often exhibit flow balancing problems, particularly if the parts are significantly different in size or shape. In the example below the molder wanted to produce the box and lid at the same time to save molding costs and to ensure a perfect color match between the mating parts. If nothing was done to balance the flow, the smaller lid would fill ahead of the larger box. Increased packing in the lid could cause a variety of problems including flash and a gloss difference. More importantly, reduced shrinkage in the highly packed lid could affect the alignment of the screw holes in the lid with the holes in the box. By reducing the diameter of the runner to the lid, the flow can be restricted, so both parts fill at the same time.

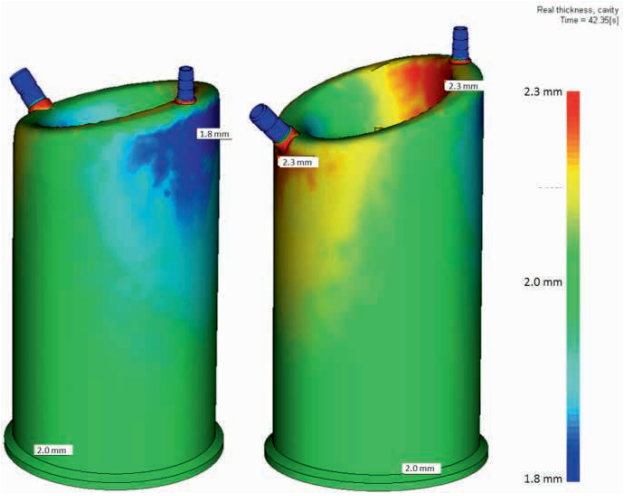


Part Balancing

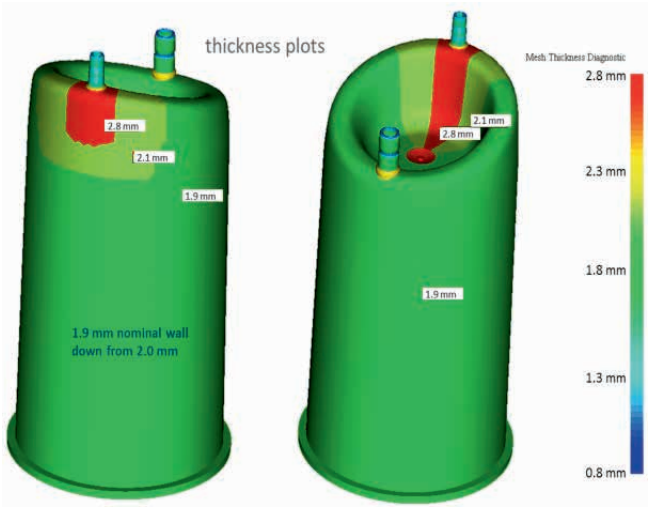
Imbalances in flow within a single part cavity can also create problems. The logical place to gate the medical part shown below is in the middle of the recessed pocket at the closed end. Because the flow length over the taller side is longer, the flow front lags behind on that side. The resulting filling imbalance is probably not enough to cause flash or packing problems, but it is enough to slightly flex the main core that forms the inside of the part.



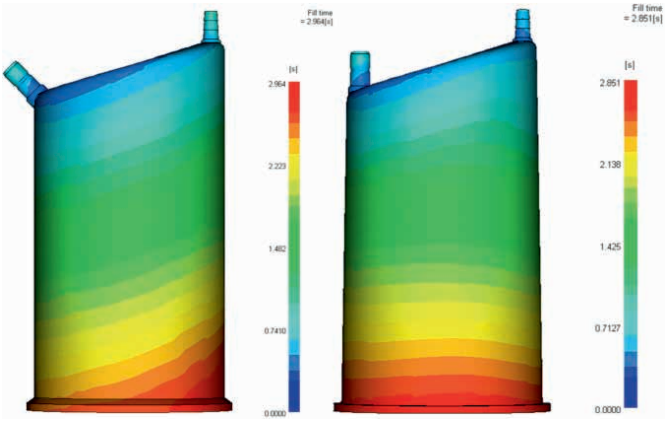
The thickness plot below shows the wall thickness variations predicted when the core bends because of the pressure imbalance acting on the core as the flow progresses faster down one side of the part than the other. The core is deflected toward the taller side. This increases the wall thickness on the surfaces facing the shorter side (red) and reduces the wall thickness on the side facing the longer side (blue). Because the core is supported at the open end of the part (bottom in this view), the deflection occurs at the closed end of the part (top). The core deflection alters the part wall thickness but can also cause filling and demolding problems as well as fatigue failures in the core.



Design permitting, wall thickness adjustments can balance filling around the main core and greatly reduce core deflection. The following figure shows the part with a flow leader added to balance the flow front. Flow leaders are areas of increased wall thickness which are intended to improve part filling. In this example, the thickness of the red flow leader was increased from the original nominal wall thickness of 2.0 mm up to 2.8 mm. The yellow-green regions represent the blending area where the thickness tapers down to the new nominal wall thickness. The flow leader was extended from the gate up toward the highest tubing port and partially down the other side. This was done to speed up the flow front to the taller side to balance filling around the main body of the core. It also reduces the pressure needed to fill the part. This allowed the nominal wall thickness to be reduced from 2.0 mm to 1.9 mm resulting in a weight and cost reduction.



The filling analysis results below show the original filling pattern on the left and the new filling pattern with the flow leader on the right. The original angled flow front shape that generated the bending stresses on the core is replaced by a straighter flow front shape that better balances the melt pressure around the core. This reduced the predicted core deflection by over 70 %. If this part had been gated via a single gate at the edge on the open end, the core deflection may have been worse as the flow front advanced from one side of the core. Two gates placed opposite each other on the open end of the part would balance the forces acting on the main core and minimize deflection.



As a general rule, parts should fill such that the flow front reaches the part extremities at about the same time. This reduces the required filling pressure and provides more uniform packing and shrinking throughout the part. Gate placement can play a key role in balancing filling. For example, a rounded part would have a shorter flow length and require less pressure with a center gate than with an edge gate.

Not every part needs to be or should be balanced. The penalty for providing balanced flow may outweigh the gains. If the filling is straight forward and there are no serious potential issues such as core shift, difficult parting line geometry, or unusual packing concerns, then the cost and complexity to add a center gate may not be justified. In the case of long narrow parts, it is often preferable to gate at one end to align the polymer chains and reduce warpage. Cosmetic constraints may also restrict the gating options. That said, the matter of part balancing should at least be considered.

Summary

Balanced filling can improve the quality and consistency of molded medical parts. Runner balancing in multi-cavity molds improves the chance that all cavities will fill and pack at the same time. This broadens the processing window and improves cavity to cavity consistency. Flow balancing is particularly important in family molds which produce parts that differ significantly in size or shape. Runner balancing is highly recommended for multi-cavity molds.

Flow balancing within parts can be achieved with flow leaders or gate placement, and can reduce problems such as core deflection, excessive filling pressure or localized over or under packing. In some instances, the benefits of balancing the flow within parts may not be worth the costs or performance penalties. This needs to be evaluated based on the specific part performance and molding requirements. While not always required, the merits of flow balancing within parts should always be considered.

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